

Exxon Valdez Oil Spill
Gulf Ecosystem Monitoring and Research Project Final Report

Investigating the Relative Roles of Natural Factors and Shoreline Harvest in Altering the
Community Structure, Dynamics and Diversity of the Kenai Peninsula's Rocky Intertidal

GEM Project 030647
Final Report

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Study History: This 2 year research project, awarded on December 16th 2002, and extended through to April 15th 2005, was conducted on the outer coast of the Kenai Peninsula, Alaska to determine the causes and consequences of a localized decline in the black leather chiton, *Katharina tunicata*, known locally as 'bidarki'. To date, two annual reports written for FY 03 and FY 04 and a TEK report prepared in April 2005 have been submitted to GEM. Conference presentations of these data have been made at the annual Marine Sciences in Alaska meetings (Anchorage 2003&2004), the World Fisheries Congress (Vancouver 2004), the annual Society for Conservation Biology meeting (Brazil 2005) and the Kachemak Bay Marine Science meeting (Homer 2006). This final report represents our final submission to GEM.

Abstract: We investigated the relative roles of natural factors and shoreline harvest leading to localized declines of the black leather chiton, *Katharina tunicata*, on the Kenai Peninsula, Alaska. Field surveys of the significant predictors of *K. tunicata* across 11 sites suggest that its current spatial variation is significantly related to human exploitation and sea otter predation. Traditional ecological knowledge further revealed that several benthic marine invertebrates (sea urchin, crab and clams) have declined sequentially, with reduced densities of *K. tunicata* being the most recent. We propose that a restriction in alternative prey species availability has led to recent intensified per capita predator impacts on *K. tunicata*. Experimental *K. tunicata* removals in the low intertidal revealed that at high densities, *K. tunicata* reduced the density of *Alaria marginata*, by 94% and species richness by 38%, and altered algal and invertebrate community structure. Across-site comparisons showed that *A. marginata* biomass was 7 times greater at exploited versus unexploited sites. Furthermore, community structure differed significantly as a function of predation pressure. These results provide evidence of a trophic cascade and reveal the extent to which fishing and natural predation, via the reduction of a shared keystone resource, indirectly alter a temperate coastal ecosystem.

Key Words: Bidarki, chiton, *Katharina tunicata*, Kenai Peninsula, marine ecosystem change, nearshore, semi-directed interviews, shoreline harvest, subsistence, traditional ecological knowledge

Project Data: The data collected for this report were derived from intertidal field surveys across eleven sites, experimental manipulations, village harvest surveys and semi-directed interviews with tribal elders. These data were entered into Excel spreadsheets and Word files. They have been described, synthesized and archived in this report. Data may be acquired by contacting, Anne Salomon, Department of Biology,

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TABLE OF CONTENTS

Study History	i
Abstract.....	i
Key Words	i
Project Data.....	i
List of Tables	vi
List of Figures.....	viii
Executive Summary	1
SYNERGISTIC SERIAL DEPLETION OF MARINE INVERTEBRATES LEADS TO THE DECLINE OF A KEYSTONE GRAZER	3
Abstract.....	4
INTRODUCTION	5
METHODS	7
Study area.....	7
Spatial variation in <i>K. tunicata</i>	7
Present- day factors governing spatial distribution of <i>K. tunicata</i>	7
Changes over time.....	9
Temporal variation in subsistence shellfish landings	9
Statistical Analysis.....	9
RESULTS	10
<i>K. tunicata</i> abundance.....	10
Current subsistence collection effort, behavior & observations	11
Non-human predators.....	11
Macroalgal productivity & physical factors	11
Current factors governing spatial variation in <i>K. tunicata</i>	12
Historical, ecological and socio-economic observations and local hypotheses.....	12
Temporal variation in subsistence shellfish landings	14
DISCUSSION	14
Present day top-down vs. bottom-up factors.....	14
Historical ecological & socio-economic events contributing to synergistic serial depletion	15
Compounding social causes of invertebrate decline.....	16
Legacy of prehistoric human alterations of northern ecosystems.....	17
Anecdotes as data and the importance of historical perspectives	17
CONCLUSION.....	18
Acknowledgments.....	18
Literature Cited.....	29

EXPLOITATION OF A KEYSTONE HERBIVORE ALTERS A TEMPERATE COASTAL ECOSYSTEM.....	33
Abstract.....	34
INTRODUCTION	35
Ecosystem-level effects of fishing.....	35
Variation in consumer impacts	35
Effects of subsistence harvest& sea otter predation on the Kenai Peninsula, Alaska	36
METHODS	37
Study area.....	37
Site comparisons of intertidal community structure, <i>K. tunicata</i> density & wave exposure	37
<i>A. marginata</i> survival and biomass.....	38
Experimental arenas.....	38
Statistical analysis & models	38
RESULTS	41
Variable intertidal community structure among survey sites	41
Variable <i>A. marginata</i> survivorship & biomass across survey sites.....	41
Variable population-level effects of <i>K. tunicata</i> across experimental sites.....	41
Constant <i>K. tunicata</i> per capita interaction strength	42
DISCUSSION	42
CONCLUSION.....	44
Acknowledgments.....	44
Literature Cited.....	55
IMAM CIMIUCIA ; OUR CHANGING SEA	59
Preface; How this Book Came to Be	59
OUR CHANGING SEA	60
Subsisting From The Sea	61
The Tides That Fed Us.....	61
Bidarkies; The Most Recent Decline	62
A Story of Multiple Causes.....	63
THE RUSSIAN ERA.....	63
From Seasonal Camps and Settlements to Established Villages	64
Our Ocean Home is Formed	64
Extinctions & Extirpations.....	65
IN LIVING MEMORY.....	66

Cannery Conundrum.....	66
Following the Fish	67
Sea Otters Return	67
Local Shellfish Begin to Decline	68
The Earthquake of '64	69
Electricity and Sewer Lines Come to the Villages	70
The Commercial Crustacean Crash	71
Changing Ocean Temperatures.....	72
Clams and Cockles, the Next to Go	73
When the Water Died.....	73
Bidarkies Go by Fed Ex	75
Nearshore Marine Invertebrates Decline One After the Next	75
Putting it All Together; Why Have Bidarkies Recently Declined?	76
Other Changes to Our Ocean Home	77
IDENTIFYING THE PROBLEMS TO CREATE THE SOLUTIONS	78
Our People and Sea otters; Predators and Competitors	78
Current Day Threats to Our Ocean	80
Sliding Baselines.....	83
Changing Life Ways	85
ENJOYING OUR MARINE RESOURCES IN THE FUTURE.....	85
Traditional Management of Marine Resources.....	86
Teaching the Next Generation	87
Qaillumi KipuCESnaiyarrtaa; How Can We Bring It Back?.....	88
The Future of Our Ocean Home	90
Quyanakcak.....	91
References.....	92

List of Tables

Table 1.1 Spatial variation in <i>K. tunicata</i> density and biomass in the low and high intertidal at 11 sites along a gradient of subsistence shoreline collection pressure on the outer Kenai Peninsula, Alaska.	19
Table 1.2 Differences in top-down and bottom-up factors among sites that may influence the spatial variation in current day <i>K. tunicata</i> density and biomass in the low intertidal.	20
Table 1.3 Strength of evidence for alternative models representing competing hypotheses on the primary factors governing the present spatial variation in <i>K. tunicata</i> density and biomass in both the low and high intertidal. Harvest pressure, sea otter presence, shorebird presence and wave exposure were the four variables considered. Models, with varying numbers of parameters (K), were compared using small sample, bias-corrected Akaike Information Criterion (AICc), AICc differences (Δ AICc), and normalized Akaike weights (w_i).	21
Table 1.4 The relative importance of four variables (harvest pressure, sea otter presence, shorebird presence and wave exposure) which contribute to the current spatial variation in <i>K. tunicata</i> density and biomass in both the high and low intertidal. Relative importance was based on variable weights which were calculated by summing the Akaike weights (w_i) over the subset of models for a specific response in which a variable was found. The sign of each variable coefficient in parentheses indicates the direction of the relationship between the response and each variable.	22
Table 1.5 Time series of historic ecological and socio-economic observations based on representative quotes from Sugpiaq elders and tribal residents from Port Graham and Nanwalek, Alaska. <i>K. tunicata</i> are known locally by their Russian name “bidarki”.	233
Table 1.6 Competing hypotheses, based on traditional & local knowledge, regarding historical decline of invertebrates and current decline of <i>K. tunicata</i> (bidarkies).	244
Table 2.1 NMDS ordination of intertidal community structure in 2003 and 2004. Individual and total proportion of the variance represented by each axis (r^2). Correlation coefficients (Pearson’s r) express the linear relationship between the ordination scores of each axis and site-specific estimates of maximum wave exposure and <i>K. tunicata</i> densities averaged for 2003 and 2004.	45
Table 2.2 Strength of evidence for alternative models of <i>K. tunicata</i> density and maximum wave exposure representing competing hypotheses on the primary factors governing <i>A. marginata</i> survivorship (Nt/No) and biomass in the low intertidal. Models, with varying numbers of parameters (K), were compared using small sample, bias-corrected Akaike Information Criterion (AICc), AICc differences (Δ AICc), and normalized Akaike weights (w_i).	45

Table 2.3 The relative importance of maximum wave exposure and *K. tunicata* density on the current spatial variation in *A. marginata* survivorship and biomass in the low intertidal. Relative importance was based on variable weights which were calculated by summing the Akaike weights (w_i) over the subset of models for a specific response in which a variable was found. The sign of each variable coefficient in parentheses indicates the direction of the relationship between the response and each variable. 45

Table 2.4 Experimental arenas reveal the varying population-level effects of *K. tunicata* on *A. marginata* spring sporeling density, summer biomass and species richness across sites varying in ambient *K. tunicata* densities.....46

Table 2.5 We did not detect an effect of ambient *K. tunicata* density and/or wave exposure on *K. tunicata*'s per capita impact on *A. marginata* spring sporeling density or summer biomass dynamics based on small sample, bias-corrected Akaike Information Criterion (AICc). Models, with varying numbers of parameters (K), were compared using AICc differences ($\Delta AICc$), and normalized Akaike weights (w_i).46

Table 2.6 The relative importance of maximum wave exposure and ambient *K. tunicata* density on *K. tunicata*'s per capita effect on *A. marginata* dynamics was low, as reflected by the low variable weights, whether interaction strength was calculated based on spring sporeling density or summer biomass. The sign of each variable coefficient in parentheses indicates the direction of the relationship between the response and each variable.....47

List of Figures

<p>Figure 1.1 A&B) This research was conducted on the outer Kenai Peninsula, Alaska, at (C) eleven rocky intertidal sites surrounding the Sugpiaq native villages of Port Graham and Nanwalek, Alaska. The sites differ in their accessibility to human harvesters and consequently encompass a gradient of shoreline collection effort. 1.Point Pogibshi, 2. Coal Mine, 3.Otter Rock, 4.Romanoff, 5.Inner Nanwalek, 6.Outer Nanwalek, 7.Flat Island, 8.Magnet Rock, 9.Golden Rocks, 10.Jagged Rocks, 11.Point Adams</p>	25
<p>Figure 1.2 Present-day spatial variation in A) black leather chiton (<i>K. tunicata</i>) density, B) annual per capita shoreline collection effort, and C) sea otter presence. Sites are ordered according to shoreline collection effort; from most heavily harvested to least heavily harvested.</p>	26
<p>Figure 1.3 A&B) Synergistic serial depletion of marine invertebrates from 1920 to 2000 revealed through traditional ecological knowledge. B) Mass of subsistence marine invertebrates landed per capita in Nanwalek and Port Graham, Alaska from 1987 to 1997.</p>	27
<p>Figure 1.4 Interaction modification (---→) by alternative prey (N_2) reduces the per capita effect of its consumer, human and sea otter predators (→) on chiton density (N_1).....</p>	28
<p>Figure 2.1 In south central Alaska, B) on the tip of the Kenai Peninsula, rocky intertidal community structure was compared across C) eleven sites () varying in wave exposure, human shoreline collection effort and sea otter predation pressure. Experimental <i>K. tunicata</i> removals were conducted at 5 sites () varying in ambient <i>K. tunicata</i> densities. Site names: 1.Point Pogibshi, 2.Coal Mine, 3.Otter Rock, 4.Romanoff, 5.Inner Nanwalek, 6.Outer Nanwalek, 7.Flat Island, 8.Magnet Rock, 9.Golden Rocks, 10.Jagged Rock, 11.Point Adams, and 12.Jagex.....</p>	48
<p>Figure 2.2 <i>K. tunicata</i> density in 2003 and 2004 across eleven sites varying in wave exposure, human harvest effort and sea otter presence. Sites are ordered according to shoreline collection effort; from most heavily harvested to least heavily harvested. From Salomon 2006b.</p>	49
<p>Figure 2.3 A comparison of rocky intertidal invertebrate and algal community structure in A) 2003 and B) 2004 by nonmetric multi-dimensional scaling (NMDS). Each site is represented by a unique symbol, whereas low (≤ 2), medium (3-6), and high (≥ 7) <i>K. tunicata</i> densities per 0.25m² quadrat are represented by white, grey and black symbols respectively.</p>	50
<p>Figure 2.4 <i>A. marginata</i> A) survivorship and B) biomass as a function of ambient <i>K. tunicata</i> densities. <i>A. marginata</i> survivorship was not quantified at one site (Adams) because no individuals were present to tag.....</p>	51

Figure 2.5 Population-level impact of *K. tunicata* on A) *A. marginata* spring sporeling density, B) *A. marginata* summer biomass and C) species richness based on data from experimental arenas constructed at 5 sites varying in ambient *K. tunicata* densities. 52

Figure 2.6 Population-level impact of *K. tunicata* on intertidal community structure based on species-specific biomass estimates from experimental arenas constructed at 5 sites varying in ambient *K. tunicata* densities. Each site is represented by a unique symbol. Experimental treatments precluding *K. tunicata* are represented by white symbols whereas experimental controls which allowed *K. tunicata* access are represented by black symbols. 53

Figure 2.7 Per capita interaction strength of *K. tunicata* on *A. marginata* dynamics as a function of ambient *K. tunicata* (predator) density. Empirical field experiment estimates (●) and bootstrapped means (X) ± standard deviations are shown. Regressions were performed on empirical per capita interaction strength estimates. Interaction strength depicted here was calculated based on *A. marginata* summer biomass, the relationship based on *A. marginata* spring sporeling density was practically identical. 54

EXECUTIVE SUMMARY

On the rocky shores of the outer Kenai Peninsula, Alaska, the black leather chiton, *Katharina tunicata*, remains an important traditional subsistence food source for Sugpiaq Natives. Known locally as ‘bidarki’, this recognized keystone grazer has declined in density and size over the past 10-15 years in Port Graham Bay. This is the most recent in a series of nearshore benthic invertebrate declines and marine ecosystem changes observed by local residents. To investigate the ecological and socioeconomic causes and consequences of *K. tunicata*’s localized reductions, we used a combination of intertidal field surveys, experimental manipulations, and the documentation of traditional knowledge held by the Elders of Port Graham and Nanwalek. Large-scale field surveys across 11 sites, spanning over 50 km of coastline, were used to quantify the major top-down (humans, sea otters, avian predators, sea stars) and bottom-up (wave exposure, ocean temperature, macroalgal production) drivers of change in the nearshore. These surveys were also used to describe differences in intertidal community structure subject to these dominant drivers of change. Small-scale field experiments were used to compliment these surveys and more precisely examine the causal mechanisms driving changes in the nearshore. Semi-directed interviews with village elders and surveys with village residents were used to document traditional ecological perspectives on historical trends and use of coastal marine subsistence resources in Port Graham Bay. In combination, these methods revealed novel insights into the causes of nearshore marine ecosystem change on the Kenai Peninsula, AK.

Based on interviews with village Elders, localized bidarki declines can be attributed to a change in social and biological dynamics. Historical subsistence harvest differed in several ways from today’s practices: harvest was less spatially concentrated because communities shifted among seasonal camps and diets included a wider range of invertebrates, such as crab, sea urchins, sea cucumbers, octopus, clams and cockles. These resources are now scarce, likely due to intensified consumption by an increasing sea otter population and historical subsistence and commercial harvest. Traditional ecological knowledge revealed that these benthic invertebrates declined serially and provided a likely mechanism for the current bidarki decline. Sequential prey switching by both humans and sea otters from most accessible preferred prey to least accessible and less preferred prey likely resulted in a restriction in alternative prey species breadth thereby leading to intensified harvest of *K. tunicata*. Therefore, the recent localized depletion of this keystone grazer and its subsequent ecosystem-level effects may reflect a concentration in the spatial distribution of harvest pressure and the synergistic serial depletion of various nearshore benthic invertebrates.

Strong evidence from our field surveys suggests that the present-day spatial variation in *K. tunicata* density and biomass in the low intertidal is driven by a combination of human harvest and sea otter predation, with the relative magnitude of these top-down factors varying among sites. There was weak evidence that avian predation played a role in the spatial variation of *K. tunicata* in the low intertidal although its importance was somewhat greater in the high intertidal. The importance of wave exposure as a structuring force governing *K. tunicata* populations only became apparent in the high intertidal when *K. tunicata* size was taken into account with our estimate of biomass; site-specific *K. tunicata* biomass was greater at more wave exposed sites. As

there was little to no difference in ocean temperature and algal growth among sites, there was no evidence that these factors contributed to the differences in spatial distribution of *K. tunicata* observed in this study.

We provide evidence that *K. tunicata* is a strongly interacting species that drives nearshore community dynamics in the rocky intertidal zone of the Kenai Peninsula, Alaska. Strongest evidence of this came from our removal experiments conducted at sites with relatively high densities of this chiton (28-38 m⁻²). At these sites, *K. tunicata* reduced *A. marginata* spring sporeling density by 94%, *A. marginata* standing stock biomass by 98%, and species richness by 38%. However, at sites with extremely low *K. tunicata* density (6 m⁻²), this chiton became functionally unimportant. These experimental results lead to predictions that community structure and function should differ substantially among sites with different densities of *K. tunicata*. Indeed this was the case. *A. marginata* survivorship was 3 times greater in exploited versus unexploited sites and *A. marginata* biomass was up to 7 times greater in exploited versus unexploited sites. Furthermore, the least exploited site, Adams, where *K. tunicata* densities were highest, had an extremely different species assemblage compared to highly exploited sites of similar wave exposure. This difference in community structure was driven by the near absence of *A. marginata*, an annual kelp, and the dominance of *H. sessile*, a perennial kelp, further illustrating the important role *K. tunicata* plays in altering nearshore benthic primary production. Because *K. tunicata* reaches low densities at sites heavily exploited by humans and/or sea otters these results provide evidence of a trophic cascade.

A unique aspect of this research project has been its strong tribal involvement; from the onset of question development, to field data collection, through to preliminary analysis and interpretation. Because of its cultural significance, this research illustrates how humans, marine resources, and the ecosystems in which they are embedded interact as social- ecological systems. Our research showcases the insight ecologists can glean from involving local communities and delving into both ecological and social history.

This final report is comprised of three chapters, the first two are based on manuscripts prepared for publication in academic journals while the last chapter is a manuscript for a book to be published by Alaska Sea Grant. The first chapter addresses the causes of localized bidarki declines. The second chapter focuses on the ecological consequences of this decline. Finally, the third chapter, written for the general public, describes observed changes to the nearshore ecosystem of south central Alaska and their possible causes from the perspective of traditional knowledge holders, a marine ecologist and an anthropologist. In sum, there are clearly both natural factors and anthropogenic impacts that influence the rocky shorelines of the Kenai Peninsula. This research has quantified their relative importance and now provides a baseline against which to judge future environmental change.

**SYNERGISTIC SERIAL DEPLETION OF MARINE INVERTEBRATES LEADS TO THE DECLINE
OF A KEYSTONE GRAZER**

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Abstract

Identifying the causes of species declines is a prerequisite for devising effective conservation measures. Because ecosystems are affected simultaneously by multiple drivers of change, ecologists must weigh the strength of evidence among competing hypothesized causes of declines, often in the absence of baseline data. On the outer Kenai Peninsula, Alaska, we investigated the relative roles of natural factors and shoreline harvest leading to recent declines of the black leather chiton (*Katharina tunicata*). This intertidal invertebrate is a local subsistence food source and a recognized keystone grazer. We took two approaches to determining causes of decline: a space-for-time substitution examining the significant predictors of *K. tunicata* density and biomass across 11 sites; and a survey of traditional ecological knowledge (TEK), supported by archeological and other historical data sources concerning changes in organism abundance and human behavior. Strong evidence suggest that current spatial variation in *K. tunicata* density is significantly related to human exploitation and sea otter (*Enhydra lutris*) predation. The important roles of these two predators were corroborated by TEK. Interviewees consistently pointed out that several benthic marine invertebrate species have sequentially declined, with reduced densities and sizes of *K. tunicata* being the most recent. The timing of these declines was coincident with changes in human behavior – central-place foraging, commercial exploitation, extractive technologies, end of culturally-based season and size restrictions – and with the reestablishment of sea otters. We propose that sequential prey switching by both humans and sea otters and a resulting restriction in alternative prey species availability has led to intensified per capita predator impacts on *K. tunicata*. Therefore, the recent localized depletion of this keystone grazer may reflect a historical concentration in the spatial distribution of shoreline collection pressure and the synergistic serial depletion of several nearshore benthic invertebrates.

INTRODUCTION

Competing hypotheses are often implicated in the decline of marine species. Because effective conservation plans and sustainable fisheries strategies necessitate that the causal mechanisms driving declines be identified, a strong impetus exists to scrutinize the strength of evidence for alternative causes (NRC 1999, 2003). This presents an enormous challenge because ecosystems are affected simultaneously by multiple drivers of change, both top-down and bottom-up (Fretwell 1977, Oksanen et al. 1981), anthropogenic and natural (Dayton et al. 1998), varying in magnitude and spatial extent (Levin 1992). Furthermore, present day perturbations operate within the context of historical alterations (Lewontin 1969) and lastly, drivers of change can interact, leading to complex and often synergistic effects (Hilborn and Stearns 1982, Paine et al. 1998). Here we examine the multiple factors driving the recent decline of a nearshore benthic invertebrate, the black leather chiton, *Katharina tunicata*, the latest in a series of marine invertebrate declines reported on the rocky shores of the outer Kenai Peninsula, Alaska.

In marine systems, species declines are often attributed to both top-down and bottom-up forces which can be either anthropogenic or natural. For example, the effects of fishing, natural predators and/or large-scale forcing functions (e.g. Pacific Decadal Oscillation) have been implicated in the collapse of Steller sea lions in Alaska (NRC 2003), Peruvian anchoveta off South America (Clark 1981), and Atlantic cod in Canada (Hutchings and Myers 1994, Mohn and Bowen 1996, Swain and Sinclair 2000). Distinguishing between these drivers of change in marine systems is difficult because food webs are complex and typically not well understood (Larkin 1978), natural forcing functions are dynamic and highly variable (Francis et al. 1998), fishing effort is widespread in space and time (Pauly et al. 2002), and true controls and replicates are often absent (Ludwig et al. 1993). Furthermore, emphasis on selected declines species-by-species or stock-by-stock can lead to a myopic perception of what is in fact a complex system and can thus mask more general phenomena such as serial depletions.

The serial decline of marine resources is a symptom of ecosystem overfishing (Murawski 2000). Typically, fisheries first target the most lucrative stock and subsequently switch to the next most profitable stock once the former has shown signs of depletion. This economic switch-point occurs when the marginal value of a stock becomes too small to make fishing it worthwhile. This mechanism has been proposed for the sequential decline of crustaceans in the Gulf of Alaska (Orensanz et al. 1998) and abalone species in California (Karpov et al. 2000). A progression of multi-species declines can also emerge when non-human predators switch among alternative prey, from most preferred and available to least preferred and rare. The concept of prey switching by predators, a common phenomena in natural systems (Holling 1959, Holt and Lawton 1994), has been proposed as one possible mechanism driving the consecutive decline of marine mammals in the north Pacific Ocean and Bering Sea (Springer et al. 2003). Sequential declines are particularly difficult to identify because research tends to consider species singly over short periods of time. Furthermore, multiple causation, possible synergisms among drivers of change, and a paucity of historical data tend to obfuscate the causal mechanisms driving serial declines. Consequently, identifying the causes of serial depletions highlights the importance of a broad ecosystem approach, the use of multiple data sources, and historical analysis.

Historical analysis is particularly important to avoid the syndrome of shifting baselines, in which the lack of past information can lead to underestimates of overall declines (Pauly 1995, Dayton et al. 1998, Jackson et al. 2001). Many changes predate ecological investigations, but, retrospective analyses of paleoecological, archeological, and traditional ecological knowledge data sources can sometimes fill this gap. Despite its lack of quantitative precision, ecological knowledge held by resource users, local residents, and others familiar with an ecosystem, can provide early accounts of factual observations on the presence, absence, and/or relative abundances of various species at particular points in time (Johannes 1998). Given their familiarity with an ecosystem and an awareness of its peculiarities, subsistence users can also offer a synthesis of relative timing and rates of ecosystem change, raise entirely new scientific questions, or propose alternative testable hypotheses unconstrained by academic dogma (Johannes 1981, Dayton and Sala 2001). Unlike other retrospective methods, subsistence users can simultaneously offer insight into the key processes governing ecosystem dynamics and the socio-economic factors driving their own behavior as predators.

In temperate nearshore ecosystems, humans (Castilla and Duran 1985), sea otters (Estes and Palmisano 1974), sea stars (Paine 1966), and shorebirds (Wootton 1992) are all predators known to directly and indirectly alter rocky intertidal community dynamics. The first two have been implicated in dramatic localized depletion of nearshore invertebrate species and ecosystem change (Simenstad et al. 1978, Castilla and Bustamante 1989, Duggins et al. 1989). To develop effective conservation plans, understanding keystone predator dynamics is essential (Soule et al. 2005). Because ecosystems are driven by coupled ecological, and socio-economic dynamics (Carpenter and Gunderson 2001), in which humans play the role of keystone predator, a strong need exists to comprehend human behavior and the socio-economic factors that motivate it (Ludwig et al. 1993).

On the rocky shores of the outer Kenai Peninsula, Alaska, the black leather chiton, *Katharina tunicata*, is an important traditional subsistence food source for the Sugpiaq people (who are also known as Aluttiq) (Stanek 1985, Chugachmiut 2000). Known locally as ‘bidarki’, this recognized keystone grazer (Paine 1992, 2002) was harvested by early inhabitants in this area as suggested by shells found in middens in neighboring Kachemak Bay dated to 1000 BC (de Laguna 1975, Klein 1996). Local Sugpiaq elders report that villagers have been harvesting this chiton for at least the past century. However, local declines of *K. tunicata* density and size were first observed 10-15 years ago, despite little human population growth in the area at that time (US Census 2000, Brown et al. 2001). Elders further report that sea otters were absent locally in the early 1900s but began to reestablish by the early 1960s.

In collaboration with two Sugpiaq villages, Port Graham and Nanwalek, we examined the relative roles of top-down and bottom-up natural factors (sea otter predation, bird predation, prey production, ocean temperature and wave exposure) and anthropogenic perturbations (shoreline Bidarki collection by humans) proposed by both village residents and ecologists as causal factors driving *K. tunicata* decline. We quantified the present day spatial variation in *K. tunicata* and the factors listed above to examine the strength of evidence among alternative hypothesized causes of black leather chiton declines. We then used historical records and semi-directed interviews with Sugpiaq elders to document historical trends in relative nearshore invertebrate

abundances, changes in subsistence harvest practices, and the socio-economic drivers that likely triggered them.

METHODS

Study area

This research was conducted in south central Alaska, at 11 sites located on the rocky shores of the outer Kenai Peninsula, surrounding two Sugpiaq villages, Port Graham and Nanwalek (Fig.1.1A, B&C). Sites were identified by tribal elders to span a gradient in *K. tunicata* subsistence collection effort. Consequently, sites were located at varying distances away from the villages, from heavily exploited accessible sites located close to the villages, to less accessible, moderately exploited sites located further from the villages (Fig.1.1C). Although officially established in the early 1880s by Russian missionaries, these two Native villages existed as fur trading posts in the late 1700s and likely as seasonal camps since people began to inhabit the area as early as 5000 years ago (de Laguna 1956, Klein 1996, Crowell et al. 2001). Archaeological excavations reveal that historical village sites in the neighboring southern shores of the Kenai Peninsula, from which the ancestors of Nanwalek and Port Graham residents came, are approximately 800 years old (Crowell and Mann 1996).

Spatial variation in K. tunicata

We quantified *K. tunicata* density and size structure in June 2003 and 2004 by measuring the maximum length of all *K. tunicata* individuals found in ten 0.25m² quadrats randomly stratified along a 50 m transect line placed at two tidal elevations representing *K. tunicata* preferred habitat (O'Clair and O'Clair 1998) (n=10 low & 10 high quadrats per site). Intertidal elevation was based on biological assemblages; low quadrats were placed in the middle of the *Alaria* and *Hedophyllum* zone, and high quadrats were placed in the middle of the *Endocladia* zone. This was done to ensure that *K. tunicata* habitat was adequately sampled given that *K. tunicata* size was observed to vary with tidal elevation. *K. tunicata* biomass was estimated from a length-weight regression: $Biomass(g) = 6 \times 10^{-5} (Length)^{2.9834}$ (n=466, R²=0.942).

Present- day factors governing spatial distribution of K. tunicata

We quantified the dominant bottom-up and top-down factors suggested by ecological theory and TEK to influence *K. tunicata* density. Bottom-up factors include macroalgal production and several physical factors (wave exposure, water temperature). Top-down factors include human collection effort and predation by other animals (sea otters, birds, sea stars). Examining the significant predictors of *K. tunicata* density and biomass across 11 sites represents a space-for-time substitution to inform recent *K. tunicata* declines.

We quantified the current spatial variation in subsistence collection of *K. tunicata* among the 11 sites by opportunistically surveying 39 village residents. Harvest surveys we conducted with a map of the area and a fixed questionnaire such that local residents

could identify where they currently and previously harvested and for how many low tides a year. We also documented locally observed trends in *K. tunicata* density and size structure. This allowed us to estimate the timing of *K. tunicata* decline and the typical sizes harvested both presently and in the past, pre-decline. We also recorded local ecological observations and perceptions of the main factors driving changes in *K. tunicata* populations.

Site-specific sea otter and bird presence was estimated based on sightings made on the approach to each site and during each site visit within 100m. Sightings were conducted in 2003 & 2004 for sea otters (*Enhydra lutris*) and in 2004 for known avian predators of *K. tunicata*: Glaucous winged gulls (*Larus hyperboreus*), black oystercatchers (*Haematopus bachmani*) and crows (*Corvus brachyrhynchos*). We quantified densities of dominant predatory sea stars (*Leptasterias* spp.) and predatory snails (*Nucella canaliculata*, *Ocenebrinus*, *Lirabuccinum*, *Fusitriton*) by recording individuals in ten 0.25m² quadrats, randomly stratified along the low intertidal transect line at each site.

We measured growth rates of the dominant benthic macroalga, *Alaria marginata*, the primary food source consumed by *K. tunicata*. Thirty individuals per site were tagged with small zip ties and vinyl numbered tube tags secured around their stipe, below their sporophylls. Initial length and maximum width was measured. We estimated growth rates by punching two small holes, one on either side of the kelp blade's midrib, 1 cm above the meristem, and returning 1 tide series later to measure the distance between the punched holes and the meristem (=growth) (Pfister and Stevens 2002). This allowed us to quantify absolute growth rates (growth/time) and relative growth rates (growth/time × 1/length_{initial} × width_{initial}).

To quantify site specific wave exposure, a factor well known to influence intertidal community assemblages, recruitment and population size structure (Dayton 1971, Menge and Sutherland 1987), we used three maximum wave force recorders (Bell and Denny 1994) deployed and revisited five times per site in June 2005. On each visit, spring extensions were measured to the nearest 0.5 mm and reset. Spring extension data collected in the field were converted into maximum wave force (Newtons) with calibration curves established earlier in the lab. When drag forces were too small to cause observable spring extension, we assumed maximum wave force values equivalent to the minimum force required to overcome initial spring compression. We estimated differences in wave exposure among sites based on the average maximum wave force recorded over the sampling period. We also ranked sites in terms of wave exposure based on the maximum wave force experienced at each site over the sampling period.

Because temperature is known to influence species interactions on a local and regional scale (Sanford 1999) and alter the effects of intertidal exploitation (Harley and Rogers-Bennett 2004), we measured site specific sea surface temperature (SST) from June to September 2004 with temperature loggers placed at mean low water (MLW). To estimate daily SST, we averaged the temperatures recorded every 90 minutes during daily high tides when sea level was ≥ 3 m above MLW. Monthly averages were calculated based on daily SST.

Changes over time

To more thoroughly explore the causes of *K. tunicata* decline, we conducted semi-directed interviews (Huntington 2000) with 10 tribal elders to document historical trends in nearshore ecosystem dynamics including changes in subsistence shellfish resources and harvest practices, commercial fishing effort, social and economic drivers, and species interactions both locally near the villages and regionally in the outer Kenai Peninsula and Gulf of Alaska. The elders were selected by recommendation from village Tribal Councils and by chain-referral (one respondent suggesting others whom we should contact). In the semi-directive interview, researchers identify a set of topics to be addressed, but the respondent can pursue his or her lines of thought rather than being constrained by the format of a questionnaire. In this way, the respondent may indicate connections or additional information that the researchers did not or could not have anticipated. Furthermore, the course of the interview can follow the respondent's understanding of the topic, rather than the researchers' views.

We used the information from the interviews in two ways. First, we identified historical observations, both ecological and socio-economic, and developed a timeline of events and trends together with an explanatory narrative. The timeline and narrative were presented to the elders and others in both communities to confirm the information and interpretation. Second, we developed a set of hypotheses proposed by the elders to explain the observed invertebrate declines. These hypotheses were also presented to the elders and others for confirmation, and were used in our analysis.

Temporal variation in subsistence shellfish landings

We compared the traditional knowledge of marine invertebrate trends in relative abundance with invertebrate subsistence landings data from 1987 and 1997 derived from the Community Profile Database maintained by the Subsistence Division of the Alaska Department of Fish and Game (Brown et al. 2001). Invertebrate landings data from both villages, Nanwalek and Port Graham, were pooled. These data we used to calibrate the documented TEK. Estimates of human population size, pooled for both villages, were derived from the ADF&G Community Profile Database, the US Census Community Database and Chugachmiut (USCensus 2000, Brown et al. 2001, Luken 2006).

Statistical Analysis

We analyzed differences in count data among sites and years with generalized linear models (GLZs) which assumed a Poisson error distribution and a log link function, fit by maximum likelihood (SAS Proc Genmod V 9.1.3). Non normal, non Poisson data were normalized with a log (x+1) transformation and differences among sites were analyzed with GLZs assuming a normal error distribution and an identity link function, fit by maximum likelihood. We analyzed differences in monthly sea surface temperatures among sites with a repeated measures GLZ and generalized estimating equations (GEEs). Post hoc comparisons were made based on Bonferroni adjusted p-values. Linear regressions were used to quantify the relationship between harvest pressure and *K. tunicata* density and biomass. Differences in present and pre-decline *K. tunicata* sizes

typically harvested in traditionally harvested areas were analyzed with a two-tailed, paired t-test as data was normally distributed with equal variances.

To assess the relative importance of various factors contributing to current spatial differences in *K. tunicata* density, we took an information theoretic model selection approach (Burnham and Anderson 1998) and compared alternative candidate models of *K. tunicata* density and biomass as a function of 4 variables; harvest pressure, sea otter presence, bird presence and wave exposure. These models, derived from integrating traditional knowledge and western science, represent *a priori* competing hypotheses regarding the primary factors governing the present spatial variation in *K. tunicata*. This approach was taken over standard multiple-regression because the latter is sensitive to stepwise selection criterion, direction of fitting and variable order. These 4 variables were chosen out of eight possible variables because they varied significantly among sites and were reasonably expected to affect *K. tunicata* distributions. We used averages in *K. tunicata* density and biomass and sea otter presence across years (2003 & 2004) when constructing each model.

We ranked candidate models based on small sample corrected Akaike's Information Criterion (AICc) which we standardized to the best fit model to produce ΔAICc values. We normalized the likelihoods to a set of positive Akaike weights (w_i) representing the strength of evidence in favor of a given model. The level of empirical support for a model is substantial when ΔAICc is ≤ 2 and $w_i \geq 0.9$. We examined the relative importance of each variable based on variable weights by summing the Akaike weights (w_i) of all of the models in which a variable was found (Burnham and Anderson 1998). This allowed us to assess the weight of evidence among the competing hypotheses on the present day causes of *K. tunicata* decline. Given that 4 explanatory variables were used to construct all possible model combinations, a total of 16 models were compared for low and mid intertidal estimates of *K. tunicata* density. We reported the top 5 models for each response variable.

RESULTS

K. tunicata abundance

K. tunicata density in the low intertidal varied significantly among sites with no site difference between years but with a significant site by year interaction (Fig.1.2A, Table 1). Spatial variation in low intertidal *K. tunicata* biomass, integrating both density and size structure, followed a similar pattern (Table 1.1). Compared to the most heavily harvested site, Inner Nanwalek, densities of chitons in 2004 were 6.1 & 7.5 times greater at two rarely harvested sites (Jagged and Adams) (Fig.1.2A), while biomass was 6.5 to 8.7 times greater. Compared to the low intertidal, *K. tunicata* densities in the high intertidal were greater but the average size was smaller. Density and biomass of *K. tunicata* recorded in the high intertidal varied significantly among sites and years with a significant site by year interaction (Table 1.1).

Current subsistence collection effort, behavior & observations

The spatial variation in current day shoreline collection effort varied significantly among the 11 sites such that the most heavily harvested site, Inner Nanwalek, experienced 60 times more collection effort than Adams, the least harvested site (Fig.1.2B, Table 2). However, in the low intertidal harvest pressure alone explained only 22% of the spatial variation in *K. tunicata* density ($df=10$ $F=2.56$, $P=0.14$) and only 18% of the spatial variation of *K. tunicata* biomass ($df=10$, $F=1.97$, $P=0.19$) across 2003 & 2004.

Out of 39 village residents surveyed, 100% currently collect and consume *K. tunicata*. 66% of residents ($n=38$) had observed a decline in the density of this chiton, while 29% had observed no change and 5% had observed an increase in density. Additionally, 89% of those surveyed had observed a decline in *K. tunicata* size. Declines in numbers were first observed 9 years ago ± 1.3 yrs ($n=20$), while declines in size were first observed 6.4 years ago ± 1.1 yrs ($n=24$). Among surveyed residents 30 yrs old and older, the typical length of *K. tunicata* collected in 2004 from traditionally harvested sites was 25mm smaller than those collected 20 years ago, pre-decline ($n=20$, $t=-5.138$, $P<0.0001$). This difference in past and present mean size collected declined but remained significant when residents who now harvest at previously unharvested sites further from the village were included ($n=23$, $t=-3.329$ $P<0.002$). 46% of village resident surveyed ($n=37$) currently send *K. tunicata* to relatives residing outside of the village, within Alaska and to states as far away as New Hampshire.

Non-human predators

Sea otter presence varied significantly among sites and between years (Fig.1.2C, Table 1.2). In 2003, sea otter sightings were 20 times greater at Otter Rock than Outer Nanwalek and 37.5 times greater in 2004. Sea otter presence was second highest at Coal Mine. Generally, more sea otters were sighted per site in 2004 than 2003. Bird presence also varied significantly among sites (Table 1.2). Flat Island, the location of a gull colony and several oyster catcher nests, had 286 times more shorebird sightings than Adams, the site with the fewest bird sightings. *K. tunicata* shells were found scattered around gull nests located on nearby island cliffs. Densities of the dominant sea star (*Leptasterias* spp.) and predatory snails varied significantly among sites and the former varied significantly among years (Table 1.2).

Macroalgal productivity & physical factors

The relative growth rate of the dominant low intertidal macroalga, *Alaria marginata*, did not vary significantly among sites (Table 1.2), although absolute growth rates ranged from 1.10 ± 0.05 cm/day (Otter) to 2.9 ± 0.18 cm/day (Jagged). Generally, sites experienced similar sea surface temperatures (SSTs) from June to August 2004, although in June, Point Pogibshi was significantly cooler than the other sites and experienced temperatures up to 4.3°C cooler than the warmest site, Flat Island. This temperature discrepancy disappeared by August. Water temperatures varied significantly among months; June ($7.8^{\circ}\text{C} \pm 0.1$), July ($9.6^{\circ}\text{C} \pm 0.2$), August ($11.1^{\circ}\text{C} \pm 0.2$) (Table 2), with August SST being on average $3.3^{\circ}\text{C} \pm 0.4$ greater than June SST. Wave exposure

varied significantly among sites (Table 1.2) and ranged from 43.4 N (Golden) to < 3.9N (Romanoff, Otter, Inner).

Current factors governing spatial variation in *K. tunicata*

There was substantial evidence that harvest pressure and sea otter presence were the two most influential variables describing the spatial variation in *K. tunicata* density and biomass in the low intertidal and *K. tunicata* density in the high intertidal. For these three response variables, harvest pressure in combination with sea otter presence comprised the best fit models, indicated by their high Akaike weights (w_i) (Table 1.3). Individually, these two factors had the greatest variable weights in all 3 cases (Table 1.4). Furthermore, their relative importance was practically equal. However, the importance of wave exposure was considerable when predicting high intertidal *K. tunicata* biomass, a metric that captures both density and size structure (Table 1.3&4). The strength of evidence for the effect of bird presence on *K. tunicata* density and biomass was weak, although it was more important in the high intertidal than the low intertidal.

Historical, ecological and socio-economic observations and local hypotheses

Historical ecological and socio-economic data collected from Sugpiaq elders and tribal members highlighted temporal changes in the relative abundance of invertebrate resources, changes in subsistence use, and sea otter presence (Fig.1.3A, Table 1.5). These data revealed a serial decline of marine invertebrates beginning in the early 1960s with the recovery of local sea otter populations and intensifying with increased human harvest effort and efficiency (Table 1.5). According to local observations, green sea urchin (*Strongylocentrotus droebachiensis*) were the first invertebrate to decline in the 1960s followed by sea cucumber (*Cucumaria* spp.) and gumboot chitons (*Cryptochiton stelleri*) locally known as 'lady slippers'. Crab (*Cancer magister*, *Chionoecetes bairdi*) and shrimp (*Pandalus* spp.) then declined in the late 1970s to mid 1980s followed by clams (*Protothaca staminea*, *Saxidoma* spp.) and cockles (*Clinocardium nuttallii*). Black leather chitons, *K. tunicata*, are the most recent in a chain of declines (Fig.1.3A). Ecological knowledge holders offered alternative hypotheses regarding causes of historical marine invertebrate declines and current *K. tunicata* reductions (Table 1.6). Based on TEK, archeological and historical records, we suggest five important historical events which likely elicited the serial decline of marine invertebrates in Port Graham Bay, Alaska:

1) Spatial restriction of human impacts

Prior to the Russian occupation in the 1780s, Sugpiaq people moved among seasonal camps and sought food where it was available (Cook and Norris 1998, Langdon 2002). With the arrival of the Russian fur traders, both commercial fur trading companies and the Russian Orthodox Church sought to centralize services in larger villages. Thus, regional consolidation led to the demise of smaller seasonal villages and the creation of larger, more permanently established villages. As a result, subsistence collecting and hunting became increasingly spatially concentrated likely leading to increased local impacts on marine invertebrate resources (Table 1.6). One hundred years later, in the late 1880s, commercial fishing and canneries gradually replaced fur trading as the major

source of local income. By centralizing jobs in canneries, subsistence hunting and shoreline collection effort became increasingly concentrated in space likely leading to increased impacts on marine invertebrates once again.

2) Extirpation and subsequent recovery of sea otters

Due to the lucrative fur trade, sea otter became locally extirpated from Alaska's coastline by the early 1900s with only several pockets of animals remaining (Estes and Palmisano 1974). From the early 1900s to the late 1950s, sea otters were never observed in Port Graham Bay or its surrounding rocky shores by today's elders (Table 1.5). However, sea otter invertebrate prey, including sea urchins, crab, clams, cockles, octopus and chitons, were abundant and kelp beds were sparse (Table 1.5). In the near absence of this keystone predator, invertebrate prey populations likely flourished from Alaska down to California throughout the early 1900s (Tegner and Dayton 2000).

With the protection of sea otters in 1911 under the Fur Seal Treaty Act, this keystone predator began to recover along Alaskan coastlines. They returned to the nearshore of Port Graham and Nanwalek by the early 1960s (Table 1.5). Green sea urchins and sea cucumbers, which were once plentiful on Nanwalek Reef in the 1940s, were mostly gone by the late 1960s.

3) New technologies leading to increased fishing efficiency and effort

With the introduction of the cash economy in the early 1900s, fishing boats which were once wooden dories were gradually replaced by motor boats for fishing and travel, thereby increasing harvest efficiency. By the early 1980s, ten years after the introduction of electricity to the villages, freezers began to be used by subsistence harvesters to store food. This storage ability allowed people to increase their harvest effort and thus local fishing mortality increased (Table 1.5).

4) Regional commercial invertebrate fisheries

In Cook Inlet, commercial crab and shrimp fisheries, whose landings peaked in the early 1960s with inshore harvests in bays like Port Graham Bay (Cook and Norris 1998), required increased effort and movement offshore to maintain harvest levels. By the early 1980s, crustacean stocks began to collapse sequentially (Orensanz et al. 1998). Coincident with the serial collapse of crustaceans in the Gulf of Alaska was a conspicuous shift in benthic species composition from shrimp in the 1970s to ground fish in the 1980s (Anderson and Piatt 1999) and variations in the distribution and abundance of marine mammals and sea birds (Springer et al. 1999), in part attributed to the climatic regime shift of 1977, otherwise known as the Pacific Decadal Oscillation (Mantua et al. 1997). Whatever the cause, these regional declines in crustacean resources were observed locally. In fact, the commercial and recreational Dungeness crab fishery in neighboring Kachemak Bay has been closed since 1990. By the 1980s, Native subsistence users found Dungeness crab increasingly hard to collect while their main competitor, the sea otter, whose populations at the time were thriving, were observed consuming juvenile Dungeness crab, among other invertebrates (Table 1.5).

5) Indirect effects of the *Exxon Valdez* oil spill

The *Exxon Valdez* oil spill in 1989, which spilled approximately 11 million gallons of oil that spread across Prince William Sound through lower Cook Inlet, had dramatic cultural, social and ecological effects in Port Graham and Nanwalek, even though relatively little oil came into Port Graham Bay itself (Table 1.5). People who were hired locally to help with the spill clean up received a lucrative income, which was often spent on new and better boats and outboard motors. Although initially people avoided subsistence foods for fear of oil contamination, subsistence harvest resumed within a few years (Fig.1.3B). With new and better boats, shoreline collectors could visit more beaches per tide and access beaches in previously prohibitive conditions (Table 1.5). Consequently, and ironically, a delayed indirect effect of the spill has been an increase in shoreline harvest efficiency and thus an increase in fishing mortality. Although the spill may have had some direct effects on local marine invertebrates, Elders observed that shellfish declines began prior to the spill (Table 1.5).

Temporal variation in subsistence shellfish landings

The black leather chiton (*K. tunicata*) and Pacific littleneck clams (*Protothaca staminea*) were the primary marine invertebrates harvested from 1987 to 1997 although their collection along with most marine subsistence invertebrate species dropped in 1989, following the Exxon Valdez oil spill (Fig.1.3B). Prior to the spill, from 1987 to 1997, landings of sea urchin (*Strongylocentrotus* spp.), sea cucumber (*Cucumaria* spp.), gumboot chitons (*Cryptochiton stelleri*), Dungeness (*Cancer magister*) and Tanner crab (*Chionoecetes bairdi*), shrimp (*Pandalus* spp.), and mussels (*Mytilus* spp.) were low, remaining below 1 pound per capita harvested per year. In 1992, little neck clam landings began to decline followed by a steep decline in butter clam (*Saxidoma* spp.) landings. Black leather chiton landings remained high throughout this period. These multi-species trends in landings provide strong evidence for the serial depletion hypothesis; alternative prey species consumption by humans was low from 1987 to 1997 while *K. tunicata* consumption remained high in the late 1990s.

DISCUSSION

Present day top-down vs. bottom-up factors

Strong evidence suggests that the present-day spatial variation in *K. tunicata* density and biomass in the low intertidal is driven by a combination of human harvest and sea otter predation (Fig.1.2, Table 1.3&4), with the relative magnitude of these top-down factors varying among sites. There was weak evidence that bird predation played a role in the spatial variation of *K. tunicata* in the low intertidal although its importance was somewhat greater in the high intertidal. At high tidal elevations, *K. tunicata* would be less obscured by macroalgae and exposed to avian predation for greater periods of time. The importance of wave exposure as a structuring force only became apparent in the high intertidal when *K. tunicata* size was taken into account with our estimate of biomass. Site-specific *K. tunicata* biomass was greater at more wave exposed sites (Adams, Jagged, Golden). As there was little to no difference in ocean temperature and

algal growth among sites, there was no evidence that these factors contributed to the differences in spatial distribution of *K. tunicata* observed in this study.

Despite the weight of evidence from field data indicating the strong effects of sea otter and human predation on the present-day variation of *K. tunicata*, causal mechanisms for longer-term trends in the ecosystem became apparent through investigation of deep historical perspective on the coupled ecological, social and economic dynamics of the local and regional marine ecosystem. This was provided by traditional ecological knowledge holders, archeological and historical data sources (Fig.1.3, Table 1.5&6).

Historical ecological & socio-economic events contributing to synergistic serial depletion

Five salient historical changes likely triggered the serial decline of marine invertebrates and localized reductions in *K. tunicata*: spatial restriction of human impacts, return of sea otters, higher per capita impacts from subsistence due to new technologies (e.g. freezers and motor boats), and regional commercial exploitation of benthic marine invertebrates. Additionally, the availability of better transportation after the Exxon Valdez oil spill, has likely indirectly increased the current spatial extent of subsistence harvest impacts.

Recent localized declines of the black leather chiton can be attributed to changes in both social and biological dynamics. Historical subsistence harvest differed in several ways from today's practices. In the past subsistence harvest effort was less spatially concentrated because communities shifted among seasonal camps. With Native village consolidation by the Russians throughout the 1800s and the onset of canneries in the early 1900s, central-place subsistence foraging replaced optimal foraging, although the current use of motor boats may be slowly reversing this trend. The introduction of modern technologies (freezers and better boats) facilitated increased harvest effort and efficiency, contributing to increased fishing mortality. Yet, even with the increased ability to travel with better boats, central-place foraging among subsistence shoreline collectors remains common, particularly in the winter when stored salmon supplies caught the previous spring become low and dangerous weather prohibits travel. Last, subsistence prey items in the 1900s included a wider range of invertebrates, such as crab, sea urchins, sea cucumbers, octopus, clams and cockles because all of these invertebrates were present in abundance. These resources became scarce, likely due to intensified consumption by an increasing sea otter population and rising local subsistence and regional commercial harvest effort.

Given these historical trends, we suggest that the recent localized depletion of *K. tunicata* is a consequence of the serial decline of alternative prey leading to increased per capita predation pressure by both humans and sea otters on *K. tunicata*. Specifically, sequential prey switching by both humans and sea otters from most accessible and preferred prey to least accessible and less preferred prey has led to recent increased mortality of *K. tunicata*. Large-scale drivers of change other than predation (i.e. 1964 earthquake, Exxon Valdez oil spill, Pacific Decadal Oscillation) would have had large-scale regional effects, meaning all 11 sites we surveyed would have been equally affected. However, observed *K. tunicata* declines are localized; fewer and smaller chitons exist at sites accessible to humans or where sea otters sightings are high, whereas,

chiton densities and sizes remain high at sites inaccessible to humans or where sea otter sightings are rare.

Interaction modifications by alternative prey can reduce the per capita impact of a predator on a focal species through predator satiation or increased handling time (Fig.1.4A) (Wootton 2002). We suggest that in the past, the presence of sea urchin, crab, clams, cockles and other alternative benthic invertebrate prey may have reduced the impact of humans and sea otters on *K. tunicata*. Consequently, present-day per capita predation rates of humans and sea otters on black leather chitons are higher because alternative prey are scarce (Table 1.2). Prey switching among alternative prey would provide a mechanism for the phenomenon of serial declines.

The hypothesis of synergistic serial depletion is substantiated by the subsistence invertebrate landings data collected in Port Graham and Nanwalek from 1987 to 1997 (Fig.1.3B). Landings of sea urchin, sea cucumber, mussels, Dungeness crab, Tanner crab, and shrimp were next to nothing in 1987 and remained well below 0.5 pound per capita for the next ten years. Relative to these invertebrates, a greater biomass of clams and cockles were landed in 1987 yet landings of these bivalves began to decline by the early 1990s. Unlike the echinoderm, crustacean and bivalve landings, the per capita pounds of black leather chitons harvested were greater in 1991 and 1992 compared with 1987 and have remained high, despite the dip in 1989 due to the oil spill.

Diet breadth and prey preferences of predators are generally assumed to remain constant. However, increasing evidence suggests that behavioral flexibility by predators is a common phenomenon (Estes et al. 2004). Evolutionary theory implies that consumers have evolved flexible responses to varying environmental conditions, such as the ability to substantially alter foraging strategies and food sources. Like sea otters, fishermen tend to switch 'targets' as relative abundance and market values change. This reinforces the importance of understanding predator behavioral dynamics for effective marine conservation planning.

Compounding social causes of invertebrate decline

Certainly, present day causal mechanisms other than overharvest and sea otter predation have contributed to black leather chiton declines (Table 1.6). Elders point to the deterioration in information transfer to the younger generation of harvesters as a critical problem leading to overall resource declines; harvest sizes deemed acceptable by younger harvesters are shrinking (i.e. shifting baselines), furthermore, traditional subsistence management practices such as seasonal restrictions are no longer being adhered to. With European colonization and the introduction of the western cash economy, cultural erosion was dramatic and remains a pivotal social issue facing native villages in Alaska today.

Furthermore, the effective human predator population size is often greater than the local human population size. Teenagers and young adults often leave the villages for city centers yet are still sent subsistence sea food items in the mail (Table 1.6). This once again illustrates the importance of understanding the social dynamics motivating human predator behavior and per capita harvest rather than focusing solely on predator impacts as a function of density alone.

Legacy of prehistoric human alterations of northern ecosystems

Undoubtedly, human-induced species declines and ecosystem alterations occurred with the early aboriginal occupation of Alaska and the High Arctic. For example, prehistoric whaling settlements in the Canadian arctic markedly changed the water chemistry of nearby lakes and ponds, a legacy still evident in present-day nutrient concentrations and atypical biota (Douglas et al. 2004). By 1741, the year of European contact in Alaska, herbivorous sea cows, once widely distributed across the northern Pacific Rim through the late Pleistocene, persisted only on the Commander Islands, the only islands in the Aleutian Islands unoccupied by aboriginal people (Estes et al. 1989). Midden remains from Amchitka Island, Alaska suggest that aboriginal Aleuts greatly reduced local sea otter populations leading to alternative ecosystem states (Simenstad et al. 1978). On the tip of the Kenai Peninsula, humans have occupied and exploited the resources as skilled mariners for at least 5000 years before present (Crowell et al. 2001). The declines observed today, in part reflect human exploitation from the past.

Anecdotes as data and the importance of historical perspectives

Although often neglected in ecological studies, historical data is vital for revealing the ‘ghosts’ of ecosystem past, the true magnitude of change of ecosystems present, and the dynamics that link the two (Pauly 1995, Dayton et al. 1998). Recognizing this inextricable link and valuing the knowledge held by local subsistence users can inform the responsible use of coastal marine resources and ecosystems (Johannes 1998). Our results reveal a strong match between the predictor variables for spatial variation in *K. tunicata* and the factors that emerged from TEK. However, an analysis of present day ecological data alone could not have explained the true causal mechanism governing recent localized *K. tunicata* declines (i.e. increased per capita predation pressure on *K. tunicata* by humans and sea otters due to reduced alternative prey). Rather, knowing the historical change in alternative invertebrate prey, human settlement patterns, subsistence harvest practices, and predatory population dynamics of sea otters was critical to our current understanding of the factors leading to recent declines of the black leather chiton.

In this case, the value of western science was in developing the quantitative relationship between predation pressure and resource density. The value of TEK was in providing qualitative assessments of resource abundance prior to ecological study. In this case, the two methods agree on the major direct drivers of environmental change. Furthermore, TEK also provided important evidence on indirect drivers of change (socioeconomic and cultural considerations).

Understandably, it is very difficult for ecologists trained in the rigors of quantitative techniques to sacrifice the elegance of analytical precision and the goal of reducing statistical uncertainty for anything less. Yet, how much accuracy (the degree to which a measured value agrees with the correct value) and precision (the degree to which individual measurements agree with each other) are we willing to forgo for an approximation of the correct value and its uncertainty? In the case presented here, benefits from the addition of a deep historical dimension based on ecological knowledge, albeit in relative terms, outweighed the pitfall of data imprecision. Historical observations, even in relative terms, can be very useful. For example, astronomers have

used ancient oriental and Arabian records of supernovas to test relevant hypotheses (Shen 1969) while oceanographers have compiled wind force data from European ship logbooks to reconstruct the North Atlantic Oscillation index (Luterbacher et al. 2001, Garcia-Herrera et al. 2005). Marine ecologists and fisheries science have just begun to use historical records and anecdotes as data (Rosenberg et al. 2005).

CONCLUSION

The localized decline of the black leather chiton on the shores of the Kenai Peninsula, Alaska is the most recent in a series of benthic invertebrate declines. We postulate that this decline was driven by sequential prey switching by both humans and sea otters resulting in a restriction in prey species breadth and increased per capita chiton mortality due to a scarcity of alternative prey. The social, economic and ecological factors from the past that likely drove this synergistic serial depletion highlight that the legacy of historical perturbations is reflected in what we observe today.

Ultimately, assessing the relative magnitudes and relationships between human impacts, interspecific interactions and physical factors will reduce our uncertainty in detecting drivers of change and increase our likelihood of designing effective conservation strategies. However, management will fail if it focuses on the most recent symptoms of decline rather than on its deep historical causes (Jackson et al. 2001). This research showcases the insight ecologists can glean from delving into both ecological and social history. By considering pivotal socio-economic drivers across multiple scales in time and space and integrating western science and traditional ecological knowledge, we obtained an enhanced understanding of the causes driving chiton declines and consequently are now better equipped to collaboratively develop an effective conservation plan for the nearshore. This was and continues to be a complex system subject to the vagaries of natural predators, the physical environment, and socio-economic factors which motivate human behavior.

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Table 1.1 Spatial variation in *K. tunicata* density and biomass in the low and high intertidal at 11 sites along a gradient of subsistence shoreline collection pressure on the outer Kenai Peninsula, Alaska.

Tidal Elevation	Model	<i>df</i>	<i>Chi-Square</i>	<i>Pr > ChiSq</i>
Low	Density			
	Site	10	342.35	< 0.0001
	Year	1	0.60	0.440
	Site*Year	10	66.59	< 0.0001
	Biomass			
	Site	10	101.66	< 0.0001
	Year	1	1.31	0.252
Site*Year	10	20.89	< 0.022	
High	Density			
	Site	10	963.99	< 0.0001
	Year	1	36.98	< 0.0001
	Site*Year	10	103.47	< 0.0001
	Biomass			
	Site	10	160.82	< 0.0001
	Year	1	5.02	0.025
Site*Year	10	22.21	0.014	

Table 1.2 Differences in top-down and bottom-up factors among sites that may influence the spatial variation in current day *K. tunicata* density and biomass in the low intertidal.

Model	<i>df</i>	<i>Chi-Square</i>	<i>Pr > ChiSq</i>
Shoreline Collection Effort^Ω			
Site	9	665.12	<0.0001
Sea Otter Sightings^Φ			
Site	10	265.04	<0.0001
Year	1	3.93	0.047
Sea Bird Sightings			
Site	10	572.03	<0.0001
Leptasterias^Φ			
Site	10	74.35	<0.0001
Year	1	4.80	0.029
Predatory Snails^Φ			
Site	10	240.26	<0.0001
Year	1	0.08	0.773
Relative <i>Alaria</i> Growth Rates^Φ			
Site	9	0.65	0.100
Maximum Wave Exposure			
Site	10	185.39	<0.0001
Sea Surface Temperature			
Site	9	17.11	0.047
Month	2	19.96	<0.0001
Site*Month	18	13.15	0.783

Note:

^Ω Pogipshi was excluded from this analysis because when included, the algorithm failed to converge due to the lack of shoreline collection visits to this site.

^Φ Although a Poisson error distribution was assumed, this model could not support an interaction term because of the high abundance of zero counts.

^Φ Adams had no individuals of *Alaria marginata* large enough to tag.

^Ψ Temperature data were not retrieved from Adams

Table 1.3. Strength of evidence for alternative models representing competing hypotheses on the primary factors governing the present spatial variation in *K. tunicata* density and biomass in both the low and high intertidal. Harvest pressure, sea otter presence, shorebird presence and wave exposure were the four variables considered. Models, with varying numbers of parameters (K), were compared using small sample, bias-corrected Akaike Information Criterion (AICc), AICc differences (Δ AICc), and normalized Akaike weights (w_i).

Response	Model	N	K	AICc	ΔAICc	w_i	R²
Density Low	Harvest + Sea Otter	11	4	18.14	0.00	0.84	0.80
	Harvest + Sea Otter + Shorebird	11	5	22.52	4.38	0.09	0.85
	Harvest + Sea Otter + Wave	11	5	25.42	7.28	0.02	0.81
	Sea Otter	11	3	26.23	8.09	0.01	0.34
	Harvest	11	3	28.12	9.98	0.01	0.22
Biomass Low	Harvest + Sea Otter	11	4	80.60	0.00	0.59	0.68
	Sea Otter	11	3	83.89	3.29	0.11	0.30
	Harvest	11	3	85.57	4.96	0.05	0.18
	Wave	11	3	86.19	5.59	0.04	0.13
	Sea Otter + Wave	11	4	87.44	6.84	0.02	0.40
Density High	Harvest + Sea Otter	11	4	49.92	0.00	0.35	0.67
	Wave	11	3	51.90	1.99	0.13	0.37
	Harvest + Sea Otter + Wave	11	5	52.27	2.35	0.11	0.79
	Sea Otter + Wave	11	4	52.55	2.64	0.09	0.59
	Harvest + Sea Otter + Shorebird	11	5	52.78	2.86	0.08	0.78
Biomass High	Wave	11	3	80.14	0.00	0.54	0.57
	Harvest + Wave	11	4	82.60	2.46	0.16	0.67
	Sea Otter + Wave	11	4	84.14	4.00	0.07	0.62
	Shorebird + Wave	11	4	85.01	4.87	0.05	0.59
	Harvest + Sea Otter + Wave	11	5	85.04	4.90	0.05	0.79

Table 1.4. The relative importance of four variables (harvest pressure, sea otter presence, shorebird presence and wave exposure) which contribute to the current spatial variation in *K. tunicata* density and biomass in both the high and low intertidal. Relative importance was based on variable weights which were calculated by summing the Akaike weights (w_i) over the subset of models for a specific response in which a variable was found. The sign of each variable coefficient in parentheses indicates the direction of the relationship between the response and each variable.

Variable	Response			
	Density Low	Biomass Low	Density High	Biomass High
Harvest Pressure	0.965 (-)	0.682 (-)	0.608 (-)	0.282 (-)
Sea Otter Presence	0.977 (-)	0.766 (-)	0.708 (-)	0.156 (-)
Shorebird Presence	0.100 (+)	0.051 (+)	0.133 (-)	0.082 (-)
Wave Exposure	0.029 (+)	0.368 (+)	0.082 (+)	0.875 (+)

Table 1.5 Time series of historic ecological and socio-economic observations based on representative quotes from Sugpiaq elders and tribal residents from Port Graham and Nanwalek, Alaska. *K. tunicata* are known locally by their Russian name “Bidarki”.

Time	Event	Quote
1800s-1960s	Sea otter extirpation	<i>When the Russians came they cleaned the sea otters out. When I was 18 yrs old [1953] there were no sea otters around Port Graham.</i>
1930s-1950s	High invertebrate densities Low kelp biomass	<i>We used to be able to get all the Dungeness we wanted. We used to collect clams and cockles, nobody ever missed a tide. I didn't have concept of poor or rich in a western world sense. We were so rich because there was so much out there. The sea back then was a dinner table set at low tides. There was not much kelp in front of Nanwalek when I was young.</i>
1960s	Sea otter recovery	<i>They came back in the early 60's. The population exploded in the late 70's early 80's. Boy, those things multiply!</i>
1960s	Invertebrate decline begins	<i>We used to see green sea urchins all over Nanwalek Reef in the early 1940s. By the late 60's sea urchins were mostly gone. I haven't had lady slippers [<i>Cryptochiton stelleri</i>] for years.</i>
1970s	↑ Harvest effort with increased storage abilities	<i>In the past we picked just enough to eat and snack on. But when electricity and then freezers became available people began to pick more because they could store them.</i>
1980s	Commercial crustacean crash	<i>Dungeness were whipped because of commercial crab fisheries and dragging. They came right into this bay. Now [the Dungeness] haven't been able to come back because of the sea otters.</i>
1989	Exxon Valdez oil spill	<i>The oil spill impacted nature's cycles, the seasonal clock work of our culture, our life ways... It had lingering effects, not only in our water but in our lives. Clams and cockles and Dungeness crab were declining before the oil spill. The oil spill may have made it worse but they were already declining before the spill.</i>
1989	↑ Harvest efficiency	<i>People locally were hired to help clean up the spill. Then, there was more money that came to the village. More money let more people own more boats and bigger boats with better outboards. Many people could now go to places that they couldn't go to in the past.</i>
1990s	Change in bidarki numbers & size	<i>I started noticing Bidarki declines 10-15 years ago. . It's harder to find the big ones now.</i>
1990s-2000s	Compensatory growth	<i>There are more little ones but they are not big enough to pick. I used to not see so many little ones.</i>
1990s-2000s	Serial decline	<i>The urchins were the first to go then crab then the clams. Bidarkies, they're the most recent change.</i>

Table 1.6 Competing hypotheses, based on traditional & local knowledge, regarding historical decline of invertebrates and current decline of *K. tunicata* (bidarkies).

Hypothesis	Quote
Historical shift in collection behavior	[before the Russian occupation] <i>when resources became depleted, people moved on. They took all of their camp out. Then they would go back when resources returned. Villages didn't exist, there were seasonal camps. They always traveled, from fall to spring. That's what is happening here, we're not moving.</i>
Sliding baselines	<i>Maybe people's range of acceptable harvest sizes has now increased.</i>
Effective population size > local population size	<i>We ship bidarkies to friends and family. Most go to Anchorage in zip-lock bags.</i>
Overfishing	<i>There are limits, limits of what you can harvest. Some people go beyond it.</i>
Growth overfishing	<i>It's harder to find the bigger ones so I'm getting the smaller ones.</i>
Recruitment overfishing	<i>They are getting whipped out and are having trouble reproducing.</i>
Lack of seasonal restrictions	<i>March was the month our elders stopped us from hunting. The animals had little ones inside. If you want to see them in the future, leave them alone. New generation, it's not that way. They go out and get what ever they want when ever they want.</i>
Breakdown in information transfer from Elders to community	<i>Now, the new generation doesn't have an understanding or meaning. Poor kids don't know no better. We elders haven't told the younger ones what the nature does. We are blaming the younger generation but we are to blame. We are not teaching them.</i>
Sea otters	<i>Sea otters are part of the problem...they eat every thing we eat.</i>
Shorebirds	<i>The bidarki remains you find on the beach mostly in the spring when the spring birds are around when the sea birds come, nesting birds will eat them that is when the bidarkies are most vulnerable.</i>
Increased harvest efficiency	<i>Now everyone has a skiff and we can see the immediate impact on the resource.</i>
Multiple Causation & sequential perturbations	<i>It's not just overharvesting. Declines are due to a chain reaction. There is still to this day, no one reason for all of these declines. Years ago, people didn't only go for bidarkies, everything was available. Why would they want to just hit the bidarkies? They had crab, mussels, & urchins. The sea otter will change their diet, like any other animal, like us. What are they going to turn to? They turn to bidarkies. Because that's our only diet from here now.</i>
Change in human and sea otter prey species breadth	<i>People always used to have native food. People eat less native food now, but people still eat bidarkies.</i>

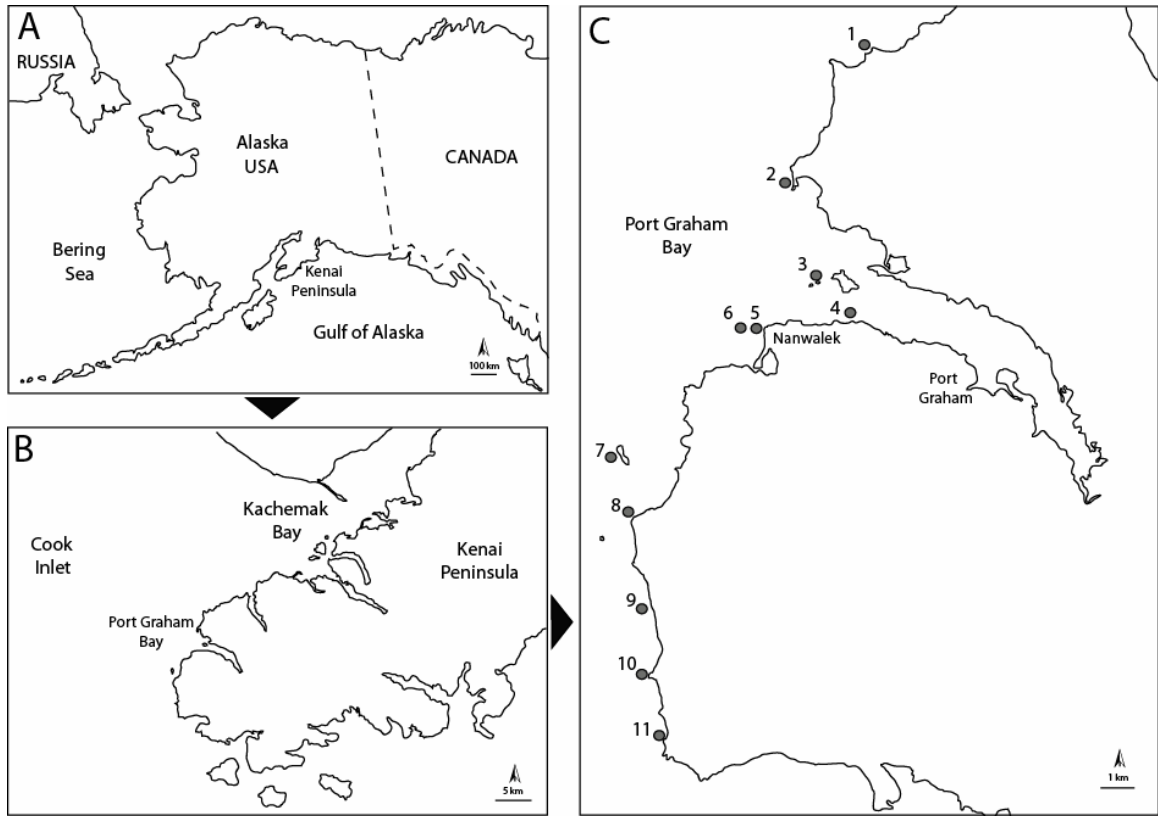


Figure 1.1 A&B) This research was conducted on the outer Kenai Peninsula, Alaska, at (C) eleven rocky intertidal sites surrounding the Sugpiaq native villages of Port Graham and Nanwalek, Alaska. The sites differ in their accessibility to human harvesters and consequently encompass a gradient of shoreline collection effort. 1.Point Pogibshi, 2. Coal Mine, 3.Otter Rock, 4.Romanoff, 5.Inner Nanwalek, 6.Outer Nanwalek, 7.Flat Island, 8.Magnet Rock, 9.Golden Rocks, 10.Jagged Rocks, 11.Point Adams

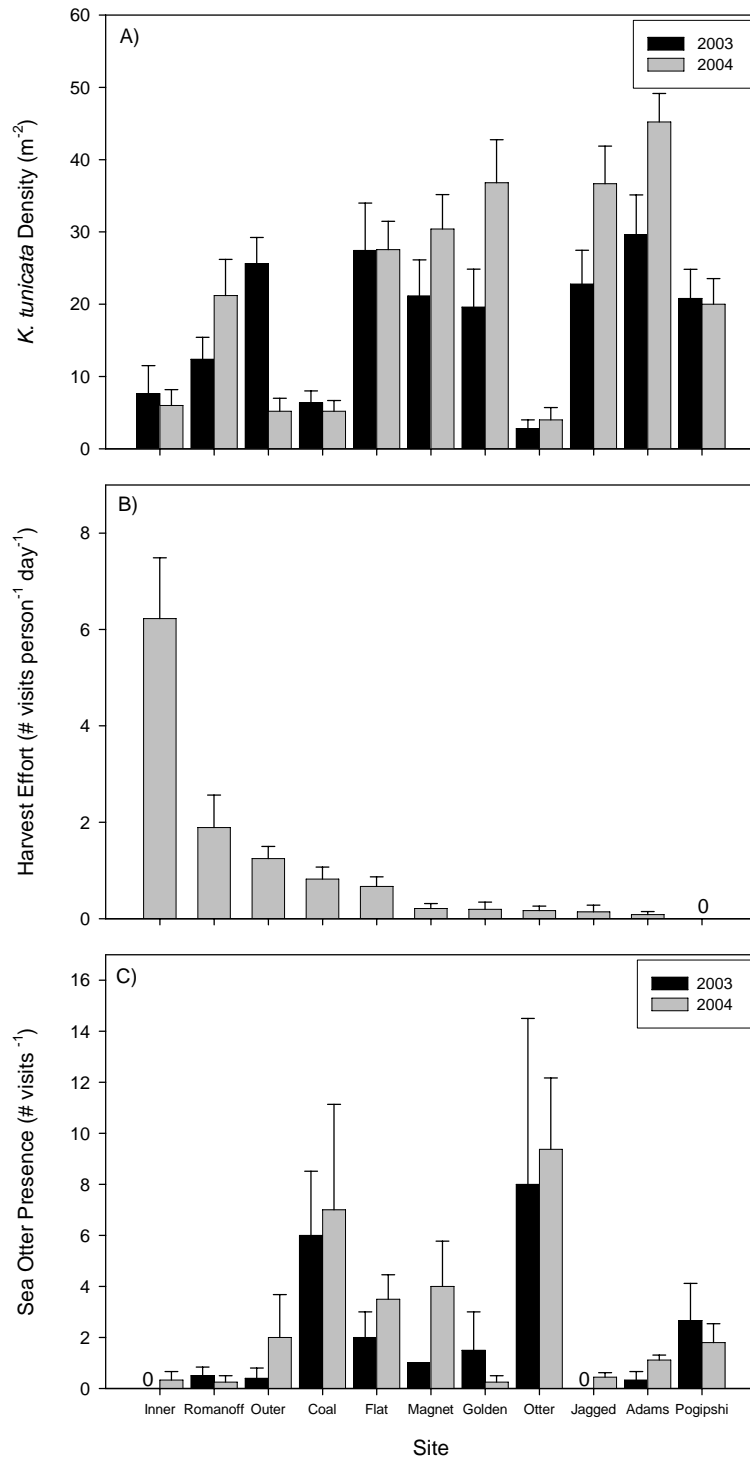


Figure 1.2 Present-day spatial variation in A) black leather chiton (*K. tunicata*) density, B) annual per capita shoreline collection effort, and C) sea otter presence. Sites are ordered according to shoreline collection effort; from most heavily harvested to least heavily harvested.

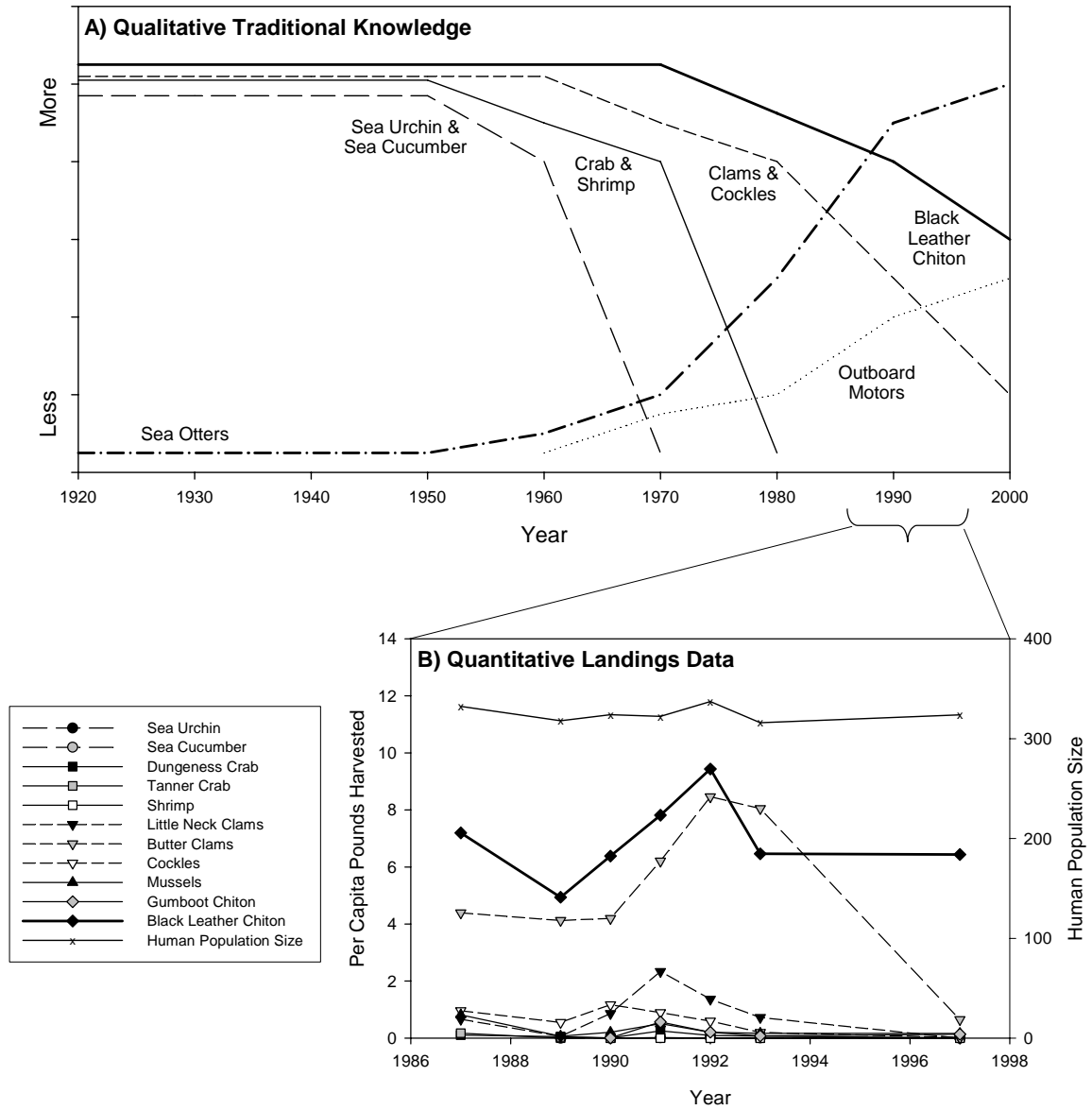


Figure 1.3 A&B) Synergistic serial depletion of marine invertebrates from 1920 to 2000 revealed through traditional ecological knowledge. B) Mass of subsistence marine invertebrates landed per capita in Nanwalek and Port Graham, Alaska from 1987 to 1997.

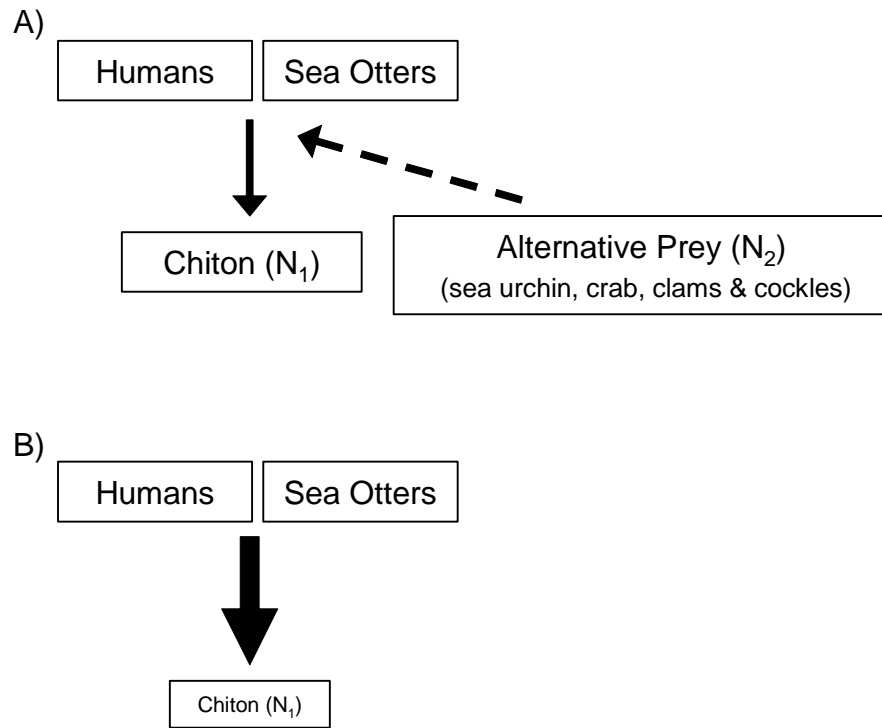


Figure 1.4 Interaction modification (---→) by alternative prey reduces the per capita effect of its consumer, human and sea otter predators (—→) on chiton density.

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**EXPLOITATION OF A KEYSTONE HERBIVORE ALTERS A TEMPERATE COASTAL
ECOSYSTEM**

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Abstract

Fishing and natural predation can alter food web structure and trophic dynamics. On the outer coast of the Kenai Peninsula, Alaska, spatial variation in the black leather chiton (*Katharina tunicata*) is a direct consequence of shoreline collection by humans and sea otter (*Enhydra lutris*) predation. Here we show that *K. tunicata* is a strongly interacting species that drives intertidal community structure and macroalgal production.

Experimental removals in the low intertidal, at 5 sites varying in ambient *K. tunicata* densities, reveal that at high densities (38m^{-2}), *K. tunicata* can reduce *A. marginata* spring sporeling density by 94%, *A. marginata* summer standing stock biomass by 98%, and species richness by 38%. However, under extreme top-down control, where *K. tunicata* densities had been severely depleted by humans and sea otters (6m^{-2}), this chiton became functionally unimportant and ceased to function as a keystone grazer. Stronger population-level impacts at higher *K. tunicata* density arise because per capita effects on *A. marginata* dynamics were constant as a function of ambient consumer densities.

Consequently, when predicting the collective impact of *K. tunicata* and its localized depletion, it is possible to scale up from per capita to population-level effects based on grazer density. Comparisons across 11 sites that differed in wave exposure and *K. tunicata* exploitation pressure by humans and sea otters revealed that *A. marginata* survival was 3 times greater and *A. marginata* biomass was 7 times greater in exploited versus unexploited sites. Furthermore, invertebrate and algal community structure differed significantly among sites such that the least exploited site with the highest *K. tunicata* density had an entirely different species assemblage compared to the 10 moderately to heavily harvested sites of similar wave exposure. Given that *K. tunicata* is locally reduced at sites heavily exploited by humans and sea otters, our results provide evidence of a trophic cascade. In sum, these results reveal the extent to which fishing and natural predation, via the reduction of a shared keystone resource, indirectly alter a temperate coastal ecosystem.

INTRODUCTION

Variations in predator populations can have cascading effects throughout a food web and thus repercussions for community structure and ecosystem dynamics (Hairston et al. 1960, Paine 1969, Estes and Palmisano 1974, Carpenter et al. 1985). Yet, predator impacts are well known to be context dependent and vary as a function of environmental factors, predator, and prey densities (Oksanen et al. 1981, Arditi and Ginzburg 1989, Hunter and Price 1992, Power 1992). In marine systems, where fishing has become a significant human endeavor, human and natural predators can have both direct and indirect ecosystem-level consequences. Here we examine the community-level effects of localized reductions in the black leather chiton, *Katharina tunicata*, a known keystone grazer (Paine 1992), locally depleted by subsistence harvest and sea otters (*Enhydra lutris*) on wave exposed rocky shores in south central Alaska (Salomon et al. 2006b).

Ecosystem-level effects of fishing

The removal of a strongly interacting species by fishing can fundamentally alter marine food web structure and trophic dynamics (Dayton et al. 1995, Botsford et al. 1997, Jackson et al. 2001). For example, in northeastern New Zealand, the reduction of snapper and lobster by fishing has resulted in an increase in their herbivorous sea urchin prey and an indirect reduction in benthic primary production by over an order of magnitude in coastal regions with repercussions for upper trophic level consumers (Babcock et al. 1999, Shears and Babcock 2002, Salomon et al. 2006a). After overexploitation of adult Atlantic cod, forage fish were able to increase and, through predation and competition, reduce juvenile cod survival, thereby preventing cod recovery (Swain and Sinclair 2000, Walters and Kitchell 2001). Intense fishing effort can even cause systems to flip into an alternative state leading to sudden changes in species composition, with economic and social consequences (Steneck 1997, Scheffer et al. 2001, Steneck et al. 2004, Hughes et al. 2005). At the same time, the concomitant role of ‘bottom-up’ abiotic forces in structuring marine systems has been well documented both at regional (Mantua et al. 1997, Anderson and Piatt 1999) and local scales (Dayton 1971, Menge and Sutherland 1987).

Increased awareness of the ecosystem-level effects of fishing has prompted a call to incorporate greater ecological considerations in fisheries management (National Research Council 1999, Hutchings 2000, Pauly et al. 2002, Pikitch et al. 2004). If the goal of ecosystem-based management is to account for both human and natural predator-prey dynamics and maintain critical ecosystem processes that support biological production (Hughes et al. 2005), then a strong need exists for methods to predict the ecological effects of species reductions. Understanding the factors which may cause the effects of species reductions to vary will reduce the uncertainty surrounding such predictions.

Variation in consumer impacts

A species’ impact is a function of its density and per capita interaction strength, that is, its per capita effect on another species’ population growth (May 1973, Bender et

al. 1984, Yodzis 1988). If per capita effects are constant, they can be multiplied by species densities to make predictions about total population-level effects (Wootton 1997). It is often assumed that pairwise predator-prey interactions have a single constant strength of interaction because theory typically describes interactions at or near equilibrium where predator effects on a prey's population growth rate can be approximated by a linear function with constant per capita effects (May 1973, Yodzis 1988). Furthermore, empirical experiments designed to measure interaction strength tend to be conducted at one time and place, at a single natural predator density (Paine 1992). Yet, in reality populations are rarely at equilibrium and species densities typically vary in space and time, particularly with the current prevalence of localized species declines. Consequently, although predator density is often used as a proxy for severity of impact, this straightforward scaling may not apply if per capita effects vary as a function of predator or prey density (Laska and Wootton 1998, Berlow et al. 1999, Wootton and Emmerson 2005).

Abundant empirical and theoretical evidence suggest that variable per capita predator impacts could be common in predator-prey systems because of non-linear functional responses (Ruesink 1998, Abrams 2001). For example, predators that are limited by handling time typically have a saturating (type 2) functional response which can lead to predator swamping. For the prey, per capita mortality risk therefore declines with increasing prey density (Holling 1959) or body size (Berlow and Navarette 1997). Furthermore, the presence of alternative prey may reduce per capita predator effects on a focal prey due to predator selectivity or satiation (Holt and Lawton 1994). Alternatively, the per capita impact of a predator may diminish at high predator densities due to behavioral interference among individuals (Fagan and Hurd 1994, Navarrete and Menge 1996). Lastly, per capita interactions may be context-dependent due to extrinsic environmental factors, such as wave exposure, influencing predator behavior (Menge and Sutherland 1987, Menge et al. 1994). Ultimately, identifying variations or consistency in a species' interaction strength will help ecologists and managers understand and predict the ecological consequences of a species' depletion (Power et al. 1996).

Effects of subsistence harvest & sea otter predation on the Kenai Peninsula, Alaska

On the rocky shores of the outer Kenai Peninsula, Alaska, localized depletions of the black leather chiton, *K. tunicata*, were first observed 10–15 years ago (Salomon et al. 2006b). This intertidal mollusc was harvested by the area's earliest inhabitants from at least 1000 BC onwards (de Laguna 1975, Klein 1996) and remains an important subsistence food source for Sugpiaq natives today (Stanek 1985, Chugachmiut 2000). Field surveys in 2003 and 2004 revealed that the current spatial variation in *K. tunicata* density is a consequence of human exploitation and sea otter predation (Salomon et al. 2006b). Traditional knowledge of Sugpiaq elders described the reestablishment of sea otters in the early 1960's, changes in subsistence practices and the serial decline of several nearshore benthic invertebrate species, *K. tunicata* being the most recent. This qualitative data coupled with empirical subsistence landings data from 1986-1996 suggests that a restriction in both human and sea otter alternative prey species breadth has led to intensified per capita predator impacts on *K. tunicata* (Salomon et al. 2006b).

Here, in collaboration with the Sugpiaq native villages of Port Graham and Nanwalek, we investigated the ecological role of *K. tunicata* in governing community structure & dynamics thereby allowing us to assess the indirect effects of its harvest and consumption by sea otters. We used a combined comparative and experimental approach and asked: 1) To what extent do *K. tunicata* and wave exposure predict spatial variation in intertidal community structure? 2) How does the total effect of *K. tunicata* vary across sites? 3) How does *K. tunicata* interaction strength vary as a function of its density and wave exposure? To address these questions, we collected data on intertidal species assemblages, wave exposure and survival and biomass of *K. tunicata*'s preferred prey, the kelp *A. marginata*, across 11 sites varying in ambient *K. tunicata* density and wave exposure. At a subset of these sites, we experimentally tested the interaction between *K. tunicata* and *A. marginata* by setting up enclosure arenas. These experimental manipulations and site comparisons conducted across sites varying in ambient *K. tunicata* density conferred a space-for-time substitution allowing us to infer the ecological consequences of *K. tunicata*'s recent decline.

METHODS

Study area

This research was conducted on the rocky shores of the Outer Kenai Peninsula, located in south central Alaska (Fig.2.1AB&C). Eleven sites surrounding the Sugpiaq native villages of Port Graham and Nanwalek were identified by tribal elders to encompass a gradient of subsistence shoreline harvest and sea otter presence. *K. tunicata* removal experiments were conducted at 5 sites varying in ambient *K. tunicata* density.

Site comparisons of intertidal community structure, K. tunicata density & wave exposure

We compared the intertidal species assemblages and *K. tunicata* densities at 11 sites spanning a gradient of wave exposure and predation pressure by humans and sea otters. In June/July 2003 and 2004, we quantified algal and invertebrate community structure in ten 0.25m² quadrats randomly stratified along a 50 m transect line placed horizontally in preferred *K. tunicata* habitat; the middle of the *A. marginata* and *Hedophyllum sessile* zone. This intertidal elevation was approximately at 0 mean low water (MLW). We estimated the percent cover of all sessile macroscopic invertebrate and algae species and the densities of all mobile macroscopic invertebrates within each quadrat. To account for extensive species overlap and the three-dimensional nature of the community, we surveyed 3 distinct layers per quadrat: the canopy, understory and substrate. Site-specific maximum wave force (N) was quantified in June 2005 with three maximum wave force recorders per site. For details on these methods see Salomon et al. 2006 b.

***A. marginata* survival and biomass**

We quantified survivorship of the benthic macroalga, *A. marginata*, *K. tunicata*'s preferred prey, across all 10 of the 11 survey sites varying in *K. tunicata* density. (Note: Adams, site 11, had no *A. marginata* individuals to tag at 0 MLW). Individuals were tagged with numbered zip ties secured around their stipe, below their sporophylls, in May 2004. Survivors greater than 10 cm in length were enumerated 3 months later in September 2004. We quantified site-specific *A. marginata* biomass by removing and weighing the wet weight of all individuals from ten 0.0625 m² quadrats per site.

Experimental arenas

To quantify the ecological impact of *K. tunicata* on *A. marginata* spring sporeling density, *A. marginata* summer standing stock biomass, intertidal species richness and community structure, we conducted small-scale removal experiments at 5 sites varying in *K. tunicata* density. Experimental arenas of nontoxic epoxy putty, 21 cm in diameter (area = 0.035m²), were constructed in the middle of the *A. marginata* and *H. sessile* zone in September 2003. To create uniform rock surfaces all organisms were removed within the arenas, the surface scraped clean and sprayed with commercial-grade oven cleaner to kill residual algal spores and microscopic gametophytes. Treatment arenas were painted with copper-based antifouling paint thereby precluding grazer entry. Controls were left unpainted.

Marine benthic algae and invertebrates were allowed to recruit at their natural rates. In April 2004, approximately 6 months after initiation, algal sporelings were counted within experimental treatment ($N_{t,E}$) and control arenas ($N_{t,C}$). In July 2004, all invertebrate and algal species within the arenas were harvested and their species-specific wet biomass quantified. *A. marginata* spring sporeling density and summer standing stock biomass were converted to a square meter basis.

The removal treatment reduced the density of all macrograzers (chiton, limpet and species). Because sea urchins (*Strongylocentrotus spp.*) do not make up a significant part of the grazer community in this area, we assumed that the majority of the impact quantified can be attributed to *K. tunicata*. This chiton has been shown to have a per capita interaction strength 5.5 fold that of limpets (*L. ochraceus*) while the grazing effect of other limpet (*Acmaea mitra* and *Lottia painei*) and chiton species (*Mopalia hindsii* and *Tonicella lineata*) on algal production has been shown to be negligible or even positive (Paine 1992).

Statistical analysis & models

Community structure

Differences in algal and invertebrate community structure among sites surveyed in 2003 and 2004 were compared with nonmetric multidimensional scaling (NMDS), an iterative optimization ordination method (PC-ORD software) (McCune and Grace 2002). Each year was analyzed separately. *K. tunicata* was removed from the species matrix and only species present in more than 3 quadrats surveyed each year were considered, thereby reducing the total number of species analyzed from 86 to 67 in 2003 and 104 to 79 in 2004. Species data was converted into proportions and arcsine-square root transformed,

and Sørensen (Bray-Curtis) distance measures were used. In preliminary analyses, we used Monte Carlo randomization tests to determine the dimensionality of the data. This test was conducted with random starting points, 100 runs with real data and 50 runs with randomized data. A scree plot of final stress versus the number of dimensions was used to confirm the Monte Carlo assessment of dimensionality. The final solution for both 2003 and 2004 was run with 500 iterations and a starting configuration determined by the preliminary analyses. The proportion of variance represented by each axis was based on the coefficient of determination (r^2). We calculated correlation coefficients (Pearson's r) to express the relationship between the ordination scores of each axis and site-specific estimates of maximum wave exposure and *K. tunicata* densities averaged for 2003 and 2004. Finally, a multi-response permutation procedure (MRPP) based on Sørensen (Bray-Curtis) distance was used to test for similarities in species assemblages between sites and between 3 groups of sites defined by *K. tunicata* density per 0.25m² (low ≤ 2 , medium 3-6, high ≥ 7) (McCune and Grace 2002).

***A. marginata* survival and biomass**

To assess the direct effects of ambient *K. tunicata* density and maximum wave exposure on *A. marginata* survivorship and biomass across 11 sites, we took an information theoretic model selection approach (Burnham and Anderson 1998) and compared alternative candidate models of *A. marginata* survivorship as a function of *K. tunicata* density and maximum wave exposure. This approach was taken over standard multiple-regression because the latter is sensitive to stepwise selection criterion, direction of fitting and variable order.

We ranked candidate models based on small sample, bias-corrected Akaike's Information Criterion (AICc) which we standardized to the best fit model to produce Δ AICc values. We normalized the likelihoods to a set of positive Akaike weights (w_i) representing the strength of evidence in favor of a given model. The level of empirical support for a model is substantial when Δ AICc is ≤ 2 and $w_i \geq 0.9$. We examined the relative importance of each variable based on variable weights by summing the Akaike weights (w_i) of all of the models in which a variable was found (Burnham and Anderson 1998). This allowed us to assess the weight of evidence among the competing hypotheses on the primary factors driving *A. marginata* survivorship.

Population-level effect of *K. tunicata*

Based on the removal experiments, we analyzed differences in *K. tunicata*'s collective, population-level impact on *A. marginata* spring sporeling density, *A. marginata* summer standing stock biomass, and species richness across 5 sites varying in ambient *K. tunicata* densities with generalized linear mixed-models fit with residual (restricted) maximum likelihood (REML) (PROC MIXED SAS version 9.1.3). Treatment and site x treatment were treated as fixed factors while site was treated as a random factor. Data were normalized with a log (x+2) transformation.

Population-level impacts by *K. tunicata* on intertidal community structure, based on species-specific summer biomass data from the removal experiments, were explored with NMDS as described above. Only species present in more than 2 arenas across all experimental sites were considered, thereby reducing the total number of species analyzed from 58 to 41 species. Species-specific biomass data were log (x+2)

transformed. A multi-response permutation procedure was used to test for similarities in species assemblages between experimental treatment ($N_{t,E}$) and control arenas ($N_{t,C}$).

***K. tunicata* per capita interaction strength**

We used a dynamic index of interaction strength that explicitly reflects the dynamics of predator-prey systems and clearly specifies the temporal scales over which our experiment was conducted (Osenberg et al. 1997). Assuming that *A. marginata* in control and treatment arenas is subject to different levels of density-independent mortality and that the resulting dynamics can be described by an exponential model, the effect of *K. tunicata* on *A. marginata*'s per capita dynamics (Δr) can be expressed as:

$$\Delta r = \frac{dN_C}{N_C dt} - \frac{dN_E}{N_E dt} \quad (1)$$

$$= \left[\ln\left(\frac{N_{t,C}}{N_{o,C}}\right) - \ln\left(\frac{N_{t,E}}{N_{o,E}}\right) \right] / t \quad (2)$$

where $N_{t,C}$ and $N_{t,E}$ are the densities (or biomass) of *A. marginata* at the end of the experiment in the control and experimental removal treatment, and t is the duration of the experiment. We assumed initial recruitment was equivalent regardless of treatment, such that $N_{o,E} = N_{o,C}$, so that equation (2) could be simplified to the known form (Osenberg and Mittelbach 1996, Osenberg et al. 1997, Wootton 1997):

$$\Delta r = \ln\left(\frac{N_{t,C}}{N_{t,E}}\right) / t \quad (3)$$

To determine the per capita effect of *K. tunicata* consumption on the per capita dynamics of *A. marginata*, equation (3) becomes:

$$\Delta r / P = \ln\left(\frac{N_{t,C}}{N_{t,E}}\right) / (tP) \quad (4)$$

where P is the ambient predator density. This index is based on the discrete-time version of Lotka-Volterra predator-prey equations and is theoretically equivalent to the coefficient of interaction strength yet makes no assumptions about equilibrium conditions (Berlow et al. 1999). Essentially, for *A. marginata* sporelings, this index of interaction strength reflects exponential sporeling decline after recruitment, in the presence and absence of predators.

To derive estimates of error surrounding empirical estimates of per capita interaction strength (4), we used a bootstrap procedure which calculated the index $\ln(N_{t,C}/N_{t,E})/tP$ based on randomly chosen $N_{t,C}$ and $N_{t,E}$ values for as many times as the experimental treatment was replicated. This procedure was repeated 1000 times to derive bootstrap means and standard deviations. This procedure reflects the field experimental protocol and preserves the sensitivity of the error estimate given the number of field

replicates. We used AICc, as described above, to detect if *K. tunicata*'s per capita impact on *A. marginata* dynamics varied as a function of ambient *K. tunicata* density and/or wave exposure.

RESULTS

Variable intertidal community structure among survey sites

Among the eleven sites varying in ambient *K. tunicata* densities (Fig.2.2), NMDS ordinations of both 2003 and 2004 community data reveal that sites varied significantly in their algal and invertebrate assemblages in both 2003 and 2004 (2003: $A=0.248$, $p<0.0001$, 2004: $A=0.314$, $p<0.0001$), as did the 3 groups of sites delineated by low, medium and high *K. tunicata* density (2003: $A=0.072$, $p<0.0001$, 2004: $A=0.06$, $p<0.0001$) (Fig.2.3A&B). For both the 2003 and 2004 analyses, the first axes, which explain the greatest proportion of the variance in the data, were more correlated to ambient *K. tunicata* density (2003: $r=0.587$, 2004: $r=0.787$) than wave exposure (2003: $r=0.254$, 2004: $r=0.226$) (Table 2.1). The least exploited site with the highest *K. tunicata* densities, Point Adams, site 11, had an extremely different species assemblage compared to the remaining 10 moderately to heavily exploited sites. This difference was driven primarily by the near absence of *A. marginata*, an annual kelp, and the dominance of *H. sessile*, a perennial kelp.

Variable A. marginata survivorship & biomass across survey sites

Substantial evidence suggests that *K. tunicata* density was the most influential variable describing the spatial variation in *A. marginata* survivorship and biomass among the 11 sites varying in *K. tunicata* exploitation by humans and sea otters (Fig.2.4A&B, Table 2.2). Predicting *A. marginata* survivorship and biomass as a function of *K. tunicata* density alone was the best fit and most parsimonious model, as judged by AICc, and explained 61% of the variation in *A. marginata* survivorship and 44% of the variation in *A. marginata* biomass. Furthermore, *K. tunicata* density was the factor with greatest variable weight in both cases, reflecting its relative importance compared to wave exposure (Table 2.3). In sum, *A. marginata* survivorship was 3 times greater in exploited versus unexploited sites, while, *A. marginata* biomass was up to 7 times greater in exploited versus unexploited sites (Fig.2.4A&B).

Variable population-level effects of K. tunicata across experimental sites

The collective, population-level effect of *K. tunicata* was evident in contrasts of *K. tunicata* enclosure arenas vs. control arenas subject to ambient grazing pressure. At its highest density (38 m⁻²), *K. tunicata* populations reduced *A. marginata* spring sporeling density up to 94%. (Fig.2.5A, Table 2.4). However, collective consumer impact on *A. marginata* differed among sites with varying ambient consumer densities. At some sites, the enclosure treatment was significant (post hoc contrasts Adams; $F_{1,57}=22.13$, $P<0.0001$, Jagex; $F_{1,57}=30.94$, $P<0.0001$, Jagged $F_{1,57}=2.45$, $P=0.123$, Roman; $F_{1,57}=28.27$, $P<0.0001$) but at others it was not (Jagged $F_{1,57}=2.45$, $P=0.123$, Coal;

$F_{1,57}=0.20$, $p=0.653$). Specifically, there was a detectable treatment effect on *A. marginata* spring sporeling density at 3 of the 5 experimental sites.

K. tunicata populations reduced *A. marginata* summer biomass up to 98% (Fig.2.5B, Table 2.4), however, here again, impact varied among sites which differed in ambient *K. tunicata* densities (post hoc contrasts Adams; $F_{1,57}=21.96$, $P<0.0001$, Jagex; $F_{1,57}=13.98$, $P<0.0004$, Roman $F_{1,57}=20.11$, $P<0.0001$, Jagged $F_{1,57}=9.51$, $P=0.0031$; Coal; $F_{1,57}=0.08$, $p=0.781$). In the case of *K. tunicata*'s impact on *A. marginata* summer biomass, there was a detectable treatment effect at 4 of the 5 experimental sites

At its highest densities, *K. tunicata* populations reduced species richness by 38%, however, *K. tunicata* populations only detectably reduced species richness at 3 of the 5 experimental sites (Fig.2.5C, Table 2.4) (post hoc contrasts Adams; $F_{1,57}=1.67$, $P<0.0001$, Jagex; $F_{1,57}=12.68$, $P=0.0008$, Roman $F_{1,57}=5.55$, $P=0.022$, Jagged $F_{1,57}=6.8$, $P=0.012$; Coal; $F_{1,57}=0.57$, $p=0.452$).

Invertebrate and algal species assemblages differed significantly between removal arenas that reduced *K. tunicata* entry and control arenas that allowed *K. tunicata* entry according to a MRPP ($A=0.081$, $p<0.0001$) (Fig.2.6). However, the magnitude of difference in community structure between removal and control arenas declines as ambient *K. tunicata* densities declines.

Constant K. tunicata per capita interaction strength

Across 5 experimental sites spanning a gradient in wave exposure and ambient grazer densities, *K. tunicata* interaction strength remained relatively constant (Fig.2.7A&B). We did not detect an effect of ambient *K. tunicata* density and/or wave exposure on *K. tunicata*'s per capita impact on *A. marginata* spring sporeling density or summer biomass dynamics based on AICc (Table 2.5). Low variable weights further revealed that the low importance of wave exposure and varying grazer density on *K. tunicata*'s per capita effect on *A. marginata* dynamics, whether interaction strength was calculated based on spring sporeling density or summer biomass (Table 2.6).

DISCUSSION

K. tunicata is a strongly interacting species that drives nearshore community dynamics in the rocky intertidal zone of the Kenai Peninsula, Alaska. Strongest evidence of this came from our removal experiments conducted at sites with relatively high densities of this chiton (28-38 m^{-2}). At these sites, *K. tunicata* reduced *A. marginata* spring sporeling density by 94%, *A. marginata* standing stock biomass by 98%, and species richness by 38% (Fig.2.5AB&C). However, at sites with extremely low *K. tunicata* density (6 m^{-2}), this chiton became functionally unimportant.

The considerable ecological role of *K. tunicata* populations at high densities was further illustrated by the significant difference in invertebrate and algal assemblages between control and removal experimental arenas (Fig.2.6). However, here again, the magnitude of difference between species assemblages in the presence or absence of *K. tunicata* decreased at experimental sites with low *K. tunicata* densities. In fact, the

divergence among species assemblages between removal and control arenas was lowest at Coal Mine where *K. tunicata* have been functionally eliminated.

This pattern of stronger population-level effects at higher *K. tunicata* density arises because *K. tunicata*'s per capita effects remained constant as a function of ambient *K. tunicata* density (Fig.2.7A&B, Table 2.5). In other words, we did not detect an effect of ambient *K. tunicata* density or wave exposure on *K. tunicata*'s per capita impact despite the wide range on densities and exposure over which these experiments were conducted (Table 2.6). If indeed predator and physical interference is negligible, this suggests that *K. tunicata*'s individual feeding efficiency is not significantly altered by consumer density or wave exposure. This may occur because feeding is done primarily at high tide when individuals are less prone to wave surge and because *A. marginata* recruitment rates are high in this area thereby decreasing potential competition for resources among individuals. Given this consistency in interaction strength, the per capita effects of *K. tunicata* at one density can be scaled linearly with density to predict its effects at another density. Therefore, in this case, it is possible to scale up from per capita to population-level effects based on predator density.

These experimental results lead to predictions that community structure and function should differ substantially among sites with different densities of *K. tunicata*. Indeed this was the case. Across-site comparisons revealed that sites with higher *K. tunicata* densities had lower *A. marginata* survival, lower *A. marginata* biomass, and different community compositions (Fig.2.3&4AB). Specifically, *A. marginata* survivorship was 3 times greater in exploited versus unexploited sites and *A. marginata* biomass was up to 7 times greater in exploited versus unexploited sites. Furthermore, the least exploited site, Adams, where *K. tunicata* densities were highest, had an extremely different species assemblage compared to highly exploited sites of similar wave exposure. This difference in community structure was driven by the near absence of *A. marginata*, an annual kelp, and the dominance of *H. sessile*, a perennial kelp, further illustrating the important role *K. tunicata* plays in altering nearshore benthic primary production.

Because *K. tunicata* reaches low densities at sites heavily exploited by humans and/or sea otters (Fig.2.2) (Salomon et al. 2006b), these results provide evidence of a trophic cascade. At high densities, *K. tunicata* exerts paramount control over community dynamics. However, under extreme top-down control by human and sea otters, where *K. tunicata* is substantially reduced in density, it becomes functionally unimportant in the system such that it ceases to be a keystone grazer. At extremely low densities, *K. tunicata* is 'just another chiton'.

Our experimental removals were 'press' perturbations (Bender et al. 1984), therefore, the direct effects of *K. tunicata* removals are mixed together with its indirect effects mediated through other members of the community (Wootton 1997). Nonetheless, results from the experimental arenas substantiate *K. tunicata* grazing intensity as the causal mechanism driving the patterns we observed from our site comparisons and therefore corroborate the important ecological role of *K. tunicata*. Experimental reductions in *K. tunicata* in the Pacific North West of the United States and Canada confirm the ecological significance of this grazer (Duggins and Dethier 1985, Markel and DeWreede 1998, Paine 2002). Because kelp-derived organic carbon is known to fuel coastal ecosystems in Alaska via particulate and dissolved organic matter (Duggins et al.

1989), *K. tunicata* reduction and resulting increase in macroalgal production, may have ramifying effects throughout the nearshore food web. For example, filter feeders such as mussels, clams and cockles may benefit from enhanced kelp detritus, as will their predators, humans and sea otters, indirectly, illustrating the potential for reciprocal feedbacks in this system.

Conclusion

Here we show, with both experimental and comparative results, that intertidal community structure and macroalgal production are strongly governed by *K. tunicata*. Given that localized reductions in *K. tunicata* are driven by its harvest by people and consumption by sea otters (Salomon et al. 2006b), these results further illustrate the indirect community-level effects of fishing and natural predation.

The ecosystem implications of fishing have been increasingly documented with evidence from large scale human exclusion experiments (i.e. marine reserves) (Castilla and Bustamante 1989, Shears and Babcock 2002, Langlois et al. 2006, Salomon et al. 2006a), regression/correlation analyses of fisheries time series data (Swain and Sinclair 2000, Worm and Myers 2003, Frank et al. 2005), and spatial gradients in fishing effort, such as the one we report here. Furthermore, there are many cases such as this one where humans and a top predator are direct competitors for a shared resource (Swain and Sinclair 2000, Yodzis 2001) thereby collectively causing indirect alterations to an ecosystem.

Given the potentially significant indirect repercussions of fishing, magnified by natural predation, a strong impetus exists to integrate ecological considerations into fisheries management. Federal, state and native fisheries managers challenged with implementing ecosystem-based management have the difficult job of identifying and accounting for the indirect effects of fishing and natural predation. Uncertainty in predicting the ecological impacts of a species' depletion, caused by fishing and/or natural mortality, can be reduced with an enhanced understanding of species interactions and some insight into the variation or consistency of species per capita effects.

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Table 2.1 NMDS ordination of intertidal community structure in 2003 and 2004. Individual and total proportion of the variance represented by each axis (r^2). Correlation coefficients (Pearson's r) express the linear relationship between the ordination scores of each axis and site-specific estimates of maximum wave exposure and *K. tunicata* densities averaged for 2003 and 2004.

Year	Axis	Proportion of Variance represented (r^2)	<i>K. tunicata</i> Density (Pearson's r)	Max Wave Force (Pearson's r)
2003	1	0.460	0.587	0.254
	2	0.139	-0.054	-0.165
	3	0.191	-0.233	-0.264
	Total	0.790		
2004	1	0.709	0.787	0.226
	2	0.111	-0.080	-0.230
	Total	0.820		

Table 2.2 Strength of evidence for alternative models of *K. tunicata* density and maximum wave exposure representing competing hypotheses on the primary factors governing *A. marginata* survivorship (Nt/No) and biomass in the low intertidal. Models, with varying numbers of parameters (K), were compared using small sample, bias-corrected Akaike Information Criterion (AICc), AICc differences (Δ AICc), and normalized Akaike weights (w_i)

Response	Model	N	K	AICc	Δ AICc	w_i	R^2
<i>A. marginata</i> Survivorship	<i>K. tunicata</i> Density	10	3	-29.553	0.000	0.787	0.606
	<i>K. tunicata</i> Density + Wave	10	4	-25.663	3.890	0.113	0.681
	1	10	2	-24.519	5.034	0.064	0.000
	Wave	10	3	-23.428	6.125	0.037	0.273
<i>A. marginata</i> Biomass	<i>K. tunicata</i> Density	11	3	27.464	0.000	0.700	0.437
	1	11	2	29.855	2.391	0.212	0.000
	<i>K. tunicata</i> Density + Wave	11	4	32.679	5.215	0.052	0.438
	Wave	11	3	33.355	5.891	0.037	0.038

Table 2.3 The relative importance of maximum wave exposure and *K. tunicata* density on the current spatial variation in *A. marginata* survivorship and biomass in the low intertidal. Relative importance was based on variable weights which were calculated by summing the Akaike weights (w_i) over the subset of models for a specific response in which a variable was found. The sign of each variable coefficient in parentheses indicates the direction of the relationship between the response and each variable.

Response	Variable	Variable weight
<i>A. marginata</i> Survivorship	Density	0.900 (-)
	Wave Exposure	0.149 (-)
<i>A. marginata</i> Biomass	Density	0.751 (-)
	Wave Exposure	0.088 (+)

Table 2.4 Experimental arenas reveal the varying population-level effects of *K. tunicata* on *A. marginata* spring sporeling density, summer biomass and species richness across sites varying in ambient *K. tunicata* densities

Response	Fixed Factor	df^o	F	Pr>F
<i>A. marginata</i> Spring Sporeling Density	Treatment	1,57	58.71	<0.0001
	Site x Treatment	8,57	15.09	<0.0001
<i>A. marginata</i> Summer Biomass	Treatment	1,57	48.42	<0.0001
	Site x Treatment	8,57	6.77	<0.0001
Species Richness	Treatment	1,57	14.88	0.0003
	Site x Treatment	8,57	3.63	0.0018

Table 2.5 we did not detect an effect of ambient *K. tunicata* density and/or wave exposure on *K. tunicata*'s per capita impact on *A. marginata* spring sporeling density or summer biomass dynamics based on small sample, bias-corrected Akaike Information Criterion (AICc). Models, with varying numbers of parameters (*K*), were compared using AICc differences (Δ AICc), and normalized Akaike weights (w_i).

Response	Model	N	K	AICc	ΔAICc	w_i	R²
Spring Sporeling	1	5	2	-16.177	0.000	0.998	0.000
	Wave	5	3	-3.499	12.678	0.002	0.769
	<i>K. tunicata</i> Density	5	3	3.629	19.806	0.000	0.038
	<i>K. tunicata</i> Density + Wave	5	4	1.798e308	1.798e308	0.000	0.777
Summer Biomass	1	5	2	-13.989	0.000	0.967	0.000
	Wave	5	3	-7.251	6.739	0.033	0.930
	<i>K. tunicata</i> Density	5	3	5.504	19.493	0.000	0.096
	<i>K. tunicata</i> Density + Wave	5	4	1.798e308	1.798e308	0.000	0.969

Table 2.6 The relative importance of maximum wave exposure and ambient *K. tunicata* density on *K. tunicata*'s per capita effect on *A. marginata* dynamics was low, as reflected by the low variable weights, whether interaction strength was calculated based on spring sporeling density or summer biomass. The sign of each variable coefficient in parentheses indicates the direction of the relationship between the response and each variable.

Response	Variable	Variable weight
Spring Sporeling	Density	0.00005 (+)
	Wave Exposure	0.00176 (+)
Summer Biomass	Density	0.00006 (+)
	Wave Exposure	0.03327 (+)

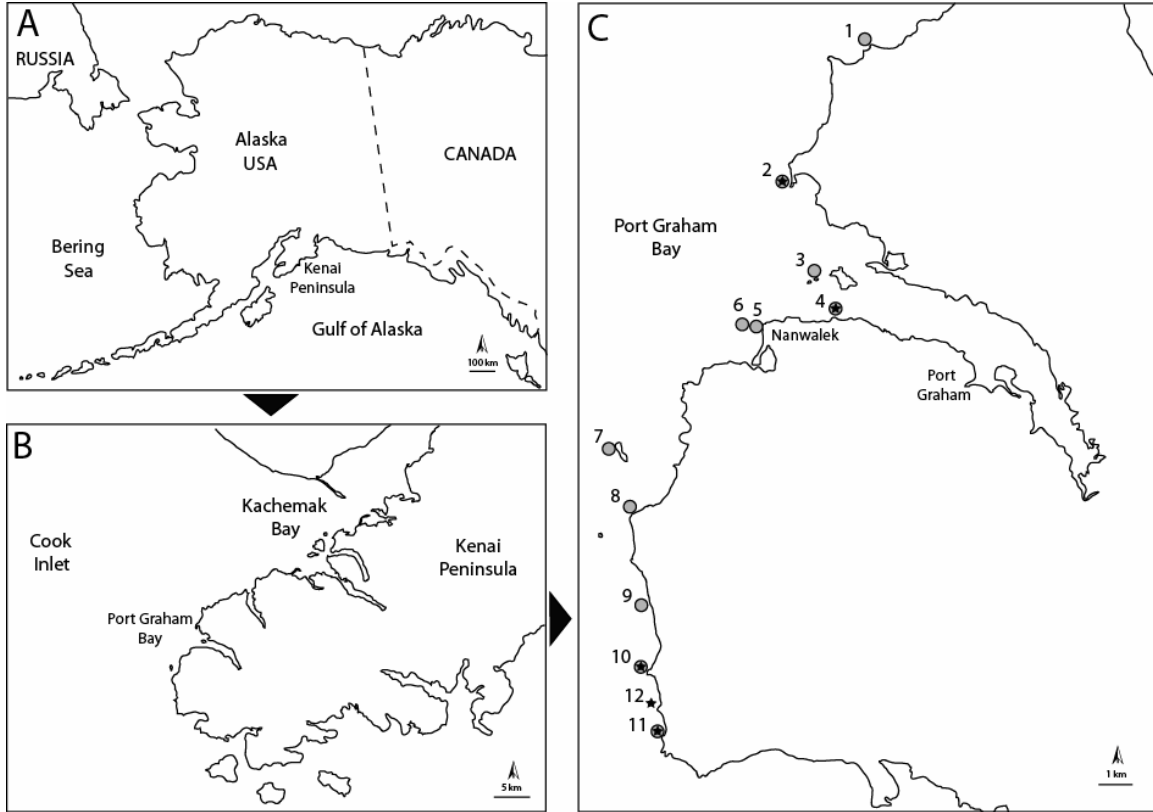


Figure 2.1 In south central Alaska, B) on the tip of the Kenai Peninsula, rocky intertidal community structure was compared across C) eleven sites (●) varying in wave exposure, human shoreline collection effort and sea otter predation pressure. Experimental *K. tunicata* removals were conducted at 5 sites (★) varying in ambient *K. tunicata* densities. Site names: 1. Point Pogibshi, 2. Coal Mine, 3. Otter Rock, 4. Romanoff, 5. Inner Nanwalek, 6. Outer Nanwalek, 7. Flat Island, 8. Magnet Rock, 9. Golden Rocks, 10. Jagged Rock, 11. Point Adams, and 12. Jagex.

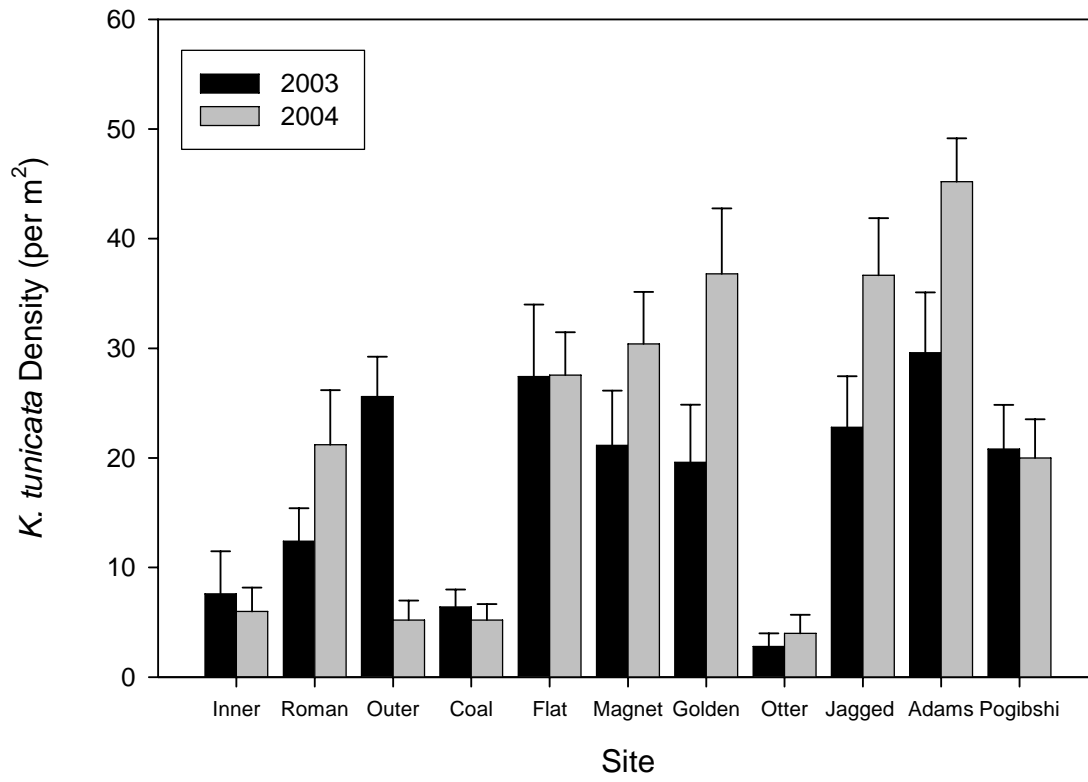


Figure 2.2 *K. tunicata* density in 2003 and 2004 across eleven sites varying in wave exposure, human harvest effort and sea otter presence. Sites are ordered according to shoreline collection effort; from most heavily harvested to least heavily harvested. From Salomon 2006b.

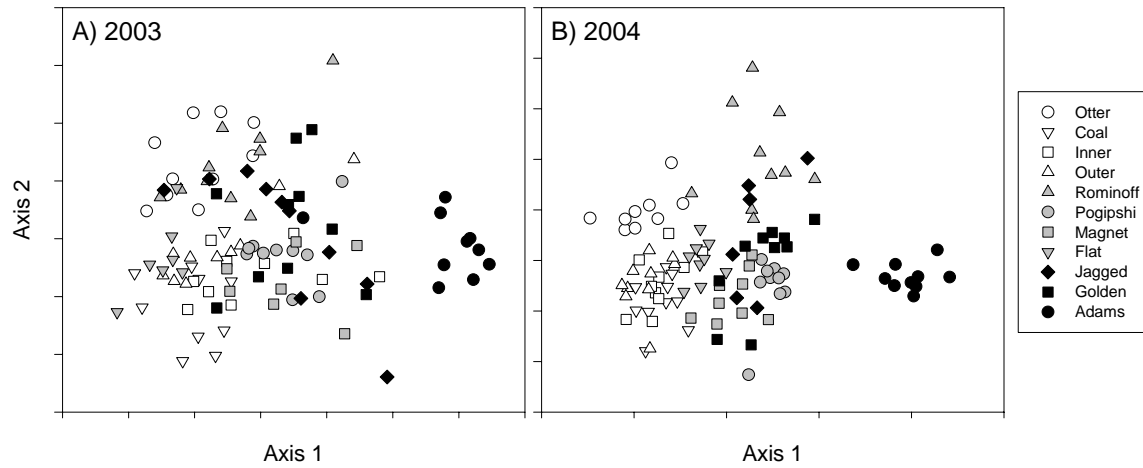


Figure 2.3 A comparison of rocky intertidal invertebrate and algal community structure in A) 2003 and B) 2004 by nonmetric multi-dimensional scaling (NMDS). Each site is represented by a unique symbol, whereas low (≤ 2), medium (3-6), and high (≥ 7) *K. tunicata* densities per 0.25m² quadrat are represented by white, grey and black symbols respectively.

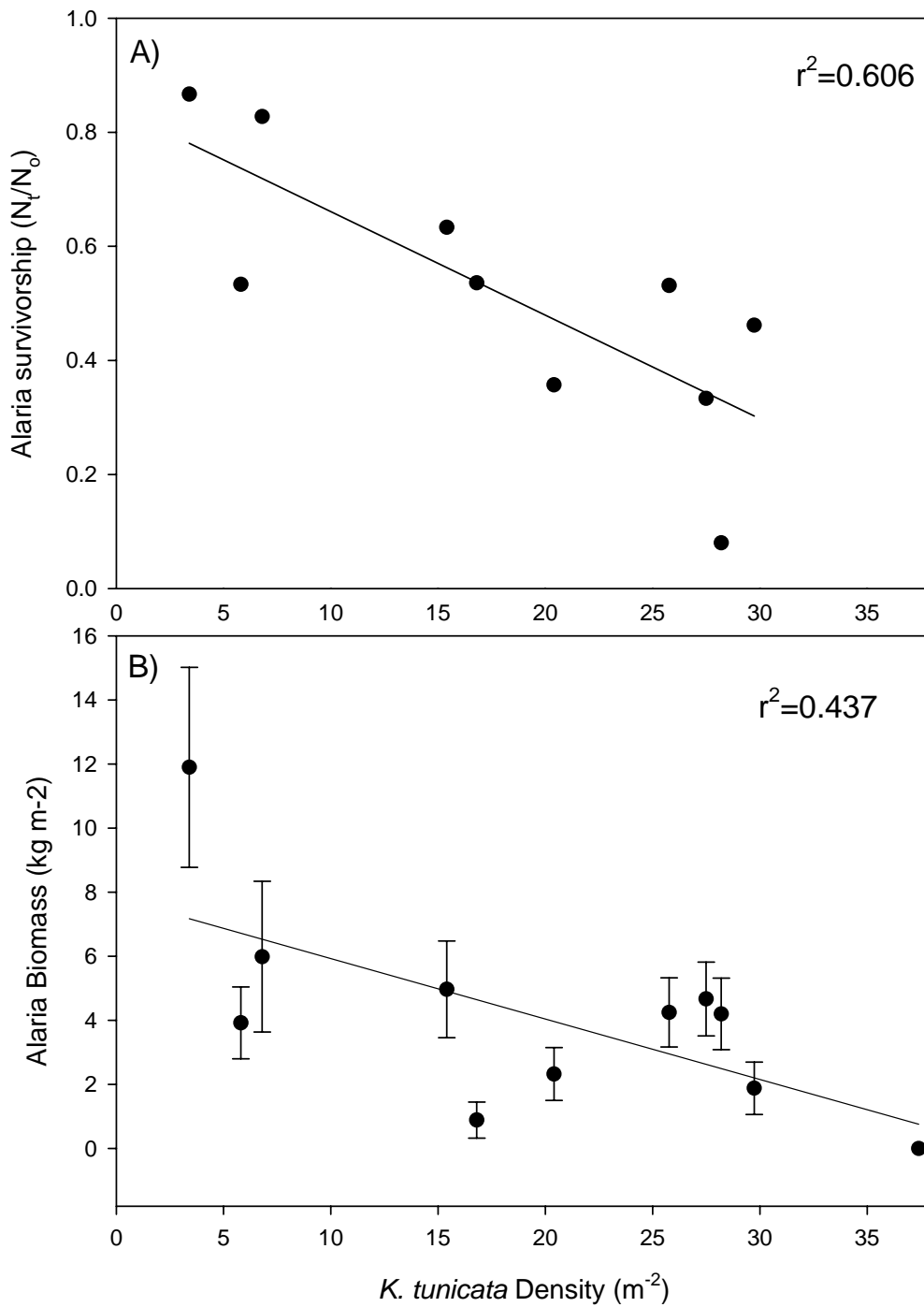


Figure 2.4 A. *marginata* A) survivorship and B) biomass as a function of ambient *K. tunicata* densities. *A. marginata* survivorship was not quantified at one site (Adams) because no individuals were present to tag.

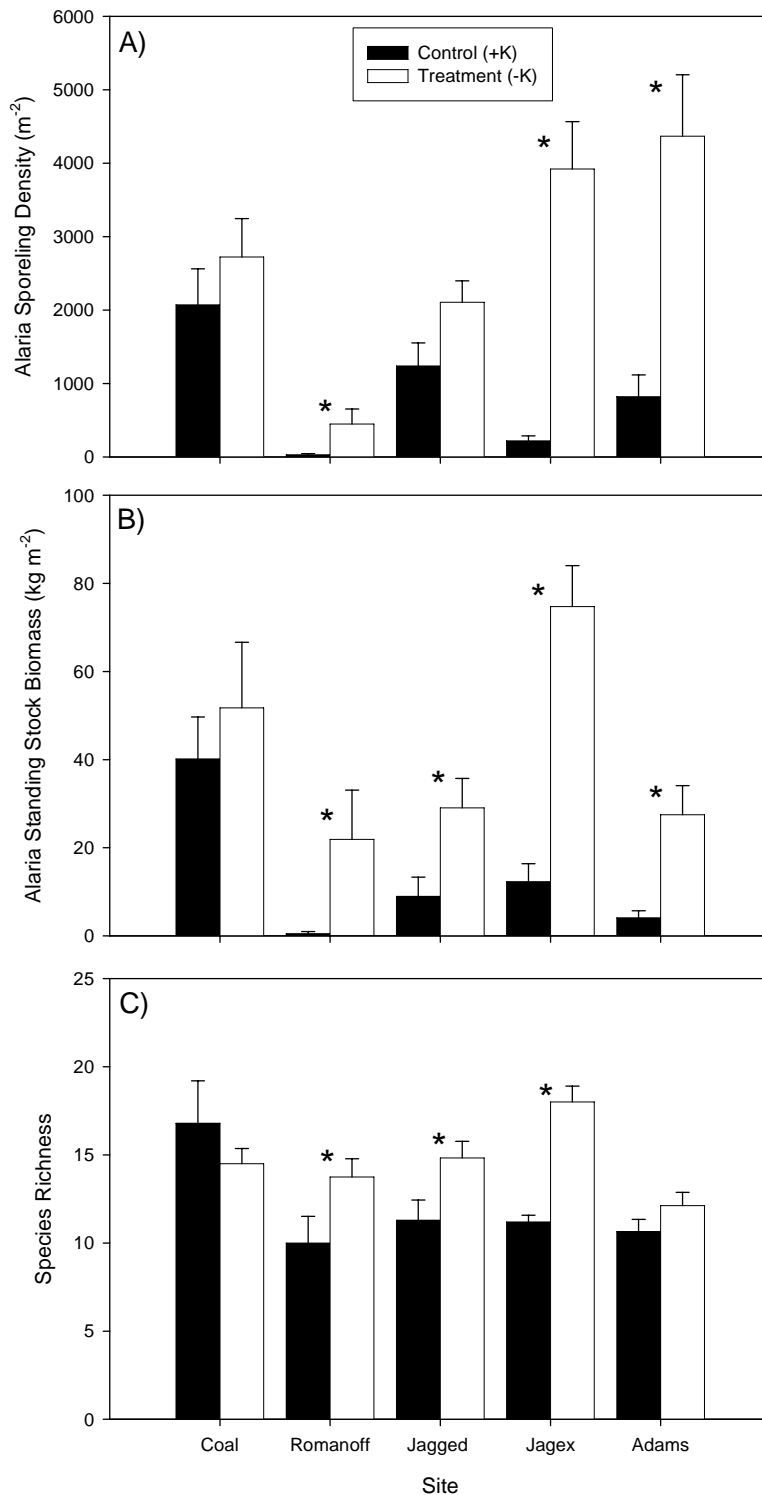


Figure 2.5 Population-level impact of *K. tunicata* on A) *A. marginata* spring sporeling density, B) *A. marginata* summer biomass and C) species richness based on data from experimental arenas constructed at 5 sites varying in ambient *K. tunicata* densities.

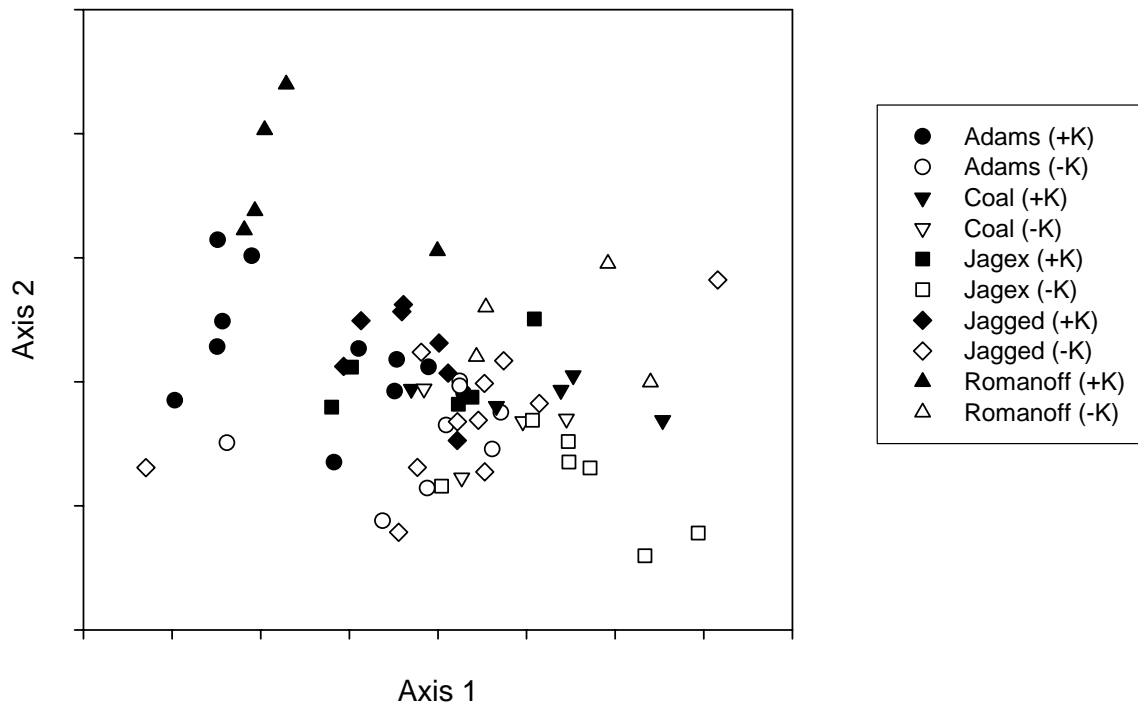


Figure 2.6 Population-level impact of *K. tunicata* on intertidal community structure based on species-specific biomass estimates from experimental arenas constructed at 5 sites varying in ambient *K. tunicata* densities. Each site is represented by a unique symbol. Experimental treatments precluding *K. tunicata* are represented by white symbols whereas experimental controls which allowed *K. tunicata* access are represented by black symbols.

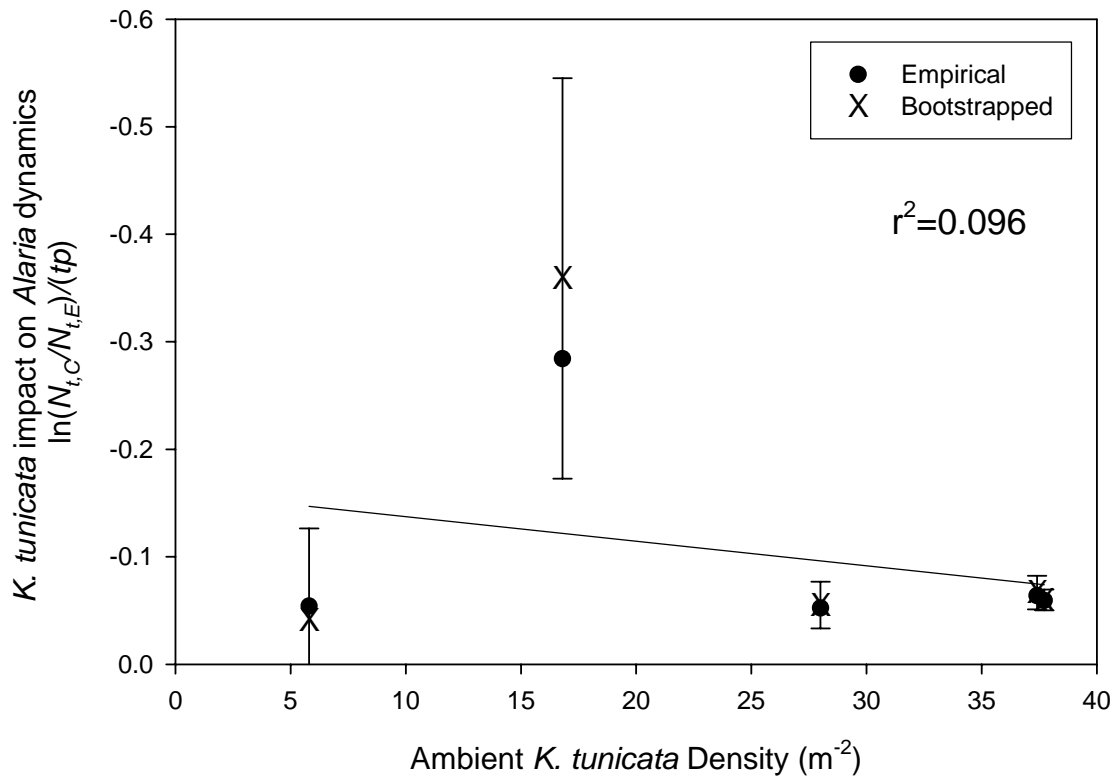


Figure 2.7 Per capita interaction strength of *K. tunicata* on *A. marginata* dynamics as a function of ambient *K. tunicata* (predator) density. Empirical field experiment estimates (●) and bootstrapped means (X) \pm standard deviations are shown. Regressions were performed on empirical per capita interaction strength estimates. Interaction strength depicted here was calculated based on *A. marginata* summer biomass, the relationship based on *A. marginata* spring sporeling density was practically identical.

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Imam Suga; Person from the Water

“The ocean is part of me. Sometimes, I just have to go down there to smell the ocean.”
(Simeon Kvasnikoff, Elder, Port Graham)

We, the Sugpiaq people, are sea people. Our lives are sustained by the sea. The sea is part of our spirit. When it changes, we change.

Preface; How this Book Came to Be

The Sugpiaq residents of Port Graham and Nanwalek have observed dramatic changes in their ocean home over the last century. The story is a familiar one; shellfish resources which were once plentiful have become scarce. Sea urchin, crab, shrimp, clams and cockles are now fewer in number and smaller. The most recent shellfish to decline is that of the black leather chiton (*Katharina tunicata*), known locally by its Russian name ‘bidarki’ and its Sugt’stun name ‘Urriitaaq’. Prompted by local concern and interest to determine the causes of change, I have had the pleasure of working in collaboration with local residents for the past five years, to uncover the causes and consequences of this latest decline. As ecological detectives, we have collectively begun to piece together the clues.

Residents from both Port Graham and Nanwalek helped with fieldwork and shared their knowledge of bidarkies and their ocean home. Working together, we learned a great deal from each other. Understanding bidarki declines required an understanding of the whole ecosystem, including humans, their relationship with the sea, and their history on the Kenai Peninsula.

Thus, our research expanded. Locally, it became known as “The Bidarki Project” and I the “Bidarki Lady”. In addition to our ecological fieldwork, we began interviews with tribal Elders and harvest surveys with village residents. To help with this part of the project, Henry Huntington joined the research team. Through the interviews, we expanded our scope to discuss changes in the conspicuous animals which inhabit nearshore waters, social changes that have taken place in the villages, and other historical events that have shaped what we see today.

It became increasingly clear to us all that present day ecological data alone could not explain the reasons behind recent localized shellfish declines. Rather, understanding the historical change in human settlement patterns, local subsistence and regional commercial harvest practices and the population dynamics of various natural predators became critical to our understanding of the factors driving recent shellfish declines. Much of this information was provided through the traditional knowledge held by Elders. Serendipitously, halfway through our research, Lisa Williams began working on a

complimentary research project, photo-documenting village residents and their coastal subsistence culture.

During our collective research, a common challenge was identified by Elders of both villages; the current lack of information transfer from Elders to younger village residents. Many Elders felt that traditional avenues for sharing such knowledge had eroded due to the realities of modern day living. They feared that “the old ways” and important knowledge regarding marine ecosystems, subsistence practices and traditional management were becoming lost. At the same time, the researchers were keen to share their findings with the local communities. Thus, we became inspired to share our collective knowledge and so blossomed the idea for this book.

As our words show in this book, the researchers, community members, local artists and Elders became “we” and “us.” Thus, our book is written in the first person, plural, and conveyed through many voices. The story is ours collectively, a fusion of western science, traditional knowledge, history, archaeology and anthropology melded together and told by us all.

During the process of co-creating and co-editing this book, it became glaringly clear that our story would be valuable to a much wider audience. Replace the major characters and the tale we tell here could be told by countless coastal communities throughout the world who have witnessed drastic changes in their ocean home given the pressure humans now impose on marine ecosystems worldwide.

We start long ago, in the days when only the Sugpiaq were here. The story moves forward, through the Russian era and into our living memory of the 20th century, with the 1964 earthquake, the 1989 *Exxon Valdez* oil spill, and other events large and small. This history, integrated with traditional and scientific knowledge, leads us to a possible explanation for the decline in shellfish, including the recent decline in bidarkies. The story then navigates us through the current day threats to our ocean and asks us to look ahead and consider the challenges we face in the future to sustain our marine resources, ecosystem and our communities.

We hope that readers can draw parallels to their ocean home thereby expanding our collective understanding and appreciation of our ocean’s resilience and limits. Finally, we hope that readers will reflect upon the intricacies of our oceans, the wisdom of our Elders, and our responsibility to future generations.

OUR CHANGING SEA

On the surf swept rocky shores of the outer Kenai Peninsula, Alaska, we, the Sugpiaq people of Port Graham and Nanwalek, have been observers, benefactors and part of the marine ecosystem for decades. Because our lives are sustained by the sea, any

ripple of difference is reflected directly in our daily lives. With a keen and contemplative eye, we have witnessed our nearshore ecosystem transform throughout the years. We are holders of this knowledge, we are the eyes that observe change.

Our marine ecosystem is affected simultaneously by multiple drivers of change, both human-caused and natural. Because both current and historical causes of change shape what we observe today, we need to explore our history to more thoroughly understand present day ecosystems¹⁻³. Traditional knowledge coupled with archaeology, historical records and western science can reveal key insights in to the causes of our changing marine ecosystem. For the past shapes our present and informs our future.

This is a story told through the eyes of tribal Elders, subsistence hunters, village residents, an anthropologist, a photojournalist and a marine biologist, each one of us bringing our observations, skills and knowledge to collectively tell a story about our changing sea.

Subsisting From The Sea

“We survived by the ocean & beach. That’s what sustained us.”
(Walter Meganack Jr., Chairman Port Graham Corporation)

For centuries, we have sustained ourselves on food from the sea. Salmon are our mainstay. We catch reds (sockeye), pinks (humpies), dogs (chum) and silvers (coho) throughout the spring and summer and king salmon (chinook) year round. Halibut, harbor seal and sea lion are also part of our diet. However, our most accessible food from the sea comes from the intertidal, that part of the seashore that disappears at high tide and reemerges at low tide.

“All my life, I depended on that shoreline. I would go down to the beach to collect anything to make chowder for that night’s dinner. If we needed food I knew where to get it. The beach provided for us.” (Elenore McMullen, Elder and Past Chief, Port Graham)

The Tides That Fed Us

“The sea back then was a dinner table set at low tides.” (James Kvasnikoff, Second Chief, Nanwalek)

When the tide is out, the table is set. This old adage is used by many coastal natives. In the past, our seashore was akin to a refrigerator full of food, accessible only at low tide. Below the sand and pebbles we collected clams and cockles, above the sand, Dungeness crab. On rocky outcrops, sea urchins, sea cucumbers, octopus and chitons

were collected. Unfortunately, many of these intertidal invertebrates are now scarce and are becoming ghosts of ecosystems past.

“There used to be so much to eat from the ocean. You didn’t have to worry about getting them, they would be there.” (Simeon Kvasnikoff, Elder, Port Graham)

“We used to be able to get all the Dungeness we wanted. We used to collect clams and cockles, no body ever missed a tide. I didn’t have concept of poor or rich in a western world sense. We were so rich because there was so much out there.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

In the intertidal, we can still find subsistence foods if we search long enough but the animals we now collect are smaller and fewer, some are rarely even seen. Now, we have to go further to collect what we used to be able to gather close to home.

“Things are disappearing and not coming back.” (John Moonin, Elder, Port Graham)

“Nature changes. Man changes. Is it natural? I feel that changes are more pronounced now. Change is happening at a faster pace now than before.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

Bidarkies; The Most Recent Decline

“Mom used to make us eat ‘shut–up dinner.’ This would be a dinner of bidarkies. The kids would be quiet as they would be busy chewing.” (Anesia Metcalf, Elder, Port Graham)

“I started noticing Bidarki declines 10-15 years ago. Now you only see the little ones.”
(Walter Meganack Jr., Chairman Port Graham Corporation)

The black leather chiton, known locally by its Russian name ‘bidarki’ and its Sugt’stun name ‘urriitaq,’ is an intertidal mollusk that remains an important subsistence resource for us. The word bidarki refers to its shape. Suctioned to the rocky shore amongst ribbon kelp (*Alaria marginata*) and sea cabbage (*Hedophyllum sessile*), this oval shaped invertebrate resembles a small overturned kayak or little boat, known in Russian as a biadarka. We eat bidarkies in casseroles, seafood salads, or raw, right off the rock.

Unfortunately, we started observing declines in the number of bidarkies about 10-15 years ago. The ones that we do see now seem to be smaller. Bidarki plates found in lower Cook Inlet middens, dated back to 3000 years before present, suggest that these chitons have been harvested for thousands of years in this area^{4,5}. In our ocean home, bidarkies have been collected throughout our living memory. Yet strangely, localized bidarki declines have been recent.

Not only was there widespread interest to determine the causes of this decline, we wanted to understand why so many other marine invertebrates had begun to disappear from our ‘nearshore refrigerator.’ Bidarkies were but one of many marine species declines. Things were changing. Why? There may be many possible reasons for the declines we have witnessed. It is by no means clear that any single factor is to blame.

A Story of Multiple Causes

“Declines are likely due to a chain reaction. There is still to this day, no one reason for all of these declines.” (Walter Meganack, Jr., Chairman, Port Graham Corporation)

Untangling the various factors that have contributed to species declines and marine ecosystem change is a difficult task. In an ecosystem, nothing happens in isolation, if one thing changes, other changes soon follow. However, some drivers of change may matter more than others. Identifying those primary causes of change may help us slow, or possibly reverse, future declines.

Both human and natural drivers of change contribute to species declines and ecosystem alterations. Some of these are short term, pulse disturbances while others are press perturbations sustained over longer periods of time. Pulse and press disturbance can occur in small areas or extend over large spatial areas. Furthermore, some changes don’t happen gradually. Long term cumulative effects can sometimes push an ecosystem beyond a tipping point. In such a case, small disturbances can have big effects over a short period. Once a system tips, rapid change can cause a cascade of events that can reverberate through an entire ecosystem, both its social and ecological components.

“Sea otters, oil pollution or the people. I want to blame one but I don’t know which one.” (John Moonin, Elder, Port Graham)

To understand what has happened to the bidarkies and the other marine species in Port Graham Bay, it is necessary to examine the pulse and press disturbances that have altered this area. In the two chapters that follow, we describe the disturbances, both natural and human-caused, that have altered our ocean home. By investigating the magnitude, spatial extent, length and timing of the disturbances and changes we have witnessed, we attempt to pinpoint those causes which have most likely contributed to our transformed marine ecosystem. When pieced together, a possible reason for the decline in marine invertebrates, including the most recent bidarki decline, begins to appear. To explore these drivers of change, we will begin by delving into history.

THE RUSSIAN ERA

From Seasonal Camps and Settlements to Established Villages

Towards the end of the last Ice Age, at least 10 000 years ago, as coastal environments warmed, glaciers melted and plant and animal life flourished, people began to inhabit Alaska's gulf coast⁶. Within the Sugpiaq region, coastal archaeological sites date back to 7500 years before present. The oldest known settlements in Prince William Sound and on the Kenai Peninsula are 4500 years old although the absence of earlier sites may reflect sea level rise and sinking shorelines rather than a true absence of settlement^{6,7}. Back then, we lived semi-nomadic lives, traveling from coast to coast, among permanent settlements and numerous seasonal camps⁸.

In 1741, Vitus Bering and the naturalist, Georg Steller sailed from Kamchatka, Russia to Alaska⁹, opening the way for Russian missionaries and fur traders. With the Russian occupation of Cook Inlet, Alaska in the 1780s both commercial fur trading companies and the Russian Orthodox Church sought to centralize services in larger villages. Thus, regional consolidation led to the demise of smaller settlements and the creation of larger, more permanently established villages^{8,10}. As a result, subsistence collecting and hunting became increasingly spatially concentrated. The sustained and localized human disturbance of harvest likely had a profound effect on local marine resources.

“When resources became limited, people moved on. They took all of their camp out. Then they would go back when resources returned. Villages didn't exist, there were seasonal camps. They always traveled, from fall to spring. That's what is happening here, we're not moving.” (Nick Tanape Sr., Elder, Nanwalek)

“They conserved by using different areas.” (Herman Moonin, Port Graham)

“Did you ever wonder why the Aleuts moved out through the Aleutian chain? They were running low on food. They fought for food. They were looking for a better place and better food.” (Simeon Kvasnikoff, Elder, Port Graham)

Our Ocean Home is Formed

Before living in the villages of Port Graham and Nanwalek, our ancestors inhabited the Kenai Fjords, on the southern shores of the Kenai Peninsula⁸. It was there, in Nuka, Yalik, and Aialik Bay that our rich maritime culture thrived. Archeological data suggest that those historic village sites are at least 800 years old although earlier sites may have been destroyed by a major earthquake, coastal subsidence and sea level rise¹¹.

With the Russian occupation, our people were coerced to hunt sea otter for the burgeoning fur trade. In fact, Nanwalek was established as a fur trading post in 1786. Large native hunting crews were assembled by the Russians. Tragically, disease epidemics, starvation and loss of political sovereignty came with this exploitation of labor¹². During the early 1880s, our ancestors were relocated from the last villages in Nuka and Aialik Bay to the more populated village of Alexandrovsk in English Bay (now Nanwalek) and Paluwik (now Port Graham) by Russian missionaries⁸.

“Of all the things we have lost since non-natives came to our land, we have never lost our connection with the water. The water is our source of life. So long as the water is alive, Chugach Natives are alive.” (Walter Meganack Sr., Past Chief, Port Graham)

Our ocean home is here now, on the westernmost tip of the Kenai Peninsula. Look to the west and we see the imposing volcanoes of Cook Inlet, to the south, the Chugach and Barren Islands in the distance, North, around the waters of Dangerous Cape and Point Pogibshi, lies Kachemak Bay. Steep mountains descend from alpine ridges, through alder meadows and spruce forests, to high cliffs that stand before curving beaches and rocky headlands. Islands and reefs dot the waters, growing and shrinking with the tides. Here, along the coastal arc of the Gulf of Alaska, the Pacific Plate collides and descends beneath the North American Plate creating a active area of earthquakes and volcanic eruptions. In the ocean, the Alaskan coastal current hits the continental shelf causing the upwelling of nutrient rich water, the basis of our marine food web and our spirit.

Extinctions & Extirpations

“When the Russians came they cleaned the sea otters out. When I was 18 yrs old [1953] there were no sea otters around Port Graham.” (Simeon Kvasnikoff, Elder, Port Graham)

Immediately after the first Russian sighting of Alaska back in 1741, two dramatic ecological events ensued. The Steller sea cow became extinct within 23 years, thereby becoming the fastest extinction on record¹³. With the Russian occupation of Cook Inlet in the 1780s, and a rampant fur trade, the sea otter became locally extirpated from Alaska’s coastline by the early 1900s with only several pockets of animals remaining¹⁴.

“The elders used to talk about sea otters but we didn’t know what they were. We wanted to see one.” (John Moonin, Elder, Port Graham)

When today’s Elders were young, sea otters were never seen in front of Nanwalek. The localized extinction of sea otters would have significantly altered the abundance of marine invertebrates in Port Graham Bay¹⁴. Without these voracious predators, their invertebrate prey, including sea urchins, crab, clams, cockles, octopus and chitons, would have increased in number. With an increase in herbivores, such as urchin and chitons, beds of bull kelp and ribbon kelp would have likely declined.

“There was not as much kelp in front of Nanwalek when I was young [early 1940s].” (John Moonin, Elder, Port Graham)

“Someone sold our land but didn’t ask us.” (Herman Moonin, Port Graham)

In 1867, the Russian era ended with the purchase of Alaska by the United States, although Alaska only became a state in 1959. With the signing of the International Fur Sea Treaty, large-scale fur hunting officially ended by 1911. By that time, a new economy, which emerged in the late 1880s with the decline of the sea otter and falling fur prices, began to blossom. Commercial fishing and canneries gradually replaced hunting and fur trading as our major source of local income.

IN LIVING MEMORY

Cannery Conundrum

“Wow, this place would stink. It was like a mountain. Piles and piles of carcasses. Every summer it would happen. Salmon, herring, head, tails, bones. Everything went on the beach.” (Dorothy Norman, Elder, Port Graham)

By the early 1900s, salmon canneries dominated the local economy on the Kenai Peninsula. The Fidalgo Island Packing Company built a cannery in Port Graham in 1912 which it maintained until 1960. The cannery brought jobs to Port Graham Bay but with opportunity came a cost. Canneries may have contributed to shifts in the bay’s ecosystem in both direct and indirect ways. The dumping of processing waste produced noticeable changes to the water quality in the bay. This practice lasted for many years. Still today, the pink salmon hatchery sends most of its fish waste into the middle of the bay.

“Cannery waste and hatchery waste attracts many predators. It’s just like saying ‘common, dinner time.’” (Nick Tanape Sr. Elder, Nanwalek)

“There were all sorts of starfish with the Fidalgo cannery waste.” (John Moonin, Elder, Port Graham)

“Sunflower starfish have increased since the 1980s. That’s another big impact.” (Lydia McMullen, Port Graham)

Some species benefit from this temporary food source. Sea gulls congregate above water and sea floor scavengers such as sunflower sea stars gather bellow. Sunflower sea stars are quick moving predators that eat clams and cockles, especially those small ones left behind after a sea otter’s dinner pit. Like clams, many other bottom dwelling marine species suffer from this introduced source of concentrated nitrogen and carbon. This pulse disturbance that still happens seasonally can render seafloor

sediments anoxic, meaning without oxygen, and can physically smother bottom dwelling animals.

Canneries had another important social implication which may have indirectly influenced our local marine ecosystem. Prior to the 1920s, we used to travel as part of our seasonal hunting, fishing and collecting rounds. The establishment of canneries in Port Graham, Seldovia and English Bay during the 1911-1920 period disrupted our seasonal cycle of movement because cannery work was available during the months when we traditionally put up salmon for winter supplies. We stopped moving as much as we did in the past, consequently, our hunting and collection became increasingly concentrated locally.

Following the Fish

Even after settling in Nanwalek and Port Graham in the 1880s, our people would travel. We would also set up seasonal hunting camps out at Port Dick and Windy Bay¹⁵. We followed, the fish, the seals, our food.

Then came the cannery and mining jobs. In 1915 a cold storage plant for halibut and cod was established in Portlock (also known as Port Chatham) and two years later a chrome mine was opened on Claim Point. Later in Portlock, a salmon cannery was built in 1928 and remained until the late 1950s⁸. Port Graham, Seldovia and English Bay also had canneries which processed king crab, shrimp & salmon. We then followed the jobs, the fish to be canned.

“People were still nomadic when I was a kid in the 40’s and 50’s. They migrated with the fish. Our people living in Portlock would come to Port Graham over land. When the cannery closed down there in Portlock, people moved to Nanwalek, Port Graham and Seldovia.” (Elenore McMullen, Past Chief and Elder, Port Graham)

With the closing of the canneries in Portlock in the late 1950s and Seldovia in the late 1960s, and the centralization of the cannery culture to Port Graham, people again became increasingly concentrated and Port Graham and Nanwalek became increasingly permanent villages. People moved less and fishing effort became, once again, more concentrated in space.

Sea Otters Return

“They came back in the early 60’s. The population exploded in the late 70’s early 80’s.” (John Moonin, Elder, Port Graham)

“Boy, those things multiply!” (Simeon Kvasnikoff, Elder, Port Graham)

With the cessation of the Russian fur trade in the early 1900s and later, with the listing of the sea otter under the US Endangered Species Act in 1974, this notorious marine mammal began to reestablish along Alaskan coastlines. They returned to the waters in front of Port Graham and Nanwalek in the early 60's. Back then, we might have caught a glimpse of a furtive individual. Today, rafts of 30 or more float around rocky headlands in the summer from Point Adams to Point Pogibshi. During the winter storms, hundreds of sea otters take shelter in Port Graham Bay. Although their ecological effects are localized, sea otters are an example of a natural press perturbation, one that is sustained, and in this case intensified as populations rise.

“Sea otters are part of the problem...they eat every thing we eat.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

Many people in our villages identify the increase in sea otters as a cause of invertebrate decline, including Bidarkies, and one of the largest causes of change to the local ecosystem. In the past decade or two, sea otter numbers have increased dramatically within the bay. Today, sea otters are plentiful and are regarded as our major competitor for shellfish and thus a pest. Our surveys suggest that at least 173 adults (+/- 14) and 43 pups (+/- 8) were living between Point Adam and Point Pogibshi during the summer of 2004. This is likely a minimum estimate as some individuals are difficult to see while others remain offshore during parts of the tidal cycle.

“In the wintertime, you don't see many people getting bidarkies. The weather has to be perfect. But the otters are eating all the time. They can get them at high tide. Our time to get them is limited.” (Lydia McMullen, Port Graham)

Local Shellfish Begin to Decline

“We used to see green sea urchins all over Nanwalek Reef in the early 1940s. By the late 50's sea urchins were mostly gone. Sea cucumbers were eaten by the elders too, we liked them better than bidarkies because they were softer... not much eaten now.”
(John Moonin, Elder, Port Graham)

Green sea urchins were plentiful on Nanwalek Reef in the 1940s, but by the late 1950s they were mostly gone. Sea urchins and sea cucumbers were the first marine invertebrates that we observed decline, just as the sea otter began to return to our shores. At the same time, commercial trawling was increasing along our coastline and urchins were often caught as bycatch. With the decline in urchins came an increase in kelp covering the reefs. These spiny herbivores are particularly well known to mow down kelp. As mentioned earlier, where urchins are absent or reduced in numbers, kelp beds thrive.

“Sea urchins. There used to be a big batch of them in the past. We used to get them in pots and seines. They suffered as bycatch from the trawling that used to happen close to shore, now most of the trawling occurs further away from the coastline.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

“I haven't had lady slippers for years.” (Annie Fomin, Elder, Port Graham)

“We used to find them after a big storm. Now we don't find many. If we do, they are smaller now.” (Irene Tanape, Nanwalek)

The next marine invertebrate to decline was the ladyslipper, also known as the gumboot chiton (*Cryptochiton stelleri*), the largest chiton in the world^{16,17}. This chiton is a close relative to the bidarki but is generally much larger, up to 20 cm (about eight inches). Its large size makes it a much more rewarding snack than a bidarki. Furthermore, ladyslippers are easier to spot. Because this chiton is brick red in color, it is not as well camouflaged as the deep brown to black colored bidarki. Unfortunately for us, yet fortunately for the otter, this chiton is found mostly subtidally, below the lowest low tide, unlike the bidarki which is primarily intertidal. Although we can find the occasional ladyslipper on a really good minus tide, they are usually out of our reach. Furthermore, because they live on both sandy and rocky sea floors, their foot, which is able to adjust to both habitats, does not have as much suction power to stick tightly to the rock as a bidarki's foot. As a result, it is easier for us and for the sea otters to collect off the rocks compared to a bidarki.

The Earthquake of '64

“After the earthquake, there was sunk land and no minus tides for about 4 years. After that it came back to normal.” (John Moonin, Elder, Port Graham)

With the Good Friday earthquake of 1964 came a tsunami that swept the Gulf of Alaska and land displacement that drastically altered the shoreline. Both subsidence and uplift caused extensive damage to coastal forests, salmon streams and shellfish habitats. Some parts of the lower Kenai Peninsula subsided as much as 7.5 ft while uplift in some areas of Prince William Sound was as high as 38ft¹⁸. In areas of great uplift (>9ft), intertidal zones that had once been covered with the incoming tides were suddenly raised far above the highest tide killing the exposed seaweeds and marine invertebrates within days¹⁹. Uplift caused extensive mortality of clam beds which were lifted above their normal upper limits. Conversely, in areas of subsidence, terrestrial zones became intertidal zones and areas which were once intertidal became subtidal.

The shoreline of our ocean home in Port Graham and Nanwalek subsided. Because the land was lower, the high and low tide lines moved up the beach and formerly productive intertidal zones became permanently covered with water. After the

earthquake, mobile midintertidal animals, such as bidarkies, survived the vertical downward displacement of their habitat by moving upwards to reestablish their proper vertical ranges. Although their main food of attached ribbon kelp (*Alaria marginata*) could not make that same journey upwards, they could graze on similar species of algal prey that existed in the midintertidal, such as sea lettuce (*Ulva* spp.) and sea cellophane (*Porphyra* spp.), that also exist in the high intertidal. Furthermore, bidarkies may have found new temporary food sources. On down thrust rock, some littorine snails were found grazing on terrestrial moss! Preearthquake populations of mussels, barnacles and rockweed (*Fucus gardneri*) were found alive in their new, lower intidal home, apparently inhibiting the establishment of critters usually found at that level (i.e the split kelp, *Laminaria bongardiana*). Land subsidence also caused a direct loss of intertidal salmon-spawning areas in streams which was particularly damaging to pink and chum salmon.

In addition to land displacement, tidal waves surged into bays and inlets sweeping away square miles of soft sediment, scouring out clam beds and redepositing layers of mud and debris in deep and shallow waters elsewhere thereby suffocating the marine life below. This caused the total mortality of clam beds in some areas of Prince William Sound¹³. Some intertidal spawning habitat of the Port Graham River was lost due to land subsidence but tsunami action did not alter the salmon spawning habitat substantially¹⁴.

“The earthquake damaged the clam beds. This quake did not take the bidarkies, snails, and other invertebrates. If it did, they came back.” (James Kvasnikoff, Second Chief, Nanwalek)

Although this pulse perturbation in 1964 had dramatic immediate effects on seashore life, recovery was quick for most species. Intertidal observations made in 1968, 5 summers after the earthquake, confirmed that intertidal communities around the corner in Prince William Sound had essentially returned to their preearthquake condition with few exceptions¹³. Snails and limpets which were scarce in 1965 were abundant in 1968, and mussel beds were back at their preearthquake intertidal level. Nonetheless, Alaska sustained heavy economic loss from the immediate impact of the earthquake on fish and shellfish resources plus the intense damage to ports, canneries and vessels used by the fishing industry. Port Graham felt the immediate hardships of this natural pulse disturbance but things quickly returned to normal. Unfortunately, the human-caused press perturbations to come were likely of greater significance to our ocean home ecosystem.

Electricity and Sewer Lines Come to the Villages

“We would eat them within 2 days. We had to.” (Vera Meganack, Port Graham)

“In the past, Bidarkies were like our popcorn, we would eat them fresh like snacks. Now I keep them in my freezer.” (Anesia Metcalf, Elder, Port Graham)

“In the past we used to pick just enough to eat and snack on. When electricity and then freezers became available people began to pick more because they could store them. Q: The tide is small, where did you get those cockles? A: From my freezer!”
(Feona Sawden, Elder Port Graham)

“Now, we clean them, freeze them, and put them away for the smaller tides.”
(Peter Anahonak Sr., Elder, Port Graham)

In 1970, Port Graham got electricity. With the modern conveniences of freezers and refrigerators came a new way of storing food. Salting and drying worked well, but they took time and effort and affected the taste of the meat. Freezing was relatively fast and easy. Before freezers, people typically ate shellfish right away. They would take only what they could eat soon. Any extras would be shared with others. With freezers, however, people could harvest many more shellfish on a single trip and stock up for later. Today, vacuum sealers are a modern convenience that allows us to preserve food for even longer.

“Our ability to freeze things – that has increased our impact.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

“Everything that goes down the kitchen sink ends up in the bay”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

After electricity came the local sewer line, putting household and other waste directly into the bay. It is not clear if the currents and tides in the bay effectively flush sewage and wastewater away from Port Graham. During strong tides, it is likely that the flushing action is strong. During weak tides, there is not as much water flow, and it is possible that the waste remains in the bay for longer periods. In either case, the steady addition of wastewater and sewage is a change from the past. At Nanwalek, on the open coast, currents and tides are more effective at taking the wastewater away at all times. Regional and global pollution is another factor altogether.

The Commercial Crustacean Crash

“We used to be able to get all the Dungeness we wanted.”
(Walter Meganack, Jr., Chairman, Port Graham Corporation)

“Dungeness were wiped because of commercial crab fisheries and dragging. They came right into this bay. Now they (the Dungeness crab) haven’t been able to come back because of the sea otters.” (Jeffrey McMullen, Port Graham)

Commercial shrimp and crab fisheries in Cook Inlet began in the early 1940s close to shore in sheltered bays and inlets³. The fleet expanded in size during the late 1950s and began fishing further offshore. In Cook Inlet, crab and shrimp landings peaked in the early 60s. In fact, Port Graham Bay was heavily harvested for Dungeness crab in the late 1960s⁸. As years went on, both fisheries required increased effort to maintain harvest levels. Fishing effort on crab and shrimp stocks peaked between 1977 and 1981. As king crab declined, followed by tanner crab, Dungeness crab were targeted more aggressively. By the mid 1980s, crab and shrimp fisheries in the Gulf of Alaska had collapsed²⁰.

The Dungeness fishery in Kachemak Bay closed in 1986 and there was no catch in Cook Inlet between 1989 -1990. We observed this dramatic decline, here in Port Graham Bay, and suffered the consequences. Some scientists suggest serial depletion as a likely mechanism for these regional crustacean declines; historical fisheries were first developed to target the most lucrative and plentiful species, they then switched to other, less significant species after the former showed signs of depletion. This process happened one species after the next, after the next.

Changing Ocean Temperatures

“The climate seems to be warming and with climate warming, water temperatures change.” (Nick Tanape, Elder, Nanwalek)

Temperatures in the Pacific Ocean cycle between warm and cold regimes on a multi-decadal time scale. This large-scale oscillation in ocean temperatures, known as the Pacific Decadal Oscillation (or PDO), affects the Gulf of Alaska and the waters in front of Port Graham and Nawalek²¹⁻²³. In the mid-1970s, the Aleutian low-pressure system shifted south and intensified, causing stronger westerly winds and warmer surface waters. With that shift, the Gulf of Alaska swung from a cold phase (1946 to 1976) to a warm phase (1977 to present). This shift in ocean temperatures during the late 1970s may have triggered an alteration in the Gulf of Alaska marine ecosystem²⁴. The recruitment of groundfish improved and salmon catches soared. In sharp contrast, some forage fish populations such as capelin and herring collapsed around this time. In small-mesh trawl surveys, the catch changed dramatically from predominantly shrimp and capelin to halibut, cod, and pollock. This ecosystem change may have had negative effects on fish-eating sea birds such as puffins and kittiwakes that rely on capelin and other fatty forage fish. At the same time as ocean temperatures were changing in the Gulf of Alaska, possibly favoring ground fish over crab and shrimp, harvest on shrimp and crab was intensifying.

People often debate whether fisheries or changing water temperatures are responsible for declining fish stocks. Yet the respective roles and relationship between these drivers of marine ecosystem change are difficult to sort out. The fact that many marine species changed in abundance in the Gulf of Alaska and in front of our ocean

home in the late 1970s, whether they were fished or not, suggests that changing ocean temperatures were responsible for the ecosystem-wide shift. Furthermore, there is a strong association between shrimp catches and water temperatures. On the other hand, large-scale fisheries can cause unfished species to decline or increase by removing their predators or competitors. Plus, an increase in predators (cod, halibut) and decline in their prey (shrimp and crab) suggests that pressure from top predators, rather than ocean temperatures, may structure the marine ecosystem of the Gulf of Alaska and our ocean home of Port Graham and Nanwalek.

Fishing can also lead to simplified food webs. When food webs are diverse, predators can switch between prey as their numbers fluctuate. This ability to switch prey, allows predators to compensate for changes in their prey abundance that may be triggered by changes in ocean temperature. However, simplified food webs render predators more dependent on the annual recruitment and population growth of fewer prey species. This in turn may decrease the predictability in predator population sizes and catches. The net effect, no pun intended, is that as a fishery removes more fish it will increasingly appear as though changes in ocean temperatures have a strong influence on the fishery when originally it did not²⁵.

So is it harvest or is it changing ocean temperatures? There is no discrete answer. Successful management requires eliminating this dichotomy and focusing on holistic approaches which consider social systems and ecological interactions in the context of changing ocean temperatures.

Clams and Cockles, the Next to Go

“The clams were so big, you only needed 6 to make a chowder. Now, you need a bucket because they are so small. You can still get them, but you have to work hard for them. You have to dig and dig and dig. I’m talking about these big clams. Not these tiny ones. I see people with buckets of small ones. No wonder they’re declining. They don’t let them grow.” (Dorothy Moonin, Elder, Port Graham)

After the decline of the urchin, sea cucumber, ladyslippers, crab and shrimp, came the clams and cockles. They were the next to go.

When the Water Died

“Oil in the water. Lots of oil. Killing lots of water. It is too shocking to understand. Never in the millennium of our tradition have we thought it possible for the water to die. But it is true. We walk our beaches. But the snails and the barnacles and the chitons are falling off the rocks. Dead... Dead water.” (Walter Meganack Sr., Past Chief, Port Graham)

“The oil spill impacted nature’s cycles, the seasonal clock work of our culture, our life ways. It effected who we are as people. It wasn’t just for a short period of time. It had lingering effects, not only in our water but in our lives.”

(Violet Yeaton, Environmental Planner, Port Graham Village Council)

On the twenty-fifth anniversary of the ‘64 earthquake came another regional disaster: the *Exxon Valdez* oil spill in 1989. The tanker ran aground on Bligh Reef in Prince William Sound spilling an estimated 11 million gallons of oil that spread across the Sound through lower Cook Inlet to Kodiak Island and beyond. Although relatively little oil came to Port Graham and Nanwalek, the spill and its aftermath had an extreme affect on our communities, ecologically and socially. People avoided subsistence foods for fear of oil contamination.

“Clams, cockles & Dungeness crab were declining before the oil spill. The oil spill may have made it worse but they were already declining before the spill.”

(Feona Sawden, Elder, Port Graham)

Interestingly, while bidarkies and other marine invertebrates along the shores of Port Graham and Nanwalek were affected by the oil, the declines in shellfish began prior to the spill.

“We walk our beaches. But instead of gathering life, we gather death. Dead birds. Dead seaweed. Before we have a chance to hold each other and share our tears, our sorrow, our loss, we suffer yet another devastation we are invaded by the oil company. Offering jobs, high pay. Lots of money. We are in shock. We need to clean the oil, get it out of our water, bring death back to life.” (Walter Meganack Sr., Elder and Past Chief, Port Graham)

Hundreds of millions of dollars have been spent to assess the environmental impacts of the spill. In Prince William Sound, changes to the food web may have had long-lasting indirect effects. Ironically, the spill, although around the corner from our ocean home, had several important indirect effects on our culture and our beaches.

“People locally were hired to help clean up the spill. Then, there was more money that came to the village. More money allowed more people to own more boats and bigger boats with better outboards, so many people could now go to places that they couldn’t go to in the past.”

(Anesia Metcalf, Elder, Port Graham)

“Big wages were made [cleaning up the oil spill] and that money was used to purchase motors, gear and nets. It made a difference, it increased accessibility even when the weather was marginal.” (Gerald Robart, Port Graham)

“Now, everyone has a skiff and we can see the immediate impact on the resource.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

With the flood of oil came a flood of money as many coastal communities were hired to help with the oil spill clean up. With the new income that was generated, people in our village bought new skiffs and motors. More and faster boats led to changes in the way we hunted, fished and collected from the shoreline. Before the oil spill, not many people had boats, so people either relied on resources near the community or traveled to camps to stay for long periods. With faster and larger boats, we were able to go out further. With better boats we could go out in rough weather that may have prevented us from going out before. These boats also allowed us to collect from more beaches in one tide.

“There never used to be so many skiffs. People now have skiffs to go hunting. Before families couldn’t afford skiffs. There is more work in the village than there used to be, this has lead to more money. People have more money because of more jobs so they buy skiffs.” (Quentin McMullen, Port Graham)

Bidarkies Go by Fed Ex

“My kids ask me; ‘mom, are you bringing some bidarkies?’” (Vera Meganack, Port Graham)

“We ship Bidarkies to friends and family. Most go to Anchorage in ziplock bags.”
(Gerry Robart, Port Graham)

“Every time someone goes to Anchorage, I send some bidarkies up to my daughter.”
(Vivian Malchoff, Port Graham)

Although the number of people in Port Graham and Nanwalek has not changed much over the past 100 years, more people are leaving the village. Friends and family from the village now live elsewhere but still enjoy their native foods from home. Luckily, with the modern convenience of fast postal delivery, seafood, including Bidarkies, can be shipped around the world. Those who have moved away from the village often return to visit in the spring and summer and go bidarki picking. This means that the number of people enjoying Bidarkies from the shores of Port Graham and Nanwalek is greater than the number of people who actually live here.

Nearshore Marine Invertebrates Decline One After the Next

“There were more urchins when I was a kid. The urchins were the first to go, then crab and clams. Bidarkies, they’re the most recent change, now they’re declining.”
(Richard Moonin, Port Graham)

“Urchins went first, then the crab and cockles, now the bidarkies are going.”
(Nina Kvasnikoff, Nanwalek)

“Urchins were the first to go, crabs were next with the cockles.”
(Ephim Moonin, Elder, Nanwalek)

After the sea urchin and sea cucumbers declined in the late 1950s and early 1960s with the ladyslippers, the crab and shrimp followed in the 1980s. Clams and cockles began to disappear quickly soon after. The decline of these invertebrates happened serially, one after the next, after the next...

“If you think about it long enough, you’ll find that all things are connected. If you are affecting one, you are doing a whole chain reaction.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

Putting it All Together; Why Have Bidarkies Recently Declined?

“Years ago, people didn’t only go for bidarkies, everything was available. Why would they want to just hit the bidarkies? They had crab, mussels, & urchins. The sea otter will change their diet, like any other animal, like us. What are they going to turn to? They turn to bidarkies. Because that’s our only diet from here now.” (Nick Tanape Sr., Elder, Nanwalek)

Historical subsistence harvest differed in several ways from today’s practices: collection was less spatially concentrated because humans shifted among seasonal camps to subsist. Diets included a wider range of marine invertebrates, such as sea urchins, sea cucumbers, ladyslippers, crab, octopus, cockles and clams. These resources are now scarce, because sea otters (predators) and human fisheries (commercial and subsistence) have increased in magnitude and spatial extent. In living memory, these marine invertebrate resources declined serially, one after the next, with chitons among the most recent to disappear.

Sequential prey switching by both humans and sea otters from most accessible preferred prey, to least accessible and less preferred prey, likely resulted in a restriction in prey species breadth thereby leading to intensified harvest of bidarkies. Large-scale phenomena such as the earthquake of ’64, changing ocean temperatures and the oil spill would have had large-scale regional effects, meaning sites close to the villages and sites further away would have been equally affected. However, the bidarki declines we have observed are localized; fewer and smaller bidarkies exist on the beaches closer to the villages compared to those beaches far way. Therefore, the recent localized depletion of

bidarkies and its subsequent ecosystem-level effects may reflect a concentration in the spatial distribution of human harvest pressure, an increase in harvest efficiency and the serial depletion of various nearshore benthic invertebrates.

“People always used to have native food. People eat less native food now, but people still eat bidarkies.” (Vera Meganack, Port Graham)

Other Changes to Our Ocean Home

Marine invertebrates weren't the only things to have declined in numbers in our living memory. Sea lions and seals are much less common now than they used to be. Our subsistence harvesters have been forced to go as far as Elizabeth Island, Anchor point or China Poot Bay to hunt for seals. The decline in Steller sea lions in the Gulf of Alaska, Bering Sea and Aleutian Islands has become so widespread that they were listed as threatened under the Endangered Species Act in 1990. Why? Ground fish fisheries in these same areas target some of the same fish species that form a large part of the sea lion's diet. At the same time, large changes in the North Pacific Ocean may have altered the distribution and abundance of fish too. But maybe Killer whales, their main predator, have increased in numbers or shifted their behavior.

“Killer whales eat sea lions and seals. I've watched two killer whales chasing a sea lion with a bunch of killer whales behind them. I've seen this many times. 6 years ago (1997) I saw killer whales eating sea otters at Coal Mine for the first time. They eat them fur and all. I've never seen this before, this was the first time. Killer whales have always been around but I've never seen them eat sea otters before. They must have been pretty hungry to eat them.” (Simeon Kvasnikoff, Elder, Port Graham)

There are other signs of change in our ocean home. Killer whales have always been known to eat salmon, while some groups of killer whales eat sea lions and seals. Yet recently, killer whales have been seen eating sea otters in front of Nanwalek by Coal Mine beach. Some villages have observed that killer whales seem to spend more time closer to shore now than they did in the past. Interestingly, the record number of sea otters that had recovered around the Aleutian Islands by the early 1970s now appear to be declining at a steady pace possibly due to predation by killer whales²⁶. Why might Killer whales have shifted their diet to these less appetizing animals? For similar reasons that we harvest bidarkies more now than we did in the past relative to other marine invertebrates which are now scarce. The number and abundance of prey species available to killer whales has decreased over time. Small baleen whales were drastically reduced in numbers due to historical whaling²⁷. Of course, pollutants and disease may also be contributing problems to increased sea otter mortality in the Aleutians. Much like the declining bidarkies in Port Graham, this is yet another case of multiple causation.

“Now you can dipnet for halibut!” (Walter Meganack Jr., Chairman, Port Graham Corporation)

Other animals have shown changes in behavior. Halibut are feeding higher in the water column. They have been filmed jumping out of the water. It is not clear why this has happened. It may reflect changes in the food items that are now available to them or changes in the water column itself. At the same time, halibut are less common and smaller than they used to be. The changes are affecting everything in the ecosystem, not just one or two species, and not just in one or two habitats.

“All the clams are gone, but the starfish are in my way. I caught one with clams in its mouth.” (Vera Meganack, Port Graham)

In the intertidal zone, many changes are taking place. Starfish, like the sunflower star, are more common than they used to be, perhaps due to the waste from the canneries in the past and the present day fish hatchery. There are fewer flounder and Irish lords and more greenling. The kelp seems thicker in most places and sea birds have increased in numbers. So why have all of these changes occurred? Are they natural? Will our ocean home support a productive ecosystem in the future?

IDENTIFYING THE PROBLEMS TO CREATE THE SOLUTIONS

One of the first steps in developing solutions to maintain a productive and healthy ocean ecosystem is to pin point the major drivers of change. In the last chapter we identified some of the historic drivers of change in our ocean home. In this chapter we focus on the issues and current threats facing our oceans. In the chapter that follows we discuss possible solutions to these problems.

Our People and Sea otters; Predators and Competitors

“I don’t pick bidarkies anymore. Now they appear in my sink. People are so generous here in Port Graham.” (John Moonin, Elder, Port Graham)

Amid all that has changed in our ocean home, some things have stayed the same. Sharing remains important, valued, and practiced. In particular, we look after our Elders. People grew up with the expectation that they would provide for our Elders, that they would give away the first animals they harvested. Providing for oneself came afterwards. These practices persist, connecting people to their surroundings and to one another.

“I curse at sea otters sometimes. I’m being selfish with bidarkies.” (Vera Meganack, Port Graham)

Sharing may, however, have limits. There is a strong sense of connection to the environment. People recognize that all creatures in the food web have a place and need to eat. Nonetheless, the plants and animals in a food web are in a constant balancing act. When top predators, such as sea otters, build up in numbers, they can cause a dramatic decline in their prey, in this case sea urchin, clams, cockles, crab, octopus, even bidarkies. As a consequence, we often perceive the sea otter as one of our main competitors feasting in our refrigerator. Yet interestingly, when predators are in abundance, multiple changes may cascade across the entire food web. Their prey may decline, while their prey's prey may increase.

In the case of the sea otter, those food web connections go far and there is a important consequence to keep in mind. Ironically, as sea otters feed on benthic grazers, the lawnmowers of the sea floor, more kelp can grow and survive. And so the balancing act begins. Systems with sea otters are known to become very productive because the kelp that grows in the absence of grazers fuels the ecosystem from the bottom-up providing food for the smaller bidarkies and urchins that evade the hungry paws of the sea otters. As the waves toss the growing kelp around bits of the blade shed off and become food for filter feeders⁹ like clams, cockles and mussels. As a result, small clams and cockles which are not eaten benefit from this kelp in the form of detritus, bits of disintegrated organic material. This kelp also provides habitat and shelter for Tom cod, greenling, even young salmon on their way out to the ocean. Certainly, a seascape without sea otters or subsistence harvesters may indeed look very different. Wall to wall benthic grazers like bidarkies and urchins would mow the sea floor clean of kelp until their populations too would suffer from a lack of food.

And yet despite some of their ecological benefits, as sea otter numbers have increased, people feel an increasing sense of competition. Although we are allowed to hunt sea otters for subsistence purposes, the otters are not regarded as good to eat and only a few of us in the villages use their pelts for handcrafts. So the sea otters are essentially undisturbed as they float in the bay, eating great quantities of clams, cockles, crabs, and bidarkies, animals that we too like to eat.

“To the tourists those sea otters are beautiful animals, but if they were in our shoes they would think differently.” (Simeon Kvasnikoff, Elder, Port Graham)

The sea otter increase touches on another aspect of recent times. People with different values and perspectives have a greater influence on national and regional policies about the environment. The fact that sea otters are protected is just one sign. The importance of bidarkies, seals, and other marine creatures to our diet and culture is not always recognized outside the villages. Instead, we now find ourselves defending practices that we have always viewed as normal and natural.

“There are fewer bidarkies now and they are smaller.” (Feona Sawden, Elder, Port Graham)

And yet the bidarkies decline. There may be many challenges to our culture, and much strength within the people. But for the bidarkies, for clams, for crabs, for cockles, the numbers keep going down. Fifty years ago, the environment provided plentiful quantities of food. Although shellfish were more common some times and less common at others, there were always things to eat. Today, many species are declining and it is a cause of great concern.

“It’s time to call the Russians back again!”

(comment at the Port Graham Elders’ Lunch in January 2004)

Consequently, sea otters are a frequent target of people’s frustration. This is not to say that sea otters are blameless. To the contrary, the increase in sea otter populations has inevitably caused changes in the ecosystem. Nonetheless, sea otters are unlikely to be the only factor. We humans have a role, too.

Both sea otters and humans are what are known as keystone species; a species whose impact on its community or ecosystem is large, and disproportionately large relative to its abundance. Both humans and sea otters can have dramatic effects on our environment, even when there are just a few of us.

“Sea otters are part of the problem. They eat everything we eat. But bidarkies can adjust to nature. It’s us they can’t adjust to.” (Walter Meganack Jr., Chairman, Port Graham Corporation)

Current Day Threats to Our Ocean

“I wouldn’t blame the sea otters, it’s us. Our exhaust, gas and oil. We are the ones damaging all that. The problem now is human impact, it’s a heavy impact.” (Nick Tanape Sr., Nanwalek)

Humans, perhaps one of the most notorious keystone species, are exerting unparalleled pressure on marine systems around the world. Even here in our ocean home, the impacts are great. Pollution from the oil industry and our own sinks and out board engines introduce toxins to our waters. Charter boats from Homer and our own skiffs are loud and may scare breeding seals and sea lions away from rookeries. Overharvest locally and regionally, outside of our community, has more than likely led to the decline of many marine species.

Oil Platform Discharge

“It’s like an elephant sitting in our living room. Where is all of this stuff going? It goes through the marine web. We know that there are elevated levels of cadmium. We know that this is one of the metals that comes out of the discharge from the oil and gas

platforms. But it's also naturally occurring. That is an uncertainty that scientists can't answer." (Violet Yeaton, Environmental Planner, Port Graham Village Council)

In 1998 EPA set a zero-discharge limit on produced water and drilling waste for all coastal oil and gas facilities in the United States. Produced water is highly saline water brought up by the drilling process. Drilling waste includes fluids and materials that are generated during the drilling process, such as drilling muds and cuttings, chemical additives and cooling water. When the EPA set these zero-discharge limits, it exempted the coastal facilities of Cook Inlet, Alaska, our ocean home.

There are currently 24 oil and gas platforms in Cook Inlet^{28,29}. While these platforms create jobs for people on the Kenai Peninsula and extract crude oil and natural gas we use to run our cars, and heat our homes, together, the platforms generate an estimated 2 billion gallons of wastewater per year which is discharged directly into Cook Inlet. Contaminants such as heavy metals, dioxins and polycyclic aromatic hydrocarbons (PAHs), molecules found in most oil byproducts, have been found in clams, snails, chitons, and salmon sampled from the shores where we traditionally harvest³⁰. Yet, it is difficult to pinpoint the source of this contamination. While some of the contaminants that were found in our foods are the same as those discharged by the platforms, natural oil seeps, source rocks and coal also release PAHs³¹. Furthermore, some of the measured contaminants are global contaminants. Despite the uncertainty in determining the source of these contaminants, their consequences have been shown to be bad for species and bad for ecosystems. Adding more toxins to our ocean simply increases the likelihood of those negative consequences. Oil industry discharge is an example of a long term, press disturbance that likely has regional effects. Sadly, the burden of proof lays on the shoulders of citizens rather than the oil and gas industry itself.

Our Own 'Nuclear Waste'

"Everyone has big boats with outboards. Our exhaust, gas and oil are killing those. Our own 'nuclear' waste from the dump goes into the ocean." (Nick Tanape Sr., Nanwalek)

"The reef right in front of Nanwalek is a desperation site (for bidarki picking), it is likely contaminated by dump runoff and our sewers." (Anthony Brewster, Nanwalek)

And yet there are other sources of pollution that we can do something about. And that is our own. There has been a big change in the number and use of skiffs in our own village and with that comes the increasing use of oil and gas. Furthermore our own dumps are growing at a faster rate as we import more items to our village. Like the cannery waste, our garbage dump attracts many visitors looking for a free meal.

"There were never ravens down in Nanwalek in the early 80's" (Lydia McMullen, Port Graham)

"The magpies used to live up on the mountain. The reason they stayed up in the mountains was they didn't want to get their aprons dirty with fish blood. They only came

down in the winter. Now you see them in the village all year round.” (Becky Norman, Port Graham; Margaret Moonin, Port Graham & Natalie Kvasnikoff, Nanwalek)

Luckily, there is now more effort in controlling solid waste and hazardous waste with our environmental program.

Charter Boats and our Own Skiffs

“The noise of charter boats disturbs seals and sea lions and they are catching fish that are the food of other fish and seals and sea lions. They even jig for cod and cod are an important part of the food chain. Change that and you are changing the food cycle.” (Walter Meganack Jr., Chairman, Port Graham Corporation)

As with other changes to the area, the increase in fishing charters has had direct and indirect impacts to the ecosystem and the food web. Fishing charters are also a symbol of change beyond the control of the community. Charter boats start in Homer, providing employment and income for many people there. But the boats simply pass by Port Graham and Nanwalek, leaving impacts but no benefits. The charter boats are regulated according to the species they seek, but their impacts to the ecosystem receive little or no attention.

Overharvest

“There are more people out harvesting bidarkies these days. Overharvesting is the biggest factor.” (Anonymous, Nanwalek)

“The decline is because so many people pick them. That is the main reason.” (Sam Moonin, Port Graham)

“Nanwalek reef is picked out so we go there less often, only in the winter.” (Jonny Moonin, Nanwalek)

Bidarkies, like other marine species, are likely being overharvested locally. As the demand for the resource increases, harvest increases. This is not only a problem in our ocean home, it's a problem world wide. According to the Food and Agriculture Organization, in 2003, 52% of the world's fish stocks were fully exploited and therefore producing catches that were close to their maximum sustainable limits. However, 16% of the world's fish stocks were overexploited, while 7% were depleted and 1% were recovering³². There is an increasing trend in the worldwide proportion of overexploited and depleted stocks from about 10% in the mid 1970s to close to 25% in the early 2000s.

“The road increased access, now people can access these sites, more people can get to these sites so there are less refuges [for the bidarkies].” (Nick Tanape Sr., Elder, Nanwalek)

As with many fisheries, increased access, either through better fishing technologies, bigger and speedier boats, or roads providing new beach access allows us to fish in places we would not have been previously able to. Therefore, natural refuges, which may have in the past sheltered spawners from our hooks, nets or knives, get found out. Those natural refuges may have been the source of young that replenish our traditional harvest beaches. Increased access thus facilitates more harvest and usually, overharvest. There are two main ways that overharvest can affect animal populations. Take bidarkies for example.

“It's harder to find the big ones now.” (Demetri Tanape, Port Graham)

“They are getting wiped out and are having trouble reproducing.”
(Emerson Kvasnikoff, Nanwalek)

Large bidarkies have a disproportionately large amount of eggs or sperm. When many of the larger individuals that make up the spawning component of the population are picked, fewer young are produced. As a consequence, less young will be around to grow and become part of the population that is harvested in the following years. This is called recruitment overfishing because fewer young (also known as recruits or young of the year) are produced due to a lack of moms and dads around. The result is that the population simply can not replace its self. This poses a serious threat to the continued existence of any biological resource.

“Some people pick them even though they are small, people just pick and pick.”
(Jennie Tanape, Nanwalek)

“It's harder to find the bigger ones so I'm getting the smaller ones.”
(Jolene Kavasnikoff, Nanwalek)

With many of the large bidarkies gone, people resort to picking the little ones. However, this can actually lead to a lower overall amount of bidarki meat to eat. This type of overfishing is called growth overfishing and it occurs when small individuals are collected before they have a chance to grow and reach their maximum size. In other words, growth overfishing occurs when individuals are harvested at a size that is smaller than the size that would produce the maximum yield per individual. Reducing the amount of juveniles harvested, or their outright protection, would actually lead to an increase in yield from bidarki picking in the future. In a nut shell, growth overfishing reduces the potential yield from a fishery such that less fishing would actually produce a greater catch.

Sliding Baselines

The range of bidarki sizes people pick in our villages vary. Older folks generally are choosy and pick the larger bidarkies greater than 8 cm. They are aware how big

bidarkies can get in areas that are rarely harvested. Younger folks, who don't have skiffs and generally pick locally may have never seen how large bidarkies can get. They pick smaller sized bidarkies.

"You are cradle robbing!" (Nina Kvasnikoff, Nanwalek, 48 yrs old)

"Well, if you want them bad enough!" (Jolene Kvasnikoff, Nanwalek, 22 yrs old)

This is an example of the 'sliding baseline syndrome'^{27,28}. Many people suffer from this syndrome including scientists, politicians, fishermen and today's young subsistence gatherers. Essentially, each new generation accepts as a baseline the size and species composition that occurred at the beginning of their careers as harvesters or scientists. They then use that baseline to evaluate change. When the next generation begins harvesting (or researching), the resource (in this case, bidarkies) has declined and individual animals have gotten smaller, but it is this new abundance and size that becomes the new baseline. The result is a gradual shift in baselines from one generation to the next. Overtime, a slow acceptance of the disappearance of a resource occurs.

"Maybe people's range of acceptable harvest sizes has now increased."
(Ephim Moonin, Elder, Nanwalek)

One way to reconcile this problem is to look into the past and get a sense of 'how big' and 'how much' and 'what species' used to be out there. As mentioned earlier, historical data is vital for revealing the 'ghosts' of ecosystems past and evaluating change in ecosystems present. This is often difficult to do because there isn't always documentation on hand. Yet, large changes in our marine ecosystem happened many years ago, before scientist were here to record them. This is where the immense value of our elders knowledge is revealed. Many elders carry knowledge and observations from the past that can be used to prevent the sliding baselines syndrome for both young subsistence harvesters and scientists alike. For this reason, their observations and this knowledge of the past is extremely valuable in allowing us to evaluate the true social and ecological changes in our ocean home today.

"Now that I've started going around the corner, bidarki sizes have increased."
(Anthony Brewster, Nanwalek)

Another way of curing the sliding baseline syndrome is to witness the abundance, size and species composition in less impacted sites, sites that have seen little harvest by humans. This new, more realistic baseline may make you reflect upon the severity of change in the places where you usually collect (or hunt or research). However, the danger of becoming aware of this new baseline, is the temptation to simply shift your fishing effort in space and carry on as usual. These once pristine areas then become heavily harvested, and again you move on to greener pastures with no recognition that a species is declining. This is a very common occurrence among fisheries. Like the crustacean crash described earlier, fisheries tend to deplete the most accessible resources and then move further away as resources dwindle locally.

Changing Life Ways

“Now, the new generation doesn’t have an understanding or meaning. That kinda bothers me. Poor kids don’t know no better. We elders haven’t told the younger ones what the nature does. This new generation don’t know a damn thing – they aren’t told reasons why they should leave them.” (Simeon Kvasnikoff, Elder, Port Graham)

“We are blaming the younger generation but we are to blame. We are not teaching them.” (John Moonin, Elder, Port Graham)

One aspect of change is the loss of knowledge. Although, perhaps it would be more accurate to speak of changes in knowledge, because there are many things that we, in Port Graham and Nanwalek, understand better today than ever before. Yet, many of our elders feel that they have not passed on the knowledge they received from their elders to our children. This may be for several reasons. Certainly, there has been a change in life ways. With modern conveniences, people today are several steps removed from their environment. But another tragic historical event may have played a role in the gradual erosion of traditional knowledge transfer from Elder to youth, and that was the establishment of English-only schools back in the 1950s. This was the primary factor that threatened our Sugcestun language and Sugpiaq culture.

“We couldn’t speak Sugt’stun in school, we weren’t allowed. We had to speak English. We had to listen to 3 languages. We’re not fluent in English. We were real fluent in Sugt’stun.” (Irene Tanape, Elder, Nanwalek)

Today’s Elders still speak Sugt’stun but much of our language is becoming lost. With that loss comes the loss of stories about traditional practices, traditional life ways and the traditional management of our coastal resources. The knowledge that has been lost, for what ever reason, is specific: it is the understanding, the wisdom, of how to look after one’s self and one’s surroundings.

ENJOYING OUR MARINE RESOURCES IN THE FUTURE

Quyaanaa- naa-naa-ruq, culiaret 2x
Auluklluta, nayurluta, piturcesluta
Una urriitaaq tuluku, Iliiluku qutmen, amlercesluki neqpet
Piturcesluki kukupet, ellitaa kukuit piturcesluki, cali
Quyaanaa-naa-naa-ruq, culiaret 2x

Thank you, please ancestry
Taking care of us, being with us, letting us eat
This bidarki, take it, put it on the beach, make plenty of our food,
Let our children eat, let their own children eat, again
Thank you, please ancestry

Song by Lydia Robart, Port Graham Elder 1947- 2001

“There are limits, limits of what you can harvest. Some people go beyond it.”
(James Kvasnikoff, Second Chief, Nanwalek)

“You have to ask yourself, ‘Can that beach sustain that?’ You have to think about these things if we want our kids to enjoy it.” (Walter Meganack Jr., Chairman, Port Graham Corporation)

Where does this leave us? Thinking about the future, there are grounds for concern and reasons for hope. There is no question that the local ecosystem has changed. There is also no question that the human communities have changed. But these changes have also forced people to think about the future, to think about the consequences of their own actions. People are asking what they can do to make things better.

“If people keep going back, it will get picked out. If you leave it alone, you’ll see a lot of the big ones.” (Vivian Malchoff, Port Graham)

There are many ideas for how to better manage the actions of people from the villages. This is what management boils down to: changing human behavior. We cannot manage ecosystems but we can consider carefully how we act and how our actions affect the rest of the system. One starting point is within our villages themselves.

Traditional Management of Marine Resources

“Our elders told us not to pick in the spring and summer. We never bothered with them in the summertime; clams, bidarkies. Early October we’d go after them, leaving them alone all summer. Our Elders use to tell us ‘you’ll get sick if you eat them during the springtime.’ I think that that was their way to scare us out of eating them during the time that they were hatching.” (John Moonin, Elder, Port Graham)

Traditional management practices were designed to sustain populations which could be harvested in the future. The rules included not picking bidarkies in the spring and summer when they are reproducing. Similar rules applied to clams, cockles, and other species. Seals and ducks were also left alone in the spring when they were reproducing. These traditional seasonal closures during spawning, calving and fledging periods made sense. Some people may have continued to harvest bidarkies year round, but the main harvests took place in winter.

“March was the month our elders stopped us from hunting. The animals had little ones inside. If you want to see them in the future, leave them alone. New generation, it’s not that way, they go out and get what ever they want when ever they want.”
(Simeon Kvasnikoff, Elder, Port Graham)

Equally important is the way that people understand their own actions and the consequences of those actions. Traditional harvest practices and the hard-won lessons from which they arose helped sustain local resources. In recent years, however, those practices and beliefs have not been passed on to younger generations. Furthermore, the loss of the resource locally has less of an immediate consequence on us now than it did in the past. In the old days, failure to take care of the resource meant that it would be depleted, and people would have to go without.

“When I was growing up, if you were a resource user you had to be a resource manager, too. You pick only what you need and leave the small ones alone, you don’t pick a beach clean. You stayed away when things were scarce. That is what we were taught” (Walter Meganack Jr., Chairman, Port Graham Corporation)

But the situation is not beyond hope. Much knowledge remains with our Elders today. If they can pass it on, if our younger people are willing to learn it, those hard-won lessons from countless generations may still be sustained in our communities, together with the healthy ecosystem that nourishes us.

Teaching the Next Generation

“The resource is depleted due to a lack of teaching by the elders and a lack of management” (Walter Meganack Jr., Chairman, Port Graham Corporation)

And the starting point within the villages is knowledge. The connections and communication between Elders and youth have weakened. The realities of sliding baselines are becoming increasingly apparent. We are the only ones who can reverse this trend. Already people are discussing how to do this.

“We need a gathering place and invite the kids of all ages so we can share our stories.” (Elenore McMullen, Elder and Past Chief, Port Graham)

“Now I pick larger Bidarkies because in the past I didn't know any better.” (Vivian Ukatish, Nanwalek)

Practices of restraint and the knowledge to recognize when a species needs to recover are in danger of being lost. We need to facilitate the transfer of knowledge and traditional management practices from Elders to our youth.

“Getting the kids to learn their cultural ways of living because if they don’t we are going to have troubles. Kids have to learn about that, if we don’t teach them now, it’s going to die.” (Simeon Kvasnikoff, Elder, Port Graham)

Traditional foods and traditional practices may not be strictly necessary for survival today. But if our culture is to continue and adapt to a changing world, then

people must take heed of the lessons of their Elders. Traditional foods and practices are a source of strength, both nutritionally and spiritually. This foundation is irreplaceable

“I am a firm believer in ‘waste not, want not.’ Sometimes if we have some bidarkies left in our freezer because we didn’t finish eating them, the next time we go out for a tide, we don’t find any. It is a lesson to us” (Vivian Malchoff, Port Graham)

Qaillumi Kipucesnaiyarrrtaa; How Can We Bring It Back?

“In order for us to continue to enjoy these resources, we have to manage them better. It is up to the village to come up with a management plan.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

“Currently we have a draft natural resource management plan. It is considered a living document that can change depending on what the Elders decide. Eventually it is going to be brought to the Tribal Council and used as a teaching tool.” (Karen Moonin, Natural Resource Planner, Port Graham)

On the foundation of Sugpiaq knowledge and wisdom, we can take action to protect the animals we use and the ecosystem that sustains them. Those actions may be similar and or different from the traditional management practices that the Elders refer to. A combination of local knowledge and science can be used to develop alternative management strategies. The effectiveness of those strategies can be monitored by using scientific techniques as well as traditional observations. A management plan for bidarkies may include size limits or seasonal closures during spawning season, protecting nursery areas or closing some beaches entirely to harvest to promote the recovery of bidarki populations.

“I leave the small ones ‘cause I know they're going to grow. If you pick the small ones, you won't have them later on.” (Robin Otis, Port Graham)

“Don't pick the little ones, they want to grow like you, you know.”
(Peter Anahonak Sr., Elder, Port Graham)

Suggesting size limits might be a good place to start. A minimum size requirement would help with the problem of growth overfishing described earlier. If small bidarkies were left to grow to a large size, each individual bidarki would be more of a meal tomorrow than if it were picked today.

“We need to leave them alone in the spring otherwise we are probably harvesting the spawning ones.” (Pat Norman, Chief, Port Graham)

There are many things from the past that are worth perpetuating. Traditional seasonal closures during the spawning period, once used in the past by our Elders, would

be a helpful management tool worth using today. By collecting bidarkies after they spawn, we will have given the next generation of bidarkies the chance to be created.

“Maybe if we left them alone, maybe they would come back.” (Jennie Tanape, Port Graham)

“Our harvest areas need to be protected. We need to protect rearing habitats.”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

One of the most promising tools to help in Bidarki recovery would be the full protection of some shorelines. These untouched areas would act like natural refuges of the past. Individual bidarkies would grow, and overtime there would be a greater abundance of large individuals with disproportionately high quantities of eggs and sperm to release into the water column. Because they are broadcast spawners, when bidarkies are in close proximity of each other, the likelihood of sperm meeting egg and fertilization occurring is much greater. After fertilization occurs, bidarki larvae, tiny early forms of the chiton, then travel in the water column for about eight days before they are able to settle on to rock and start their life as a bottom dwelling animal. During those 8 days, larvae can travel great distances depending on ocean currents, waves, local eddies and thus the degree of local retention. The idea is that some of those larvae from the protected area could then replenish harvested sites with new young bidarkies. The process of larvae produced within a protected area and dispersing into adjacent fished areas is called ‘spillover’ and has been documented in numerous places in reserves around the world.

“Protecting some areas wouldn’t work because it would have to be voluntary compliance and some people would cheat. We’d need bylaws. Fish and Game would have to come in. We’d have to call in the National Guard! It is a good idea but it would cause social feuding and rumors would spread. That is why education is so important.” (Nick Tanape Sr., Elder, Nanwalek)

And yet, the social realities of setting aside protected areas need to be carefully considered. It is true that protected areas will only work to replenish adjacent fished areas if everyone in the village abided by them. This may be difficult because some people may find themselves drawn to the opportunity to collect large bidarkies, even if they are protected. So, it is true that these protected areas would have to be enforced in some way and that may be a very difficult thing to do socially. As with many things, short-term social losses often outweigh long term gains, even if those gains are great. To overcome this hurdle, education on the possible benefits of protected areas would help our community recognize the value of investing in them. The community might be convinced, once people started seeing the positive consequences of protecting some shorelines. Consequently, it is important to demonstrate that the long-term gains of preserving spawning areas and protecting ecosystem integrity outweigh short-term losses of reduced harvest areas.

Although protected areas may be an important component in the recovery of bidarkies and other marine species, alone they would not be sufficient. This is simply because displacing fishing pressure from one area will result in its concentration in another. If fishing effort stays the same and say half of the harvest areas are protected, then twice as much harvest will occur in half the area. The implication is that protected areas must be coupled with an overall reduction in fishing pressure outside of their boundaries. Ultimately, it may take a combination of tools; education, size guidelines, seasonal closures, protected beaches and a reduction in collection in general to promote the recovery of bidarkies and other subsistence shellfish resources. This indeed is a lot to ask.

“We need to figure out how to protect the resources, not only from ourselves but from others too.” (Walter Meganack Jr., Chairman, Port Graham Corporation)

As we, the people of Port Graham and Nanwalek, take the initiative to manage our own activities, it is only fair to look also at impacts from beyond the villages. Developing regional research and management plans is one approach. Convincing government agencies and others to participate may not be easy in a time of declining funding for management and increasing competition for space and resources. But fragmentation of effort and regulations will not help the marine resources and services we depend on.

“There are still changes that will happen that we haven’t foreseen”
(Walter Meganack Jr., Chairman, Port Graham Corporation)

The best-laid plans can still go astray. It is impossible to predict what will happen in a complex and dynamic system such as the marine environment of lower Cook Inlet. What is important is to establish a system that can adapt quickly as conditions change. This requires experimenting with some management policies, careful monitoring to detect what changes do occur, communication to let people know what has happened, and support for the management program so that people will respond as needed. In other words, it requires people to be involved.

The Future of Our Ocean Home

“I want to go back to the old ways.” (Anesia Metcalf, Elder, Port Graham)

Not everyone may wish to go back in time. But a past when marine resources were plentiful is more desirable to many of us than our dwindling shoreline resources of today. Our present and our future are contingent on everything that came before. Any change in any step in the sequence of the past alters our present. Here in the Gulf of Alaska, in lower Cook Inlet, in our ocean home, a sequence of removing top predators, the rapid development of competing fisheries, the return of sea otters and a major change

in ocean temperatures, have together caused a tipping point, a major reorganization of our coastal ecosystem.

Ironically, humans now have the power to influence the future more than ever before. As a consequence, the results of our own activities are becoming more severe. This coupled with a decline in knowledge transfer from Elders to youth and from scientists to local ocean observers has hindered our ability to determine the causes of change and develop solutions. Luckily, a transformation in our attitudes has begun. This book is one example.

You have listened to a story told through the voice of many storytellers; Elders, village residents, an anthropologist, several photographers and a marine biologist. Collectively, we have pieced together bits of our history and our combined knowledge to more holistically understand the complex drivers of change in our ocean home. By sharing this knowledge, we hope to inspire solutions for the future. By integrating knowledge systems and delving into our ecological and social past we hope to foster a culture of sustainability, one that acknowledges both ecological and human systems and the need to shift our time frame of thinking into the deep past and far into the future.

Quyanakcak

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