EVOSTC FY17-FY21 INVITATION FOR PROPOSALS
FY21 (YEAR 10) CONTINUING PROJECT PROPOSAL SUMMARY PAGE

Project Number and Title

Gulf Watch Alaska: Environmental Drivers Component Project

21120114-I—Long-term Monitoring of Oceanographic Conditions in the Alaska Coastal Current from Hydrographic Station GAK-1

Primary Investigator(s) and Affiliation(s)

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Date Proposal Submitted

August 14, 2020

Project Abstract

This project continues a nearly half-century time-series of temperature and salinity measurements at hydrographic station GAK-1. With first sampling in 1970, the data set consists of nominally monthly conductivity-temperature versus depth casts and a mooring outfitted with seven temperature/conductivity recorders distributed throughout the water column and a fluorometer at 20 m depth. The project monitors five important Alaska Coastal Current (ACC) ecosystem parameters that quantify and help us understand hourly to seasonal, interannual, and multi-decadal period variability in: 1) temperature and salinity throughout the 250 m-deep water column, 2) near surface stratification, 3) surface pressure fluctuations, 4) fluorescence as an index of phytoplankton biomass, and 5) along-shelf transport in the ACC. All of these parameters are basic descriptors that characterize the workings of the inner shelf and the ACC, an important habitat and migratory corridor for organisms inhabiting the northern Gulf of Alaska, including Prince William Sound, and resources injured by the *Exxon Valdez* oil spill. We are aware of over 100 publications utilizing data collected at station GAK-1, and since 2010 the citation list has grown by nearly five publications per year. These publications range from physical, chemical, and biological oceanography to climate studies, fisheries research, fisheries management applications, and ecosystem-based management applications. Recent water temperatures remain warmer than the long-term average throughout the water column, while near-surface waters have freshened over time and near-bottom waters have salinized. An increase of stratification that carries important and far-reaching implications for ecosystem dynamics. We are not proposing any major changes to this project in FY21. COVID-19 pandemic impacts include missed and reduced surveys and delays in data processing. The 22-year CTD profile for the May Seward Line time series is intact. Moving forward, we anticipate being able to make our regularly scheduled monthly CTD profiles. We propose no major changes for FY21.

EVOSTC Funding Requested* *(must include 9% GA)*

FY17	FY18	FY19	FY20	FY21	TOTAL
$146,800	$148,400	$132,600	$125,600	$127,400	$680,800

Non-EVOSTC Funds to be used, please include source and amount per source: (see Section 6C for details)

FY17	FY18	FY19	FY20	FY21	TOTAL
$0	$0	$0	$285,000	$290,000	$575,000

1. PROJECT EXECUTIVE SUMMARY

The goal of the GAK-1 project is to provide a long-term high-quality reference dataset for the coastal northern Gulf of Alaska (GOA) that enables scientists, students, commercial and subsistence fishers, and resource managers to better understand climatic and ecological conditions, their changes, and ramifications of change (Table 1, Fig. 1). Understanding, anticipating, and responding to change requires a stationary frame of reference in the form of long-term in situ observations. Such datasets are the best means to guide our assessments and interpretations of system variability. Untangling the relations between climatic and other drivers of change (e.g., oil spills or fishing regulations) similarly requires long reference time-series. Environmental time-series data can provide information valuable to the management of fish and shellfish populations and fisheries (Anderson and Piatt 1999, Munro and Tide 2014).

There exists no other full water column temperature and salinity time-series in the northern GOA with comparable data quality, temporal extent, and frequency of sampling. Hence, the GAK-1 dataset is the premier reference dataset for evaluating hypotheses that seek mechanistic descriptions of the regional ocean environment and ecosystem. As shown by an ever-increasing number of publications that utilize the GAK-1 dataset, the value of this unique time-series continues to grow and even accelerate with the passing years and decades.

The GAK-1 dataset is collected under the fundamental hypothesis that oceanic conditions are important to the physical and biological functioning of the Prince William Sound and GOA ecosystems. To that end, many dozens of papers have examined this hypothesis from numerous perspectives (for a comprehensive listing, see the GAK-1 home page at http://www.ims.uaf.edu/gak1/). As the chemical and biological datasets begin to catch up (via quality of resolution, duration, and frequency) to the physical measurements we expect that the insights gleaned through interdisciplinary analyses will grow in kind. To date, the 48-year GAK-1 time-series has helped show:

1. There are large interannual differences associated with El Nino and La Nina events, including substantial differences in the spring bloom between these phenomena (Weingartner et al. 2003, Childers et al. 2005).
2. There is an intimate connection between coastal freshwater discharge and the depth-varying evolution of winter and spring temperatures over the shelf (Janout 2009, Janout et al. 2010).
3. GAK-1 provides a reliable index of Alaska Coastal Current (ACC) transports of mass, heat, and freshwater (Weingartner et al. 2005).
4. GAK-1 near-surface salinities are correlated with coastal freshwater discharge from around the GOA (Weingartner et al. 2005).
5. There are variations in mixed-layer depth in the northern GOA, which affects primary production (Sakar et al. 2006).
6. GAK-1 data demonstrate decadal scale trends in salinity and temperature, (Royer 2005, Royer and Grosch 2006, Weingartner et al. 2005, Janout et al. 2010, Kelley 2015).
7. There are relationships between temperature and salinity variations and the Pacific Decadal Oscillation and the strength and position of the Aleutian Low (Royer 2005, Weingartner et al. 2005, Janout et al. 2010).
8. The GAK-1 record can guide understanding of the variability in iron concentrations, a potentially limiting micro-nutrient required by many phytoplankton; preliminary efforts indicate that iron and surface salinity are correlated at least in certain seasons (Wu et al. 2008).

9. Between about 1000 and 1500 years before present, the northern GOA likely experienced a cooler, more sluggish and higher salinity ACC, whereas between 600 and 1000 years before present a stronger Aleutian Low may have driven a stronger and fresher ACC (Hallmann et al. 2011).
10. Ocean acidification (carbonate) system variability can be described using multiple linear regression models to predict dissolved inorganic carbon and total alkalinity using observations of nitrate, temperature, salinity, and pressure (Evans et al. 2013).
11. There is a decoupling of near-surface and near-bottom waters through increased stratification (Kelley, 2015) with implications for nutrient resupply to the euphotic zone and long-term changes in shelf productivity.

As shown and discussed by Mueter et al. (1994), Mueter (2004), and Spies (2009), these factors affect and relate to many ecosystem processes on both the shelf and within Prince William Sound and lower Cook Inlet/Kachemak Bay. Therefore, GAK-1 provides critical contemporary and historic reference points for all components of the Gulf Watch Alaska (GWA) program.

COVID-19 disruptions to the GAK1 project were limited to the delay of the mooring turnaround (carried out in May instead of March) and we lost water column profiles in March and April. However, because we got the mooring back, the impact of the data loss is minimal.

Table 1. Statistics of the near surface (0-50 m) and near seafloor (200-250 m) salinity and temperature trends over the period of record. Parameters include the date range, depth range, number of data points (N), trend slope (per decade) and confidence interval, and the correlation squared r^2 and p-value for the best fit linear trend.

Parameter (units)	**Date Range**	**Depth Range (m)**	**N**	**Slope**	**r^2**	**p**
Salinity	1970-2019	0-50	411	-0.071 +/- 0.032	0.040	1.48E-05
Salinity	1970-2019	200-250	407	0.025 +/- 0.017	0.020	4.75E-03
Temperature (°C)	1970-2019	0-50	411	0.235 +/- 0.061	0.120	2.05E-13
Temperature (°C)	1970-2019	200-250	409	0.167 +/- 0.036	0.170	8.40E-18

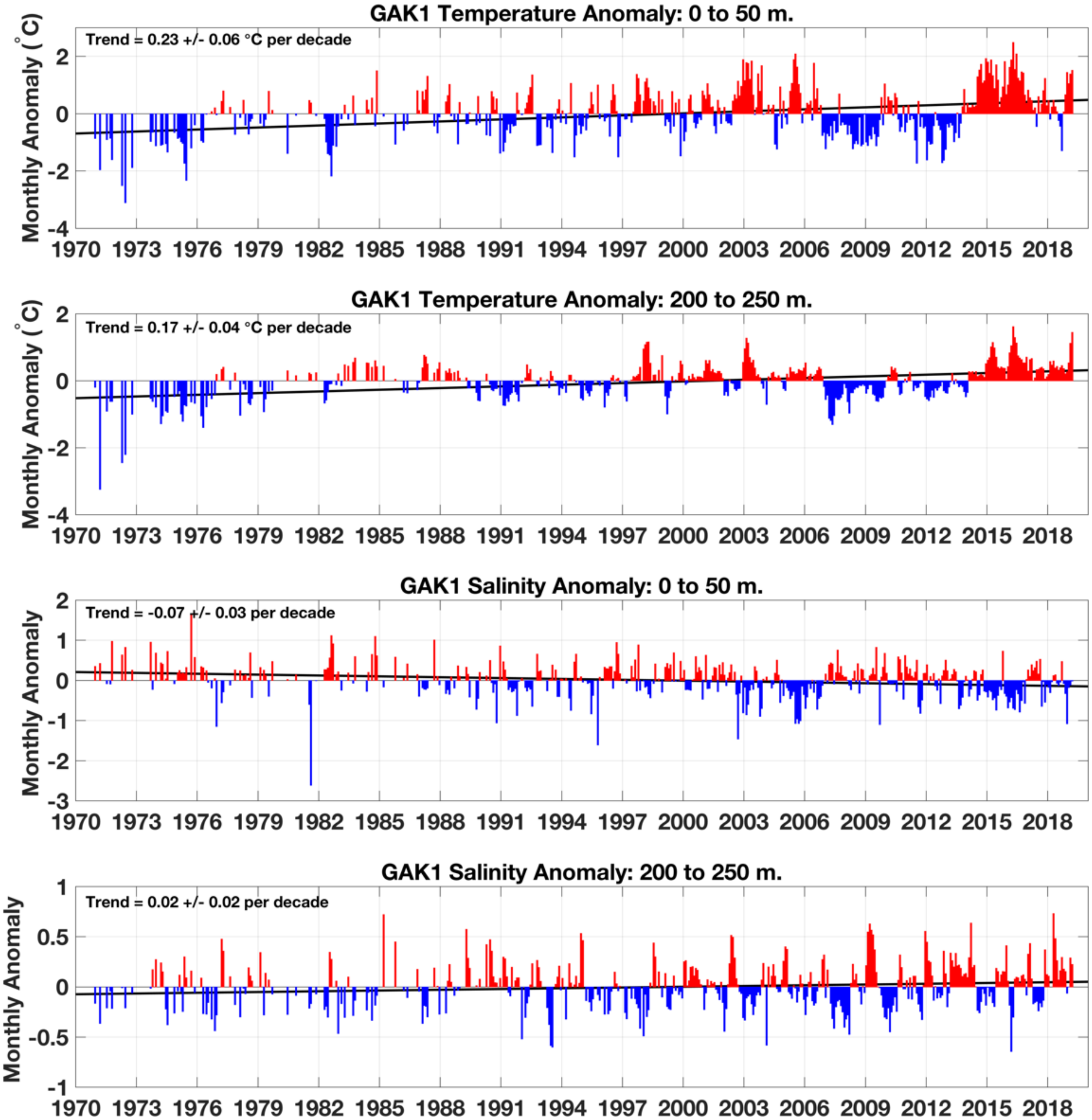

Figure 1. GAK-1 monthly anomaly time series for the 1970-2019 period of record. Temperature (upper two panels) and salinity (lower two panels) anomalies represent averages over the uppermost and lowermost 50 m of the water column. The data exhibit a long-term trend in warming punctuated by signals associated with the cycles of El Nino and other phenomena. Black lines show the least squares best fit trend over the period of record. Text provides trend statistics (best fit least squares linear) over the record length.

2. PROJECT STATUS OF SCHEDULED ACCOMPLISHMENTS

A. Project Milestones and Tasks

Table 2. This table breaks down project deliverables and their status into milestones and task progress by fiscal year and quarter, beginning February 1, 2017. C = completed, X = planned or not completed, V = cancelled due to COVID-19, P = partially completed, due to constraints of COVID-19.. Fiscal year quarters: 1 = Feb 1 – April 30; 2 = May 1 – July 31; 3 = Aug. 1 – Oct. 31; 4 = Nov. 1 – Jan. 31.

	FY17				**FY18**				**FY19**				**FY20**				**FY21**			
Milestone/Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone 1: Data collection & processing																				
Monthly CTD Cruises	C	C	C	C	C	C	C	C	C	C	C	C	C	C	X	X	X	X	X	X
CTD Data Processing	C	C	C	C	C	C	C	C	C	C	C	C	P	P	X	X	X	X	X	X
CTD Data Upload to Web	C	C	C	C	C	C	C	C	C	C	C	C	P	P	X	X	X	X	X	X
Mooring Turnaround	C					C			C					C			X			
Moored Data Processing				C				C				C				X				X
Mooring Data Upload to Web				C				C				C				X				X
Milestone 2: Reporting																				
Annual Reports	C				C				C				C				X			
Annual PI meeting				C				C				C				X				X
FY Work Plan (DPD)			C				C				C				C					
Milestone 3: Replacement survey vessel																				
Secure funding					C															
Award build contract							C													
Vessel delivery										C										

In addition to the primary project deliverables in Table 2, during the past year we led or contributed to four presentations and contributed two website updates for outreach. Seward Line/GAK1 temperature indicators were contributed to the Annual Ecosystem Status Report to the North Pacific Fishery Management Council. Additional publications by participants in the GAK-1 project are: two peer-reviewed papers, one PhD dissertation, and an agency technical paper in review (see Section 7). We anticipate completing FY20 and FY21 milestones and tasks as planned.

B. Explanation for not completing any planned milestones and tasks

The global novel coronavirus pandemic of 2020 has impacted nearly every facet of life, and the GAK-1 project is no exception. Due to the rapidly unfolding nature of the disease and rapidly changing guidance from the University of Alaska Fairbanks (UAF) administration, we were unable to undertake the GAK-1 mooring turn-around in March and GAK-1 conductivity-temperature versus depth (CTD) profiles in March and April. We were able to do the turnaround in May from R/V Sikuliaq as part of specially-permitted cruise (the rest of the University-National Oceanographic Laboratory System [UNOLS] fleet was tied up until July 1) to keep the 22-year May Seward Line time series intact. We got the GAK-1 CTD in June from on board R/V Nanuq (Nanuq is not a UNOLS vessel). The July CTD profile was done from R/V Sikuliaq as part of the summer Seward Line sampling, and August 2020 is scheduled again for R/V Nanuq. Looking forward, we anticipate being able to make our regularly scheduled monthly CTD profiles. Each time we go out during the pandemic carries some risk, which we attempt to minimize by following best practices for not spreading the virus.

Other disruptions from COVID-19 have come in the form of delayed data processing – we have spent so much time this summer in Zoom meetings, in re-arranging summer 2020 field plans for all projects, and in learning how to effectively work from home – that a full update of the GAK-1 time series is not presently available. We anticipate being on track by November 2020 prior to the fall principal investigators (PI) meeting.

C. Justification for new milestones/tasks

No new milestones and tasks have been added.

3. PROJECT COORDINATION AND COLLABORATION

A. Within an EVOSTC-funded Program

GAK-1 data provide high-resolution long-term contextual environmental data for the GWA scientific team, other researchers and agency personnel and the public at large. Data and data plots are available online at the GAK-1 website home page (http://www.ims.uaf.edu/gak1/) and through the Alaska Ocean Observing System (AOOS) Gulf of Alaska Data Portal served by Axiom. After processing, the data are posted to the GAK-1 website, submitted to the GWA data management team for archiving, and published to the Gulf of Alaska Data Portal.

Gulf Watch Alaska

This project is part of the *Exxon Valdez* Oil Spill Trustee (EVOSTC)-funded Long-term Monitoring Program associated with the Environmental Drivers portion of GWA. We share data with all other projects within this portion of the GWA program including the following: Continuous Plankton Recorder (project 20120114-D, PI Batten), Seward Line (project 20120114-L, PI Hopcroft), Oceanographic Conditions in Lower Cook Inlet (project 20120114-J, PIs Holderied and Baird), Oceanographic Conditions in Prince William Sound (project 20120114-G, PI Campbell), and Nearshore (project 20120114-H, PI Coletti et al.). We share logistics at least three times per year with the Seward Line project. We are examining the spatial and temporal coherence in temperature and salinity with the Cook Inlet and Prince William Sound projects. The latter effort is to determine the degree of spatial heterogeneity in these variables over the inner shelf of the GOA. In addition, we are collaborating with multiple GWA PIs on science synthesis efforts: Monson et al. evaluating the coherence in intertidal and oceanic sea surface temperatures during the Pacific warm anomaly, Arimitsu et al. assessing environmental drivers and prey condition leading to the murre die-off in the GOA, and Suryan et al. evaluating ecosystem variability in the GOA during a marine heatwave.

Herring Research and Monitoring

The primary value of the GAK-1 data set is to provide the principal investigators of other programs an appreciation of the longer-term variability of the Gulf of Alaska as they examine their data sets. The GAK-1 project makes physical and biological data available to the Herring Research and Monitoring program and has been used to assess energetic costs of overwintering herring (Heintz, pers. comm).

PI Bishop of the Herring Research and Monitoring program inquired about the availability of GAK-1 as a platform for mounting an acoustic tag receiver for the purpose of detecting tagged fishes. We installed this sensor on the GAK-1 mooring deployed in spring 2019, spring 2020 and will continue to do so for future deployments as needed.

Data Management

This project coordinates with the data management program by submitting data and preparing metadata for publication on the Gulf of Alaska Data Portal and DataONE within the timeframes required.

B. With Other EVOSTC-funded Projects

This project will coordinate with other EVOSTC-funded projects as appropriate by providing data, discussing the relevance and interpretation of data, and collaborating on reports and publications.

C. With Trustee or Management Agencies

Our data have been used in the National Oceanic and Atmospheric Administration Gulf of Alaska Ecosystem Considerations report to the North Pacific Fishery Management Council annually since 2009 (e.g., Zador 2013). Like other Environmental Driver components, GAK-1 data also are available to the Alaska Department of Fish and Game for salmon forecasting.

Also, we have assisted the National Park Service (NPS) in establishing a similar monthly sampling and data processing protocol in Glacier Bay National Park and Preserve through the Inventory and Monitoring program (http://science.nature.nps.gov/im/units/sean/default.aspx), which also serves their data online. The sampling in Glacier Bay therefore provides a complementary data set that is collected upstream in terms of the general circulation characteristics of the GOA shelf. Collectively, the Glacier Bay, Prince William Sound, Cook Inlet, and GAK-1 data sets provide a broad-scale perspective of the GOA shelf environment. We are collaborating at no cost to this proposal with NPS scientists using conductivity-temperature-depth sampling and analysis protocols identical to those at GAK-1. Since southeast Alaska waters contribute to the ACC, the 26-year Glacier Bay time-series provides the opportunity to assess variability in the northeast and northwest GOA and to understand how these regions co-vary and how the ACC evolves as if flows westward toward PWS.

GAK-1 data are also used by the AOOS-supported ocean acidification monitoring study on the surface buoy nearby to GAK-1, which is known as mooring GAK-OA (Evans et al. 2013). Many other similar examples can be found in the extensive publication list at the GAK-1 website (http://www.ims.uaf.edu/gak1/).

4. PROJECT DESIGN

A. Overall Project Objectives

The fundamental goal of this program is to provide high quality, long-term data to quantify and understand variations that occur over short (hours to days) to long (inter-annual to multi-decadal) period variability of the GOA shelf. This measurement provides the broader temporal and spatial perspective important to our ecosystem-level understanding and management of the northern GOA. Specifically, we will:

Objective 1. Measure temperature and salinity throughout the water column

Objective 2. Measure near-surface pressure fluctuations

Objective 3. Measure water column stratification since this affects phytoplankton bloom dynamics

Objective 4. Measure chlorophyll fluorescence as an index for phytoplankton standing crop

B. Changes to Project Design and Objectives

We lost GAK-1 CTD profiles in March and April 2020 due to cruise cancellations because of COVID-19. Because the mooring was recovered in May, the loss of the CTD had a relatively minor impact on the project. As safe working protocols were developed over the course of the 2020 spring and summer, we were able to re-commence the monthly CTD sampling. We hope for minimal other impacts, although this will depend on how state and UAF research mandates change over the coming months.

The following is a chronological update of the replacement of the UAF coastal research vessel that services GAK1:

- Summer 2017: We noted that the UAF Seward Marine Center coastal research vessel, the R/V Little Dipper, recently suffered an engine failure. It was determined that the Dipper would likely be repaired and usable at least as a fair-weather vessel but that this was not an ideal long-term or year-round solution. In the meantime, the GAK1 project chartered the M/V Dora on a more regular basis, at a somewhat more costly day rate to the project, although at that time there was not a need for a revised budget. The age of the vessel, its hull condition, safety for the crew, and other factors propelled the project to seek replacement options.
- Summer 2018 update: UAF identified funding sources for a replacement upgrade for the R/V Little Dipper (including Little Dipper sale proceeds), defined the requisite minimum specifications, and issued a Request for Proposals from vessel manufacturers. Proposals were under evaluated with anticipation of issuing contract in the fall. We anticipated having a replacement vessel in place by August 2019. In the meantime, we continued to charter the M/V Dora from Seward to accomplish the monthly sampling.
- Summer 2019 update: UAF awarded a winning bid for the construction of an R/V Little Dipper replacement in October 2018 to Armstrong Marine of Port Angeles, WA. R/V Nanuq was subsequently delivered to Seward in mid-July 2019 (Fig. 2). Nanuq's larger displacement and greater speed (40' length, 13' width, 22 kts, vs. Dipper's 28' length, 12' width, 7 kts) means that we will be able to take advantage of smaller weather windows and that we will only need a partial day to accomplish our GAK-1 and RES2.5 sampling rather than an extended day. In addition to the monthly CTDs, we hope to use R/V Nanuq for mooring deployments. R/V Nanuq will reside in a Seward harbor slip so mobilization for all cruises will gain efficiency.
- Summer 2020 update: R/V Nanuq is now fully operational. The vessel has been outfitted with an underway thermosalinograph, an uncontaminated seawater intake port for surface underway sampling, an integrated datalogging computer system, a pole mount for acoustic transducers,

and other upgrades. We anticipate that this new highly capable vessel will be a valuable asset for many marine studies in the northern Gulf coast region for many years.

Figure 2. R/V Nanuq, GAK-1's new support vessel.

5. PROJECT PERSONNEL – CHANGES AND UPDATES

No changes in personnel to report.

6. PROJECT BUDGET

A. Budget Forms (See GWA FY20 Budget Workbook)

Please see project budget forms compiled for the program.

EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
PROGRAM PROJECT BUDGET PROPOSAL AND REPORTING FORM

Budget Category:	Proposed FY 17	Proposed FY 18	Proposed FY 19	Proposed FY 20	Proposed FY 21	TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	$47.1	$48.2	$49.3	$50.4	$51.6	$246.6	
Travel	$4.4	$4.4	$4.4	$4.4	$4.4	$21.9	
Contractual	$18.7	$18.7	$18.7	$18.7	$18.7	$93.3	
Commodities	$6.1	$6.1	$6.1	$6.1	$6.1	$30.5	
Equipment	$39.3	$39.5	$23.7	$15.8	$16.0	$134.3	
Indirect Costs (*25% of non-equip.*)	$19.1	$19.3	$19.6	$19.9	$20.2	$98.1	
SUBTOTAL	$134.6	$136.2	$121.7	$115.2	$116.8	$624.6	$0.0
General Administration (9% of	$12.1	$12.3	$11.0	$10.4	$10.5	$56.2	N/A
PROJECT TOTAL	$146.8	$148.4	$132.6	$125.6	$127.4	$680.8	
Other Resources (Cost Share	$0.0	$0.0	$0.0	$285.0	$290.0	$575.0	

B. Changes from Original Project Proposal

No changes to report.

C. Sources of Additional Project Funding

No external funding to report.

The GAK-1 project benefits from cruise-of-opportunity CTD sampling of GAK-1 by other projects, including, but not limited to, the GWA Seward Line project (20120114-L). We have a standing request to the captain and technical support team of the R/V Sikuliaq for them to occupy GAK-1 whenever feasible as Sikuliaq enters or leaves Resurrection Bay. This cruise-of-opportunity sampling occasionally fills in data gaps that would otherwise exist due to weather limitations of the small boat operations. Additional unquantifiable in-kind benefits also derive from the GWA Seward Line component and the National Science Foundation-funded Northern Gulf of Alaska (NGA) Long-Term Ecological Research (LTER) program. These efforts leverage and enhance many GWA program activities, including at GAK-1. For example, the first five-year block of the NGA LTER program will fund at least three UAF graduate students who will spend time working with both GWA and NGA LTER data collections. GWA/NGA LTER visits to GAK-1 provide much richer data collections than we can manage on the monthly GAK-1 sampling efforts and so provide ecological and environmental context above and beyond the core GAK-1 data collections.

In-kind contributions to the project from Danielson's UAF Mooring Loft inventory assist this project with the following equipment: two sets of mooring gear that includes acoustic releases, line, shackles and floats, conductivity-temperature-depth dataloggers, dataloggers for chlorophyll a fluorescence and photosynthetically active radiation. Together, instrumentation represents about $200k worth of equipment. Additional equipment needed for the deployment and recovery of the moorings include an acoustic release deck box and specialized rigging gear, about $15k in value. We also provide a conducting-wire winch and associated CTD rosette/water sampler, CTD, CTD sensors, and CTD deck unit that we use for the monthly CTD casts. These represent about $75k in value.

In addition, we use UAF-Seward Marine Center Mooring Loft storage facilities, tools, test tanks, and associated infrastructure. This includes shop tools such as (drill presses, line counters), forklifts and scales, and special data servers that allow us to seamlessly move raw data from Seward to Fairbanks inside the UAF internet firewall. We require a coastal vessel for the CTD profile and mooring deployment field work. We require a vessel with a crane and/or A-frame capable of lifting 1000 lbs with a clearance of at least 10' above the deck to be able to lift an anchor, anchor chain, and acoustic release over the stern. We are hopeful that the new R/V Nanuq will be able to cost-effectively serve both functions. Replacement cost for R/V Nanuk was about $700k.

More than $300K of in-kind equipment and other resources are directly used on an annual basis for this project.

7. FY17-20 PROJECT PUBLICATIONS AND PRODUCTS

<u>Publications</u>

Aguilar-Islas, A., M.J. Seguret, R. Rember, K.N. Buck, P. Proctor, C.W. Mordy, and N.B. Kachel. 2016. Temporal variability of reactive iron over the Gulf of Alaska shelf. Deep-Sea Research II 132 90-106.

Batten, S.D., D.E. Raitsos, S.L. Danielson, R.R. Hopcroft, K.C. Coyle, and A. McQuatters-Gollop. 2018. Interannual variability in lower trophic levels on the Alaskan Shelf. Deep Sea Research II 147:58-68. http://dx.doi.org/10.1016/j.dsr2.2017.04.023

Chenoweth, E.M., and K.R. Criddle. 2019. The Economic Impacts of Humpback Whale Depredation on Hatchery-Released Juvenile Pacific Salmon in Southeast Alaska. Marine and Coastal Fisheries 11:62-75. https://doi.org/10.1002/mcf2.10061

Chenoweth, E.M. 2018. Bioenergetic and economic impacts of humpback whale depredation at salmon hatchery release sites, Ph.D. Dissertation, University of Alaska Fairbanks, Fairbanks, AK

Coyle, K.O., A.J. Hermann, and R.R. Hopcroft. 2019. Modeled spatial-temporal distribution of productivity, chlorophyll, iron and nitrate on the northern Gulf of Alaska shelf relative to field observations. Deep Sea Research II doi:10.1016/j.dsr2.2019.05.006.

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Danielson, S.L., D.F. Hill, K.S. Hedstrom, J. Beamer, and E. Curchitser. 2020. Coupled terrestrial hydrological and ocean circulation modeling across the Gulf of Alaska coastal interface. WRR/JGR Oceans special issue on Coastal Hydrology and Oceanography DOI:10.1029/2019JC015724

Doyle, M.J., S.S. Strom, K.O. Coyle, A.J. Hermann, C. Ladd, A.C. Matarese, S.K. Shotwell, and Hopcroft. 2019. Early life history phenology among Gulf of Alaska fish species: Strategies, synchronies, and sensitivities. Deep Sea Research II doi:10.1016/j.dsr2.2019.06.005.

Helser, T., C. Kastelle, A. Crowell, T. Ushikubo, I.J. Orland, R. Kozdon, and J.W. Valley. 2017. A 200-year archaeozoological record of Pacific cod (*Gadus macrocephalus*) life history as revealed through ion microprobe oxygen isotope ratios in otoliths. Journal of Archaeological Science: Reports http://dx.doi.org/10.1016/j.jasrep.2017.06.037.

Laurel, B.J., and L.A. Rogers. 2020. Loss of spawning habitat and prerecruits of Pacific cod during a Gulf of Alaska heatwave. Canadian Journal of Fisheries and Aquatic Sciences 77:644-650.

Litzow, M.A., Malick, M.J., Bond, N.A., Cunningham, C.J., Gosselin, J.L. and Ward, E.J., Quantifying a Novel Climate Through Changes in PDO-Climate and PDO-Salmon Relationships. *Geophysical Research Letters*, p.e2020GL087972.

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Olson, A.P., C.E. Siddon, and G.L. Eckert. 2018. Spatial variability in size at maturity of golden king crab (*Lithodes aequispinus*) and implications for fisheries management. Royal Society Open Science 5. http://doi.org/10.1098/rsos.171802

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