

**ATTACHMENT B. Annual Project Report Form (Revised 11.21.19)**

**1. Project Number:**

19120114-G

**2. Project Title:**

Monitoring the Oceanographic Conditions of Prince William Sound

**3. Principal Investigator(s) Names:**

Robert W. Campbell, Prince William Sound Science Center

**4. Time Period Covered by the Report:**

February 1, 2019-January 31, 2020

**5. Date of Report:**

March 2020

**6. Project Website (if applicable):**

[www.gulfwatchalaska.org](http://www.gulfwatchalaska.org)

**7. Summary of Work Performed:**

The planned surveys of Prince William Sound (PWS) were conducted during the reporting period (Table 1), and all 12 standard stations were occupied. All conductivity and temperature at depth (CTD) data collected to date have been processed, and seasonally detrended anomalies of temperature at selected depths in central PWS are shown in Fig. 1. Temperatures in central PWS have been above average since late 2013, as has been observed elsewhere in the Gulf of Alaska (see Seward Line, project 19120114-L, and GAK1, project 19120114-I, reports), and late 2013 to 2016 has been labelled a basin scale marine heatwave (Gentemann et al. 2017). PWS exhibited the same warm anomaly seen throughout the Gulf with approximately the same timing, although PWS remained slightly above average into 2017, while the Gulf of Alaska appeared to be returning to an average or perhaps cooler than average state as a result of the 2017-18 La Niña. Following a weak cooling trend into early 2018 and a brief period of negative anomalies, anomalies have again trended warmer than average, which corresponds to basin-wide increases in sea surface temperature observed in late 2018 and 2019 (e.g., see: <https://www.ospo.noaa.gov/Products/ocean/sst/anomaly/>).

Near-surface temperature anomalies in 2019 exceeded those observed during the 2013-2016 marine heatwave and appear to be the result of a similar mechanism: a persistent atmospheric ridge (Bond et al. 2015).

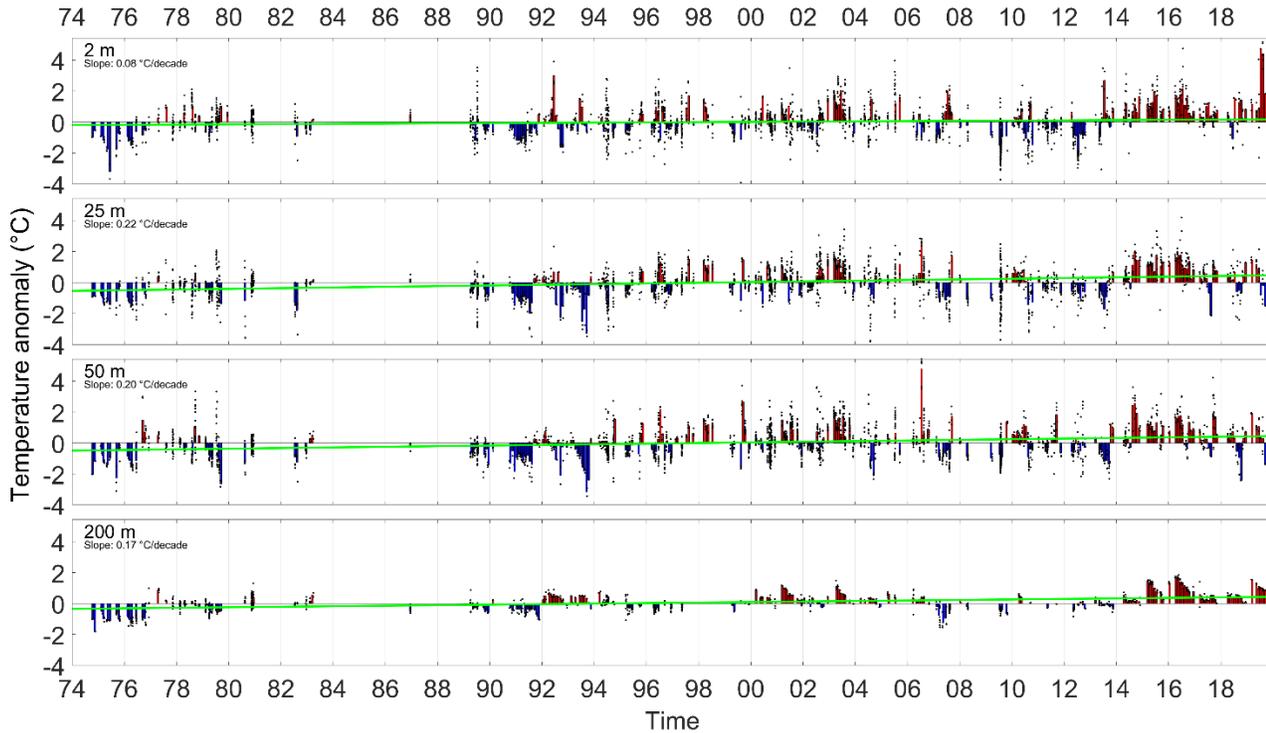
*Table 1. Status of project milestones for FY19.*

Deliverable/Milestone	Status
PWS Survey	Conducted 3-7 March 2019
Deploy profiling mooring	Deployed 31 March 2019
PWS Survey	Conducted 12-16 May 2019
Service mooring	Conducted 13 May 2019
Service mooring	Conducted 13 June 2019
PWS Survey	Conducted 18-19 June 2019
Service mooring	Conducted 10 July 2019
PWS Survey	Conducted 10-12 August 2019
Service mooring	Conducted 10 August 2019
Service mooring	Conducted 17 September 2019
Recover profiler	Recovered 21 September 2019
Redeploy profiler	Conducted 24 September 2019
Recover profiler	Recovered 26 October 2019
PWS Survey	Conducted 2-5 November 2019
CTD Data processed	Completed December 2019
Chlorophyll- samples processed	75% complete, to be completed in Q1 2020
Plankton samples enumerated	Ongoing (this project and 19120114-J)

Plankton and chlorophyll-a samples were collected from all stations with no incidents. Caitlin McKinstry, the technician who enumerates zooplankton and does the chlorophyll analysis, has been focusing most of her time on a manuscript describing the zooplankton in lower Cook Inlet collected by the Oceanography of lower Cook Inlet and Kachemak Bay project (19120114-J) with principal investigators (PIs) Holderied and Baird, using the methods developed in McKinstry and Campbell (2018). She will return to analyzing the plankton samples when the draft manuscript is substantially complete. Ongoing results from the draft manuscript will be presented in a poster at the 2020 Ocean Sciences Meeting.

Analysis of the 2010 to 2018 samples suggests that there was a shift in zooplankton taxa in PWS during the marine heatwave years (Fig. 2). When copepod species are split into the “warm” and “cool” water species assemblages used by Fisher et al. (2017), it is apparent that although changes in overall zooplankton abundance have been relatively small (not different axes scaling in the panels of Fig. 2), abundances of “warm” water copepod species increased, while that of the canonical “cool” water subarctic copepod species decreased. A shift back towards increased cool water species and decreased warm water species occurred in 2018. A lag of 1-2 years between the onset of warmer conditions (Fig. 1) and changes in the zooplankton composition (Fig. 2) is apparent. The lag can be

attributable to both transport (i.e., the advection of taxa more common to the California Current to the north), and/or enhanced productivity of warm-preferring taxa in place. No studies showing changes in transport during the marine heatwave years have been published as yet, and the canonical warm water species used here have been observed in the PWS region previously (e.g., Cooney and Coyle 1985), which supports the latter hypothesis. A detailed analysis of the changes in species composition is outlined in McKinstry and Campbell (2018).



*Figure 1. Temperature anomalies at four selected depths in central Prince William Sound. Anomalies were calculated as the residual to a second order cosine curve fit to all years data (to remove seasonality: Campbell, 2018). Black points are observations, bars are quarterly averages, and the green line indicates the linear trend. All slopes were significantly different from zero ( $p < 0.05$ ).*

The profiling mooring was deployed March 31, 2019, in advance of the spring bloom, and did two profiles per day with small gaps in May and September when the batteries ran out before the weather allowed a service visit (Fig. 3). A breakaway event during a storm in late September lead to a slightly longer gap as the profiler was tested extensively prior to re-deployment after recovery. The 2019 time series from the profiler shows the annual cycle of surface warming, with the onset of thermal stratification in spring/early summer and the breakdown of stability in autumn. Temperature anomalies were near climatology (if slightly warm) in spring, but near surface anomalies became strongly positive June through August, reaching a 5°C positive anomaly in August (the 2013-2016 marine heatwave maximum anomaly was ~4°C). The negative temperature anomalies at depth during summer months likely reflect a shallowing of the annual mixed layer (discussed in Campbell

2018). There was elevated nitrate near-surface when the profiler was deployed, which was rapidly drawn down in mid-April as the spring bloom began. Following the spring bloom, productivity was centered on the nitricline (Fig. 3), which has been observed in prior years. The time of the warmest near-surface temperatures in late July and early August corresponded with low chlorophyll-a concentrations, but paradoxically relatively high near-surface nitrate concentrations, which is unusual (nitrate concentrations are usually depleted near surface until the breakdown of stability in September-October). That low productivity signal may have been a result of thermal stress brought on by the unprecedentedly high temperatures (in the 40-year CTD time series for the region: Campbell 2018) that occurred.

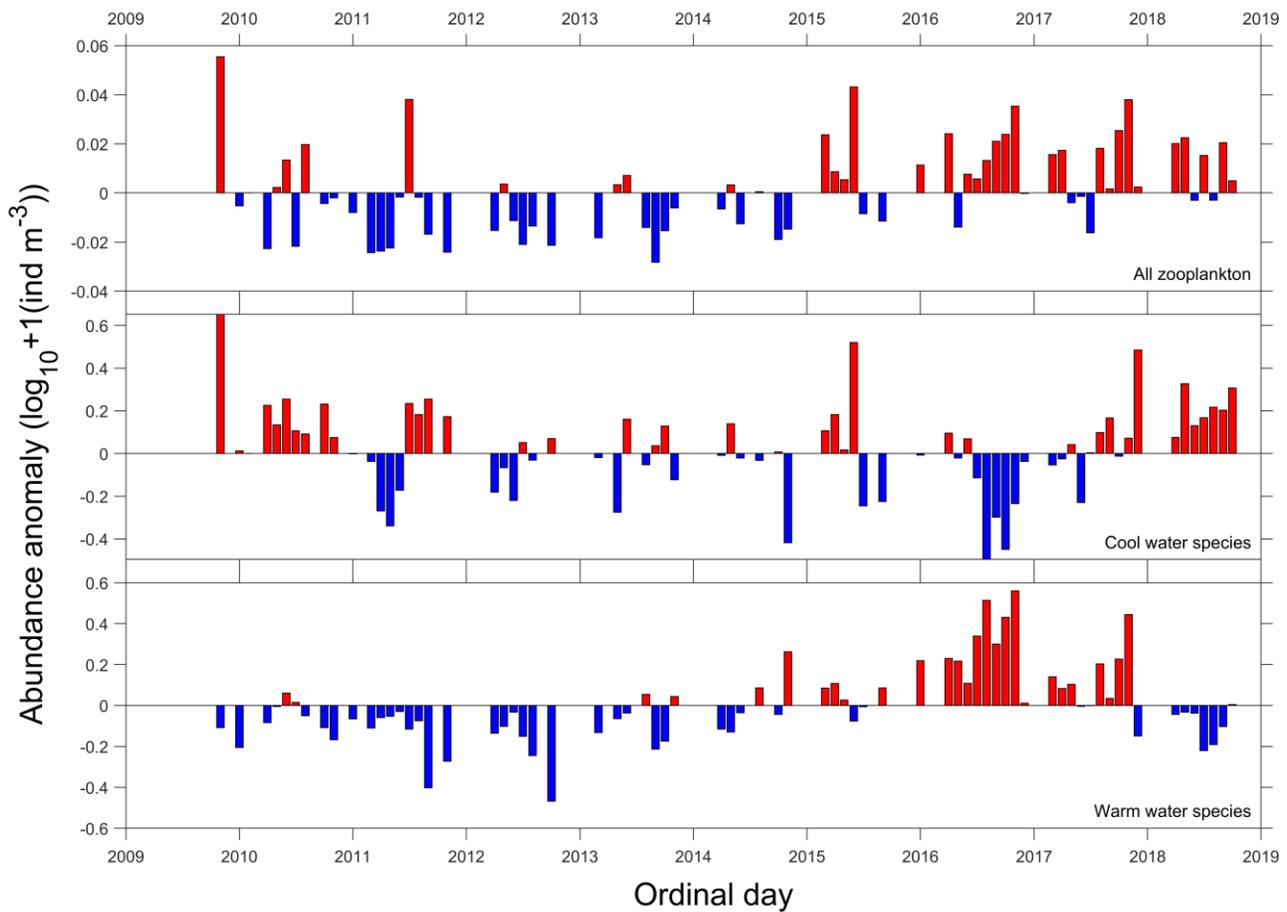


Figure 2. Time series of zooplankton anomalies in PWS, 2010-2018. Zooplankton were divided into “warm” and “cool” water copepod species per Peterson et al. (2017) and average anomalies calculated across groups per Fisher et al. (2015). Warm water species were *Calanus pacificus*, *Clausocalanus sp.*, *Corycaeus anglicus*, *Ctenocalanus vanus*, *Mesocalanus tenuicornis* and *Paracalanus parvus*. Cool water species were *Acartia longiremis*, *Calanus marshallae*, *Oithona similis*, and *Pseudocalanus sp.* Abundances were  $\log_{10}+1$  transformed prior to calculating anomalies. Note that the scaling of the ordinate varies among panels.

A plankton camera was developed and installed on the profiler in 2016, with funding from the North Pacific Research Board. The plankton camera collected 871,385 images during the 2019 deployment, occupying just over 34 gigabytes on disk. The highest particle concentrations were during the spring bloom in late April/early May (Fig. 3, bottom panel), there was also a large number of particles in the surface mixed layer in late June / early July. Pronounced diel differences are also notable, with “banding” (i.e., alternating bright and dark coloring in adjacent profiles) evident from profile to profile, particularly in May-June and mid-July-August. The banding effect was caused by diel differences in the number of plankton in the surface layer, with more plankton observed during nighttime profiles. A manual perusal of the images suggests that the differences are largely due to calanoid copepods, particularly of the genus *Metridia*, which are known to undertake large diurnal migrations.

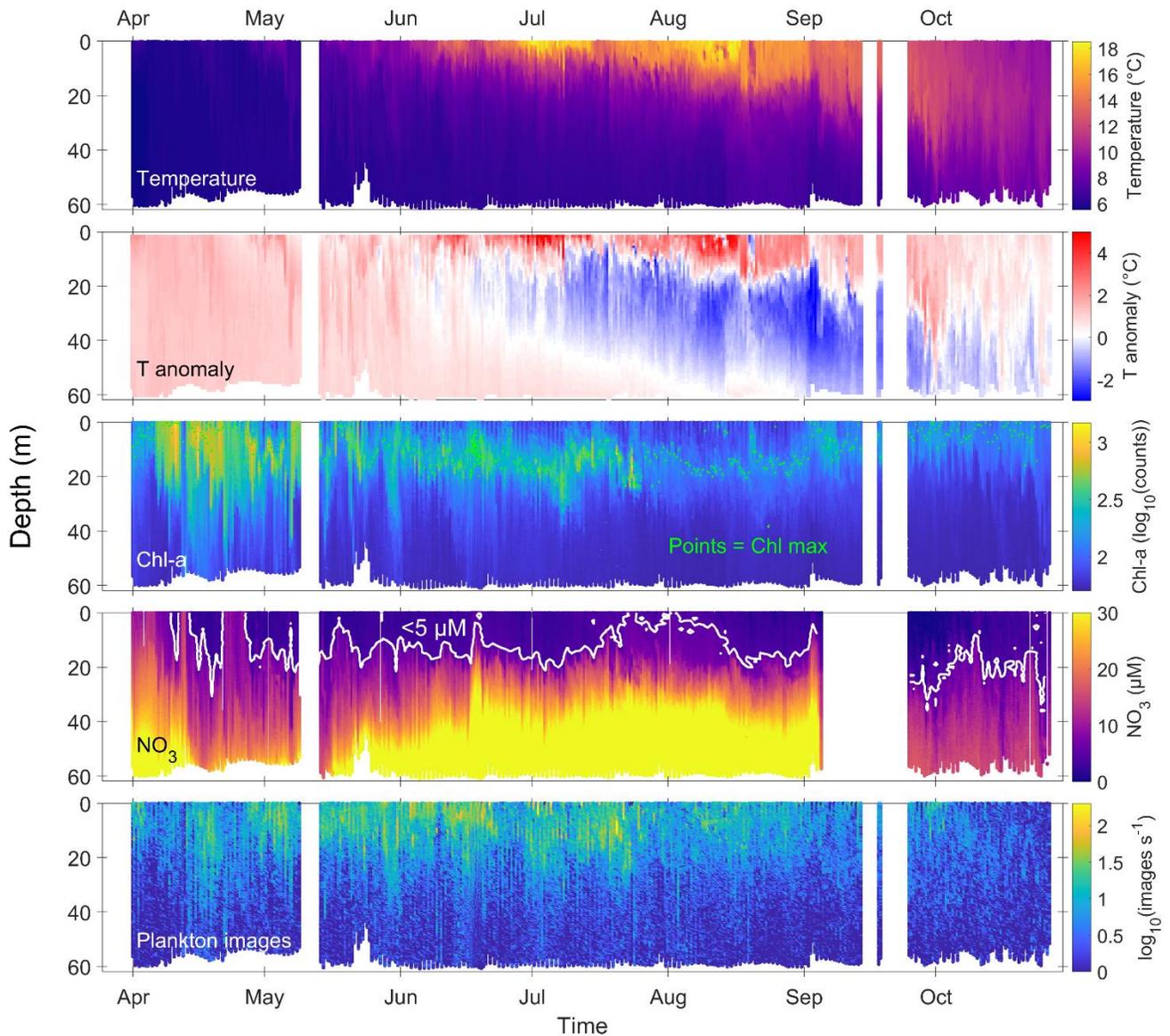


Figure 3. Time series of observations made by the PWS autonomous profiler in 2019. Top panel: temperature ( $^{\circ}\text{C}$ ). Second panel: Temperature anomaly ( $^{\circ}\text{C}$ ). Temperature anomalies were calculated with the method of Campbell (2018). Third panel: Chlorophyll-a fluorescence. Chlorophyll is presented as  $\log_{10}$  transformed digital counts (counts are linearly proportional to chlorophyll-a concentration); green dots represent the depth of the maximum chlorophyll-a concentration in each profile. Fourth panel: Nitrate concentration ( $\mu\text{M}$ ) from a Satlantic SUNA. The white line of the nitrate panel indicates the depth of the  $5\ \mu\text{M}$  contour. Bottom panel: Plankton images collected (per second) by the in situ plankton camera ( $\log_{10}$  transformed).

One focus of 2018 and 2019 included generating a training set to feed into machine vision models to automate the identification of the plankton images that have been collected. A training set of ~20,000 manually identified images in 43 different taxa and visually distinctive groups has been produced, and used to train a version of the Google-developed Inception v3 convolutional neural net (CNN) merged with a second neural network to include measurements of size and texture. CNNs necessarily discard size information, and we have found that including size information allows discrimination of similar taxa (e.g., calanoid copepods of different size). Application of a probability filtering technique that assesses the relative confidence of the classifier is returning accuracy values >90% for numerous groups (Fig. 4). Most confusion is concentrated in the less informative classes (catchall groups like “large copepods” versus specific species), and in smaller classes that tend to be less sharp. The classifier is now being applied to the full image set, and the depth-time relationship of specific taxa groups may be examined to very fine scales (~5cm in the vertical). For instance, observations of different large copepod taxa show interannual differences, as well as differences among species (Fig. 5). The large calanoids *Neocalanus* sp. and *Calanus* sp. were most common in spring, and the depth distribution shifted towards deeper depths over the course of the year, presumably due to their annual downward ontogenic migration. The diel migrant calanoid *Metridia* sp. has what appears to be a consistent change in its depth range each year, that may be in response to changes in the depth range of primary producers. A manuscript describing the profiler, camera system, and classifier was accepted by the ICES Journal of Marine Science in February 2020. A companion manuscript on the use of the classifier to track the annual cycles of specific taxa is in preparation and will be the topic of a presentation at the 2020 Ocean Sciences Meeting.



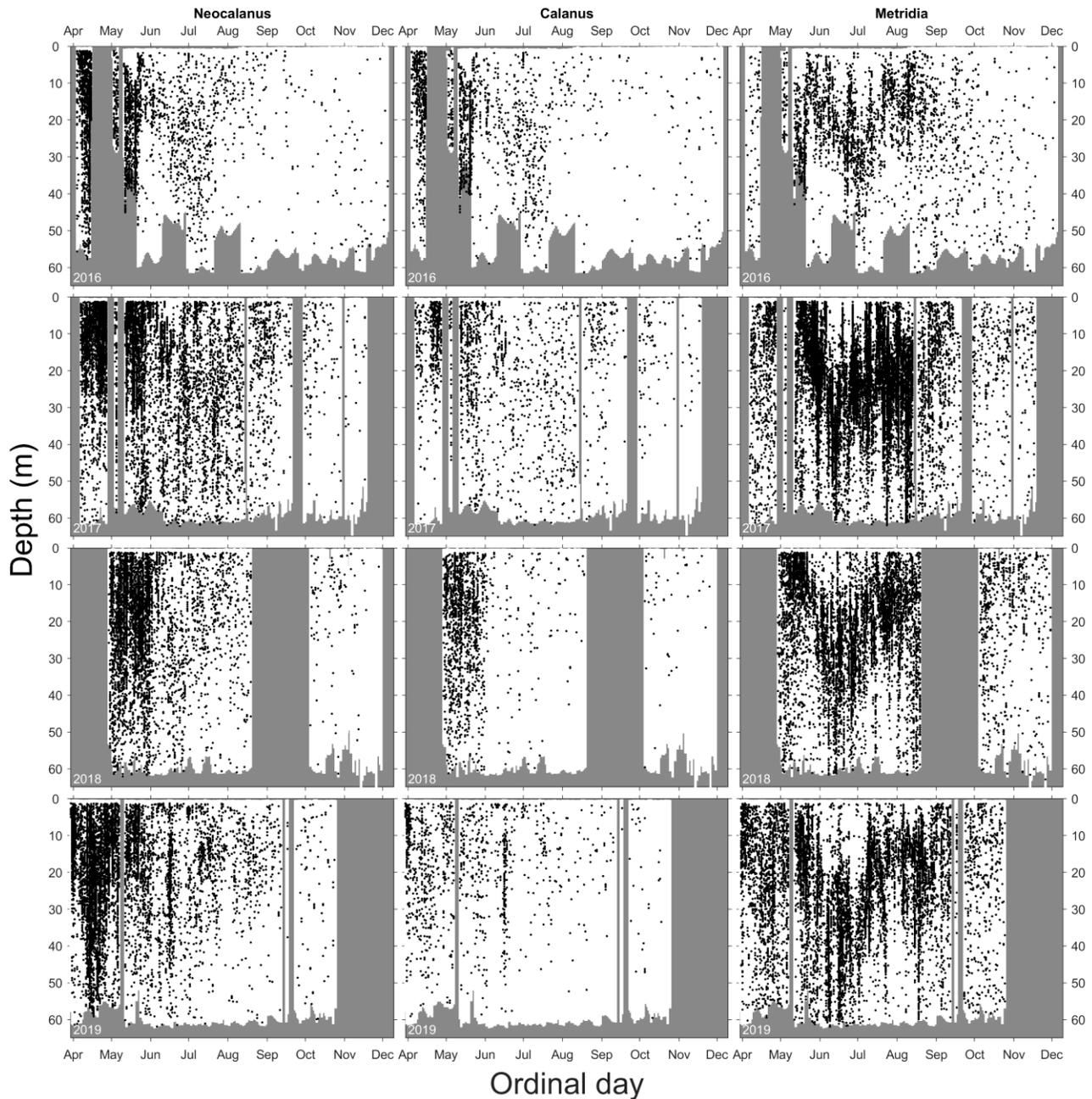


Figure 5. Time-depth distributions of individual plankters of three of the more common large calanoid copepod genera in Prince William Sound (column-wise: *Neocalanus*, *Calanus*, and *Metridia*) in each year of deployments (row-wise). Each point represents an image that was classified as being of an individual plankter of the species. Each image was time-stamped (nearest millisecond) when collected and the depth then determined from the time-pressure record of the CTD on the profiler.

## **8. Coordination/Collaboration: See, Reporting Policy at II (C) (8).**

### **A. Long-term Monitoring and Research Program Projects**

#### **1. Within the Program**

All plankton samples collected as part of project 19120114-J (Long-term monitoring of oceanographic conditions in Cook Inlet/Kachemak Bay) are processed and identified by this project; we are working with PIs Baird and Holderied on a manuscript on their collections. Following advice from the Science Panel in 2018, modifications were made to the PWS Science Center vessel to accommodate a bird observer from project 19120114-E (Fall and Winter seabird abundance). Joint cruises were completed in March and November 2019 and are planned to continue going forward. We contributed temperature and zooplankton data for two GWA science synthesis manuscripts, one led by Robert Suryan (project 19120114-A-B), and the other by Mayumi Arimitsu (project 19120114-C)

#### **2. Across Programs**

##### **a. Herring Research and Monitoring**

Technicians from Project 18160111-B (Annual Herring Migration Cycle) have participated in surveys done by this project to upload data from the tracking arrays in Hinchinbrook Entrance and Montague Strait and to recover/deploy receivers in other locations in PWS. A receiver was also installed on the profiling mooring in 2019 to further extend the reach of the array. The receiver did detect a herring tagged in 2019 during the deployment and will be re-deployed in 2020. We also provided data to David McGowan for a HRM program science synthesis manuscript on herring spawn timing in PWS.

##### **b. 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. Individual Projects**

We are not coordinating with individually funded *Exxon Valdez* Oil Spill Trustee Council projects at this time and will gladly share data and information to support project efforts as requested.

### **C. With Trustee or Management Agencies**

We generally endeavor to conduct a spring cruise around the time of herring spawning when the Alaska Department of Fish and Game is doing their surveys (contact: Stormy Haught, Alaska Department of Fish and Game, Cordova).

A North Pacific Research Board project (1801: Prevalence of Paralytic Shellfish Toxins in the Marine Food Webs of Prince William Sound and Kachemak Bay, Alaska) began in Sept. 2018. Dr. Xiuning Du (Oregon State University) is the lead PI and Campbell is a co-investigator.

Phytoplankton and toxin samples are being collected for that project at all sites visited by this program. Campbell is also coordinating sampling efforts of larger taxa in PWS (shellfish, forage fish

and salmon). Samples are being analyzed for saxitoxin by Dr. Steve Kibler (National Oceanic and Atmospheric Administration [NOAA], Beaufort Lab).

In addition, we contribute indicators to NOAA's Gulf of Alaska Ecosystem Status Report to the North Pacific Fisheries Management Council for 2019 (Zador et al. 2019, <https://access.afsc.noaa.gov/REFM/REEM/ecoweb/index.php>): 1) Zooplankton trends in Prince William Sound and 2) Temperature trends in the surface waters of Prince William Sound.

## **9. Information and Data Transfer: See, Reporting Policy at II (C) (9).**

### **A. Publications Produced During the Reporting Period**

#### **1. Peer-reviewed Publications**

Campbell, R.W., P.L. Roberts, and J. Jaffe. *In press*. The Prince William Sound Plankton Camera: a profiling *in situ* observatory of plankton and particulates. Accepted, ICES J. Mar. Sci., 02/2020.

#### **2. Reports**

Arimitsu, M., J. Piatt, R.M. Suryan, S. Batten, M.A. Bishop, R.W. Campbell, H. Coletti, D. Cushing, K. Gorman, S. Hatch, S. Haught, R.R. Hopcroft, K.J. Kuletz, C. Marsteller, C. McKinstry, D. McGowan, J. Moran, R.S. Pegau, A. Schaefer, S. Schoen, J. Straley, and V.R. von Biela. 2019. Chapter 3 Synchronous collapse of forage species disrupts trophic transfer during a prolonged marine heatwave. In R.M. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. *The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (Exxon Valdez Oil Spill Trustee Council Program 19120114)*. Exxon Valdez Oil Spill Trustee Council, Anchorage, Alaska.

Campbell, R.W. 2019. Monitoring the Oceanographic Conditions of Prince William Sound. FY18 annual report to the Exxon Valdez Oil Spill Trustee Council, project 17120114-G.

Campbell, R.W. and C.A. McKinstry, 2019. Temperature trends in the surface waters of Prince William Sound. pp. 62-63 in Zador, S., Yasumiishi, E. and G.A. Whitehouse (eds) Ecosystem Status Report 2019: Gulf of Alaska. North Pacific Fishery Management Council. <https://access.afsc.noaa.gov/REFM/REEM/ecoweb/pdf/2019GOAecosys.pdf>

Campbell, R.W. and C.A. McKinstry, 2019. Zooplankton trends in Prince William Sound. pp. 85-87 in Zador, S., Yasumiishi, E. and G.A. Whitehouse (eds) Ecosystem Status Report 2019: Gulf of Alaska. North Pacific Fishery Management Council. <https://access.afsc.noaa.gov/REFM/REEM/ecoweb/pdf/2019GOAecosys.pdf>

Danielson, S.L., T.D. Hennon, D.H. Monson, R.M. Suryan, R.W. Campbell, S.J. Baird, K. Holderied, and T.J. Weingartner. 2019. Chapter 1 A study of marine temperature variations in the northern Gulf of Alaska across years of marine heatwaves and cold

spells. In R.M. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. *The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska*. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (*Exxon Valdez* Oil Spill Trustee Council Program 19120114). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

Suryan, R.M., M. Arimitsu, H. Coletti, R.R. Hopcroft, M.R. Lindeberg, S. Batten, M.A. Bishop, R. Brenner, R. Campbell, D. Cushing, S. Danielson, D. Esler, T. Gelatt, S. Hatch, S. Haught, K. Holderied, K. Iken, D. Irons, D. Kimmel, B. Konar, K. Kuletz, B. Laurel, J.M. Maniscalco, C. Matkin, C. McKinstry, D. Monson, J. Moran, D. Olsen, S. Pegau, J. Piatt, L. Rogers, A. Schaefer, J. Straley, K. Seeney, M. Szymkowiak, B. Weitzman, J. Bodkin, and S. Zador. 2019. Chapter 4 Ecosystem response to a prolonged marine heatwave in the Gulf of Alaska. In R.M. Suryan, M.R. Lindeberg, and D.R. Aderhold, eds. *The Pacific Marine Heatwave: Monitoring During a Major Perturbation in the Gulf of Alaska*. Gulf Watch Alaska Long-Term Monitoring Program Draft Synthesis Report (*Exxon Valdez* Oil Spill Trustee Council Program 19120114). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska.

### **3. Popular articles**

Campbell, R.W., J. Jaffe, and P. Roberts. 2019. Computers to identify plankton images from Prince William Sound. PWSSC Delta Sound Connections ([https://pwssc.org/wp-content/uploads/2019/05/DSC-2019\\_WEB.pdf](https://pwssc.org/wp-content/uploads/2019/05/DSC-2019_WEB.pdf)).

Danielson, S., R. Hopcroft, K. Holderied, and R. Campbell. 2019. Tracking water layers in the ocean. PWSSC Delta Sound Connections ([https://pwssc.org/wp-content/uploads/2019/05/DSC-2019\\_WEB.pdf](https://pwssc.org/wp-content/uploads/2019/05/DSC-2019_WEB.pdf)).

Yelverton, J. 2019. The fragile world of Prince William Sound. Anchorage Press (cover story, Jan 29, 2020) [https://www.anchoragepress.com/news/the-fragile-world-of-prince-william-sound/article\\_67b68770-413f-11ea-97fc-9f581d3d2d77.html](https://www.anchoragepress.com/news/the-fragile-world-of-prince-william-sound/article_67b68770-413f-11ea-97fc-9f581d3d2d77.html)

## **B. Dates and Locations of any Conference or Workshop Presentations where EVOSTC-funded Work was Presented**

### **1. Conferences and Workshops**

Campbell, R.W., P.L. Roberts, and J. Jaffe. 2020. The Annual Secondary Productivity Cycle in Prince William Sound Measured with the Prince William Sound Plankton Camera. Alaska Marine Science Symposium, Anchorage, January 2020.

Kibler, S., B. Wright, X. Du, R.W. Campbell, K. Holderied, D. Hondolero, R. Masui, C. Guo, and C. Walker. 2020. NPRB 1801 - Prevalence of Paralytic Shellfish Toxins in the Marine Food Web of Southcentral and Southwest Alaska: Year 1 Update. Alaska Marine Science Symposium, Anchorage, January 2020.

## 2. Public presentations

Campbell, R.W., J. Jaffe, and P. Roberts. 2019. The PWS Plankton Cam: an underwater microscope to view the zooplankton ecosystem of Prince William Sound. PWSSC Tuesday Night Talk, Cordova.

### C. Data and/or Information Products Developed During the Reporting Period, if Applicable

No new contributions for this reporting period. We continue to update annual ecosystem indicators for the NOAA Ecosystem Status Report (Zador et al. 2019) as stated in section 8.C.

### D. Data Sets and Associated Metadata that have been Uploaded to the Program's Data Portal

CTD data has been uploaded to the workspace

(<https://workspace.aos.org/project/23640/folder/2638352/pws-oceanography-data,-2017-2021>).

Zooplankton and chlorophyll-a data will be uploaded when analysis has been completed.

<b>10. Response to EVOSTC Review, Recommendations and Comments: See, Reporting Policy at II (C) (10).</b>
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**Science Panel Comments (FY20):** *The Science Panel is pleased that the plankton camera is running again on the autonomous profilers. We note this project continues to be productive. Data show the magnitude of bloom has changed but the timing has not. Do you have indications about the reasons for these findings? Might it have something to do with increased water column stability and reduced nutrient flux (freshwater input and/or upwelling)? Is there some indication about the potential influences of increased temperature, freshwater input (e.g. increased glacial melt), or photoperiod? This project, and two others, noted the switch among warm- and cold-water zooplankton. Is there evidence to indicate the mechanism to be differential local production or advection of these species from other areas? The Panel appreciates the amount and quality of the data and would like to see if data analyses can address the questions above.*

**PI Response (FY20):** I thank the science panel for their comments. The mechanisms forcing the spring bloom in PWS are as complicated as one might expect, and the first approximation appears to be an interaction between light, stability (primarily thermal but also salinity), and wind mixing (Eslinger et al. 2001: doi 10.1046/j.1054-6006.2001.00036.x; Henson, 2007: doi 10.1357/002224007784219002). Stability is set up in ~April/May and the bloom initiates if it is not disrupted by wind mixing. The timing of the bloom will therefore depend on the timing of stability onset and wind events, while the magnitude will depend on the amount of nitrate available at the surface -- the bloom terminates after nitrate is depleted in surface waters.

We do not have a tremendously long time series of the nutrient biochemistry in PWS, but the system is largely advective, and much of the nitrate input is likely from deepwater renewal events that bring in off-shelf waters (high salinity, low oxygen and high nitrate) to the basins of PWS in summer when downwelling relaxes. That deep water is mixed up into the surface waters over the winter and is what drives the spring bloom. At depth in PWS there is a modest trend towards increased salinity

over the last few decades (Campbell 2018: doi 10.1016/j.dsr2.2017.08.014), which is presumably driven by decreased downwelling and enhanced deepwater transport. That would imply that nitrate flux might actually be increasing somewhat in the deep waters of PWS.

The Campbell (2018) study also found a shoaling of mixed layer depths in the last 40 years, which seems a likely explanation for the reduction in overall productivity, as the science panel suggests. An interesting pattern that we have observed at the profiler site since the onset of the 2013-2014 marine heat wave (MHW) is a fairly consistent negative temperature anomaly in waters immediately underlying the mixed layer. This can be seen in 2018 in the profiler temperature anomaly panel (2nd from top) of Fig. 7 of the project 20120114-G FY20 work plan. Given that deep waters of PWS are exhibiting a warming trend, the presence of a cold anomaly suggests to me that the surface mixed layer is much thinner presently than in the climatology, which manifests as cooler anomalies at depth. In other words, the shoaling and strengthening of the mixed layer means that "deep water" (which is cooler) is found closer to the surface than previously. It follows that the total amount of near-surface nitrate available to the phytoplankton in the seasonal mixed layer will be reduced which will ultimately result in a smaller bloom.

With regard to zooplankton species compositions, even prior to the marine heatwave, Russ Hopcroft (Seward Line PI) and I noticed that the species we designate now as "warm species" were often present in PWS in low abundance, but comparatively rare on the shelf along his GAK line. We hypothesized that PWS may be a refugium of sorts for those species. Smaller embayments around the periphery of PWS (particularly the non-glaciated ones) can become considerably warmer in summer than central PWS or on the shelf. So, the marine heatwave may have made the environment in PWS a more amenable habitat to those species, and conversely less amenable to the canonical subarctic taxa we designate as "cool water" ones. The two-year lag between the onset of the marine heatwave and the largest anomalies is interesting but could be due to enhanced local production or advection – they are not mutually exclusive. It seems likely that the reality was a mix of the two – some species have always been present and did better during the marine heatwave years (a closer look at stage compositions may be informative), while others were advected northward by the prevailing currents. At least one species, *Corycaeus anglicus*, was extremely rare prior to the marine heatwave (not seen some years, 1-2 observations in others) but is now prevalent throughout PWS.

The questions highlighted by the science panel are of considerable interest and are the focus of ongoing analyses that the science panel can expect to see in future reports. Our recent focus was fairly broad descriptive manuscripts on the hydrography and the plankton ecosystem in PWS (published in the Gulf Watch Alaska/Herring Research and Monitoring Deep-Sea Research II volume). In FY19 we have been focused on synthesis activities, a manuscript on the profiler and plankton camera (reviews received September 23, 2019 and will be accepted pending revisions), and a manuscript in preparation on the Kachemak Bay plankton ecosystem. We are looking forward to diving into more of the details in future work.

**Additional PI comments (this report):** For the most part I think my prior comments still stand. The addition of another two years of data seems to still align with the expectation that the species

assemblages tend to shift in response to changes in temperatures, with a one to two year lag; the record-breaking temperatures observed in the PWS region in 2019 suggests that the species assemblage might again shift towards warm-water species in the next year.

The plankton observations from the Gulf Watch Alaska program did feature in one of the synthesis manuscripts prepared this year, as well as the overall synthesis report. A dedicated manuscript comparing the plankton assemblages of the different regions sampled by all the Gulf Watch Alaska projects is on the (rather large) list of manuscripts we intend to develop from the large amounts of data we have collected so far.

FY19 was a busy year for this project, I started the year off by breaking an arm two weeks prior to the first cruise and the first few cruises were done one-handed; the project had 28 at-sea days in 2019. The three synthesis manuscripts that I participated in took a significant amount of time, and I am gratified that the first manuscript on the profiler/plankton camera has been accepted. The companion manuscript on PWS zooplankton cycles from the image time series is >50% complete and should be submitted in FY20. Following that I would like to begin working on a manuscript examining the spring bloom in PWS and investigating why it might be changing.

**Science Panel Comment (FY19):** *Science Panel appreciates this time series and looks forward to seeing how the zooplankton community in Cook Inlet relates to oceanographic conditions. The Panel notes that there was a significant increase in warm water zooplankton species in 2016/2017 (Figure 5) after the blob occurred and would like to see analyses that might explain that lag response. We acknowledge that analyses are underway and encourage the PI to publish.*

**PI Response (FY19):** A region-wide comparison of the results of the PWS, Seward Line, and lower Cook Inlet projects has been identified as a good potential synthesis manuscript topic and is part of our ongoing science synthesis discussions.

Analysis of a now 40-year CTD profile database in the PWS region shows that temperatures there tend to lag those in the Gulf of Alaska (GOA; as proxied by the Pacific Decadal Oscillation index) by about 12 months (see Fig. 12 in Campbell 2018). Temperature anomalies did shift towards positive anomalies in late 2013 in PWS as they did in the GOA during the emergence of the marine heatwave. An estimate of heat flux at the mid-PWS National Data Buoy Center buoy (Buoy 46060) suggests that heat flux out of the surface ocean in PWS was low in the marine heatwave years (late 2013-2016), which has also been proposed as the mechanism for the genesis of the marine heatwave (e.g., Bond et al. 2015). We take from this that the same atmospheric phenomenon (the “ridiculously resilient ridge” as stated in Swain 2015) that drove the formation of the marine heatwave in the central GOA was also operating in PWS and led to those positive anomalies. The transport lags into PWS discussed in Campbell (2018) then led to temperature anomalies in PWS remaining elevated longer than they were in the GOA, well into 2017.

There was already some indication of a higher prevalence of warm water zooplankton species in PWS in 2013, but it is a good observation that it was not until 2015/2016 that they are almost uniformly prevalent. We would attribute that to both the lag due to transport and the lag that one can

expect from a biological system responding to a physical forcing. McKinstry and Campbell (2018) discuss in detail some of the species shifts observed during the marine heatwave years (see section 4.2. Climatic shifts and zooplankton variation). Briefly, several of the “warm water” species identified in Fig. 5 of project 19120114-G’s FY19 work plan have been observed in PWS for some time; many of them fell into what our Indicator Species Analysis termed “winter taxa.” While recently comparing our observations with those by Russ Hopcroft’s along the Seward Line, we have noticed that a number of those species tend to be more prevalent in PWS and hypothesize that it might be some sort of refugium for those species. We would extend that hypothesis and suggest that those already present warm-water species were at a comparative advantage during the marine heatwave years (and cool-preferring species may have conversely been at a disadvantage), and so there was a trend to become more prevalent over time as conditions remained advantageous. So rather than there being a large shift in 2015, there was a trend towards more warm water species over time (with some noise, as one expects from plankton observations). There are other possible explanations, but this is perhaps the most plausible hypothesis given the available data. Approaching the question quantitatively would be difficult, but we will be vigilant for potential opportunities. The basic life histories of many of the warm water diagnostic species (*Mesocalanus tenuicornus*, *Clausocalanus anglicus*, *Corycaeus pacificus*) are not well described in general (really, *Calanus pacificus* is the sole exception), much less so in Alaska, and even less is known about their vital rates. As the Gulf Watch Alaska oceanographic time series extend beyond the impact of the marine heatwave, program PIs expect to be able to say more about the lags in zooplankton populations.

**11. Budget: See, Reporting Policy at II (C) (11).**

Please see provided program workbook. Spending is currently on track.

Budget Category:	Proposed FY 17	Proposed FY 18	Proposed FY 19	Proposed FY 20	Proposed FY 21	TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	\$145.0	\$149.3	\$153.8	\$158.4	\$163.2	\$769.7	\$369.4
Travel	\$1.0	\$1.0	\$1.0	\$1.0	\$1.0	\$5.0	\$6.9
Contractual	\$43.7	\$43.7	\$43.7	\$43.7	\$43.7	\$218.3	\$138.4
Commodities	\$11.0	\$11.0	\$11.0	\$11.0	\$11.0	\$55.0	\$22.8
Equipment	\$0.0	\$0.0	\$0.0	\$0.0	\$0.0	\$0.0	\$0.0
Indirect Costs (waived)							
<b>SUBTOTAL</b>	<b>\$200.6</b>	<b>\$205.0</b>	<b>\$209.5</b>	<b>\$214.1</b>	<b>\$218.8</b>	<b>\$1,048.0</b>	<b>\$537.5</b>
General Administration (9% of subtotal)	\$18.1	\$18.4	\$18.9	\$19.3	\$19.7	\$94.3	N/A
<b>PROJECT TOTAL</b>	<b>\$218.7</b>	<b>\$223.4</b>	<b>\$228.3</b>	<b>\$233.3</b>	<b>\$238.5</b>	<b>\$1,142.3</b>	
Other Resources (Cost Share Funds)	\$300.0	\$300.0	\$275.0	\$275.0	\$275.0	\$1,425.0	

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