Biological Productivity in Arctic Lagoons:

Pilot Study to Assess Diversity, Abundance, and Interannual Dynamics of Zooplankton Populations

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Cover Photograph – Krusenstern Lagoon taken by Marguerite Tibbles.

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Executive Summary

Eight coastal lagoons in and around Cape Krusenstern National Monument and Cape Thompson, Alaska were sampled for zooplankton diversity and abundance during 2017-2018 field visits by Wildlife Conservation Society crews. Water quality and chemistry were also assessed and related to zooplankton findings. Zooplankton from 75 samples were sorted taxonomically and counted in the laboratory by Alexei Pinchuk at the University of Alaska, Fairbanks. Results showed that Arctic coastal lagoons support dense herbivorous calanoid copepod populations suggesting high levels of pelagic production. Zooplankton composition, abundance and biomass varied between geomorphologically similar lagoons, creating drastically different feeding environments for pelagic predators. However, the composition within lagoons was remarkably consistent even across decades, when compared with historical studies. Based on these findings, it is likely that lagoons act as a portfolio of diverse rearing and feeding habitats for planktivorous invertebrates and fish to utilize. The high inter-lagoon variation in zooplankton composition, yet stable intra-lagoon composition over years undoubtedly shapes fish life history strategies and facilitates fish population bet-hedging to ensure successful recruitment and overall population health. Thus, these lagoons are undoubtedly integral to the population health of important subsistence fishes that inhabit them (e.g.s, whitefish and salmon species). Given the diverse nature of lagoon zooplankton assemblages, accelerating anthropogenic or climate change-driven effects in the region such as coastal erosion, permafrost thawing, or infrastructure development could upset the habitat conditions that drive species composition. This could potentially cause homogenization of zooplankton assemblages among lagoons and result in a lack of diverse prey options for subsistence fish species, thus decreasing fish population bet-hedging ability. Recommended follow-on work includes investigating the "seeding" of lagoons in early spring to answer the question of where zooplankton originate from, and why this differs across lagoons. It is likely that lagoons which freeze to the bottom during winter are places where species with resting (dormant) eggs thrive, while the lagoons with ice free bottom water provide refugia for euryhaline species.

Introduction

The Arctic is experiencing impacts of climate change faster and more severe than in most of the rest of the world. The impacts are most readily manifested by rapid warming and sea ice decline, which in turn will dramatically affect coastal ecosystems. Wind-induced advection and mixing in the absence of ice, increasing primary productivity, changes in amounts of terrestrial-derived carbon, altered freshwater runoff regimes, and coastal erosion, are among the important processes which influence biology of nearshore species and communities. The climate-related impacts are further exacerbated by potential anthropogenic threats resulting from exploration of newly accessible oil and gas fields, shipping, and coastal infrastructure development. Despite the growing number of marine research efforts in the Arctic, much of this is offshore, leaving considerable gaps in knowledge of the Arctic nearshore ecosystems.

Previous surveys of Chukchi Sea coastal waters emphasized the abundance and diversity of Arctic Ocean fishes, and more recently, the slow intrusion of Bering Sea species (e.g., Norcross et al. 2010; Eisner et al. 2013; Logerwell et al. 2015). Large-scale studies have been conducted throughout the southern Chukchi Sea over the past 10 years, but they have typically focused on offshore waters (>5 m deep). A comprehensive synthesis of fish surveys conducted in the eastern Chukchi Sea during 2007-2012 highlights the tremendous gap for nearshore and beach habitats, identifying “surveys of the lagoons of the Chukchi Sea” as a key need (Logerwell et al. 2015). Furthermore, during a December 2016 workshop on community coastal resilience and adaptation in Western Arctic Alaska, community members, tribal representatives, scientists, and managers identified “changes in the nearshore environment and nearshore marine species” as a high science priority.

Substantial stretches of the Arctic coast of the Chukchi and Beaufort seas are comprised of a matrix of shallow (<6 m) lagoons protected by barrier islands from the bordering marine waters. In summer, some lagoons receive discharge from rivers and creeks and form distinct habitats with brackish (<25 ppt) salinities and warmer temperatures compared to the adjacent ocean. A subset of these lagoons may intermittently open and close based on such events as spring outflows that breach lagoon berms, and summer storms that close them up again. Lagoons that remain persistently closed over a few years may trend toward shallow freshwater lake physical conditions and biological community composition, while those that do not reclose may trend toward brackish conditions and ecosystems. In winter many of the shallower lagoons freeze to the bottom or host conditions inhospitable for fish due to low oxygen and hypersalinity which resets the lagoons each year (Tibbles, 2018; Tibbles et al., 2018).

Despite their ephemeral nature, we know from the limited scientific literature and shared Traditional Ecological Knowledge about the region that coastal lagoons can play an important role in the functioning of a highly productive southeastern Chukchi Sea ecosystem: At certain times and places, they provide critical breeding and feeding habitat for anadromous fish (e.g., salmon, whitefish), as well as for other ecologically important forage species (e.g., herring, smelt, and stickleback); and they provide staging habitat for migratory shorebirds and waterfowl (Wilimovsky and Wolfe 1966, Brown 2006, Craig 1984, George et al. 2007; Johnson et al. 2007; Logerwell et al. 2015; Whiting et al. 2011). Because of their productivity and their physical layout that facilitates interception of fishes in shallow, sheltered waters, many lagoons have been sources of important subsistence resources for local peoples for millennia (Georgette and Shiedt 2005). Residents of the region currently obtain up to 70% of their annual wild food harvest from the fish, marine mammals, and birds that depend on nearshore habitat (Whiting et al. 2011).

However, the mechanisms driving the functions of Arctic lagoons in Alaska remain poorly described in the scientific literature, in part, because of their remoteness and difficultly to access by conventional survey vessels.

Similar to many estuarine ecosystems throughout the world (e.g. Connolly et al 2009, Antonio et al 2010), food webs in the Arctic lagoons are thought to be dominated by benthic detritovores dependent on microbial processing of terrestrial carbon delivered by river flux as dissolved or/and particular organic carbon (mainly peat). However, in contrast, pelagic primary production in the western Beaufort nearshore lagoons was reported to be low, presumably due to insufficient inorganic-N concentrations (Dunton et al 2006, 2012). The resulting low phytoplankton standing stock combined with almost complete freeze-up during winter, and short open-water season is assumed to result in overall low biological productivity in the water column of these Beaufort lagoons. The absence of resident (based on stable isotope composition) copepod fauna in the studied lagoons further supports the conclusion about generally oligotrophic nature of Arctic estuarine waters and suggests the strongest trophic linkages between terrigenous organic matter and apex consumers (e.g. fish and birds) are via benthic invertebrates (Dunton et al 2012).

Zooplankton (both pelagic and epibenthic) dynamics are critical to these coastal ecosystems as they are an important trophic link, playing a key role in transfer of energy from primary producers to apex predators (Tibbles and Robards, 2018). Nearshore environments often sustain high zooplankton biomass, because the combination of abundant land-derived nutrients, shallow depths penetrated by sunlight and warmer temperatures accelerates phytoplankton growth, which, in turn, fuels zooplankton production. There is compelling evidence that frontal and plume zones formed in estuaries and deltas of many Arctic rivers can support dense populations of brackish-water zooplankton communities (Lischka et al 2001, Hirche et al 2003, Walkusz et al 2010), which appear to depend mainly on allochthonous phytoplankton brought by the riverine flux (Arashkevich et al 2010, Drits et al 2016). These zooplankton contribute substantially to biological production within the high physical gradient estuarine biotope (Flint et al 2010). The zooplankton biomass may then be used by larval and juvenile fish, thus serving as an important forage and/or nursery area for many ecologically and commercially important fish species (Pirozhnikov 1950) and those that contribute to local food security (Georgette and Shiedt, 2005; Raymond-Yakoubian, 2013).

The major goal of this project was to analyze and interpret data on seasonal and interannual changes in diversity, abundance and biomass of zooplankton from a variety of shallow lagoons within Cape Krusenstern National Monument and in the vicinity of Cape Thompson along the southeastern Chukchi Sea coast. The information will substantially increase our knowledge of diversity of aquatic biota and of environmental mechanisms which facilitate biological production in Alaskan coastal lagoons, and the success of species harvested by local communities for subsistence.

Methods

Samples were collected by Wildlife Conservation Society through the National Park Service's "Vital Sign" program and the National Fish and Wildlife Foundation's "Protecting Coastal Lagoons in the Southern Chukchi Sea: Project Chariot Revisited" project in summer 2017 and 2018. Eight intermittently open lagoons along the southeastern Chukchi Sea coast were targeted for the study (Figs. 1, 2). Three lagoons within Cape Krusenstern National Monument (Kotlik, Aukulak and Krusenstern) were sampled both twice each in 2017 and in 2018 to assess seasonal changes in environment, zooplankton community composition and population structures (Fig 1, Inset A). In

2018, the survey was extended to Cape Thompson area where an additional five lagoons (Kemegrak, Akoviknak, Mapsorak, Atosik, and Singoalik) were sampled once a year (Fig.1, Inset 2). The lagoons at Cape Thompson had been previously sampled during the late 1950s supporting a long-term comparison of community structure (Wilimovsky and Wolfe, 1966). Three to five station were sampled in each lagoon to account for spatial variability of zooplankton within each lagoon.

Environmental parameters (temperature, salinity, PH, and oxygen content) were measured with a YSI probe at 1-m depth. In 2017, zooplankton was sampled with a 0.3 m diameter 80 µm mesh Wisconsin plankton net. In 2018, a larger net was used comprised of a 0.5 m diameter 150 µm ring net that allowed us to match sampling technique applied in historical Cape Thompson studies (e.g. Johnson, 1961; Wilimovsky and Wolfe, 1966). Each net was equipped with a General Oceanics flowmeter mounted inside the net. The nets were towed under the surface to filter ~ 5-10 m^{-3} of water. All samples were preserved in 5% formalin for later processing.

Each mesozooplankton sample was sequentially split using a Folsom splitter until the smallest subsample contained 200-300 specimens of the most abundant taxa. All taxa in the smallest subsamples were identified, staged and counted. Each larger subsample was examined to identify, count and weigh the larger, less abundant taxa. Blotted wet mass for each taxa and stage were determined. Biomass estimates for small copepods were based on the number of individuals of each prey taxon in the sample and average mass of that prey type based on fresh samples collected as part of a separate study (Tibbles and Robards, 2018). Wet mass on other larger and soft-bodied taxa were measured and recorded for each sample. All animals in the samples were identified to the lowest taxonomic category possible.

Results and Discussion

Physical Environment

Cape Thompson study area (Table 2): Thermal conditions ranged among the lagoons from the warmest (~15ºC) at Kemegrak and Akoviknak to the coldest (~8ºC) at Mapsorak. All lagoons except for Singoalik were freshwater in nature (<2 PSU). The brackish (9.25 PSU) Singoalik apparently had a recent contact with the adjacent ocean. None of the lagoons showed any signs of hypoxia maintaining the dissolved oxygen content over 100%.

Cape Krusenstern National Monument (Table 1): Physical conditions were similar across the lagoons with the warmest (~16-17ºC) water in July. All lagoons remained fresh (<2 PSU) during 2017, while in 2018 Kotlik and Aukulak were brackish (>10 PSU), indicating greater (although intermittent) connectivity with the neighboring ocean. Dissolved oxygen values were higher in July and decreasing below saturation (~96-98%) by August in Kotlik and Aukulak. Krusenstern remained fully oxygenated throughout the season, probably because of its larger area responding to wind stress facilitated better mixing. In Kotlik and Aukulak, chlorophyll-a content was 1.5 times higher in August than in July, however the maximum chlorophyll-a values were consistently recorded in Krusenstern throughout the season. The observations indicate that seasonal primary production peak occurred in mid-summer, however, it is unclear from the current study how much of this primary production is attributable to freshwater inflow.

Zooplankton

We collected a total of 75 zooplankton samples, which were analyzed to determine taxonomic composition, population structure, abundance, and biomass. Zooplankton diversity in the studied lagoons was generally low, consisting mainly of brackish *Acartia hudsonica, Eurytemora* spp. and juvenile cyclopoid and harpacticoid copepodites.

Zooplankton communities in all lagoons were drastically different from that in the adjacent nearshore Chukchi Sea as evident from comparison with data collected with similar gear in August 2012 during the Arctic EIS survey (Pinchuk and Eisner 2017). At the most nearshore station where zooplankton was collected by this cruise (Fig. 10), samples were dominated by neritic larvaceans and meroplankton, followed by neritic copepods *Oithona similis* and *Pseudocalanus spp*. In general, Cape Thomson lagoons appeared more productive than Cape Krusenstern lagoons in the one time period where all lagoons were sampled – August 2018. These observations further corroborate the unique character of coastal lagoon biota warranting the need for future studies.

<u>Cape Thompson study area</u>

In Cape Thompson lagoons freshwater *Limnocalanus johanseni* and *Daphnia* spp. as well as Notostraca (*Triops* sp.), Anostraca and Diplostraca were present. *Eurytemora* species complex comprised five species: larger low-salinity *E. raboti* and *E. canadiensis*, and smaller *E. gracilicauda* and *E. composita*, and euryhaline *E. pacifica* and *E. herdmani*. The latter, a common species in brackish nearshore waters, was extremely rare in the lagoons, indicating autochtoneous character of lagoon fauna. However, low taxonomic diversity was compensated by high abundances of occurring taxa. The prevalence of only one or two taxa in each lagoon (which is a common feature of relatively small water bodies; O'Brien et al. 2004) underlines the importance of conservation of extensive areas of the Arctic coast to preserve ecosystem diversity under the rapidly changing environment.

Comparison of the 2018 data with historical data collected within the same lagoons at Cape Thompson in 1959 (from Johnson 1961, Table 2 – but see also Johnson, 1966) shows remarkable similarities in some lagoons (Fig. 8). Zooplankton composition in Singoalik in 1959 was also dominated by the brackish species which also occur in the coastal Bering and Chukchi nearshore waters. It appears that intermittent connection of Singoalik with the adjacent sea remained a key factor structuring the zooplankton community in the lagoon. In contrast, zooplankton in Atosik, Akoviknak and Kemegrak remained distinctly freshwater indicating long-term isolation from the marine environment. Interestingly, only Mapsorak zooplankton community changed from distinctly coastal marine (as evidenced by *A. longiremis*) in 1959 to entirely freshwater in 2018, perhaps indicating a change in local geomorphology preventing substantial advection of seawater into the lagoon. In general, the zooplankton communities in the lagoons showed remarkable resilience despite almost six decades having passed between collection events.

Zooplankton abundance and biomass varied among Cape Thompson lagoons (Table 4). Maximum abundance was recorded in Kemegrak and composed mainly of *Eurytemora* spp. copepodites, while maximum biomass values occurred in Atosik and were attributed to larger *Limnocalanus johanseni* and *Daphnia* spp. (Figs 3, 4).

Cape Krusenstern National Monument

Zooplankton quantitative distribution was extremely heterogeneous over the study area, reflecting strong environmental gradients over space and time. In Cape Krusenstern lagoons, while our abundances were 1-2 orders of magnitude higher in 2017 with copepod nauplii comprising the bulk of the catch (Table 3), this difference is entirely due to the finer mesh used in our zooplankton sampler in 2017 which captured small nauplii and earlier copepodites more effectively. Average zooplankton abundance in 2018 ranged between 28 - 2,443 individuals m^{-3}, and average zooplankton biomass ranged between 17.5–2,061 mg m^{-3}. Kotlik appeared to be less productive than Aukulak and Krusenstern during both years. Interestingly, Kotlik was the only lagoon where brackish *Acartia hudsonica* clearly dominated any other zooplankton taxa

Seasonal changes in zooplankton populations were studied in the Cape Krusenstern study area (Figs. 5, 6, 7). The brackish water calanoid copepod *Eurytemora* species complex was predominant in Aukulak in 2017 (Fig. 5). *E. raboti, E. canadiensis* and *E. gracilicauda* were identified among adult stages. Copepod nauplii were abundant in July, while in August they disappeared indicating one seasonal peak of copepod reproduction. *Eurytemora* spp. population structure in Aukulak Lagoon underwent substantial change over the month. Young early copepod development stages (C1-C2) copepodites dominated in July but almost entirely disappeared later in the season. In contrast, older C5 and adult C6 comprised the majority of the population in August indicating one seasonal spawning peak in early summer for *Eurytemora* spp. In contrast during 2018, brackish adult *Acartia hudsonica* contributed ~25% of total zooplankton abundance, probably responding to increased salinity. The proportion of young (C1-C3) *Eurytemora* spp. copepodites was lower than in July 2017, and adult *Eurytemora* spp. dominated the population. In August, *A. hudsonica* remained in the lagoon, but instead of adults the population consisted of young C1-C3 stages, indicating successful reproduction. Adult *Eurytemora* spp. disappeared from the lagoon in August 2018, and the population comprised young copepodites, indicating either later spawning or slower growth. Most of Eurytemora species found in Aukulak (and other lagoons) were stenohaline preferring low-salinity and fresh waters. The rise in salinity in 2018 may have impacted their seasonal growth and reproduction.

In contrast, zooplankton abundance in Kotlik Lagoon was dominated by copepod nauplii and euryhaline copepods *Acartia hudsonica* typically occurring at larger (>7) salinities (Fig. 6). Copepod nauplii were predominant in July, and they were still present in substantial numbers in August indicating prolonged reproduction. *Acartia hudsonica* population structure in Kotlik Lagoon did not substantially change over the month indicating continuous spawning during the warmth of summer. Under relatively warm temperatures and apparently abundant food observed in the lagoons, *A. hudsonica* finish their development in about 20-30 days, which allows for at least two generations during summer.

Finally, zooplankton in Krusenstern Lagoon did not show substantial seasonal differences, and it was dominated by copepod nauplii in July and August 2017 (50-75% of total abundance), followed by juvenile cyclopoids and harpacticoids (25%) and young *Eurytemora* spp. copepodites (Fig. 7). In 2018, contribution of cyclopoids and harpacticoids to the total zooplankton abundance decreased and *Eurytemora* spp. copepodites predominated.

Modifications for Continued Monitoring

In the future, we would maintain use of the larger 150-micron mesh net used in 2018 rather than the 80-micron net used in 2017. The smaller net is effective for quantitatively sampling nauplii and earlier copepodites, but the net misses larger or rarer species. The larger net still samples the youngest stages, but some pass through the mesh. However, while that presents some limitations on quantification of younger stages, that only affects questions about naupliar biology. For instance, if a project was investigating feeding of larval fish which consume copepod nauplii, a fine mesh net may be used in addition to the regular one to get estimates on specific naupliar densities.

Recommendations for Future Work

- Investigate the "seeding" of the lagoons in early spring, trying to answer the question of where is all the zooplankton coming from and why they are different across lagoons. A working hypothesis could be that in the lagoons which freeze up completely during winter are places where species with resting (dormant) eggs thrive, while the lagoons with ice free bottom water provide refugia for euryhaline species;
- Investigate the carbon balance in the lagoons, trying to find out the origin of carbon entering into the system, which portion is due to bacterial decomposition of higher plants remains (e.g. peat), or to local photosynthesis, or to riverine transport, and how zooplankton uses these pathways. For instance, mysids are probably an important vector transferring decomposed detritus into pelagic production cycle;
- Investigate secondary production in the lagoons trying to determine turnover rates and potential fate of synthesized organics, i.e. how much might be consumed by apex predators, and how much would be deposited in the sediments fueling benthic communities, and how do different zooplankton life strategies and traits affect these processes. Ultimately, this should give us an idea which lagoons are productive and which are not and why;
- Investigate utilization of zooplankton resource by fish predators studying their diets and comparing them with prey fields. This would match nicely with concurrent fishing efforts. This directly addresses the importance of lagoons to specific fishes including those important to Indigenous communities. This is also the most significant aspect of the Beaufort Sea lagoons studies and offers opportunities for cross-region comparison of different lagoon types. All the Beaufort lagoons have permanent connection to the ocean and the major theme of their studies is the interaction between the land and the sea and the lagoons in-between as mediators during a changing climate. The lagoons of the southern Chukchi Sea are practically isolated with short-term transgressions during storms presenting a need for creative thinking on mechanisms that are comparable or in contrast across regions.

Conclusions

- Arctic coastal lagoons support dense herbivorous calanoid copepod populations suggesting high levels of pelagic production inside the lagoons.
- Zooplankton composition, abundance and biomass vary between geomorphologically similar lagoons creating drastically different feeding environment for pelagic predators. However, the composition within lagoons can be remarkably consistent even across decades.
- The mechanisms facilitating these differences in zooplankton composition are not yet clear and require future studies.
- Based on the zooplankton findings, it is likely that these lagoons act as a portfolio of diverse rearing and feeding habitats for juvenile fishes to utilize. The high inter-lagoon variation in zooplankton composition, yet stable intra-lagoon composition over years undoubtedly shapes fish life history strategies and facilitates fish population bet-hedging to ensure successful recruitment and overall population health. Thus, these lagoons are likely integral to the population health of important subsistence fishes that inhabit them (e.g.s, whitefish and salmon species).
- Given the diverse (inter-lagoon) yet stable over years (intra-lagoon) nature of zooplankton composition, accelerating anthropogenic or climate change-driven effects in the region such as coastal erosion, permafrost thawing, or infrastructure development could upset the habitat conditions that drive zooplankton composition. This could potentially cause homogenization of zooplankton assemblages among lagoons and result in a lack of diverse prey options for subsistence fish species, thus decreasing fish population bet-hedging ability.

References

Antonio E.S., Kasai A., Ueno M., Kurikawa Y., Tsuchiya K., Toyohara H., Ishihi Y., Yokoyama H., Yamashita Y. 2010. Consumption of terrestrial organic matter by estuarine molluscs determined by analysis of their stable isotopes and cellulase activity. Estuarine, Coastal and Shelf Science 86: 401–407.

Arashkevich E.G., Flint M.V., Nikishina A.B., Pasternak A.F., Timonin A.G., Vasilieva J.V., Mosharov S.A., Soloviev K.A. 2010. The role of zooplankton in transformation of organic matter in the Ob estuary, on the shelf and in the deep regions of the Kara Sea. Oceanology 50: 780-792

Connelly T.L, McClelland J.W., Crump B.C., Kellogg C.T.E., Dunton K.H. 2015 Seasonal changes in quantity and composition of suspended particulate organic matter in lagoons of the Alaskan Beaufort Sea. Marine Ecology Progress Series 527: 31-45.

Craig P.C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: a review. Transactions of the American Fisheries Society 113:265–282.

Drits A.V., Pasternak A.F., Nikishina A.B., Semenova T. N., Sergeeva V. M., Polukhin A.A., Flint, M.V. 2016. The dominant copepods *Senecella siberica* and *Limnocalanus macrurus* in the Ob Estuary: ecology in a high-gradient environment. Polar Biology 39: 1527–1538

Dunton K.H., Weingartner T., Carmack E.C. 2006. The nearshore western Beaufort Sea ecosystem: circulation and importance of terrestrial carbon in arctic coastal food webs. Progress in Oceanography 71: 362–378.

Dunton K.H., Schonberg S.V., Cooper L.W. 2012 Food web structure of the Alaskan nearshore shelf and estuarine lagoons of the Beaufort Sea. Estuaries Coasts 35: 416−435.

George, J. C., L. M. Moulton, and M. Johnson. 2007. A field guide to the common fishes of the North Slope of Alaska. North Slope Borough, Department of Wildlife Management, Barrow, AK. 93 pp.

Georgette, S. and Shiedt, A., 2005. *Whitefish: traditional ecological knowledge and subsistence fishing in the Kotzebue Sound Region, Alaska* (No. 290). Alaska Department of Fish and Game, Division of Subsistence.

Hirche H.J., Fetzer I., Graeve M., Kattner G. 2003 *Limnocalanus macrurus* in the Kara Sea (Arctic Ocean): as opportunistic copepod as evident from distribution and lipid patterns. Polar Biology 26: 720-726.

Johnson, M.W., 1961. On zooplankton of some arctic coastal lagoons of northwestern Alaska, with description of a new species of Eurytemora.

Johnson, M.W., 1966. Zooplankton of some Arctic coastal lagoons. *Environment of the Cape Thompson region, Alaska. Oak Ridge, Tenn.(United States Atomic Energy Commission), 679*, p.793.

Johnson, S. W., J. F. Thedinga, A. D. Neff, and J. C. George 2007. Fish assemblages in nearshore waters of Chukchi and Beaufort Seas, Alaska. NOAA Fisheries. Viewed online 16 March 2012 at: ftp://ftp.afsc.noaa.gov/posters/pSWJohnson06_fish-assemblages.pdf

Lischka S., Knickmeier K., Hagen W. 2001. Mesozooplankton assemblages in the shallow Arctic Laptev Sea in summer 1993 and autumn 1995. Polar Biology 24: 186-199.

Logerwell, E., M. Busby, C. Carothers, S. Cotton, J. Duffy-Anderson, E. Farley, P. Goddard, R. Heintz, B. Holladay, J. Horne, S. Johnson, B. Lauth, L. Moulton, D. Neff, B. Norcross, S. Parker-Stetter, J. Seigle, and T. Sformo. 2015. Fish communities across a spectrum of habitats in the western Beaufort Sea and Chukchi Sea. Progress in Oceanography 136: 115–132.

O'Brien, W.J., Barfield, M., Bettez, N.D., Gettel, G.M., Hershey, A.E., McDonald, M.E., Miller, M.C., Mooers, H., Pastor, J., Richards, C., and Schuldt, J. 2004. Physical, chemical, and biotic impacts on arctic zooplankton communities and diversity. Limnology and Oceanography 49: 1250–1261.

Pinchuk A.I., Eisner L.B. 2017. Spatial heterogeneity in zooplankton summer distribution in the eastern Chukchi Sea in 2012–2013 as a result of large-scale interactions of water masses. Deep-Sea Research II 135: 27-39.

Pirozhnikov P.L. 1950. On the feeding of white fish in the estuarine regions. Zoologicheski Zhurnal 29: 140–146.

Raymond-Yakoubian, J., 2013. *When the Fish Come, We Go Fishing: Local ecological knowledge of Non-salmon fish used for subsistence in the Bering Strait Region*. Kawerak Incorporated.

Tibbles, M., Falke, J.A., Mahoney, A.R., Robards, M.D. and Seitz, A.C., 2018. An Interferometric Synthetic Aperture Radar (In SAR) Habitat Suitability Model to Identify Overwinter Conditions for Coregonine Whitefishes in Arctic Lagoons. Transactions of the American Fisheries Society 147(6): 1167-1178.

Tibbles, M., 2018. *The seasonal dynamics of coastal Arctic lagoons in Northwest Alaska* (Doctoral dissertation).

Tibbles, M. and Robards, M.D., 2018. Critical trophic links in southern Chukchi Sea lagoons. Food Webs 17: e00099.

Walkusz W., Pauli J.E., Kwamniewski S., Williams W.J., Wong S., Papst M.H. 2010. Distribution, diversity and biomass of summer zooplankton from the coastal Canadian Beaufort Sea. Polar Biology 33: 321-335.

Whiting, A., D. Griffith, S. Jewett, L. Clough, W. Ambrose, and J. Johnson. 2011. Combining Inupiaq and scientific knowledge: Ecology in northern Kotzebue Sound, Alaska. Alaska Sea Grant, University of Alaska Fairbanks, SG- ED-72, Fairbanks. 71 pp.

Wilimovsky N.J., Wolfe J.N. 1966. Environment of the Cape Thompson Region, Alaska. United States Atomic Energy Commission. Division of Technical Information.

Appendix: Supplemental Data Documents

MS ACCESS databases for 2017 and 2017 which include linked geographical physical and biological data available for analysis.

Poster presentation: Pinchuk A, Robards M, Smith B.2019. **Zooplankton production in Arctic coastal lagoons: preliminary results of biological monitoring in Cape Krusenstern National Monument**. AMSS-2019, Anchorage, Alaska.

Table 1. Physical environment in the Cape Krusenstern National Monument lagoons (KO – Kotlik, AU – Aukulak, KR – Krusenstern) in summer 2017-2018.

	July 2017			August 2017			July 2018			August 2018		
	KO	AU	KR	KO	AU	KR	KO	AU	KR	KO	AU	KR
Temperature, ºC	15.8	17.1	16.6	9.4	11.7	9.6	14.3	15.1	16.2	11.2	14.3	13.6
Salinity, ppt	0.44	0.42	0.22	1.2	0.36	0.21	21.5	12.1	3.7	17.5	12.5	4.29
DO (%)	106.8	103.8	114.5	98.1	95.8	106.2	106.6	99.1	114.7	96.9	103.2	101.7
PH	5.7	5.95	7.35	10.3	8.69	10.36	8.51	7.9	9.22	8.17	8.11	9.04
Chlorophyll, mg/l	1.95	4.59	13.08	2.91	6.87	16.84						

Table 2. Physical properties of Cape Thompson lagoons in August 2018.

	Kemegrak	Akoviknak	Mapsorak	Atosik	Singoalik
Temperature, ºC	15.73	15.71	8.77	9.63	10.66
Salinity, ppt	1.21	1.89	0.73	1.62	9.25
DO (%)	104	101	101	105	104
PH	8.8	8.3	7.8	7.8	8.2

Table 3. Zooplankton abundance and biomass in Cape Krusenstern National Monument lagoons in summer 2017-2018 (KO – Kotlik, AU – Aukulak, KR – Krusenstern)

	July 2017			August 2017			July 2018			August 2018		
	KO	AU	KR	KO	AU	KR	KO	AU	KR	KO	AU	KR
Abundance, ind m^{-3}	51,507	150,032	6,694	29,833	44,802	393,055	439	2,160	2,443	2,753	286	1,66
Biomass, mg m^{-3}	649	1,356	477	684	1,771	2,061	17.5	132	456	37	91.7	42.7

Table 4. Zooplankton abundance and biomass in Cape Thompson study area lagoons in August 2018.

	Kemegrak	Akoviknak	Mapsorak	Atosik	Singoalik
Abundance, ind m^{-3}	72,444	17,838	2,822	7,372	3,523
Biomass, mg m^{-3}	1,013	694	934	2,196	28.6

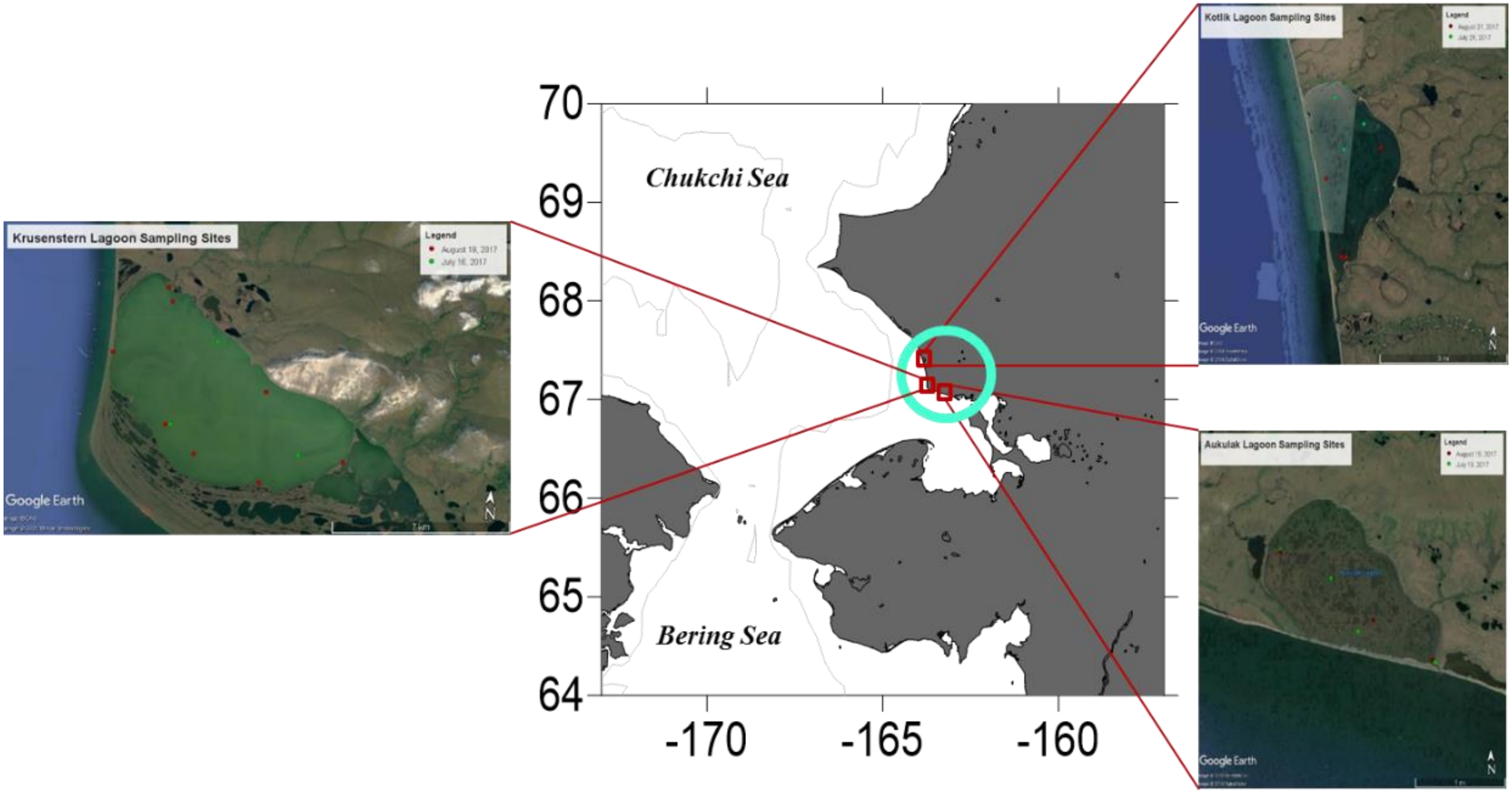

Figure 1. Sampling locations in Cape Krusenstern National Monument study area.

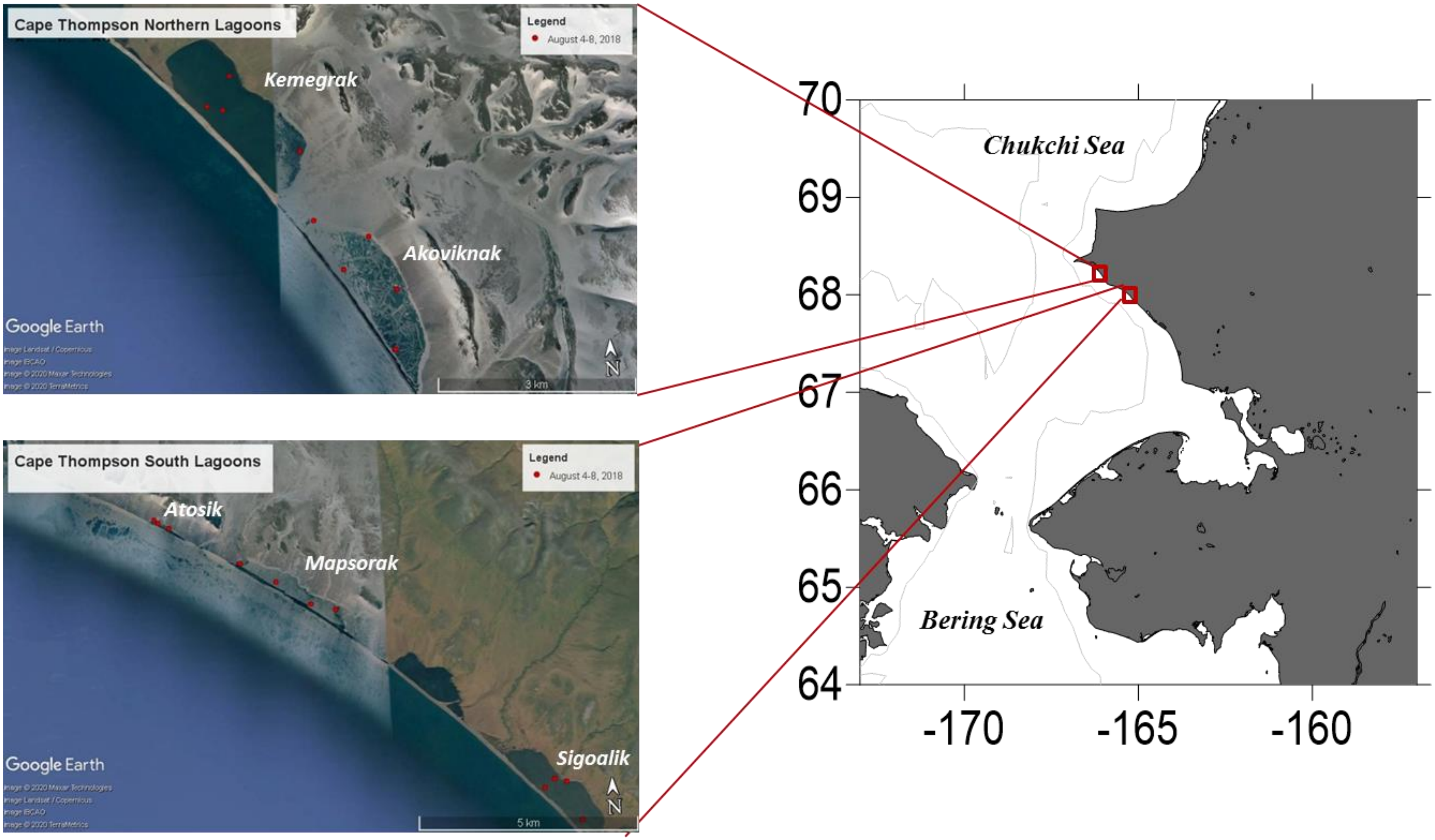

Figure 2. Sampling locations in Cape Thompson study area.

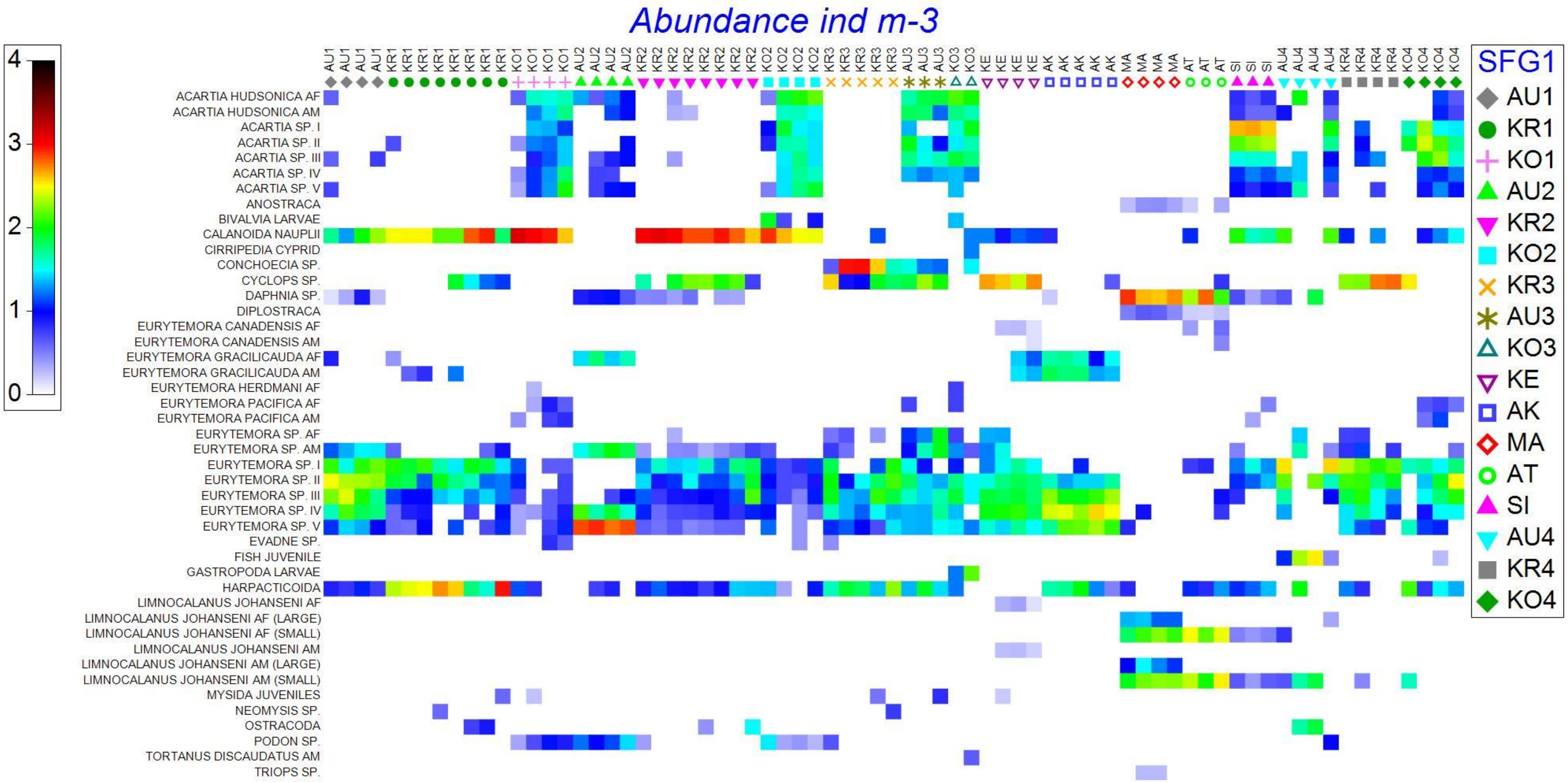

Figure 3. Transformed (^0.25) zooplankton abundance (ind. m^{-3}) in Cape Krusenstern and Cape Thompson lagoons in summer 2017-2018 grouped by lagoon and sampling month (AU1- Aukulak July 2017, KR1 – Krusenstern July 2017, KO1 – Kotlik July 2017, AU2 – Aukulak August 2017, KR2 – Krusenstern August 2017, KO2 – Kotlik August 2017, AU3 – Aukulak July 2018, KR3 – Krusenstern July 2018, KO3 – Kotlik July 2018, AU4 – Aukulak August 2018, KR4 – Krusenstern August 2018, KO4 – Kotlik August 2018, KE – Kemegrak, AK – Akoviknak, MA – Mapsorak, AT – Atosik, SI – Singoalik)

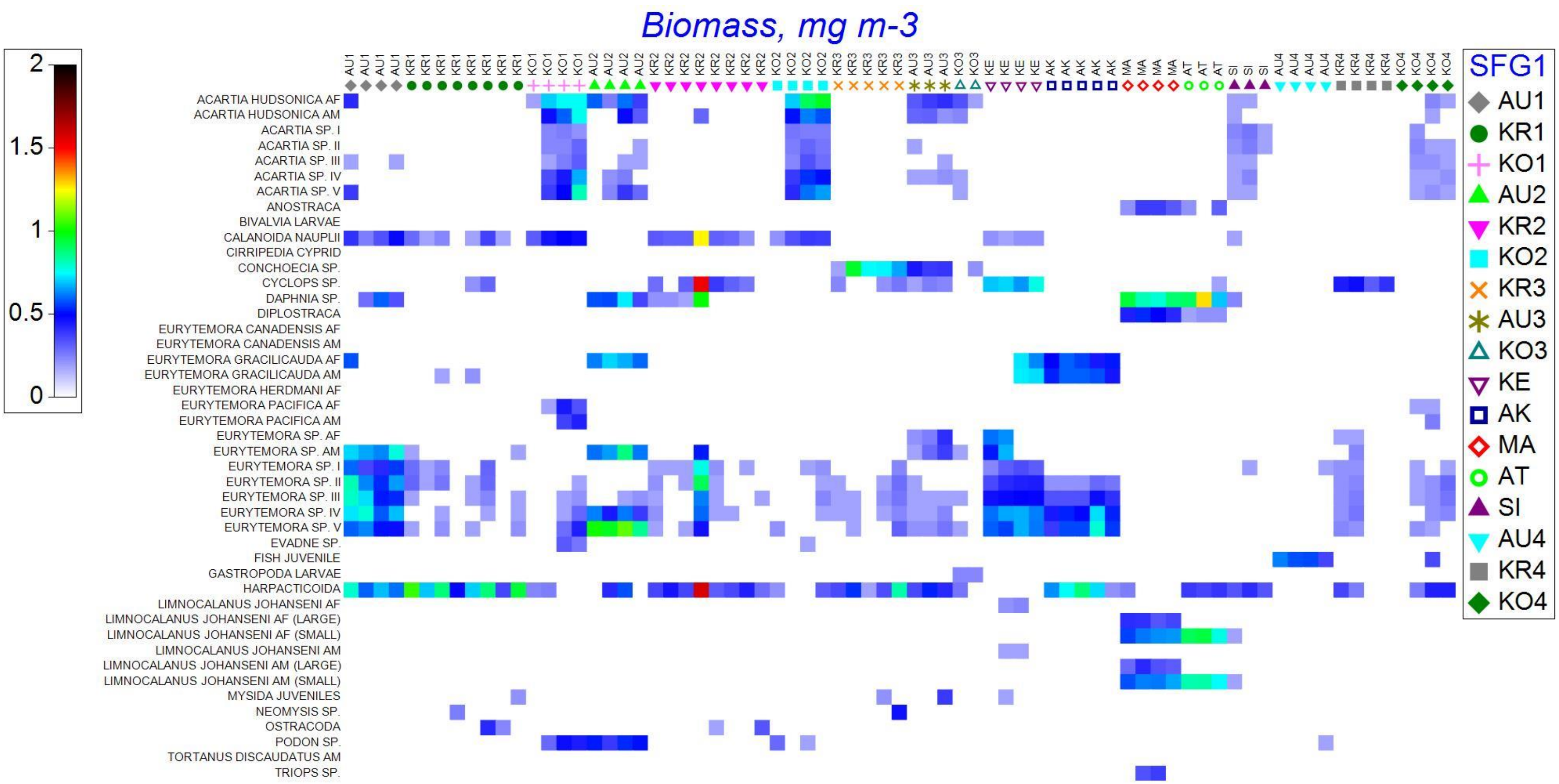

Figure 4. Transformed (^0.25) zooplankton biomass (g m^{-3}) in Cape Krusenstern and Cape Thompson lagoons in summer 2017-2018 grouped by lagoon and sampling month (AU1- Aukulak July 2017, KR1 – Krusenstern July 2017, KO1 – Kotlik July 2017, AU2 – Aukulak August 2017, KR2 – Krusenstern August 2017, KO2 – Kotlik August 2017, AU3 – Aukulak July 2018, KR3 – Krusenstern July 2018, KO3 – Kotlik July 2018, AU4 – Aukulak August 2018, KR4 – Krusenstern August 2018, KO4 – Kotlik August 2018, KE – Kemegrak, AK – Akoviknak, MA – Mapsorak, AT – Atosik, SI – Singoalik).

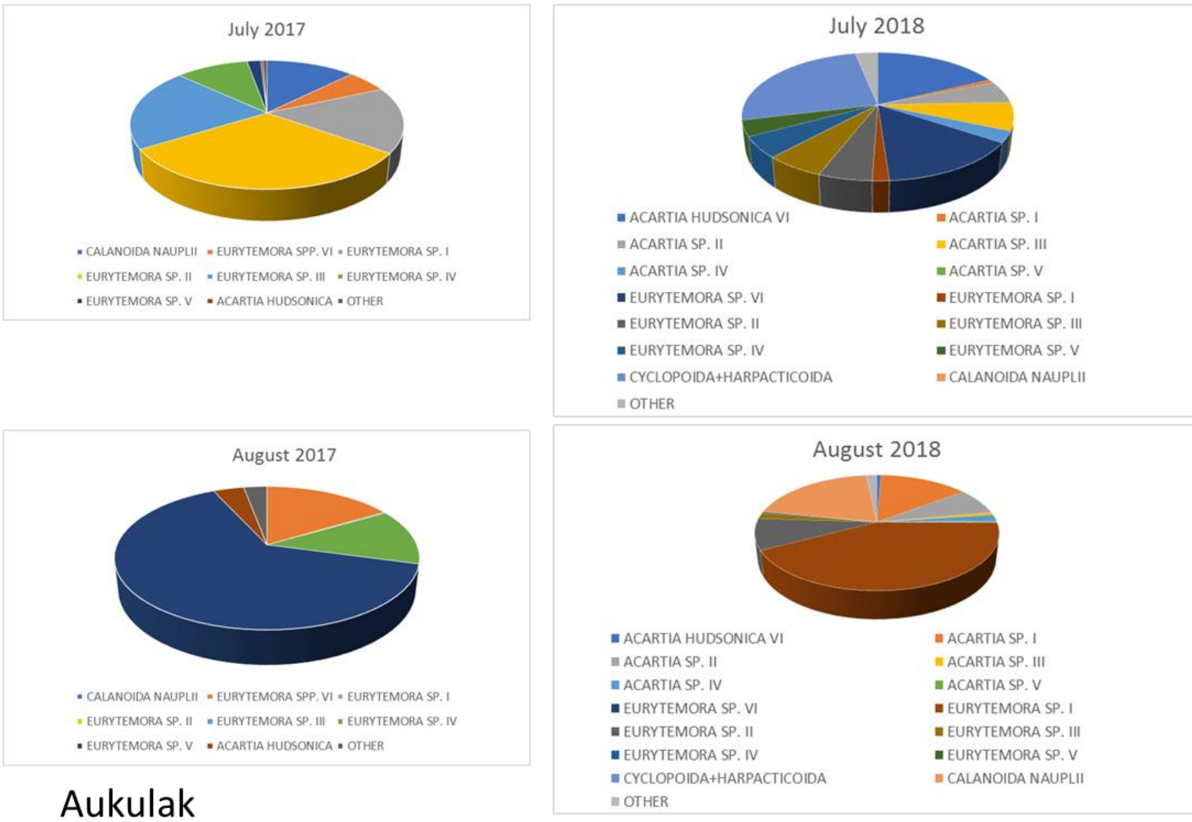

Figure 5. Seasonal changes in zooplankton abundance population structures in Aukulak Lagoon.

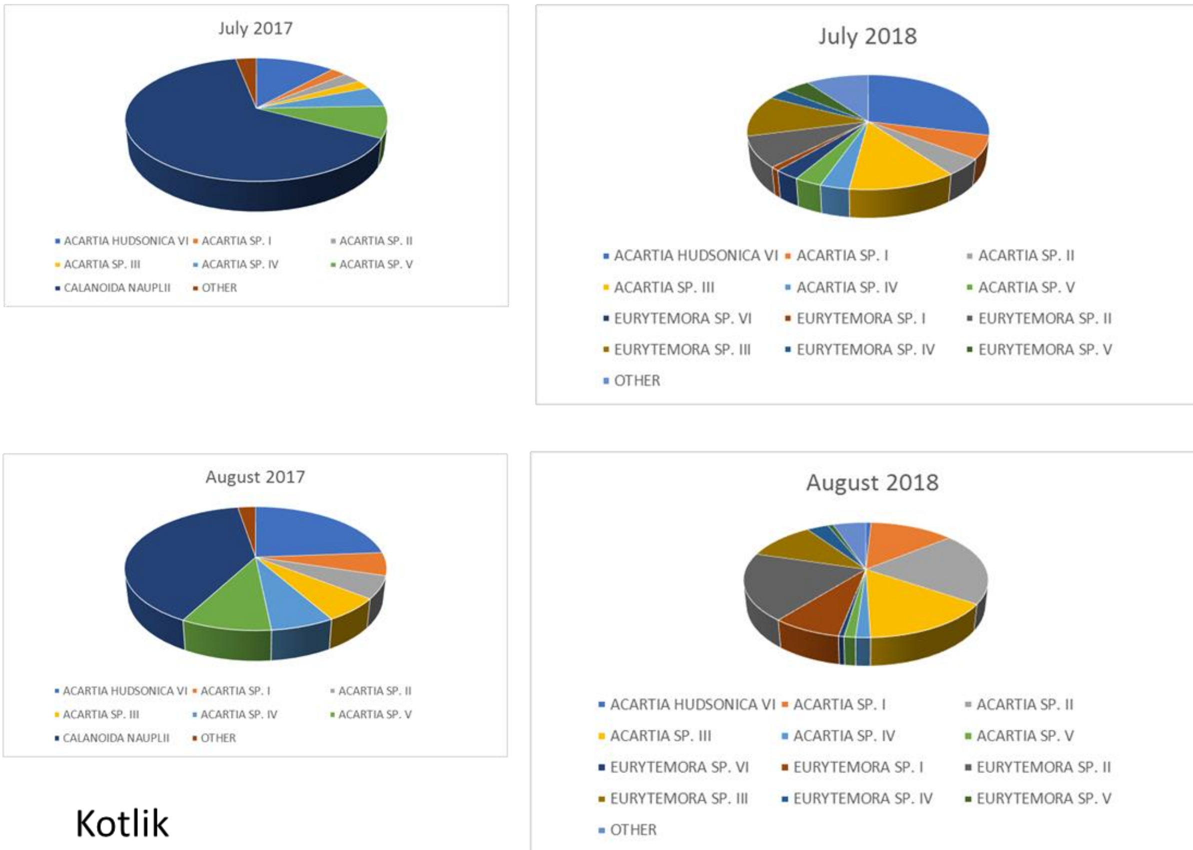

Figure 6. Seasonal changes in zooplankton abundance population structures in Kotlik Lagoon.

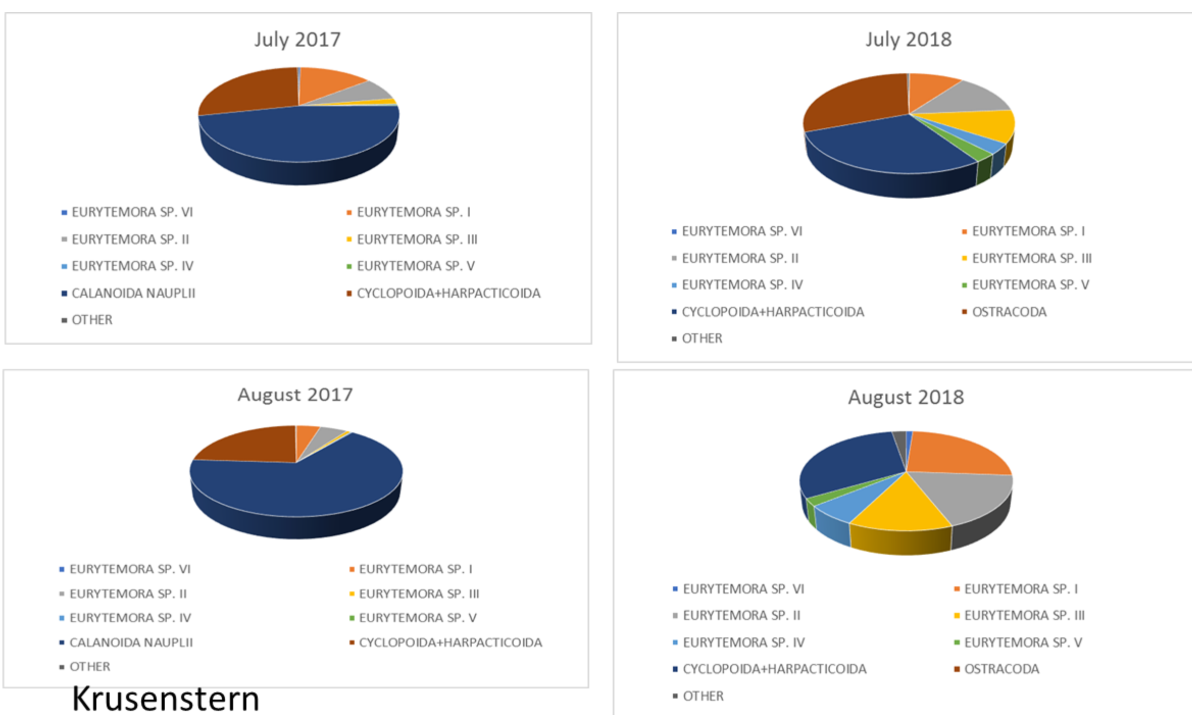

Figure 7. Seasonal changes in zooplankton abundance population structures in Krusenstern Lagoon.

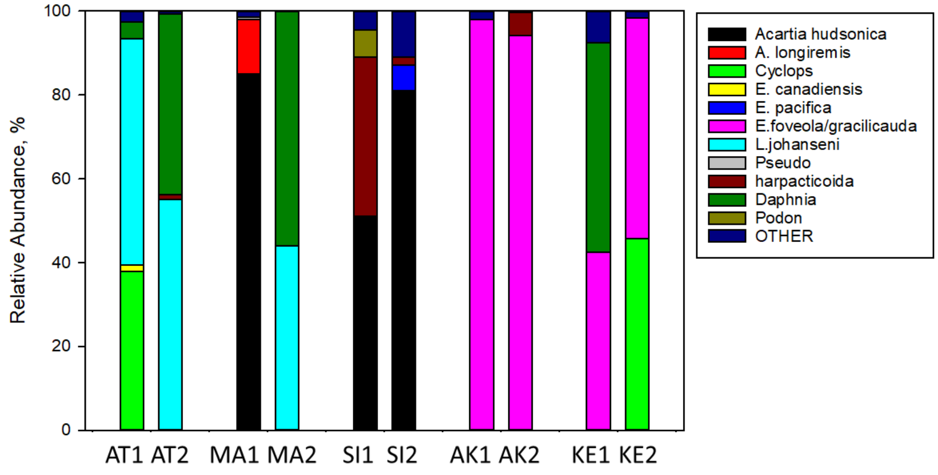

Figure 8. Community composition in Cape Thompson lagoons in August of 1959 (1) and 2018 (2). KE – Kemegrak, AK – Akoviknak, MA – Mapsorak, AT – Atosik, SI – Singoalik.

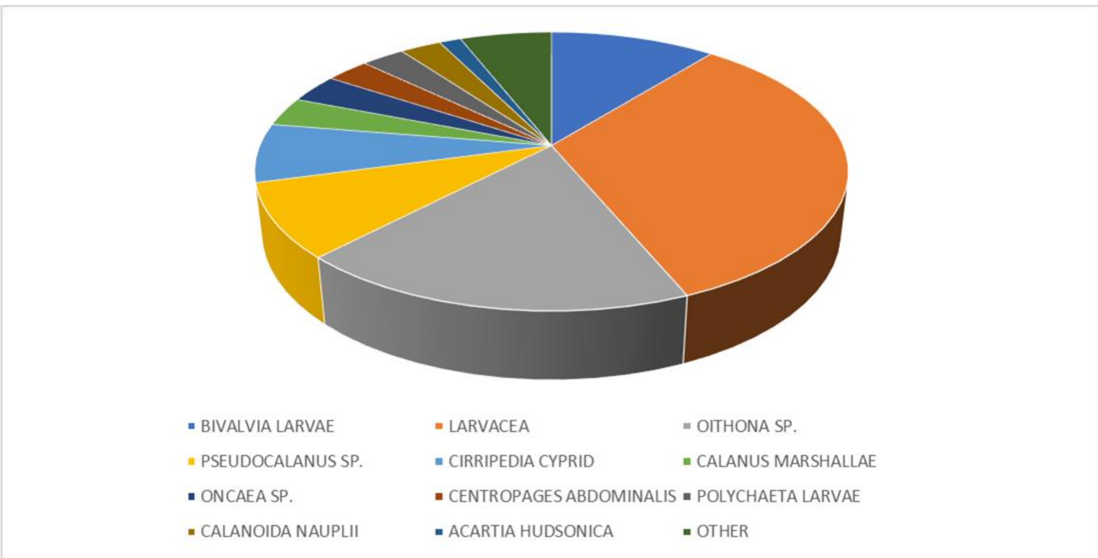

Figure 9. Zooplankton community composition in the southern Chukchi Sea nearshore area in August 2012.

Figure 10: Location of August 2012 sampling locations during the Arctic EIS survey (Pinchuk and Eisner 2017).