Seabirds as indicators of forage fish stocks and marine ecosystems in the eastern Aleutian Islands

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Abstract

Forage fish play a vital role in marine ecosystems because they funnel biomass and energy from lower trophic levels to higher marine vertebrates, including commercial groundfish, seabirds and marine mammals. Any study of forage fish therefore benefits from the investigation of factors influencing their populations from the bottom up (e.g. oceanographic conditions and primary production), and the status of predators that influence them from the top down. Some of our information about forage fish in Alaska comes from directed study, but much is inferred from commercial or research fish surveys that were not designed to sample forage species. An alternative avenue of investigation is to use seabirds as samplers of regional food webs. Seabirds are conspicuous, highly mobile forage fish consumers that go to great distances (100+ km) and depths (≤200 m) to locate ephemeral prey. Data on seabird dietary habits can therefore provide a valuable complement to traditional fisheries sampling. In particular, the Tufted Puffin (*Fratercula cirrhata*) is a piscivore with a broad diet, and appears to consume the most abundant and available prey within a substantial radius (50+ km) around their breeding colonies. They feed their chicks meals comprised of numerous whole prey items, which are then easily identified and counted. This allows us to characterize forage fish community composition in waters surrounding colonies.

In this preliminary study, we collected data on the diet of Tufted Puffin chicks at 10 islands from the mid to eastern Aleutian Islands, Alaska, during August 13-22, 2012. In addition, we measured a sample of puffin chicks at each colony to obtain an index of their body condition, which integrates the seasonal success of adults in finding food and raising young. When time and logistic constraints permitted, we also conducted at-sea surveys to measure seabird abundance and distribution, hydroacoustic surveys as a proxy for forage fish biomass, and oceanographic sampling to measure related environmental variables (temperature and salinity). We collected 3,641 individuals of 31 species of forage fish from over 2400 puffin burrows and measured over 160 chicks. Walleye pollock *(Theragra chalcogramma)* dominated the prey community, representing 76% of individual prey items and 67% of total biomass. This represents a major transition in the forage community from one that has been dominated by other species (e.g., sand lance, capelin) during most of the 2000's, according to a 25-year time series of puffin diet composition at a reference site (Aiktak Island) in the eastern Aleutians. With limited personnel and time for work at sea, we also completed nearly 530 km of at-sea marine bird surveys, and collected ancillary data on fish abundance and the marine environment during those surveys. Preliminary analysis suggests that sites with cool, low salinity waters supported higher forage biomass and puffin densities at sea, larger prey loads for delivery to chicks, and better body condition of puffin chicks.


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Introduction

Forage fish are a unique category of fishes and zooplankton defined by their key ecological role in marine ecosystems. Generally speaking, these relatively small fish and moderately large zooplankton (such as krill) are of exceptional trophic value due to their high abundance, tendency to form dense aggregations, and nutritional content (often high in fat and protein). Forage fish can play a disproportionate role in the transfer of energy and carbon through marine food webs from primary producers to secondary consumers and top predators. Forage fish often constitute a large fraction of the diet of upper trophic level (UTL) species such as marine mammals, seabirds, and large predatory fish, and are therefore central to predator-prey relationships (e.g., functional responses, Cury et al. 2011) and population dynamics (Hunsicker et al. 2011). Hence, understanding the spatio-temporal dynamics of forage fish is an important key to understanding and forecasting the ecological status and health of marine ecosystems, as well as assessing impacts of human factors such as fishing and climate change. This is increasingly a prescribed mandate for fisheries management (Zador 2011) and research (NPRB 2005) organizations.

The distribution and abundance of small, schooling forage fish in Alaska is known from some directed small-scale studies that have employed traditional methods of capture (e.g., mid-water trawl, beach seine) and/or hydroacoustic surveys (e.g., Sigler et al. 2004, Abookire and Piatt 2005) but is mostly inferred from incidental catches in large-scale/large-mesh trawls that were not designed (by gear or location) to sample forage species (M. Martin, p. 147-148 in: Zador 2011). In contrast, seabirds are conspicuous, highly mobile samplers of forage fish. They may target schools at great distances from their colonies, dive to great depths to capture them, and most employ information exchange to locate ephemeral prey patches with great efficiency. Thus, data on seabird dietary habits can provide a valuable complement to traditional fisheries sampling and provide quantitative information on abundance, distribution, temporal variability, condition, and community structure of local prey stocks (e.g., Hatch and Sanger 1992, Litzow et al. 2000, Davorn and Montevecchi 2003). In turn, the availability and quality of prey resources is a central factor influencing marine bird populations in Alaska (Boldt 2004), and forage fish sustain more than 10 million breeding seabirds in the Gulf of Alaska and Bering Sea/Aleutian Island region of Alaska alone (Byrd et al. 2005).

At colonies, seabirds gather en masse annually to reproduce, so it is often possible to monitor large numbers to estimate parameters of their biology or behavior such as their diet, timing of breeding (phenology), breeding success, chick growth, and population status. Changes in many of these variables have been correlated with changes in food supply and/or with climate indices, presumably via indirect effects of climate on food supplies (e.g., Sydeman et al. 2001, Gjerdrum et al. 2003, Fredericksen et al. 2005, Reid et al. 2005). Moreover, they show strong responses to variation in environmental variables such as temperature and salinity, making it possible to test related hypotheses.

In this project we focused on three parameters of seabird ecology as indicators of the health of forage fish communities in Alaska: chick diet composition and growth at colonies, and the proximal density of foraging adults at-sea. These parameters were chosen because in Alaska and elsewhere in the world they show strong connections with food resources in the environment, a quality that is desirable for use as indicators (Durant et al. 2009). Tufted Puffins (*Fratercula cirrhata*) are an ideal study subject because they are colonial piscivores with broad diets that appear to consume the most abundant and available prey near colonies (Piatt and Kitaysky 2002). They also feed their chicks whole food items, which are easily identified (Piatt and Kitaysky 2002). In addition to studying forage fish through seabird parameters, we aim to estimate marine biomass and characterize the biophysical attributes of pelagic habitats within the study areas, and relate forage species and their predators to these habitat characteristics.

In this annual progress report we present selected findings from our survey of seabirds as indicators in the Aleutian Archipelago. We used the Alaska Maritime National Wildlife Refuge vessel R/V *Tiĝlax̂* to visit ten different seabird colonies in the eastern Aleutian Islands and we conducted sampling of the diet and growth of Tufted Puffin chicks at each colony. Although we did not have adequate personnel to mount a large scale study to characterize the marine environment, we were able to opportunistically conduct marine bird surveys, hydroacoustic surveys, and thermosalinograph sampling while en route between colonies, and on systematic transects around colonies to varying degrees.

Methods

Study Area

Our study area covers the western Gulf of Alaska, from the central to the eastern Aleutian Islands, Alaska, USA (Fig. 1). The Aleutian Archipelago is formed by a volcanic mountain range that spans nearly 2000 km from the Alaska Peninsula to the Kamchatka Peninsula. There is a general northward flow of waters from the Gulf of Alaska or North Pacific into the Bering Sea through several major passes between the islands. These types of topographic features are associated with tidal mixing, and can influence local nutrients and salinity (Ladd et al. 2005). Recent studies have shown that abrupt changes in oceanographic conditions, zooplankton and benthic fish community composition occur at Samalga Pass in the eastern Aleutian Islands, which has a major influence on patterns of predator abundance (Hunt & Stabeno 2005). Additionally, productivity declines as you move westward along the Aleutian Archipelago as surface water nutrients become depleted (Hunt & Stabeno 2005).

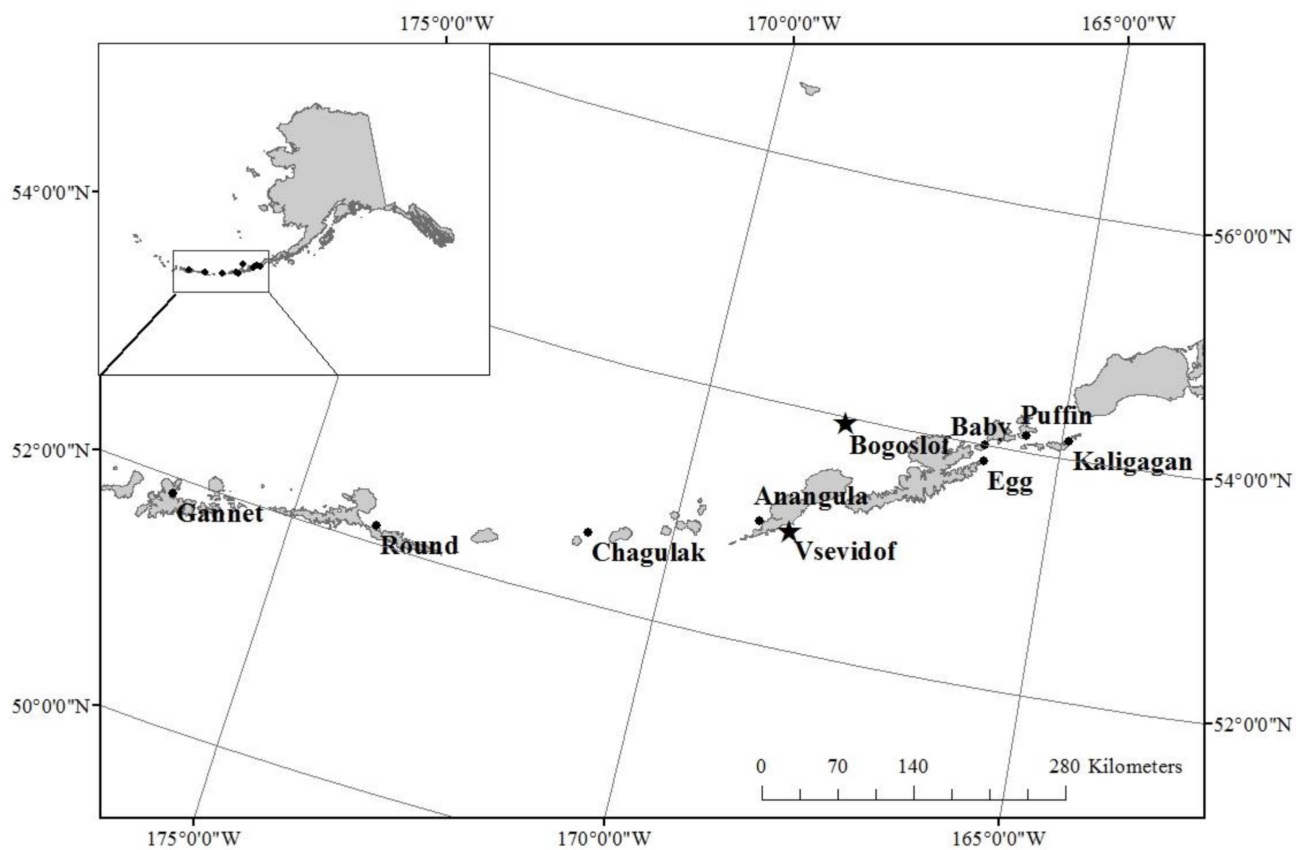

Figure 1. Study area for biological and oceanographic sampling from the R/V $Ti\hat{g}la\hat{x}$ in the central and eastern Aleutian Islands, Alaska, USA, August 13-22, 2012.

Data Collection and Analyses

We focused our sampling of forage fish, seabirds, and oceanographic conditions near Tufted Puffin colonies. We conducted surveys from aboard the R/V *Tiĝlax̂* August 13-22, 2012, spending a day sampling at each of ten islands (Table 1, Fig. 1). We collected data on: 1) diet and growth of Tufted Puffin chicks, 2) abundance of marine birds at sea, 3) hydro-acoustic fish biomass, and, 4) sea surface temperature and salinity. In general, our schedule was designed to maximize visitation to as many colonies as possible, spaced out amongst the entire study area. We typically sampled each colony from daybreak until 1700-1800 hours, at which point we got underway for the next colony. While en route to the next site we processed prey samples in the lab and conducted bird surveys until nightfall. There are many puffin colonies scattered throughout this region, and the decision about which colonies to sample was based largely on logistic constraints (weather, suitable anchorages, accessibility of colonies, safe landing conditions, potential for wildlife disturbances, etc.) and biological considerations (colony size and burrow density, presence of historical data, etc.). At-sea survey work was constrained by logistics (weather, coastal geography, time required to get to next colony) and availability of personnel. With limited staff, all biologists initially went ashore to collect diet and growth data, and two personnel later returned to the vessel for systematic surveys around the colonies until the vessel headed to the next colony. In addition to a general overview of our preliminary results, and because we have yet to fully analyze all datasets, we focused on a comparison of Vsevidof and Bogoslof islands for this progress report. We chose to compare these islands because 1) we were able to conduct fairly complete spatial sampling around both islands, and 2) the islands are relatively close to each other, but are quite different ecologically, thus providing an informative contrast. Vsevidof Island is in the North Pacific in the western Gulf of Alaska, whereas Bogoslof Island is in the Bering Sea, and they are influenced by different currents, with different oceanographic properties (Hunt & Stabeno 2005). Additionally, Vsevidof Island is on a 200 m continental shelf, whereas Bogoslof is a volcanic pinnacle (Hunt & Stabeno 2005).

Diet and growth of Tufted Puffin chicks

Methods for the collection of puffin chick meals are described in detail by Hatch and Sanger (1992). In brief, we placed small wire-mesh screens over the entrances of puffin burrows so that adults returning with food for chicks could not enter their burrows, and subsequently dropped the meal at the burrow entrance. Some samples were also obtained from the ground where they had been dropped by startled or flying puffins. We generally placed screens at several hundred burrow entrances at each island starting around 0900-0930 hours (it usually required about 1-2 hours to travel to shore, land, and access suitable puffin breeding habitat). On the vessel, samples were measured and identified to the lowest possible taxon. Total lengths of individual prey were measured to the nearest mm and prey was weighed to the nearest 0.1 g. We did not weigh every prey item; if a prey item was whole and was of a common species and size class we occasionally measured only its total length. For those items we assigned an estimated mass: the average mass of species of that length from that island. If there was not a prey item with those specifications we used the average mass for that length from all islands.

In addition to collecting chick meals, puffin chicks were removed from burrows to measure wing chord lengths (stretched, mm), weights (g), culmen (mm), and tarsus (mm) lengths at nine different colonies (Table 1). Because feather growth rate is a relatively fixed function of chick age (Wehle 1980), average wing lengths obtained from brief visits to colonies can be used to assess breeding phenology (Hatch and Sanger 1992). We calculated an index of chick condition by dividing chick mass (g) by wing chord lengths (mm).

At-sea marine bird surveys

In order to evaluate marine bird abundance and distribution in our study area we conducted surveys for seabirds on the R/V $Ti\hat{g}la\hat{x}$ using standard protocols (Gould and Forsell 1989). We censused seabirds in a 300 m-wide strip on the side (left or right) of the ship's center line with the best visibility, and 300 m in front of the vessel. The vessel traveled at a consistent speed of about 7–10 knots whenever possible along transects, which included spokes extending approximately 5 km from the islands (Fig. 2). One observer and one recorder identified and counted birds along transects, and sightings were recorded using a computer-based system (dLog, R. G. Ford Consulting, Portland, Oregon) which assigned GPS positions in real time. The observer counted the number and noted the species of birds on the water continuously, and conducted instantaneous counts of flying birds every 300 m on average, or 60 seconds, adjusting the count time according to vessel speed. Both counts (on the water and flying) were combined to provide the total numbers of birds per transect with which to calculate densities (number of birds/km^2). For details of methods, assumptions, and sources of data, see Gould et al. (1982) and Gould and Forsell (1989).

Hydroacoustic sampling

We recorded acoustic backscatter continuously using a hull-mounted Simrad®1 EK500 split beam echosounder (38 and 120 kHz, power 2000 W, ping rate 1 sec-1, transmitted pulse length 1.00 ms). Hydroacoustic data were georeferenced going east from Anangula Island (Table 1). Hydroacoustic data were integrated using SonarData Echoview® software version 2.10.29. Although both the 38 and 120 kHz data were archived, only the 120 kHz data were processed at this time due to the large quantity of data collected during transits. The two frequencies are commonly used in fisheries research; fish with air bladders are detected well with the 38 kHz frequency, and zooplankton and fish without air bladders are detected using the 120 kHz frequency (Simmonds and Maclennan 2005). A minimum threshold for integration was set at -80 db. Sound speed and absorption coefficients were determined from mean temperature and salinity collected from the thermosalinograph. Surface noise (in the upper 5-6 m, depending on conditions) and the bottom signal, determined by visually examining the echograms, were excluded. The integration output for acoustic backscatter was expressed as nautical area scattering coefficient (NASC [m^2/nm^2]), which was a proxy for biomass.

Thermosalinograph sampling

We measured sea surface temperature and salinity using the ship's hull-mounted thermosalinograph (SeaBird® SBE 21). The speed of the vessel during transit was approximately 10 kt. We collected thermosalinograph data continuously during transit starting from Anangula Island (Table 1).

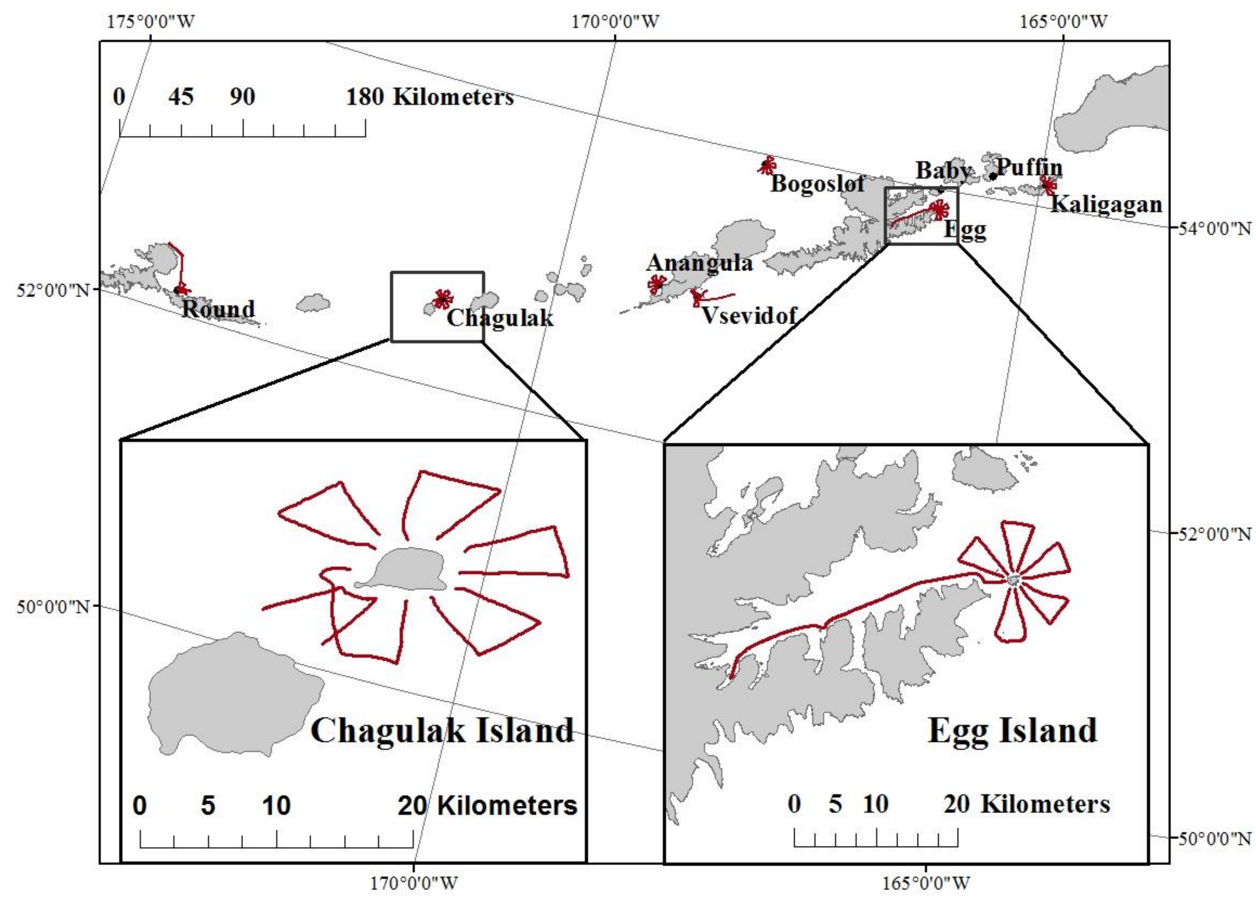

Figure 2. At-sea marine bird transects from the R/V $Ti\hat{g}la\hat{x}$ from the central to eastern Aleutian Islands, Alaska, USA, August 14-21, 2012. We have enlarged two of the sampling islands for which we were able to complete our sampling design to show the design in detail.

Table 1. Biological and oceanographic sampling from the R/V $Ti\hat{g}la\hat{x}$ from the central to eastern Aleutian Islands, Alaska, USA, August 13-22, 2012.

Island	**Latitude**	**Longitude**	**Screens Set**	**Puffin meals collected**	**Prey items**	**Meals/ screen**	**Puffin chicks measured**	**Seabird survey transects (spokes only)**			**Hydro-acoustic transects**	**Thermo-salinograph transects**
								Length (km)	Marine bird density (birds/km^2[SE])	Area (km^2)		
Gannet	51.8673	-176.6091	1	1	4		-	-	-	-	No	No
Round	52.1438	-173.8947	211	8	21	0.04	15	30.9	18.49 (1.15)	9.36	Yes (not geo-referenced)	Yes (not geo-referenced)
Chagulak	52.5722	-171.1367	271	35	420	0.13	25	70.4	43.37 (17.31)	21.21	Yes (not geo-referenced)	Yes (not geo-referenced)
Anangula	53.0078	-168.9028	158	40	368	0.25	14	61.5	19.81 (3.44)	18.53	Yes	Yes
Vsevidof	52.9817	-168.4761	339	86	793	0.25	16	27.3	30.07 (8.21)	8.28	Yes	Yes
Bogoslof	53.9325	-168.0366	395	78	654	0.20	29	58.7	30.47 (2.96)	16.81	Yes	Yes
Baby	53.9900	-166.0614	250	41	281	0.16	12	-	-	-	Yes	Yes
Egg	53.8642	-166.0444	299	42	332	0.14	19	80.6	20.22 (3.39)	24.28	Yes	Yes
Puffin	54.1397	-165.5222	275	53	441	0.19	17	-	-	-	Yes	Yes
Kaligagan	54.1453	-164.9128	330	55	327	0.17	14	59.8	38.56 (6.09)	18.03	Yes	Yes
Sum			**2459**	**439**	**3641**		**161**	**389.2**		**116.5**		

Preliminary Results

We collected data from 10 islands between Adak and just east of Dutch Harbor August 13-22, 2012 (Table 1, Fig. 1). We screened >2400 puffin burrows and collected 439 chick meals composed of 3,641 individuals and at least 31 forage fish species. Gadids (which were primarily walleye pollock) dominated the prey, representing nearly 70% of the total biomass (Fig. 3). The next most abundant prey groups in terms of biomass were cephalopods, Atka mackerel, prowfish, and Pacific sand lance (Fig. 3). There was a general increase in the percentage of the diet that was made up of gadids moving from west to east, with more gadids at the more productive islands (Fig. 4). Considering our “contrast islands” (see Methods), more of the prey biomass at Vsevidof was comprised of gadids compared to Bogoslof, while puffins delivered greater quantities of cephalopods at Bogoslof than anywhere else (Fig. 4). The greatest mean meal masses were found on Anangula Island, followed by Vsevidof; meal masses were lower at Bogoslof Island (Fig. 5).

We measured over 160 Tufted Puffin chicks, and found the longest mean wing length at Bogoslof Island, and the heaviest mean mass at Baby Island (Fig. 6). Overall, chicks were larger in the east than the west, indicating that nesting phenology was more advanced in the east than the west (Fig. 6). Puffin chicks on Bogoslof Island had longer wings than chicks on Vsevidof, but the mean mass of chicks was greater on Vsevidof than on Bogoslof (Fig. 6). There was a positive correlation between our index of chick condition (mass/wing length) and the size of the primary prey, walleye pollock. In other words, the larger the size of prey delivered, the better the chick’s condition, irrespective of the size (age) of the chick (Fig. 7). Once again, the “contrast colonies” provide a good example: Chicks on Vsevidof Island were fed larger walleye pollock and were in much better condition than chicks on Bogoslof Island (Fig. 7).

We conducted nearly 530 km of at-sea marine bird surveys, including over 380 km of systematic transects, and observed an average density of 29 marine birds/km^2 near colonies. We observed the greatest density of marine birds around Chagulak Island (Fig. 8). The density of all marine birds near Vsevidof and Bogoslof islands were similar, but the density of Tufted Puffins near Vsevidof was much greater than near Bogoslof (Fig. 8).

Hydroacoustic and oceanographic data were collected throughout our cruise track (Table 1). Bogoslof Island had comparatively lower hydroacoustic backscatter (NASC values) than Vsevidof Island (Fig. 9), and biomass estimates peaked at a shallower depth near Bogoslof than Vsevidof, even though water depth was much greater at Bogoslof (Figs. 10 and 11). Temperature and salinity values varied spatially across our sampling area (Figs. 12 and 13). Temperatures ranged from 6.17-13.97ºC (Fig. 12) and salinity ranged from 21.80-34.63 PPT (Fig. 13). Sea surface temperatures were cooler, and sea surface salinities were lower at Vsevidof than Bogoslof Island (Table 2, Figs. 12 and 13).

Summary

Walleye pollock were the dominant food source for Tufted Puffin chicks across our study area, and their importance in the diet of Tufted Puffin chicks appeared to increase from west to east, along with a known gradient in production (Hunt & Stabeno 2005). We observed variation in the prey composition across sample sites, and as much as a 2-fold difference in the mass of food delivered to chicks among islands. Chicks were generally more advanced in phenology in the east. The condition of chicks appears to be related to the quality of their prey, in this case the size of pollock. The composition of marine bird communities at sea varied across sites, but Tufted Puffins were the dominant species at most sites and overall. We also observed differences among sites in prey abundance and availability, and in sea surface temperature and salinity.

Our comparison of Bogoslof and Vsevidof islands provides some insight into what we hope to gain from a multi-colony and multi-disciplinary approach to food-web studies. In summary (Table 2), our results indicate that Tufted Puffin adults delivered larger meals to chicks on Vsevidof Island than Bogoslof, and the mean length of their primary prey, walleye pollock, was greater on Vsevidof than Bogoslof. The apparent result of that disparity in rates of provisioning was that the average condition of chicks was greater on Vsevidof than Bogoslof. Although total seabird densities were similar between islands, the density of Tufted Puffins near Vsevidof was more than double that observed around Bogoslof Island. Furthermore, ship-based measurements suggest that prey availability, as indexed by hydroacoustic biomass, was an order of magnitude greater near Vsevidof than Bogoslof. Waters were cooler and fresher (less saline) near Vsevidof than Bogoslof. Taken together, among-site differences in trophic ecology are likely explained in good measure by the distinct currents and water masses surrounding each colony, as well as their distances to the continental shelf and local bathymetry (Hunt & Stabeno 2005).

A more complete analysis of the at-sea data from other colony sites may reveal similar patterns over a broader spatial scale, and shed more light on processes influencing marine forage fish communities and some of their dependent avian predators. We will continue to analyze our at-sea data and report on results in the future. We plan to conduct more studies in summer of 2013, and will collect comparable data in the western Aleutians (Adak to Attu islands). We plan to increase our data collection efforts at sea, and we are also planning to include sampling of adult diets in collaboration with an ongoing study of seabird trophic relationships in the Aleutians by the University of Alaska (Doug Causey, pers. comm.).

Acknowledgements

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Table 2. Comparison of colony and ship indices measured on Vsevidof and Bogoslof islands in the eastern Aleutian Islands, August 17-18, 2012.

	Index	**Vsevidof**	**Bogoslof**
Colony Indices	Meal Mass	+	-
	Mean Pollock Length	+	-
	Chick Condition	+	-
Ship Indices	Hydroacoustic Biomass	+	-
	SST (°C)	-	+
	SSS (PPT)	-	+
	Seabird Density	=	=
	Puffin Density	+	-

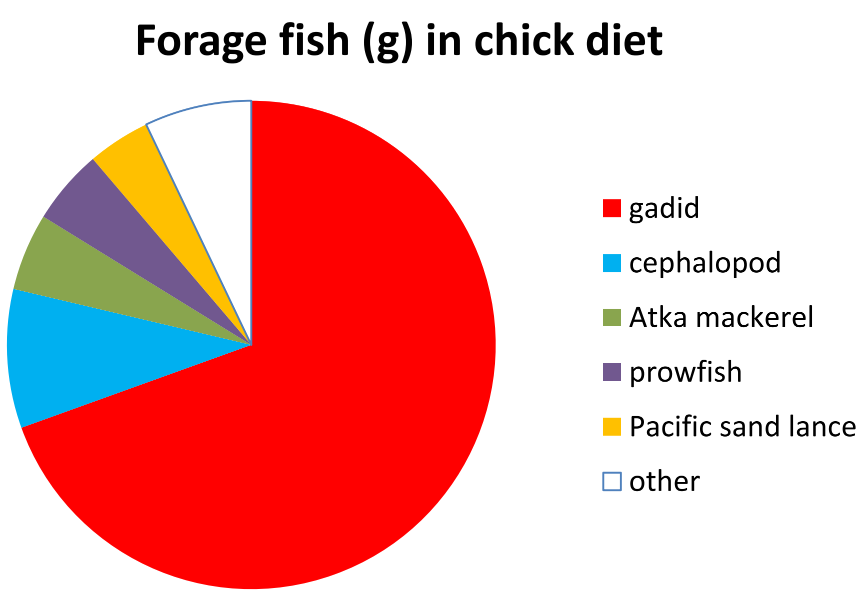

Figure 3. Proportional biomass of forage fish delivered to Tufted Puffin chicks on islands (*n* = 10) in the central and eastern Aleutian Islands, Alaska, USA, August 13-22, 2012. The top five prey types by mass (g) are displayed.

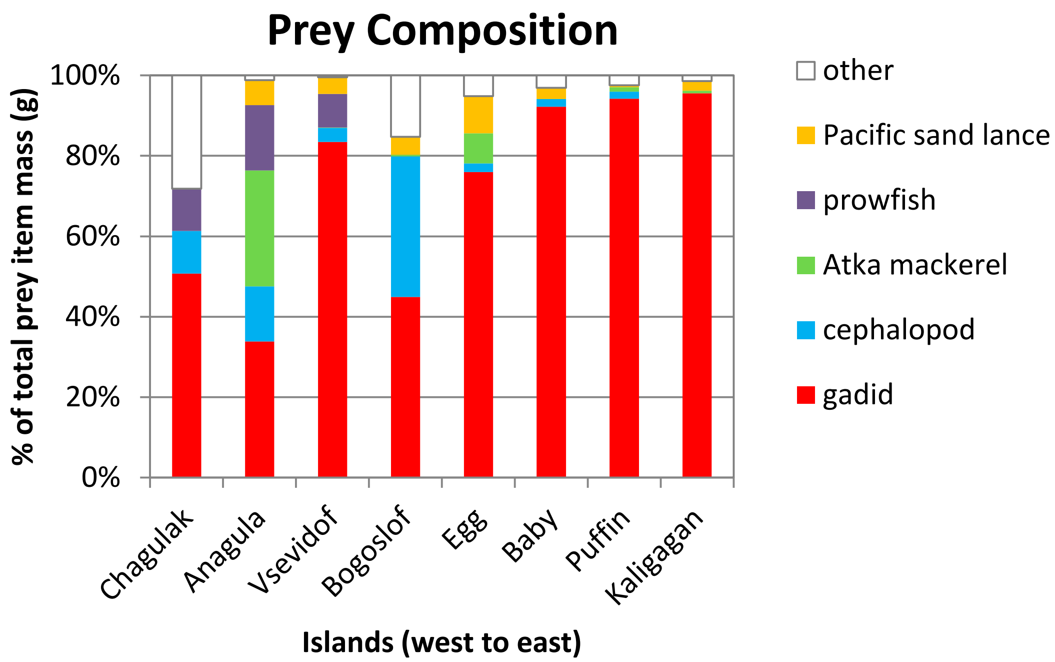

Figure 4. Percent of total forage fish biomass (g) delivered to Tufted Puffin chicks per island (n = 8) from the central to eastern Aleutian Islands, Alaska, USA, August 15-22, 2012.

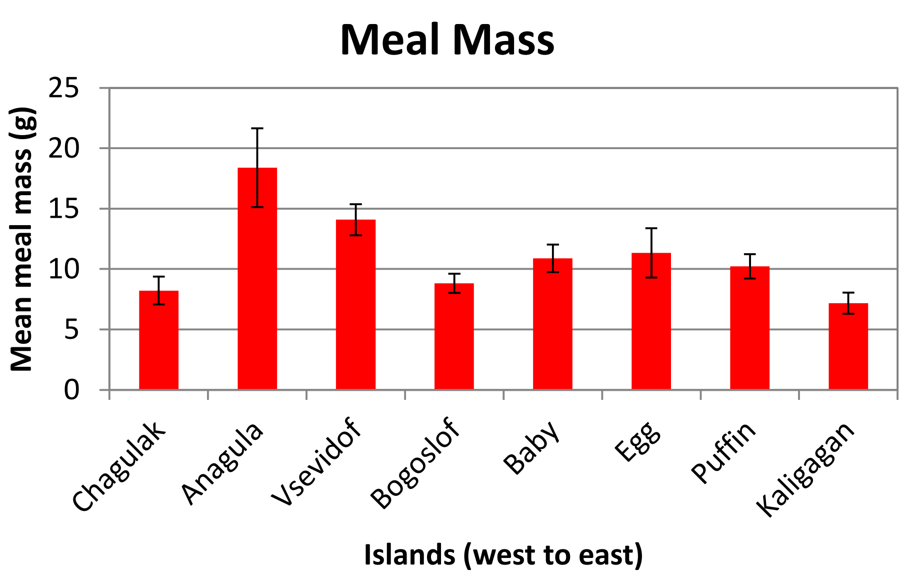

Figure 5. Mean mass (g) of meals (± SE) delivered to Tufted Puffin chicks per island (n = 8) from the central to eastern Aleutian Islands, Alaska, USA, August 15-22, 2012.

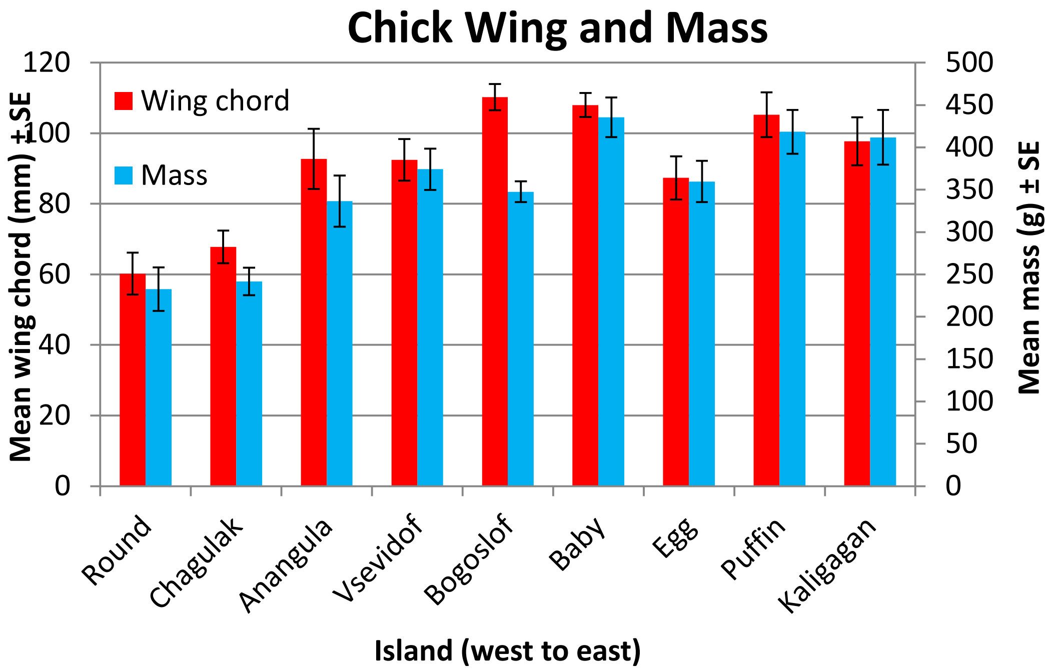

Figure 6. Mean wing chord length (mm) and mass (g) (± SE) of Tufted Puffin chicks per island (*n* = 9) from the central to eastern Aleutian Islands, Alaska, USA, August 14-22, 2012.

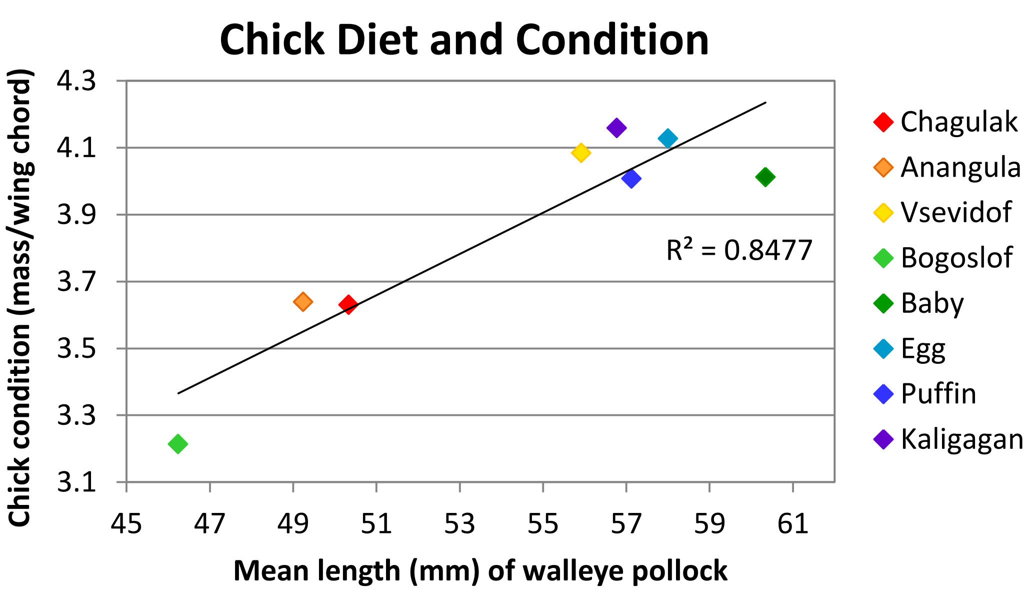

Figure 7. Correlation between the mean length (mm) of the primary diet item of Tufted Puffin chicks (walleye pollock) and an index of chick health (mean wing chord length (mm)/mass (g)) per island (*n* = 8) from the central to eastern Aleutian Islands, Alaska, USA, August 15-22, 2012.

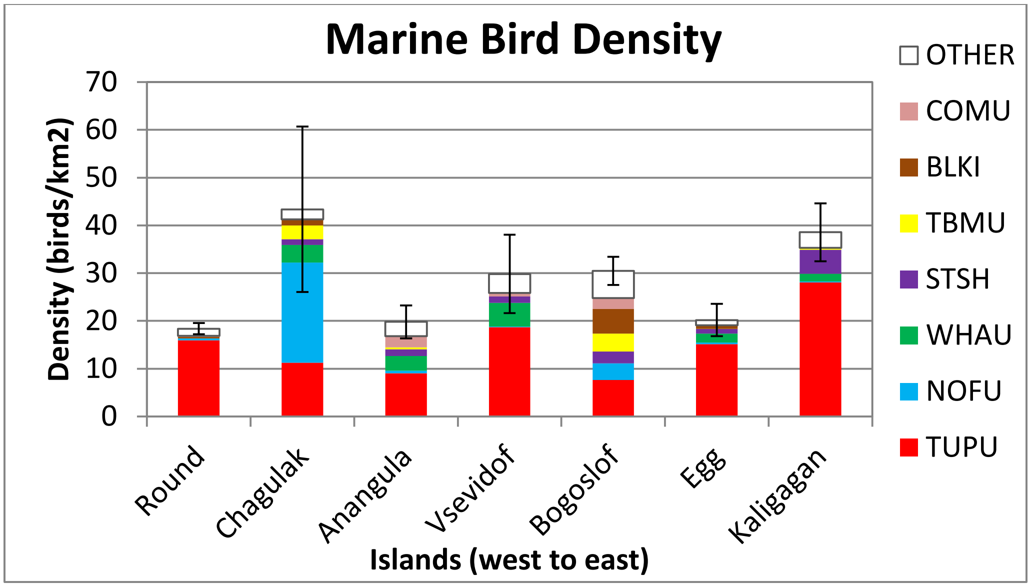

Figure 8. Mean density (birds/km^2) of marine birds (± SE) observed within a 300 m strip width on surveys conducted near islands (*n* = 7) from the central to eastern Aleutian Islands, Alaska, USA, August 14-22, 2012. Bird species observed were: Tufted Puffin (TUPU), Northern Fulmar (NOFU), Whiskered Auklet (WHAU), Short-tailed Shearwater (STSH), Thick-billed Murre (TBMU), Black-legged Kittiwake (BLKI), Common Murre (COMU), and other species (OTHER).

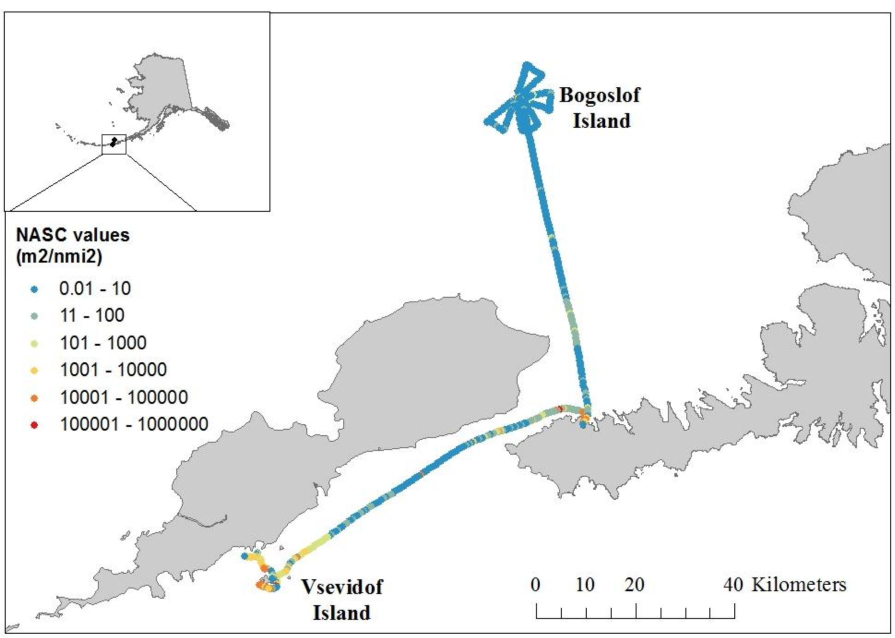

Figure 9. Hydroacoustic backscatter (Nautical Area Scattering Coefficient [m^2/nm^2]), a proxy for biomass, summed over depth between Bogoslof and Vsevidof Islands, Alaska, USA, August 17-18, 2012. Lower backscatter values are displayed in cooler colors and warmer colors represent backscatter values.

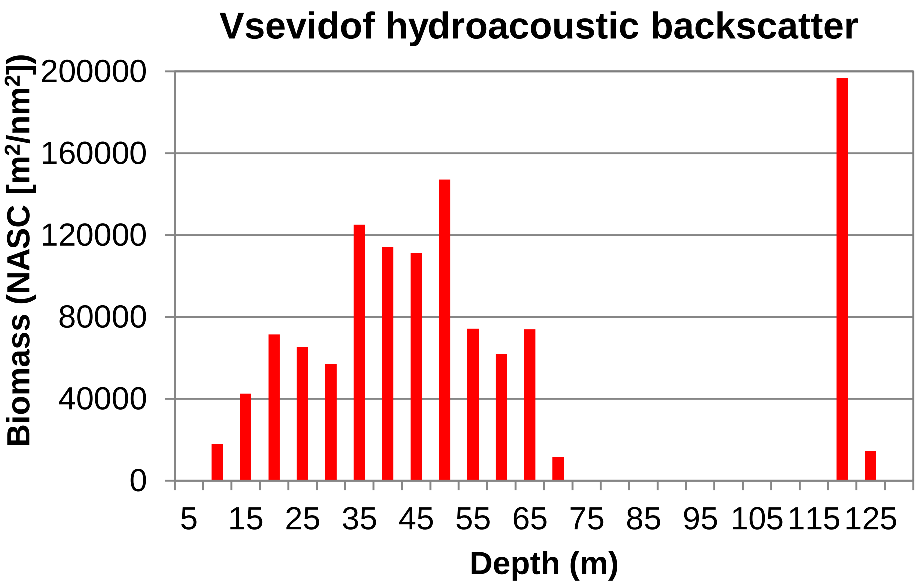

Figure 10. Hydroacoustic backscatter (Nautical Area Scattering Coefficient [m^2/nm^2]) by depth (m) at Vsevidof Island, Alaska, USA, August 18, 2012.

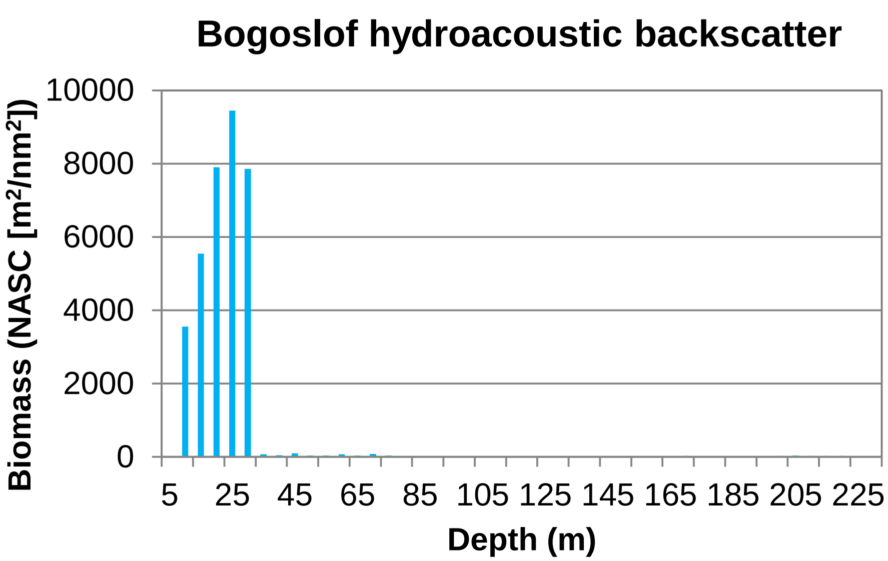

Figure 11. Hydroacoustic backscatter (Nautical Area Scattering Coefficient [m^2/nm^2]) by depth (m) at Bogoslof Island, Alaska, USA, August 17, 2012.

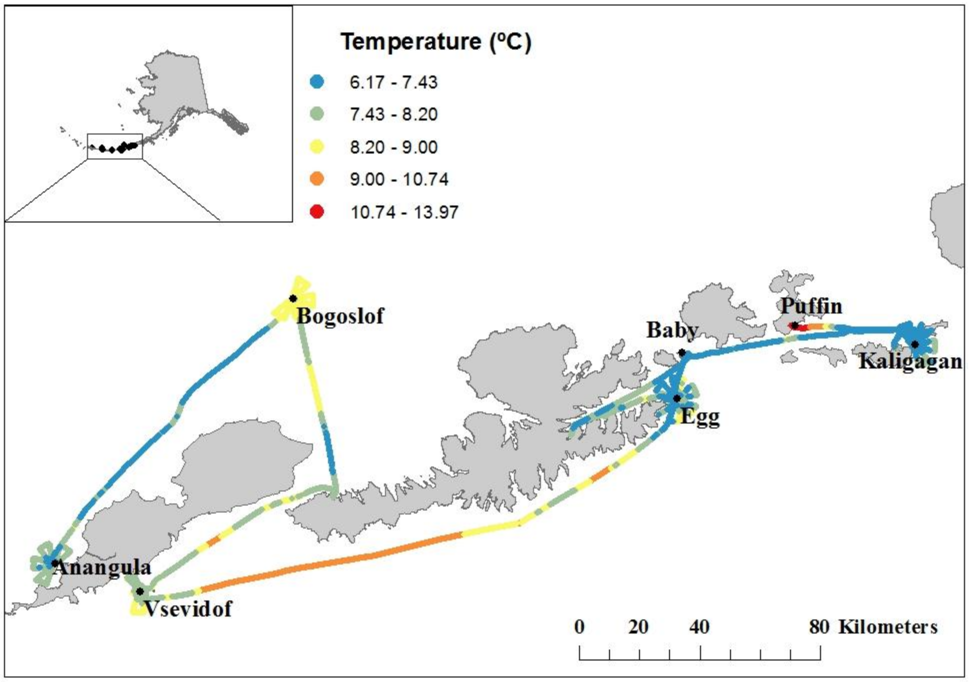

Figure 12. Sea-surface temperature (° C) measured with a thermosalinograph during transit from the central to eastern Aleutian Islands, Alaska, USA, August 16-22, 2012.

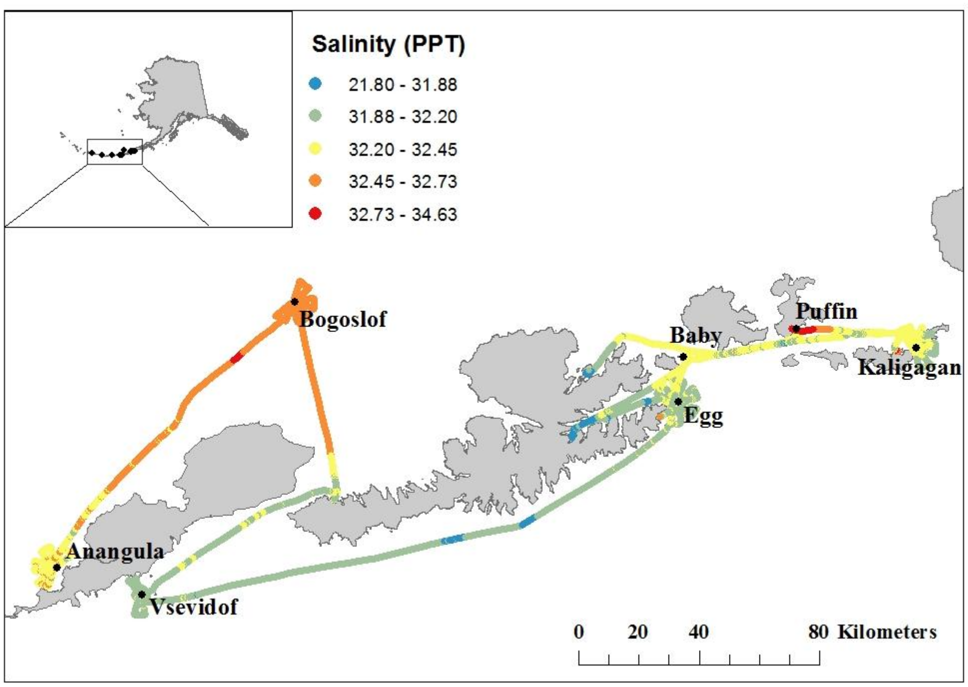

Figure 13. Sea-surface salinity (PPT) measured with a thermosalinograph during transit from the central to eastern Aleutian Islands, Alaska, USA, August 16-22, 2012.

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