

Form Rev. 9.14.17

1. Project Number:

17120114-C

2. Project Title:

Monitoring long-term changes in forage fish distribution, abundance, and body conditions in PWS

3. Principal Investigator(s) Names:

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4. Time Period Covered by the Report:

February 1, 2017-January 31, 2018 (Year 6)

5. Date of Report:

March 2018

6. Project Website (if applicable):www.gulfwatchalaska.org**7. Summary of Work Performed:**

The Gulf Watch Alaska (GWA) forage fish project has two main objectives, these include support for the longest time series of seabird diets in the Gulf of Alaska at Middleton Island in collaboration with Scott Hatch (Institute for Seabird Research and Conservation, ISRC), and the Integrated Marine Predator Prey (IMPP) survey in Prince William Sound (PWS) in collaboration with the humpback whale (17120114-O), and fall and winter marine bird (17120114-E) projects. In FY17, project tasks including contracting, permitting, equipment calibrations, data management, and field work were conducted according to planned schedules and protocols. In this report we focus on 2017 field efforts, as detailed below.

Middleton Island

Seabird diet samples at Middleton Island were collected in Apr-Aug 2017. For black-legged kittiwakes this included 509 diet samples, and for rhinoceros auklets this included 328 diet samples. A detailed report on findings from Middleton Island is provided as an appendix (Hatch 2017). Briefly, kittiwake diets in April and May 2017

were composed primarily of invertebrates, which was similar to early season diets observed in 2015 and 2016 but different from 2012-14 when spring diets were composed mainly of fish (Fig. 1, Appendix). During summer, kittiwake diets (Jun-Aug) and rhinoceros auklet chick diets (Jul-Aug) indicate greater composition of herring (Fig. 2) than in previous years. Capelin and sand lance frequency of occurrence in kittiwake diets remained relatively low in 2017, compared to previous years, although sand lance proportion of biomass in rhinoceros auklet chick diets increased in 2016-17 after several years of relatively low biomass beginning in 2011.

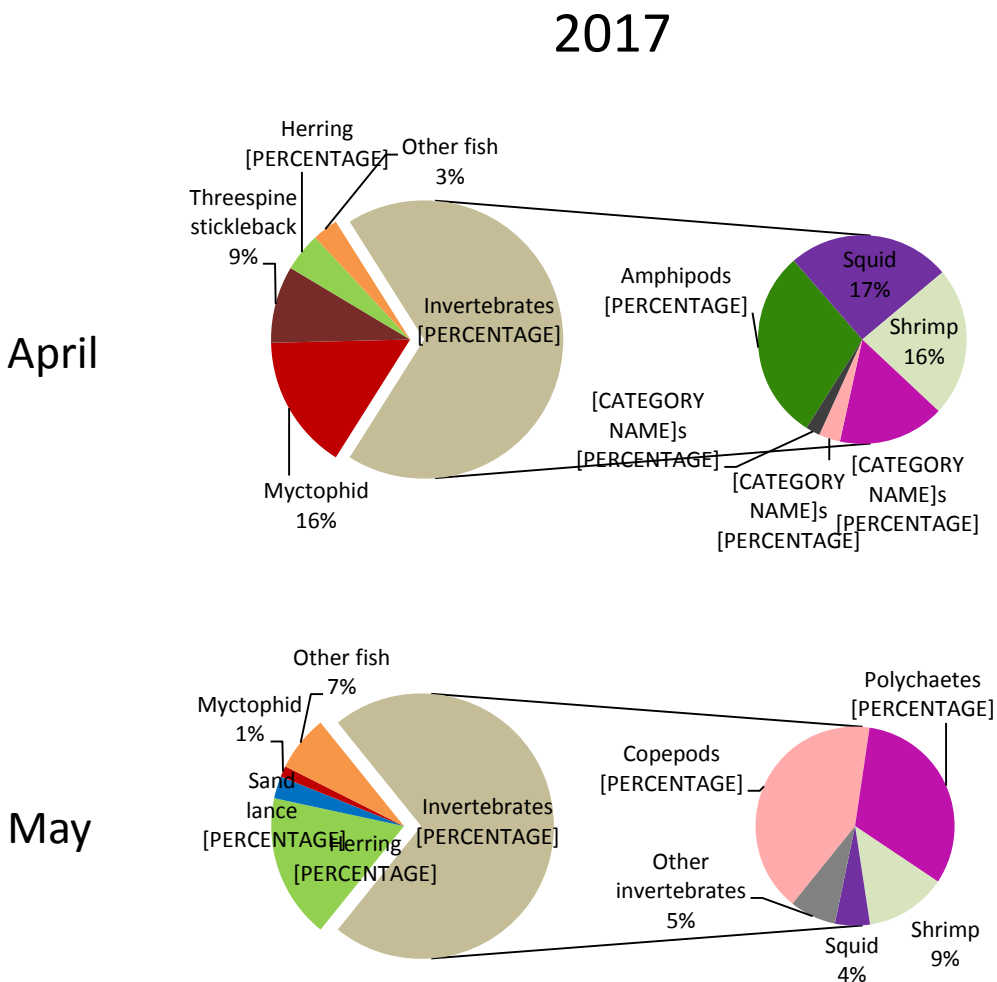


Figure 1. Middleton Island kittiwake diet composition (frequency of occurrence) in April and May, 2017.

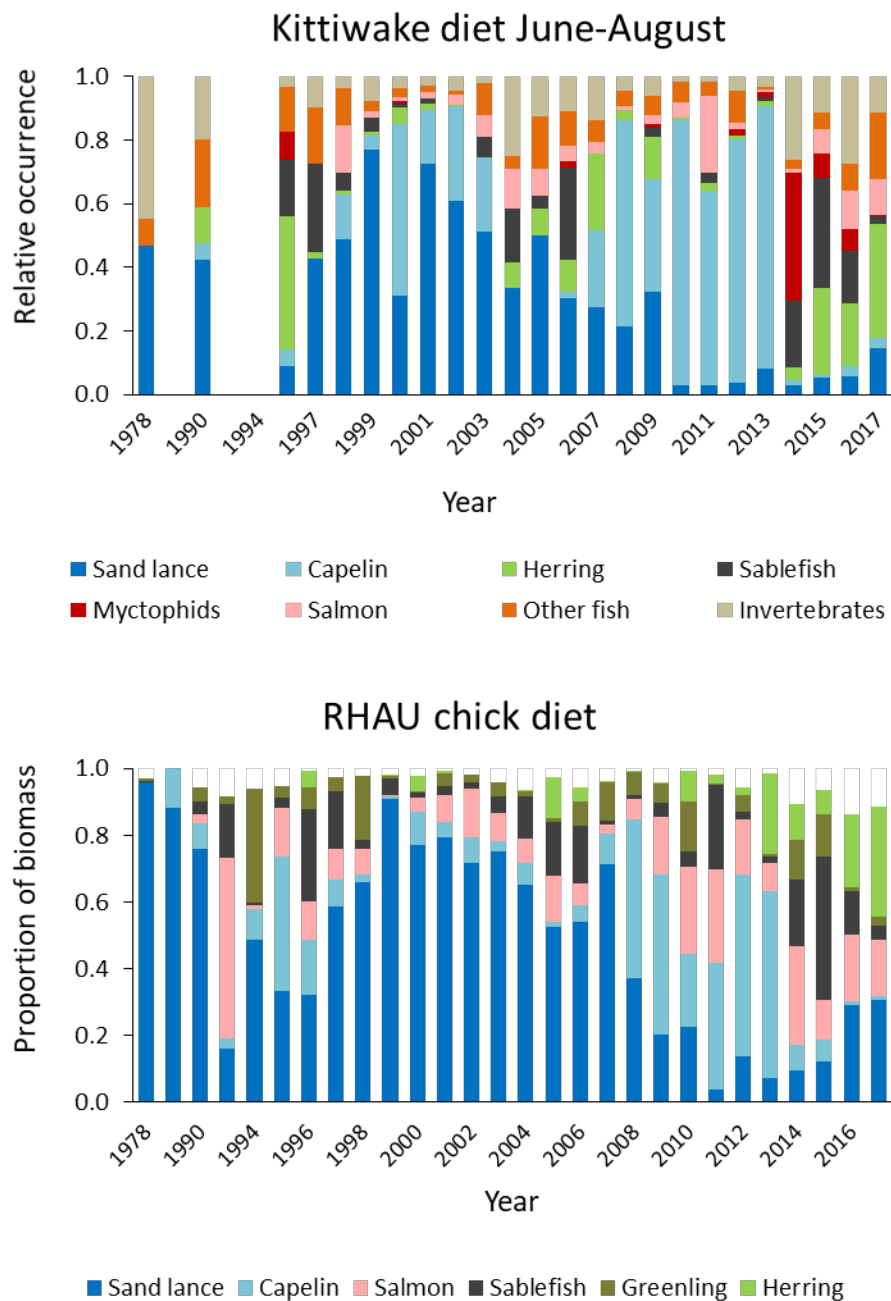


Figure 2. Middleton Island seabird diets species composition in 1978-2017, (top) Black-legged kittiwake frequency of occurrence in June-August, (bottom) Rhinoceros Auklet chick diets proportion of biomass in July-August.

Integrated Marine Predator Prey (IMPP) survey in PWS

In September 2017 we conducted the IMPP survey in collaboration with the humpback whale and fall/winter marine bird surveys. During a 10-day cruise on September 15-26 we conducted hydroacoustic surveys with a split beam dual frequency echosounder (120-38 kHz Simrad EK60) along 164 km of transects in three sub-regions in Bainbridge Passage, Montague Strait, and Port Gravina (Fig. 3). We conducted a total of 9 trawls with the Aluette net, set a small-meshed gill net at 5 locations, sampled fish under a feeding flock at one location, and sampled fish sign near the bottom with jigs at one location (Fig. 3). At fixed habitat sampling stations (n = 6) we measured oceanographic conditions with a SBE 19 plus v2 conductivity-temperature-depth profiler (CTD) equipped with fluorometer, turbidity sensor, beam-transmissometer, photosynthetically active radiation sensor, dissolved oxygen, pH sensor, and water sampler to sample nutrients and chlorophyll a at discrete depths (0, 10, near bottom depths). After each CTD cast we will also collect zooplankton samples with a 50 m vertical haul of a 150 μ -mesh zooplankton net. In addition to fixed transects in three sub-regions with historically persistent predator aggregations, we also characterized prey density more closely associated with individual or groups of whales along 30 km of focal follows near feeding whales. In September 2017 there were relatively few whales sighted (n = 12), thus there were not many opportunities to conduct dedicated whale focal follow effort.

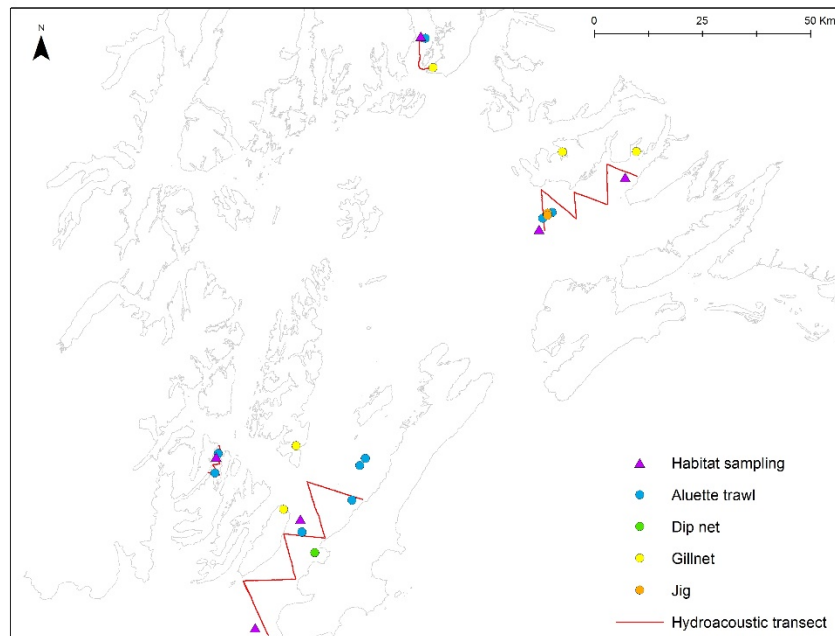


Figure 3. Map of September 2017 Integrated Predator Prey survey effort in Prince William Sound.

We are actively processing the various datasets from our September 2017 cruise, but a complete summary of findings was not available at the time of this report. Catches of walleye pollock and Pacific herring suggest these forage fish species dominated the forage fish community during our surveys in 2017 (Table 1). We observed whales and feeding flocks of birds near schools of age-0 herring in Montague Strait, but we did not observe any shoals of adult herring in that sub-region. We did encounter small scattered adult herring sign, which we sampled with jigs, near Knowles Head in the Port Gravina sub-region. Krill catches were composed primarily of *Thysanoessa spinifera* and *Euphausia pacifica* (Table 1). An unusual observation included the collection of five Pacific saury, which is a more offshore species, during gill net sampling near the north end of La Touche Island. A more detailed analysis of biomass indices and whale/marine bird prey composition and habitat will be conducted when all of the datasets are processed.

Table 1. Catch totals, and mean total length of fishes collected by aluette trawl, jig, dip net or gillnet in Prince William Sound during September 2017.

Common name	Scientific name	Total catch	Average TL (mm)	Standard dev TL (mm)
Crescent gunnel	<i>Pholis laeta</i>	1	214	
Daubed shanny	<i>Leptoclinus maculatus</i>	1	79	
E. pacifica (krill)	<i>Euphausia pacifica</i>	16	25.13	3.74
Eulachon	<i>Thaleichthys pacificus</i>	5	92.8	5.07
Glass shrimp	<i>Pasiphaeidae</i>	1		
Hyperia pacifica (amphipod)	<i>Hyperia pacifica</i>	22		
Northern smoothtongue	<i>Leuroglossus schmidtii</i>	2	35	2.83
Ronquil (family)	<i>Bathymasteridae</i>	1	32	
Lingcod	<i>Ophiodon elongatus</i>	2	175.5	12.02
Pacific herring	<i>Clupea pallasii</i>	230	95.41	33.47
Pacific saury	<i>Cololabis saira</i>	5	184.6	92.48
Pacific staghorn sculpin	<i>Leptocottus armatus</i>	1	112	
Pandalus shrimp	<i>Pandalus</i>	22		
T. raschii (krill)	<i>Thysanoessa raschii</i>	3	28.33	6.66
T. spinifera (krill)	<i>Thysanoessa spinifera</i>	661	31.02	4.04
Amphipod (family)	<i>Hyperia</i>	1		
salmon	<i>Onchorynchus sp.</i>	2	193.5	2.12
shrimp	<i>Decapoda</i>	6		
Walleye pollock	<i>Gadus chalcogrammus</i>	195	181.45	69.28

8. Coordination/Collaboration:

A. Projects Within a Trustee Council-funded program

1. Within the Program

The forage fish project is integrated with two predator studies (Moran/Straley Humpback whale [17120114-O] and Bishop fall/winter marine birds [17120114-E]), by operating at the same time and locations, and using the same vessels. The IMPP surveys require close coordination with the humpback whale and winter bird component team leads to conduct the work. This collaboration will afford efficiencies in field work, as well as facilitate greater understanding of predator-prey interactions in the Sound.

Additionally, it has been shown that the Middleton Island seabird diet collections, which are supported by the *Exxon Valdez* Oil Spill Trustee Council within the forage fish program, are directly relevant to understanding changes in seabird prey in PWS. The marine birds from Middleton are feeding in and around PWS (see Appendix), the seabird diet data collected at Middleton Island will provide information on prey relevant to marine bird trends in PWS.

2. Across Programs

a. Herring Research and Monitoring

The GWA forage fish and humpback whale projects are closely aligned with the Herring Research and Monitoring (HRM) program through data collection and information sharing. We accommodated (and benefitted from) an HRM researcher, Kristin Gorman (Prince William Sound Science Center [PWSSC]) on our IMPP cruise to facilitate the collection of adult herring for her maturation study (17170111-D). Dr. Gorman conducted gill net sampling each night at anchorages during the cruise, which benefitted our fish sampling effort.

Additionally, in December 2017, National Oceanic and Atmospheric Administration (NOAA) researchers collected hydroacoustic data on a shoal of herring near feeding whales at Graveyard Point in PWS. M. Arimitsu, Johanna Vollenweider, and John Moran provided an analysis of these data, including echointegration, mapping, and biomass estimates (see humpback whale annual report, 17120114-O), to Scott Pegau (HRM, PWSSC) and we presented this information at the Alaska Marine Science Symposium in January 2018.

b. Data Management

We are coordinating with the Data Management team to upload data to the Research Workspace and make it available on the Gulf of Alaska data portal and review metadata and update for accuracy.

c. Lingering Oil

None

3. Projects not Within a Trustee Council-funded program

None

B. With Trustee or Management Agencies

The Department of Interior has trust responsibility for migratory birds in Alaska. Under this mandate, and in conjunction with partners at the U.S. Fish and Wildlife Service (USFWS), information regarding changes in seabird prey during the winter 2015-16 Common Murre die-off in PWS and the Gulf of Alaska have been used extensively to understand the underlying cause of this event. The GWA forage fish and the Middleton Island long-term seabird diet data have provided key information on lower quantity and lower quality prey resources available to marine predators during the die-off.

The value of Middleton Island long-term seabird diets is recognized by the NOAA-National Marine Fisheries Service (NMFS) groundfish stock assessment team, and the data are presented within the Ecosystems Considerations report for the North Pacific Fisheries Management Council. In 2016, the first Gulf of Alaska-wide trends for capelin and sand lance incorporate data from marine predators (piscivorous fish and seabirds) in the region. These data suggest steep declines in occurrence of capelin and sand lance in predator diets beginning in 2014 (Zador & Yasumiishi 2016). Another way Middleton Island data have been used to directly inform the NMFS stock assessment process is through the Ecosystem-Socioeconomic Profile (ESP) summary for sablefish in Alaska (Shotwell et al. 2017). Because age-0 sablefish are difficult to study, Middleton Island seabird diets provide the only time-series information related to recruitment and age-0 growth for this commercially important species. In 2017 we provided data and information on growth of age-0 sablefish from seabird diets at Middleton for the ESP in the stock assessment fishery evaluation. Additionally, during the field season Scott Hatch provided real-time observations of sablefish in seabird diets to NMFS biologists, and this information effectively directed their survey efforts to regions in the Gulf of Alaska where they successfully caught age-0 sablefish required to meet their research needs.

9. Information and Data Transfer:
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A. Publications Produced During the Reporting Period

Moran, J., M. O'Dell, **M. Arimitsu**, J. Straley, D. Dickenson. 2017. Seasonal distribution of Dall's porpoise in Prince William Sound. Deep Sea Research II.
<https://doi.org/10.1016/j.dsr2.2017.11.002>.

Arimitsu, M. L., J. F. Piatt, B. Heflin, V. von Biela, S. K. Schoen. 2018. Monitoring long-term changes in forage fish distribution, abundance and body condition. *Exxon*

Valdez Oil Spill Restoration Project Final Report (Restoration Project 16120114-O). *Exxon Valdez Oil Spill Trustee Council*, Anchorage, Alaska.

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

Arimitsu, M., J. Piatt, B. Heflin, and S. Schoen. 2017. Jellyfish blooms in warm water may signal trouble for forage fish in a warming climate. **Poster presentation.** ICES/PICES Drivers of Dynamics of Small Pelagic Fish Resources, Mar 6-11, 2017, Victoria, BC.

Arimitsu, M., M. A. Bishop, d. Cushing, S. Hatch, B. Heflin, R. Kaler, K. Kuletz, C. Matkin, J. Moran, D. Olsen, J. Piatt, A. Schaefer, and J. Straley. 2018. Changes in marine predator and prey populations in the aftermath of the North Pacific Heat Wave: Gulf Watch Alaska Pelagic update 2017. **Poster presentation.** Alaska Marine Science Symposium, Jan 23-26, 2018, Anchorage, AK.

Arimitsu, M., J. Piatt, S. Schoen, B. Heflin, V. von Biela, and S. Hatch. 2018. Changes in forage fish during the winter 2015-16 seabird die-off and the North Pacific marine heat wave. **Oral presentation.** Alaska Marine Science Symposium, Jan 23-26, 2018, Anchorage, AK.

Arimitsu, M.L., J.F. Piatt, S.K. Schoen, and B. Heflin. 2017. Forage fish in hot water contribute to seabird die-off. **Article.** Delta Sound Connections. <http://pwssc.org/wp-content/uploads/2017/06/DSC-2017-web2.pdf>.

Suryan, R., M. Lindeberg, D. Aderhold, K. Hoffman, M. Arimitsu, H. Coletti, and R. Hopcroft. 2018. Gulf Watch Alaska: taking the pulse of the northern Gulf of Alaska. **Poster presentation.** Alaska Marine Science Symposium, Jan 23-26, 2018, Anchorage, AK.

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

Arimitsu, M. L., Piatt, J. F. and Heflin, B., 2017, Pelagic Forage Fish Distribution Abundance and Body Condition: U.S. Geological Survey data release. <https://dx.doi.org/10.5066/F74J0C9Z>.

Hatch, S. 2017. Data contributed to the NOAA Ecosystem Considerations Report 2017 for the Gulf of Alaska region. Full reports may be found at the following link: <https://access.afsc.noaa.gov/reem/ecoweb/Index.php>.

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

Final datasets and metadata for GWA 2012-15 were uploaded to the data portal by March 2017 meeting requirements. In response to the common murre die-off during

winter of 2015-16, the USGS supported an additional year of field work in summer 2016, and resulting datasets from PWS were uploaded to the workspace by Dec. 2017.

Echointegration data from the aerial-acoustic random stratified forage fish surveys. Acoustic data were obtained from a hull-mounted SIMRAD ER60 split beam dual frequency echosounder operating at 120 and 38 kHz. Both transducers were calibrated at the start of each survey.

Fish catch and morphological data from various net sampling methods including modified herring trawl, beach seine, cast net, dip net, jig, gill net and purse seine.

At-sea distribution and abundance of marine birds and mammals. Transects were conducted following standard U.S. Fish and Wildlife Service protocols for strip transect surveys and modified for work in coastal Alaska.

Zooplankton biomass. Samples were collected with a 150 micron mesh 0.25 m diameter paired ring net on a 50 m. vertical haul during daylight hours.

CTD profiles. Oceanographic conditions were sampled with a Seabird Electronics SBE19 (2012) and SBE19Plus v2 (2013-2015) CTD equipped with various sensors (e.g., oxygen, pH, fluorescence, turbidity, beam transmission and photosynthetically active irradiance).

Inorganic nutrient concentration, including phosphate, nitrate, nitrite and silicic acid.

10. Response to EVOSTC Review, Recommendations and Comments:

Science Panel Comments and Responses on Revised FY17-21 Proposal, September 2016

In September 2016, the Science Review Panel commented: The Panel expressed some concern about how the data would be interpreted. The PIs recognize they cannot provide sound-wide abundance estimates because of limited spatial sampling, but do not consider the implications of their limited sampling being a biased subset of potential sampling locations (only locations with whales). Some interpretations seem potentially circular: if there are fewer predators and fewer prey is that because the prey populations have declined and predators are declining or moving elsewhere, or because predators have reduced prey populations and are foraging elsewhere? Presumably within a season the correlation might even shift from initially positive to negative as the season moves on. Care will need to be taken in the interpretation of these data and what they mean for forage fish abundance. The PIs should carefully consider exactly how and for what the data will be used.

Regarding the Middleton Island sampling, the Panel considered the relevance of this sampling both on biological and geographic considerations. It was not clear to us how the PIs would use data on presence in the diet to estimate abundance of forage fish? Presumably the bird diet is not just a strict reflection of abundance due to prey selectivity, spatial patterns in abundance of different prey species, etc. The Panel has concerns regarding the location of this work in the project and recommends the removal of the proposed effort at Middleton Island.

PI Response: The methods for this project, including the integrated predator-prey surveys in PWS and the long-term data from seabird diets (Middleton Island data), were clarified in the FY2018 work plan.

Science Panel Comments and Responses on FY18 Work Plans, September 2017

In September 2017, the Science Panel commented: The Panel was gratified to see a broader and stronger use of the Middleton Island monitoring data into the overall project and appreciates the sound science being conducted by the PIs. Huge improvements were made in data management, which can be attributed to the leadership of the Program.

PI Response: Thank you for your comments.

11. Budget:

Please see provided program workbook.

Current expenditures of some line items exceed $\pm 10\%$ deviation from the originally proposed amount in cases where reporting accounts lagged behind actual expenses, inconsistencies between federal and *Exxon Valdez* Oil Spill Trustee Council fiscal year start dates, and because USGS budget system categories differ from those shown on the *Exxon Valdez* Oil Spill Trustee Council proposal. All expenditures are within keeping to our planned budget. For example, in FY17 we went over budget on equipment because we needed to purchase licensing for acoustic data processing software to analyze the data we collected during this project. These costs will even out over time and we expect to spend the total proposed budget amount by the end of the project.

Appendix



INTRODUCTION

In 2017, the Institute for Seabird Research and Conservation (ISRC) entered into a cooperative agreement with the U.S. Geological Survey, Alaska Science Center, to continue field studies of seabirds on Middleton Island as part of GulfWatch Alaska. The latter program, a 20-year effort (2012-2031) funded by the Exxon-Valdez Oil Spill Trustee Council, is intended to uncover and monitor natural and anthropogenic factors affecting ecosystem functioning in the Gulf of Alaska and Prince William Sound. The particular contribution of Middleton seabird monitoring will be to quantify dietary shifts in predator species, especially black-legged kittiwakes and rhinoceros auklets, as indicators of forage fish dynamics in the region.

Additional lines of research in 2017 were possible by way of research personnel and financial support contributed by McGill University (National Science Education and Research Council of Canada), the University of Guelph, Bucknell University, Queen's University (Ontario, Canada), and the French Polar Institute (IPEV) and National Center for Scientific Research (CNRS). Those efforts included instrumentation of several species with GPS trackers and accelerometers and collection of kittiwake tissue samples for intergenerational genetic analysis, RNA deep sequencing (RNA-seq) and development of an annotated transcriptome for kittiwakes. With the partial exception of GPS tracking results for kittiwakes, the outcomes of those special investigations are not included in this report.

In 2017, the Middleton research station was occupied by members of the field crew from 2 April through 15 August.

Acknowledgements—Special thanks to GulfWatch Alaska principal investigators John Piatt and Yumi Arimitsu for facilitating the USGS-ISRC Cooperative Agreement and securing vital financial support through the EVOS Trustee Council and USGS. Members of the field crew were Josh Cunningham and Sydney Collins (University of Guelph), Shannon Whelan, Anne Moullier, Kristen Lalla, and Kyle Elliott (McGill University), Drew Sauve (Queen's University), Mae Lacey and Morgan Benowitz-Fredericks (Bucknell University), Maxime Pineaux, Ségolène Humann-Guilleminot, Thomas Pagnon, Lucie Abolivier, Camille Toscani, and Sarah Leclaire (CNRS), and Scott and Martha Hatch (ISRC). Thanks also to Shawn and Kelly Pummill for assistance with facilities renovation during April. As always, the project benefitted from logistics-sharing and favors coming from many quarters, including in 2017 the following: Federal Aviation Administration (Dave Baxter, Doug Clary, Allen Oskolkoff, et al.), Alaska Department of Fish and Game (Jason Schamber, Mike Petrula, et al.), the Eyak Native Village Council (Clark Pearson et al.), and Marine Exchange Alaska (Bryan Hinderberger, Bill Benning, and Shawn Mauldin).

RESULTS AND DISCUSSION

PRODUCTIVITY

Rhinoceros Auklet—In general, rhinoceros auklets have consistently high breeding success on Middleton, and their population is increasing (currently ~20,000 individuals). At 0.52 chicks/egg laid, production in 2017 was a little lower than the long-term average of 0.68 (Table 1).

Tufted Puffin—Tufted puffins have struggled in recent years to rear young on Middleton. For 5 years prior to 2015, the virtual absence of fish-carrying adults seen was a clear indication of scant chick production. With 0.35 chicks/egg in 2015 and 0.24 chicks/egg in 2016 (Table 1), puffins seemed to achieve at least a partial return to normal production in the past couple of years, despite ocean conditions unfavorable to surface-feeders such as black-legged kittiwakes (see below). With production of only 0.17

chicks/egg in 2017, however, puffins clearly have not returned to a level consistent with normal production in a healthy colony. Despite their comparatively poor performance during breeding, puffin numbers have increased substantially on Middleton—i.e., roughly 20,000 individuals today versus 5,000 in the 1970s.

Pelagic Cormorant—Since 2002, pelagic cormorants have been monitored in the tower colony, where both numbers (~50-140 pairs) and breeding success (from ~0.1 to nearly 2 chicks per egg-laying pair) are quite variable (Table 2). Production in 2017 (1.6 chicks/nest) was well above the long-term average (1.1 chicks/pair), although the number of nests constructed on the tower was comparatively low (Table 2).

Black-legged Kittiwake—Among 74 fed pairs of kittiwakes on the Middleton tower, production was 0.76 fledglings/nest in 2017, whereas 104 unfed pairs produced 0.22 chicks/nest (Table 3). The difference between groups indicated poor foraging conditions in 2017 for surface-feeding kittiwakes, as contrasted with divers such as rhinoceros auklets and pelagic cormorants. This season continued a trend toward poor breeding performance of kittiwakes that began with the emergence in 2014 of an unusual warm-water event in the northeast Pacific.

DIETS

Black-legged Kittiwake—In most years since 2000, regurgitated food samples have been collected from adult and/or nestling kittiwakes on the tower during all months April through August (Table 4). From an evaluation of alternate methods of analyzing and reporting diet results (Hatch 2013, Appendix 2), the preferred metric for kittiwakes is prey relative occurrence, for which the relevant sample units are numbers of identified prey types in a given sample (Table 5).

On average, Middleton kittiwakes take about equal amounts of Pacific sand lance, capelin, and invertebrates, with lesser amounts of herring, sablefish, salmon, and myctophids, depending on stage of the season (Fig. 1.). A salient finding during the previously mentioned warm-water event has been the virtual disappearance of capelin from the kittiwake diet on Middleton, following 6 prior years when capelin were predominant (Fig. 2).

Middleton Island is close to the continental shelf break, and for a few weeks after they arrive in spring kittiwakes typically forage over deep ocean waters at night, taking vertically migrating prey such as lanternfish (myctophids), squids, polychaetes, and crustaceans. This was clearly the case in 2012, a year in which kittiwakes switched to capelin as the primary prey during incubation and chick-rearing (Fig. 2). Notably, because it had never been seen previously, capelin dominated throughout the following year, including even the spring arrival stage (a sizeable sample having been obtained in late March 2013). In 2014, the spring diet reverted to a mix of myctophids and invertebrates, and for the first and only time observed, kittiwakes continued to rely on pelagic prey throughout the summer, apparently because prey usually obtained in the neritic (shelf) zone during June-August failed to materialize. In 2015, yet another previously unknown sequence occurred, as neither myctophids nor capelin were available early in the season, and large herring supplemented a predominantly invertebrate diet. During later stages of breeding in 2015, large herring and first-year sablefish comprised the bulk of the diet (Fig. 2).

The 2016 season was another extreme year within the ongoing, exceptional warming event. Increased use of invertebrates seen over the course of this event crested that year with a virtual absence of fish in the diet during both April (Fig. 3) and May (Fig. 4). Typically, the two main contributors to the invertebrate fraction of the diet are squids and polychaetes (the latter being a pelagic, swimming species apparently obtained only at night). In 2016, it appeared that the kittiwake diet in the first week or two after the birds' spring arrival at the colony (which normally occurs in late March) consisted almost exclusively of polychaetes. By May, squids were the dominant invertebrates and main prey overall (Figs. 3 & 4). As in

other years, small numbers of the amphipod *Paracallisoma alberti* appeared regularly in the spring diet. The occurrence of the hydrozoan *Velella velella* was a first in 2016, and unexpected because that species is normally associated with warmer waters than usually occur in the northern Gulf of Alaska.

In 2017, squids and polychaetes were less prominent in the early-season diet than in several of the immediately preceding, warm-water years. Instead, the dominant fraction of the invertebrate diet this year consisted of crustaceans such as shrimp, amphipods, and copepods (Fig. 5). The prevalence of copepods, especially during May, is notable because historically those prey occur but rarely in the kittiwake diet at Middleton. Copepods arguably would be a food source of last resort for a bird predator accustomed to having ready access to forage fish like myctophids or herring or energy-rich polychaetes. Also notable in 2017 was the regular occurrence of threespine sticklebacks during April (Fig. 5). Being abundant inhabitants of the intertidal zone and brackish ponds around the island, sticklebacks are an ever-present food source on Middleton, albeit one that is largely ignored by kittiwakes except perhaps when the birds struggle to find much else in the way of oceanic prey. The paucity and generally small mass of regurgitated food samples found around the grounds of the research station this year was further evidence of poor foraging conditions in spring 2017.

Rhinoceros Auklets—Auklet diets are monitored by collecting bill-loads from chick-provisioning adults, usually once or twice a week from early July through early or mid-August. Sampling in 2017 was intensive, with 328 samples (~10 kg) of food collected (Table 6). Overall, the auklet diet at Middleton is composed largely of a few species of forage fish, especially Pacific sand lance, capelin, salmon (including both pink and chum), and sablefish, in that order of importance (Fig. 1). The years 2014 through 2017 have seen significant breaks from the past, with historically dominant species—sand lance and capelin—being largely supplanted by sablefish, salmon, and herring (Fig. 6).

Since 1978, more than 100 kg of auklet prey samples have been collected on Middleton (Table 6), and auklet diet monitoring provides our single best indicator of seabird prey dynamics in the region. By all appearances, sand lance were the overwhelmingly dominant forage species in the late 1970s through the early 1980s. Following a period of reduced availability in the mid 1990s, sand lance made a strong comeback by the end of that decade. However, sand lance steadily declined in importance after 2000 and for the most part have contributed little to seabird diets since 2008 (Fig. 6). However, the appearance of about 30% sand lance in the auklet diet in 2016-2017 is consistent with a known association of sand lance with warm-water conditions (Hatch 2013). Pacific herring seem also to have benefitted from the recent warming of surface waters in the region (Fig. 7).

The juxtaposition of time series for kittiwakes and rhinoceros auklets since 1978 (Fig. 6) shows general agreement vis-à-vis the decline of sand lance and, since 2008, the emergence of capelin as a dominant forage species. In the last several years, however, when neither sand lance nor capelin were prevalent, the diets of surface-feeding kittiwakes and diving auklets diverged substantially (Fig. 6).

KITTIWAKE FORAGING

During chick-rearing in 2017, the destinations of foraging kittiwakes from Middleton were primarily the nearshore waters along outer islands of Prince William Sound, barrier islands of the Copper River Delta, and east to Cape St. Elias on Kayak Island (Fig. 8). Thus, the typical foraging radius was 80-100 km. In comparison, most foraging by kittiwakes during one productive prior year (2008) occurred within a radius of ~50 km of the colony (Hatch 2013). GPS tracking also revealed one remarkable and record-setting foraging excursion by a kittiwake that traveled from Middleton Island to Cross Sound and Icy Strait in southeast Alaska, a trip lasting more than 4 days and covering some 1500 km in overall flight distance (Fig. 9). This female, supplementally fed at an earlier stage of the season, was unfed and actively rearing

a chick during the tracking episode. Her chick survived and eventually fledged from the Middleton tower.

OCEAN REGIME INDICATORS

Using data from Middleton Island seabird monitoring through 2011, Hatch (2013) described an apparent regime shift in the Gulf of Alaska ecosystem that occurred around 2008. This transition entailed: (1) a switch from mostly positive PDO indices (since 1977) to negative values after 2008, (2) the emergence of capelin as a dominant prey species at Middleton, and (3) markedly improved breeding performance by black-legged kittiwakes. These patterns persisted for at least another 2 years (i.e., through 2013) and, with occasional interludes of opposing conditions, can be expected to continue for another 2 decades or longer (Hatch 2013). One such interlude is now evident for the period 2014-2017, a widespread anomaly nicknamed “The Blob.” (Bond et al. 2015). Examples of dramatic species range shifts associated with this warm-water event are listed in Bond et al. (2015), to which we added the first-ever appearance of male California sea lions (*Zalophus californianus*) among ~100 Steller sea lions hauling out on Middleton in April, May and June in 2016. A similar complement of California sea lions was observed among the males hauling out on Middleton in April 2017.

Anomalous conditions are also reflected in monthly PDO indices and in seabird indicators from Middleton Island—namely, dietary capelin and kittiwake productivity—both of which dropped precipitously beginning in 2014 (Table 7, Fig. 10). The prevalence of invertebrates (mainly polychaetes and squids, but also including copepods and the normally warm-water hydrozoan *Velella velella*) in the spring diet during 2016-2017 is especially noteworthy. As nocturnal vertical migrants from mesopelagic depths, myctophids are available to foraging kittiwakes only at night, and then only if the fish rise to within a meter or so of the ocean surface. Evidently, anomalous surface conditions in 2015 and 2016 prevented myctophids from doing so in April, and mesopelagic fish remained a relatively minor component of the spring diet in 2017. During most years there is an increase in the PDO monthly index in winter, with a temporally local peak around the time when kittiwakes are returning to colonies and preparing to breed in the northern Gulf of Alaska (Fig. 11). This pattern was less pronounced in 2017, suggesting a possible return to normal background (i.e., “post-blob”) conditions is in the offing. However, the continued large effect of supplemental feeding on laying dates and clutch sizes in 2017 (Table 8) confirmed the difficulty kittiwakes were having in acquiring sufficient energy for breeding.

That comparison of breeding performance in fed and unfed kittiwake pairs on Middleton furnishes a powerful indicator of ocean conditions, for the simple reason that kittiwakes prefer to feed themselves. In poor years, characterized by positive PDO, low capelin availability, and poor kittiwake breeding performance, the difference between fed and unfed treatment groups is accentuated, and vice versa (Table 8, Fig. 12). The events of 2014-2017 have only increased the strength and predictive power of relations among the PDO, prey dynamics, and kittiwake breeding performance (Table 9). As of fall 2017, the PDO shows signs of a possible return to ocean conditions expected if a background cold phase in the PDO since 2008 still prevails. Thus, we look forward to the next iteration, possibly in 2018, of this natural experiment, when a return to cold water conditions, capelin, and high kittiwake performance would more or less clinch these simple, yet portentous, relationships. As noted, the current cold phase of the PDO is predicted to continue through the 2030s, all else being equal. Potentially, however, global warming could have a counteracting effect, with far-reaching consequences for seabirds, marine mammals, and fisheries.

LITERATURE CITED

Hatch, S.A. 2013. Kittiwake diets and chick production signal a 2008 regime shift in the Northeast Pacific. Mar. Ecol. Prog. Ser. 477: 271-284.

Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 warm anomaly in the NE Pacific. *Geophys. Res. Lett.* 42: 3414–3420. doi: [10.1002/2015GL063306](https://doi.org/10.1002/2015GL063306).

Table 1. Productivity of rhinoceros auklets and tufted puffins breeding on Middleton Island in 2015-2017.

Parameter	Rhinoceros auklet			Tufted puffin		
	2015	2016	2017	2015	2016	2017
Burrows with eggs	60	61	62	52	82	71
Eggs hatched	42	38	40	21	27	17
Late-stage chicks	38	33	32	18	20	12
Chicks/egg laid	0.63	0.54	0.52	0.35	0.24	0.17

Table 2. Breeding performance of pelagic cormorants on the Middleton tower, 2002-2017.^a

Year	A-egg date (Julian day)				Clutch size				Chicks fledged/nest built			
	n	Mean	SE	SD	n	Mean	SE	SD	n	Mean	SE	SD
2002	77	139.7	0.95	8.325	86	3.7	0.18	1.707	86	1.6	0.15	1.371
2003	78	138.2	0.97	8.540	80	4.0	0.16	1.441	80	1.9	0.16	1.400
2004	62	144.0	0.88	6.941	76	2.8	0.18	1.607	76	0.4	0.07	0.650
2005	31	142.5	1.32	7.352	31	3.5	0.18	1.028	31	1.2	0.23	1.283
2006	92	148.3	0.90	8.635	101	3.0	0.12	1.228	101	1.1	0.12	1.156
2007	142	147.8	0.93	11.130	144	3.8	0.11	1.275	144	1.6	0.12	1.425
2008	145	146.4	0.94	11.370	145	3.8	0.10	1.165	145	1.6	0.11	1.319
2009	113	155.0	0.68	7.223	128	2.9	0.11	1.232	128	1.4	0.10	1.175
2010	71	154.7	0.72	6.037	71	2.6	0.10	0.851	71	0.1	0.05	0.445
2011	95	161.3	0.96	9.314	109	2.5	0.12	1.281	109	0.5	0.07	0.741
2012	85	159.4	0.86	7.884	85	3.0	0.12	1.107	85	0.5	0.08	0.765
2013	89	150.3	0.73	6.842	90	3.4	0.09	0.880	90	1.9	0.12	1.167
2014	--	--	--	--	--	--	--	--	~87	~1.2	0.13	1.170
2015	58	155.0	0.91	6.910	85	2.1	0.16	1.470	85	0.6	0.09	0.823
2016	53	152.8	1.62	11.78	53	2.9	0.17	1.210	53	0.9	0.14	1.050
2017	69	150.9	1.08	8.951	69	3.3	0.10	0.845	69	1.6	0.16	1.306
Totals	1,260	149.7	0.96	8.48	1,353	3.1	0.13	1.222	1,353	1.1	0.12	1.078

^a The estimate of fledglings in 2014 is 102 chicks from 87 nests built, a relatively crude figure that should not be taken as strictly comparable to other years. The estimate is based on a final (premature) count of chicks in tower nests on 14 July, >3 weeks before final checks in other years. Additional mortality that would have occurred before fledging was perhaps offset by 10 nests still being incubated on 14 July, which are assumed to have produced no fledged chicks.

Table 3. Breeding performance of supplementally fed and unfed pairs of black-legged kittiwakes on the Middleton tower, 1996-2017.^a

Year	Unfed pairs												Fed pairs											
	Julian lay date				Clutch size ^a				Chicks fledged				Julian lay date				Clutch size ^a				Chicks fledged			
	n	Mean	s.e.	s.d.	n	Mean	s.e.	s.d.	n	Mean	s.e.	s.d.	n	Mean	s.e.	s.d.	n	Mean	s.e.	s.d.	n	Mean	s.e.	s.d.
1996	59	159	0.75	5.728	63	1.73	0.07	0.574	63	0.60	0.08	0.636	25	157	1.07	5.342	27	1.74	0.11	0.594	27	1.22	0.15	0.801
1997	59	158	0.44	3.386	65	1.48	0.08	0.664	65	0.32	0.06	0.503	25	155	1.09	5.427	25	1.80	0.08	0.408	25	0.96	0.16	0.790
1998	59	160	0.92	7.032	70	1.29	0.09	0.745	70	0.36	0.06	0.539	27	155	1.12	5.797	29	1.69	0.14	0.761	29	0.62	0.12	0.622
1999	65	169	0.59	4.771	156	0.47	0.05	0.606	156	0.21	0.04	0.468	44	161	1.01	6.684	46	1.61	0.09	0.614	46	0.59	0.11	0.717
2000	135	151	0.63	7.322	152	1.68	0.06	0.706	152	0.99	0.07	0.814	67	149	0.66	5.403	71	1.83	0.07	0.609	71	1.18	0.10	0.833
2001	166	153	0.46	5.942	174	1.78	0.04	0.560	174	1.03	0.06	0.853	67	151	0.41	3.342	71	1.93	0.07	0.569	71	1.28	0.10	0.848
2002	168	149	0.66	8.581	179	1.73	0.04	0.586	179	0.97	0.06	0.796	70	149	0.94	7.825	72	1.83	0.06	0.475	72	0.97	0.09	0.769
2003	95	157	0.47	4.600	102	1.67	0.06	0.603	102	0.50	0.06	0.609	66	152	0.74	6.003	69	1.81	0.07	0.550	69	0.91	0.10	0.836
2004	88	154	0.42	3.949	102	1.58	0.07	0.750	102	0.18	0.04	0.432	68	151	0.70	5.742	69	1.99	0.04	0.364	69	0.97	0.10	0.804
2005	214	157	0.30	4.321	221	1.67	0.04	0.553	221	0.37	0.04	0.553	71	151	0.57	4.775	72	1.86	0.05	0.421	72	1.03	0.08	0.712
2006	216	158	0.38	5.537	233	1.56	0.04	0.627	233	0.47	0.04	0.587	71	151	0.43	3.642	73	1.90	0.05	0.446	73	1.14	0.10	0.822
2007	172	163	0.43	5.606	197	1.34	0.05	0.693	197	0.42	0.04	0.606	63	158	0.74	5.900	73	1.58	0.08	0.725	73	0.77	0.10	0.874
2008	125	153	0.58	6.498	130	1.73	0.05	0.554	130	0.78	0.06	0.707	70	150	0.70	5.887	71	1.92	0.06	0.470	71	0.90	0.10	0.813
2009	90	155	0.57	5.439	98	1.69	0.07	0.649	98	0.20	0.04	0.405	75	150	0.81	7.056	76	1.89	0.04	0.386	76	0.75	0.08	0.656
2010	68	148	0.87	7.160	74	1.81	0.07	0.612	74	0.78	0.09	0.815	58	150	1.07	8.174	61	1.82	0.07	0.563	61	0.89	0.10	0.819
2011	41	158	0.64	4.092	42	1.62	0.08	0.539	42	0.50	0.09	0.552	47	152	1.26	8.624	48	1.83	0.07	0.519	48	0.92	0.11	0.794
2012	72	153	0.78	6.582	78	1.82	0.07	0.619	78	0.87	0.09	0.779	72	152	0.86	7.262	75	1.88	0.06	0.544	75	0.93	0.09	0.811
2013	63	148	1.06	8.413	68	1.84	0.06	0.507	68	1.00	0.10	0.792	67	148	0.97	7.965	70	1.97	0.06	0.538	70	1.04	0.10	0.842
2014	--	--	--	--	--	--	--	--	143	0.45	0.04	0.526	--	--	--	--	--	--	--	--	--	--	--	--
2015	296	153	0.29	4.986	352	1.51	0.04	0.762	352	0.21	0.02	0.422	70	152	0.47	3.895	72	1.90	0.05	0.449	72	0.96	0.09	0.740
2016	79	165	0.73	6.444	155	0.74	0.06	0.806	155	0.08	0.02	0.301	73	156	0.99	8.434	74	1.80	0.05	0.437	74	0.81	0.06	0.541
2017	72	161	0.52	4.407	104	0.95	0.07	0.755	104	0.22	0.04	0.417	72	155	0.58	4.948	74	1.82	0.04	0.371	74	0.76	0.08	0.679

^a Mean clutch size includes zero-egg nests, reflecting both breeding propensity and egg production by laying pairs.

Table 4. Temporal distribution of diet samples from black-legged kittiwakes on Middleton Island, 1978 – 2017.

Year	Adults			June			July			August			Total
	Mar	April	May	Adults	Chicks	Total	Adults	Chicks	Total	Adults	Chicks	Total	
1978								38	38		2	2	40
1989		2	2				5		5				9
1990		17	7	18		18	21	9	30				72
1992			1							3		3	4
1994		3											3
1996			19					37	37		17	17	73
1997			4	4	3	7	3	107	110	1	35	36	157
1998			32	11	16	27	13	130	143	7	64	71	273
1999			11	11		11	9	51	60	2	45	47	129
2000		41	7	13	1	14	4	87	91		29	29	182
2001		10	19	7	23	30	10	321	331		31	31	421
2002		26	14	2	22	24	1	193	194		22	22	280
2003		4	22	24	3	27	22	15	37	5	2	7	97
2004		9	8		1	1	11	7	18				36
2005		4	12	3		3	5	10	15	1	2	3	37
2006			6	6	8	14		100	100		19	19	139
2007		1	21	4		4	13	3	16	1	3	4	46
2008		44	10	4	2	6	2	40	42	2	13	15	117
2009		36	21	16	2	18	22	27	49	2	7	9	133
2010		39	51	39	34	73	27	128	155	4	36	40	358
2011		32	14	3		3	9	18	27	8	13	21	97
2012		10	75	5	10	15	60	238	298	11	67	78	476
2013	114	7	64	50	17	67	23	110	133	8	26	34	419
2014		179	6	1	1	2	3	100	103	14	14	28	318
2015		63	63	12	4	16	33	32	65	4	12	16	223
2016		135	129	27	5	32	42	123	165	3	26	29	490
2017		87	67	34	0	34	69	77	146	6	31	37	371
Total	114	749	685	294	152	446	407	2001	2408	82	516	598	5000

Table 5. Numbers of prey types identified in kittiwake food samples—the basis for computations of relative occurrence—by month on Middleton Island from 1978 through 2017.

Year	Prey type identifications						Total
	March	April	May	June	July	August	
1978					56	4	60
1989		4	3		10		17
1990		25	9	34	46		114
1992			1			4	5
1994		7					7
1996			21		38	19	78
1997			4	9	132	47	192
1998			40	34	190	111	375
1999			14	15	75	65	169
2000		64	7	16	108	41	236
2001		12	21	30	409	44	516
2002		41	14	24	222	28	329
2003		6	31	34	47	9	127
2004		11	10	2	22		45
2005		5	13	3	17	4	42
2006			7	17	143	24	191
2007		1	26	4	21	4	56
2008		69	13	6	44	15	147
2009		48	22	23	65	11	169
2010		45	58	78	160	48	389
2011		37	17	3	34	29	120
2012		12	80	20	339	89	540
2013	129	7	64	68	139	44	451
2014		218	6	2	156	39	421
2015		77	71	23	88	20	279
2016		202	158	45	260	46	711
2017		134	74	46	207	48	509
Total	129	1025	784	536	3028	793	6295

Table 6. Food samples (bill loads, partial bill loads, and ground samples) obtained annually from rhinoceros auklets on Middleton Island from 1978 through 2017

Year	No. samples	TotalMass (g)
1978	72	3109.2
1986	4	97.7
1990	17	199.4
1993	70	1407.2
1994	190	3680.1
1995	146	2217.1
1996	78	1488.0
1997	138	1707.6
1998	315	7816.6
1999	100	2688.3
2000	106	2537.8
2001	126	3888.6
2002	95	2706.7
2003	121	3461.6
2004	107	2889.9
2005	95	2749.3
2006	113	4393.8
2007	100	2470.0
2008	130	4514.9
2009	111	3079.4
2010	175	6297.6
2011	115	3430.8
2012	260	7011.6
2013	248	8732.3
2014	180	5920.0
2015	334	9351.0
2016	306	8988.5
2017	328	10,056.8
All years	4180	116,891.8

Table 7. Time series of kittiwake productivity, dietary capelin and PDO index during the breeding season on Middleton Island from 1978 through 2017.

Year	Mean PDO index (Jun- Aug)	Productivity	Capelin in diet (Jun- Aug)
1978	-0.55	0.14	0.0000
1979	0.51	--	--
1980	0.17	--	--
1981	0.90	0.47	--
1982	0.06	0.30	--
1983	2.57	0.03	--
1984	-0.01	0.76	--
1985	0.69	0.04	--
1986	0.83	0.05	--
1987	1.86	0.00	--
1988	0.52	0.21	--
1989	0.43	0.00	--
1990	0.27	0.00	0.0500
1991	-0.40	0.22	--
1992	1.53	0.24	--
1993	2.46	0.01	--
1994	-0.09	0.32	--
1995	1.06	0.17	--
1996	0.58	0.60	0.0526
1997	2.63	0.32	0.0000
1998	0.05	0.42	0.1373
1999	-0.97	0.19	0.0452
2000	-0.76	0.99	0.5394
2001	-0.85	1.03	0.1677
2002	-0.02	0.97	0.2956
2003	0.84	0.50	0.2333
2004	0.44	0.20	0.0000
2005	0.69	0.37	0.0000
2006	0.25	0.47	0.0163
2007	0.46	0.42	0.2414
2008	-1.57	0.78	0.6462
2009	-0.25	0.20	0.3535
2010	-0.85	0.78	0.8322
2011	-1.43	0.50	0.6061
2012	-1.44	0.87	0.7634
2013	-1.02	1.00	0.8247
2014	0.73	0.45	0.0152
2015	1.65	0.21	0.0076
2016	1.27	0.08	0.0313
2017	0.33	0.22	0.0332

Table 8. Effects of supplemental feeding on laying dates, clutch sizes and overall productivity of black-legged kittiwakes on the Middleton tower since 1996.

Year	Treatment effect (Fed - Unfed pairs)		
	Julian lay date	Clutch size	Chicks fledged
1996	-2.30	0.01	0.62
1997	-3.23	0.32	0.64
1998	-5.19	0.40	0.26
1999	-8.78	1.14	0.38
2000	-2.03	0.15	0.19
2001	-2.65	0.15	0.25
2002	0.79	0.10	0.00
2003	-4.58	0.14	0.41
2004	-2.87	0.41	0.79
2005	-6.67	0.19	0.66
2006	-7.09	0.34	0.67
2007	-4.90	0.24	0.35
2008	-3.13	0.19	0.12
2009	-4.40	0.20	0.55
2010	2.24	0.01	0.11
2011	-5.55	0.21	0.42
2012	-1.55	0.06	0.06
2013	0.15	0.13	0.04
2014	--	--	--
2015	-1.62	0.39	0.75
2016	-8.52	1.06	0.73
2017	-6.00	0.87	0.54
Mean	-3.71	0.32	0.41

Table 9. Pearson correlations among the Pacific Decadal Oscillation (PDO) index (June to August), relative occurrence of dietary capelin, and kittiwake chick production on Middleton Island over 38 years between 1978 and 2017.

Variable	Statistic	Variable	
		Chick production	Capelin in diet
Capelin in diet			
	Pearson's <i>r</i>	0.686	---
	<i>P</i> (2-tailed)	<0.001	---
	n (years)	24	---
PDO (Jun-Aug)			
	Pearson's <i>r</i>	-0.597	-0.700
	<i>P</i> (2-tailed)	<0.001	<0.001
	n (years)	38	24

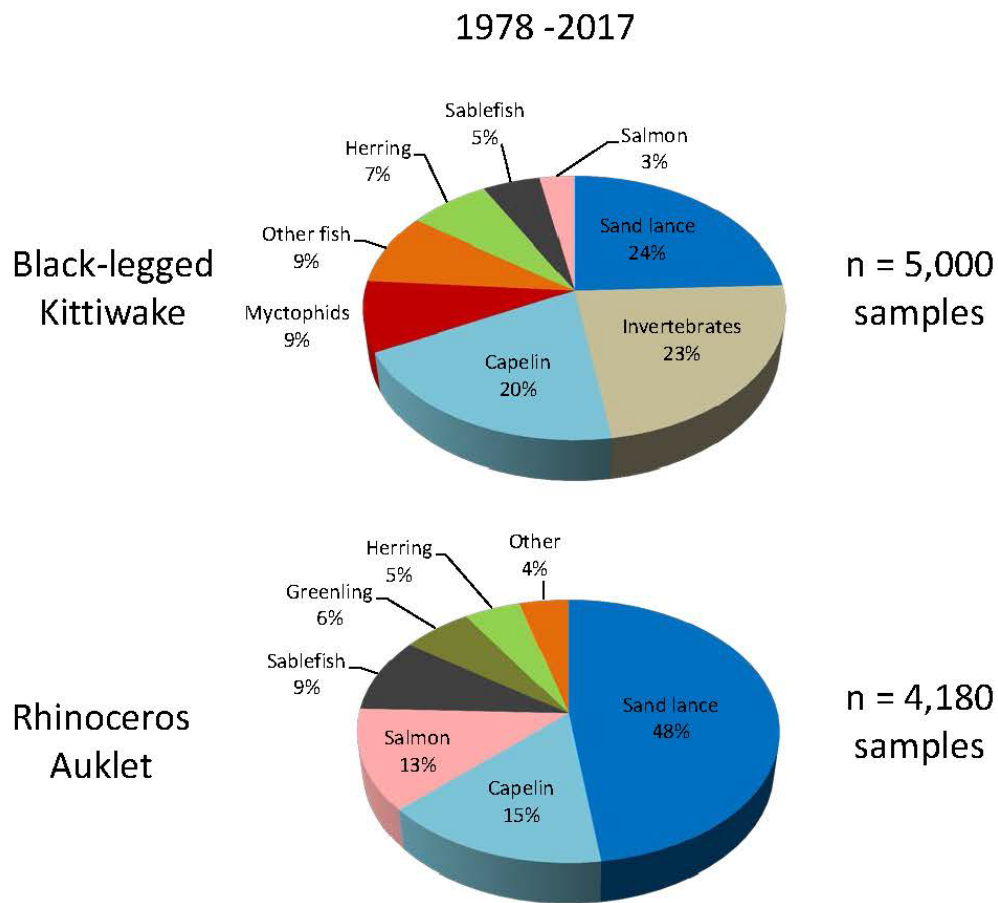


Figure 1. Overall composition of food samples obtained from black-legged kittiwakes (relative occurrence, April – August) and chick-rearing rhinoceros auklets (% biomass, July – August) on Middleton Island from 1978 to 2017.

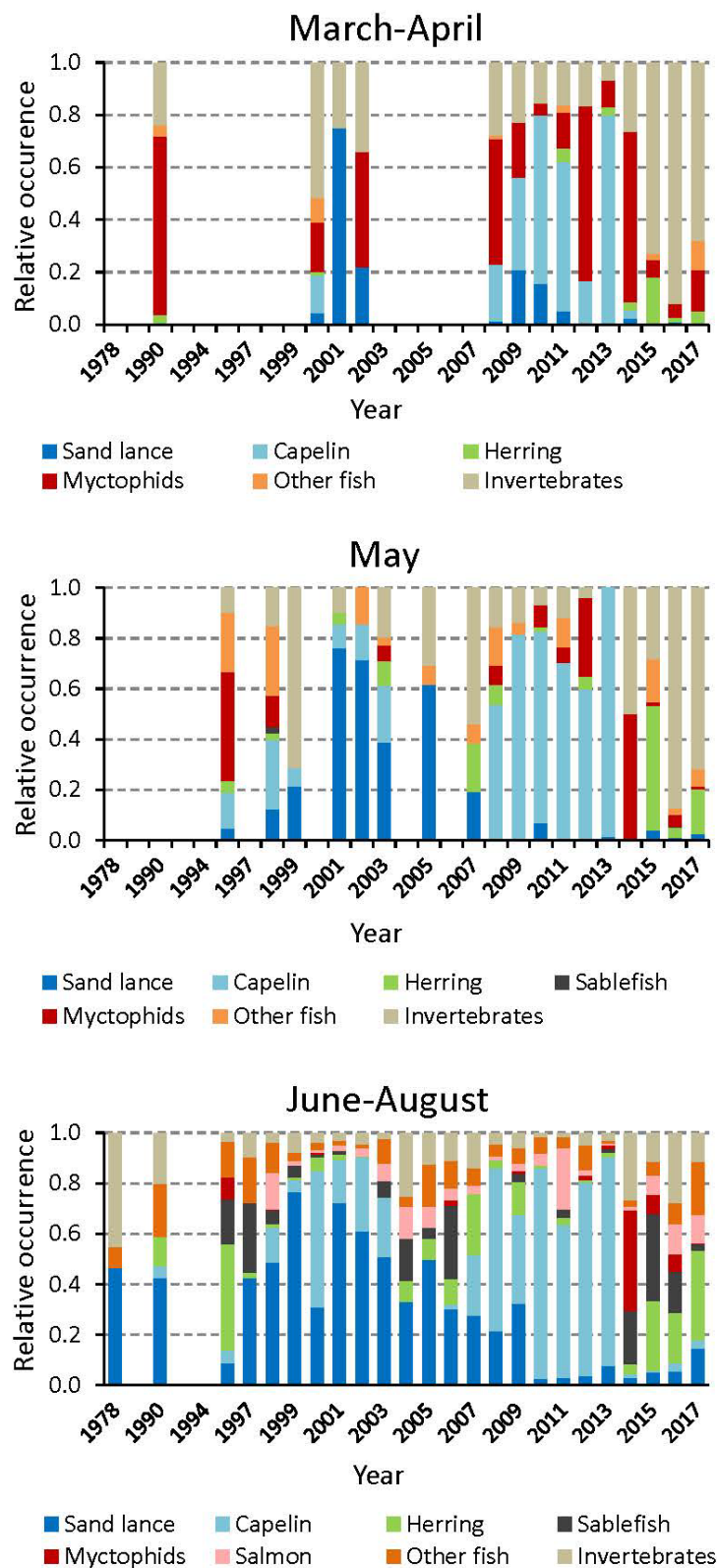


Figure 2. Interannual variation in kittiwake diet composition at three stages of breeding on Middleton Island, 1978 to 2017. Sample sizes as listed in Tables 4 and 5.

March -April

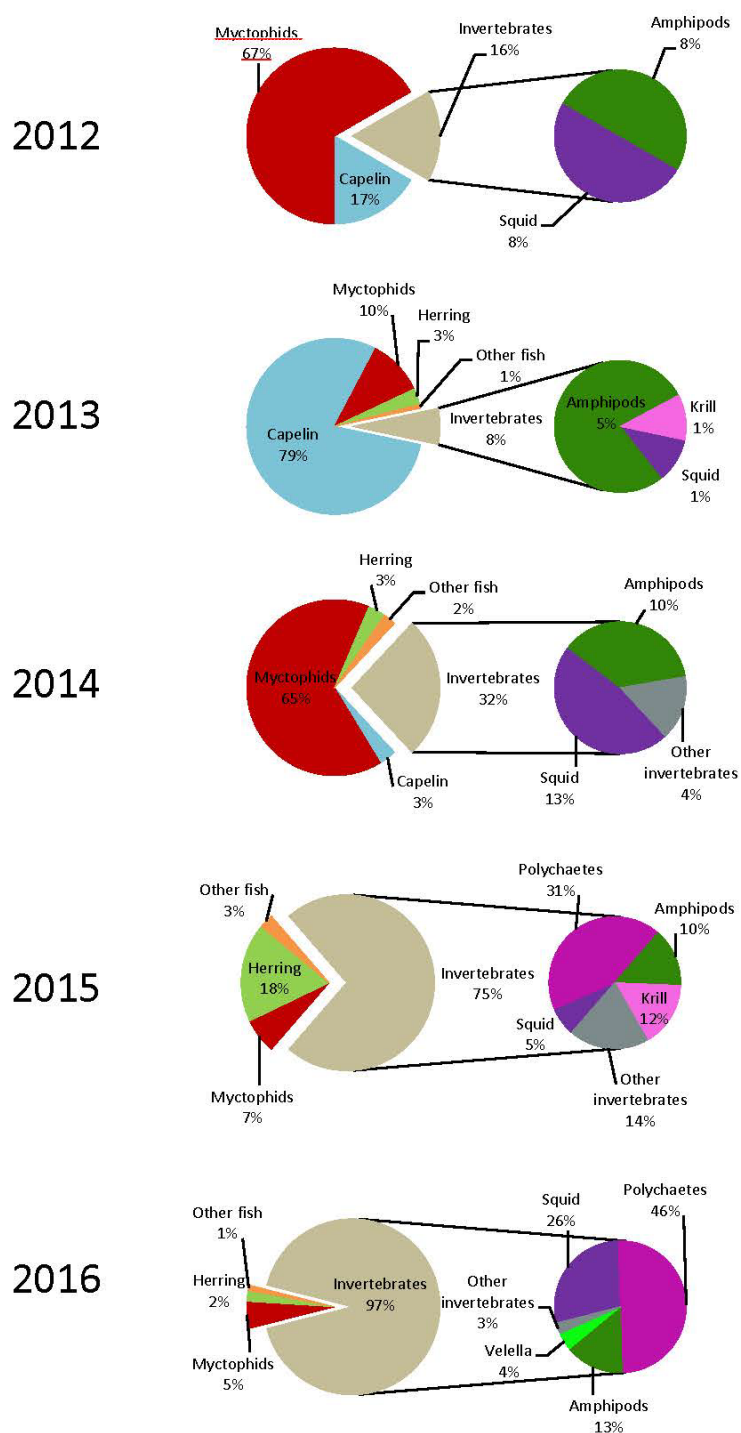


Figure 3. Variation in the relative occurrence and composition of invertebrates in the diet of black-legged kittiwakes on Middleton Island from spring arrival through April in 2012-2016.

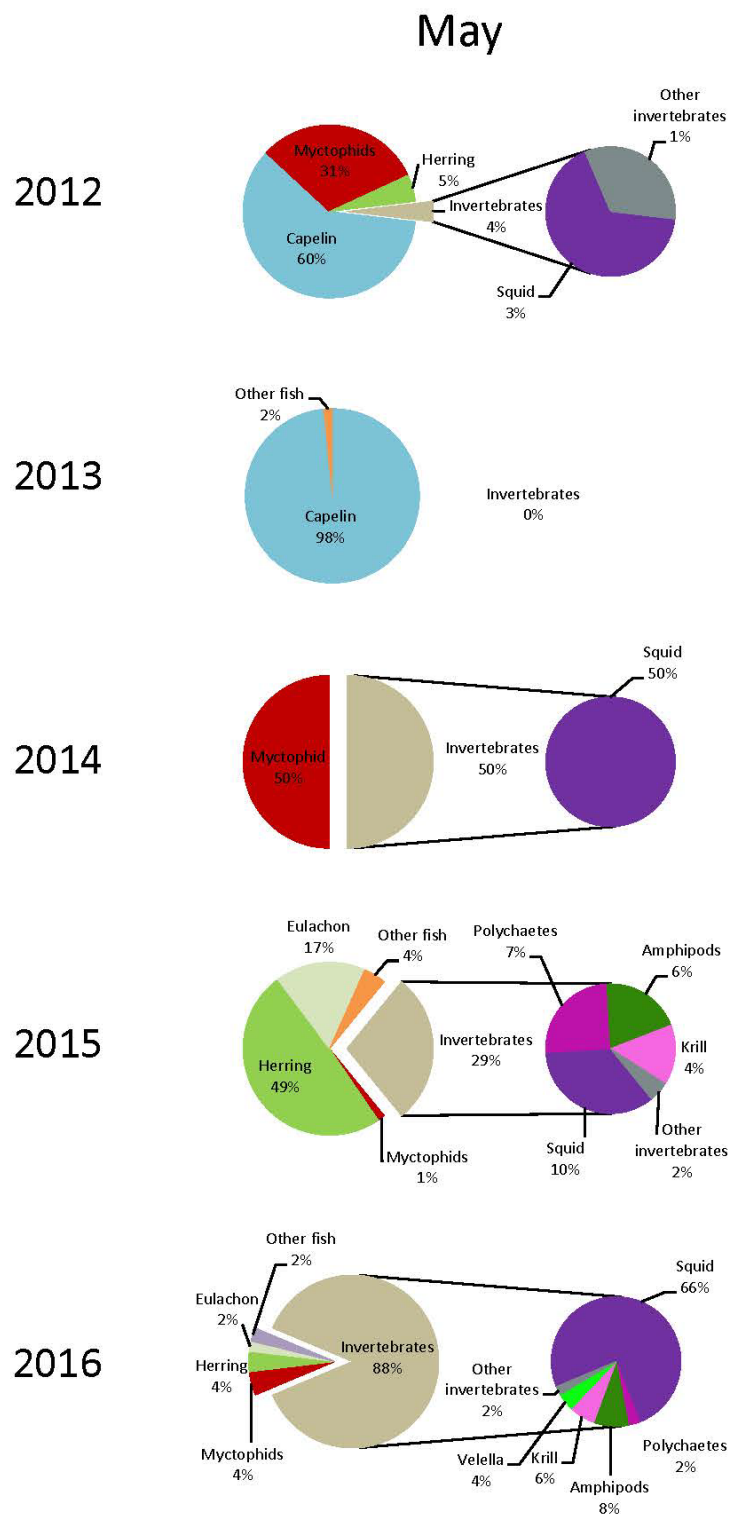


Figure 4. Variation in the relative occurrence and composition of invertebrates in the diet of black-legged kittiwakes on Middleton Island during May in 2012-2016.

2017

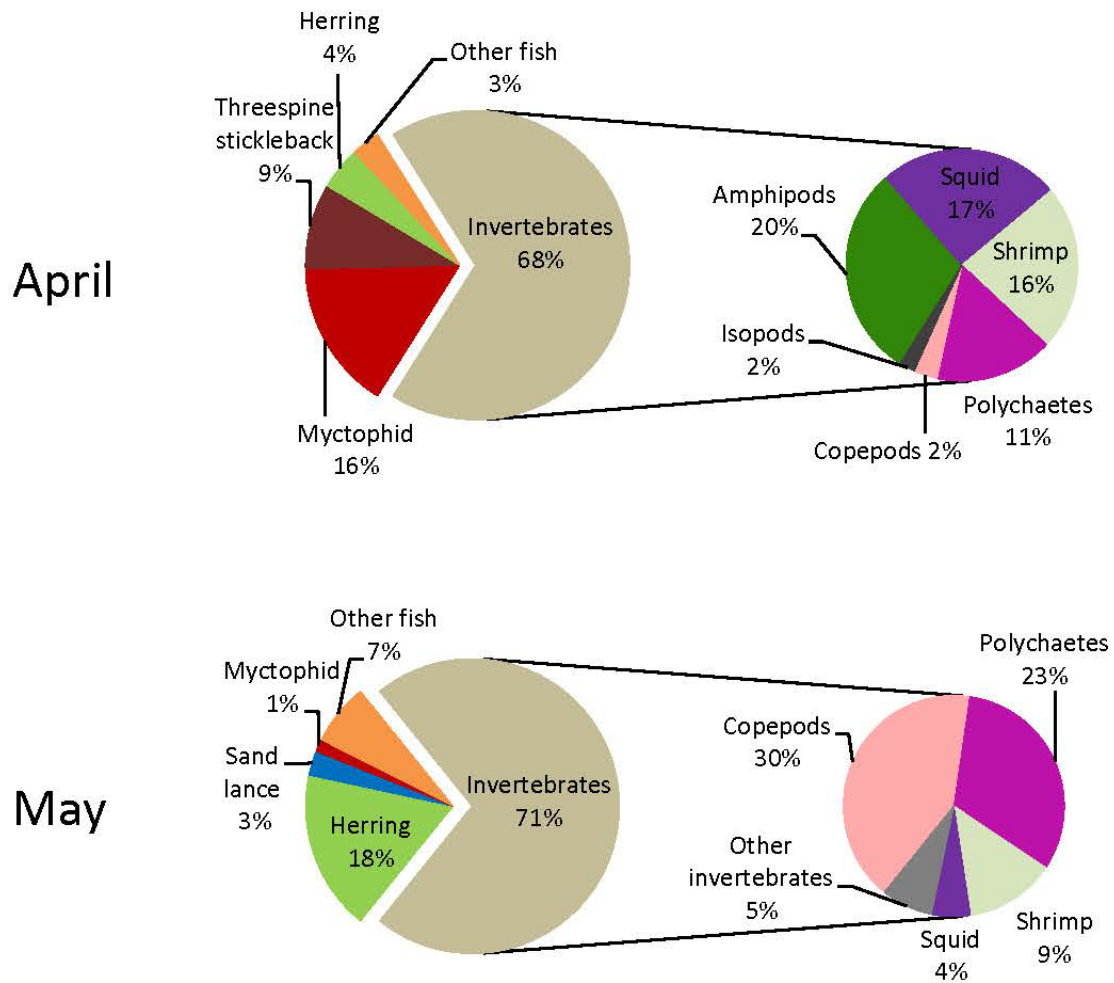


Figure 5. Variation in the relative occurrence and composition of invertebrates in the diet of black-legged kittiwakes on Middleton Island during April and May in 2017.

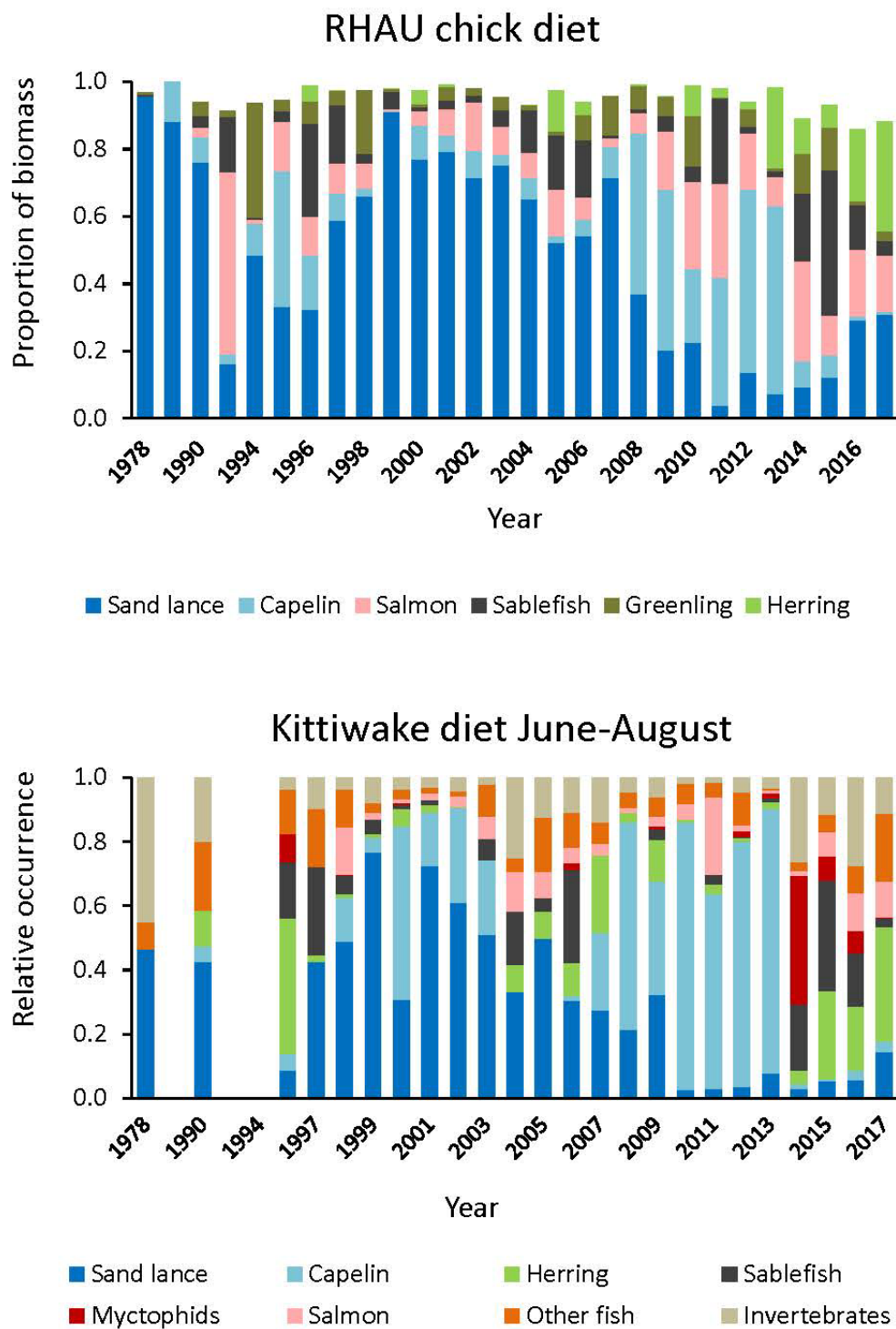


Figure 6. Interannual variation in diet composition of chick-rearing rhinoceros auklets on Middleton Island, 1978 to 2017, with a similar time series for black-legged kittiwakes (lower panel) for comparison. Sample sizes as listed in Tables 4, 5 and 6.

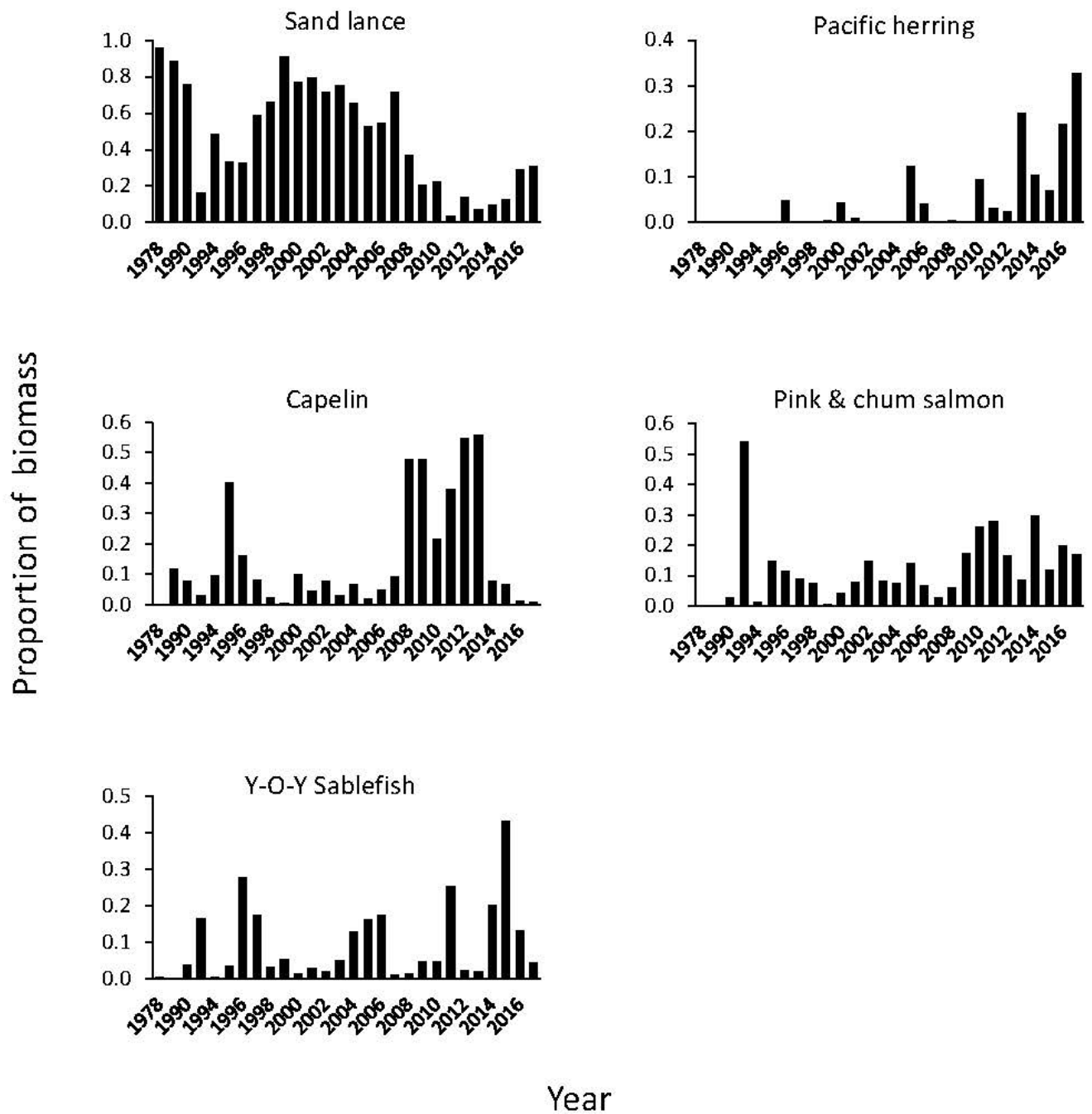


Figure 7. Indices of prey species occurrence in the nestling diet of rhinoceros auklets on Middleton Island from 1978 through 2017.

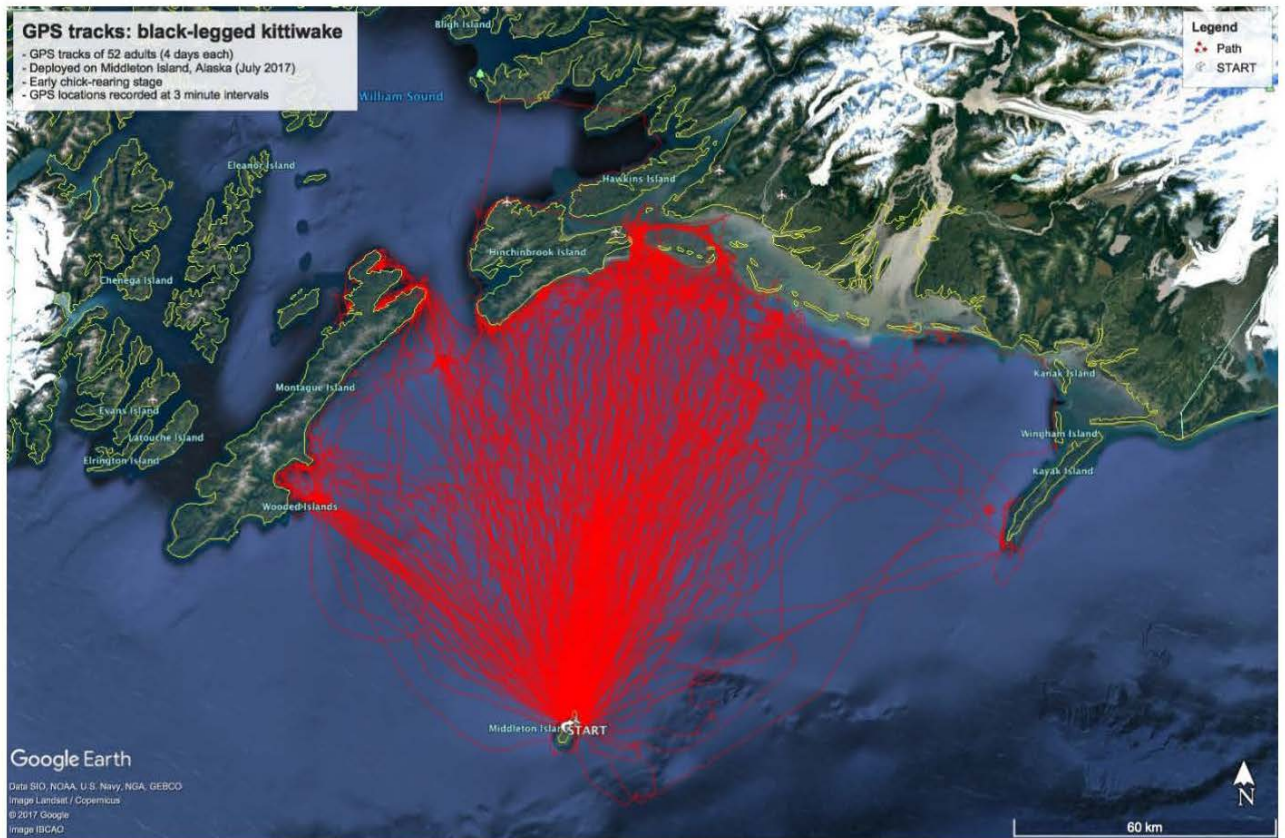


Figure 8. Foraging areas of Middleton Island kittiwakes during early chick-rearing as revealed by GPS tracking devices deployed on 52 individuals in July, 2017.

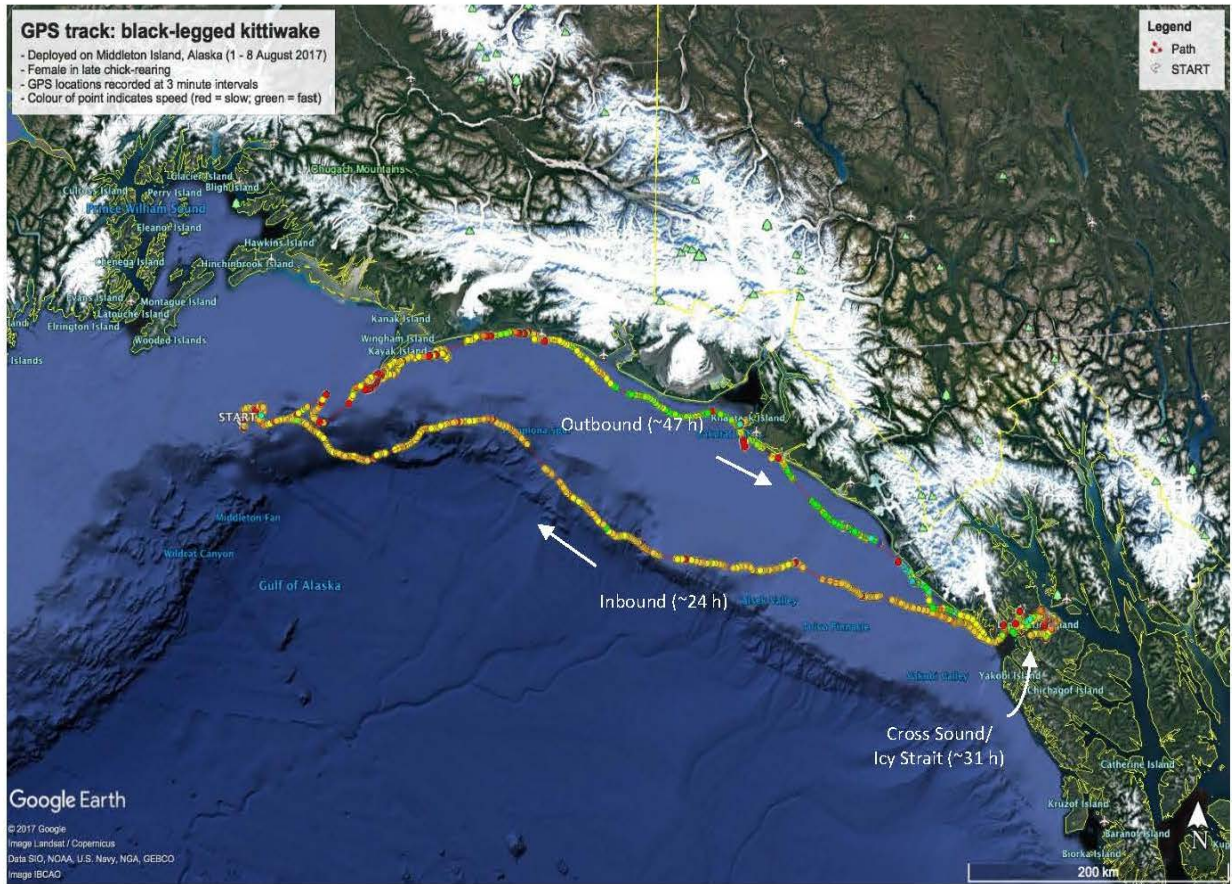


Figure 9. Long-distance foraging by a female, chick-rearing kittiwake from Middleton Island in early August, 2017.

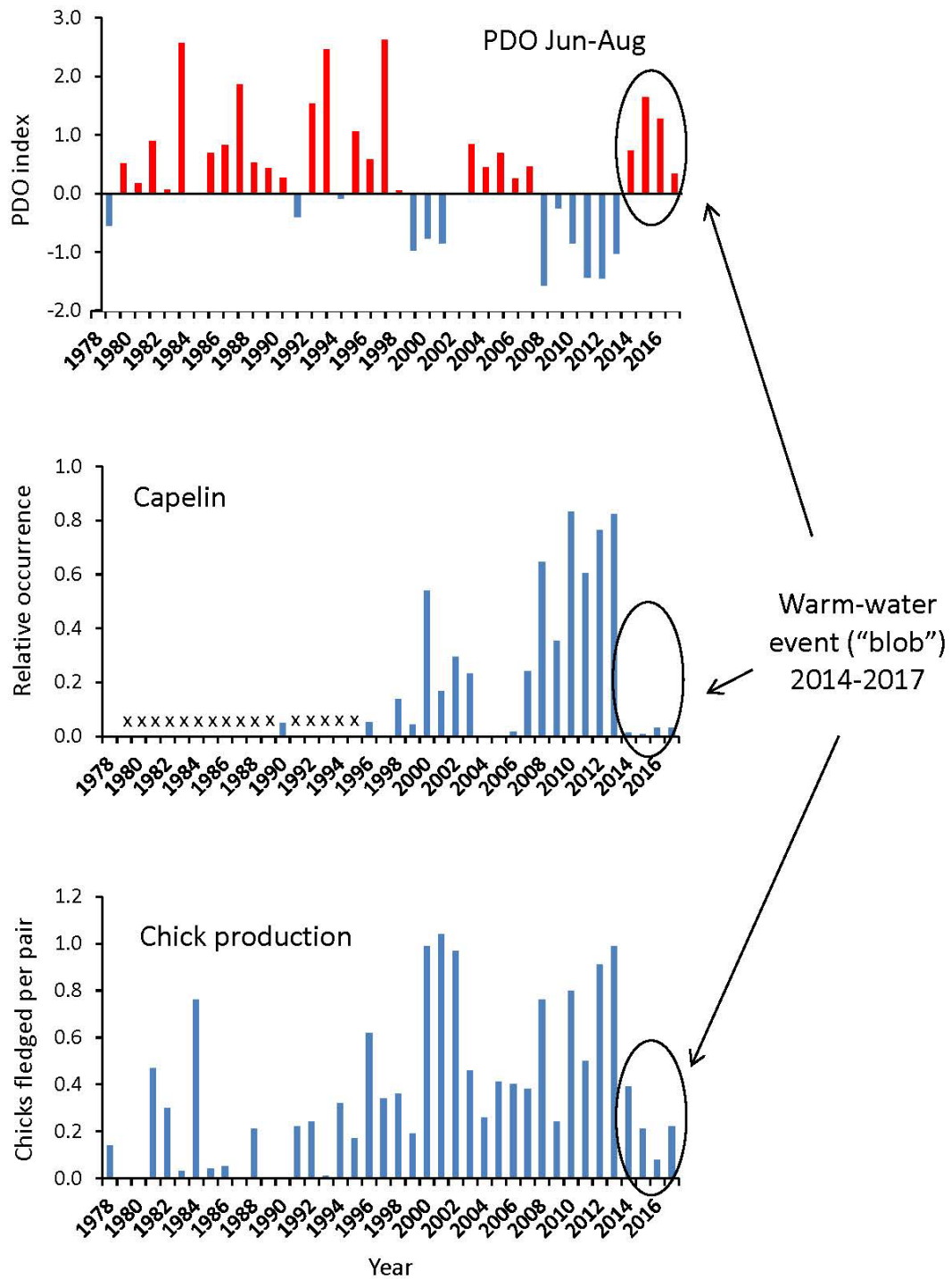


Figure 10. Relations among the Pacific Decadal Oscillation (PDO) index (June – August), the relative occurrence of dietary capelin, and the annual production of chicks by kittiwakes on Middleton Island, 1978 to 2017. Missing data denoted by ‘x’.

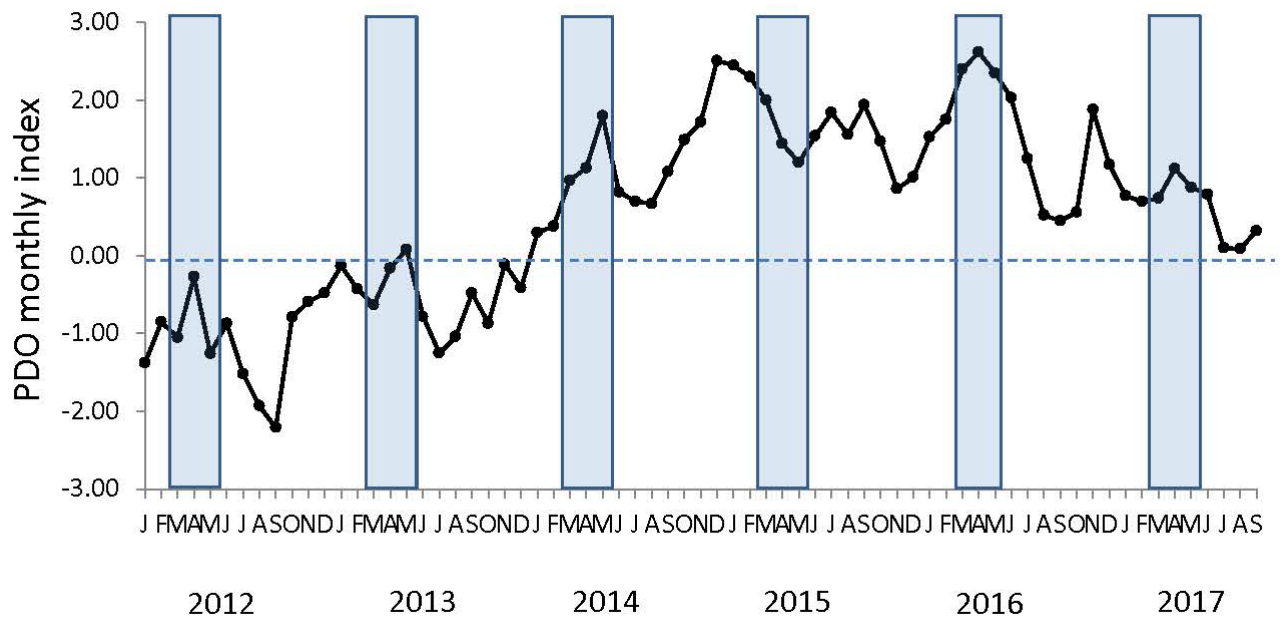


Figure 11. Pacific decadal oscillation (PDO) monthly index from January 2012 through September 2017, illustrating changes during the warm-water event from 2014-2017 and conditions prevailing during the spring prebreeding period (March – May) of kittiwakes on Middleton Island.

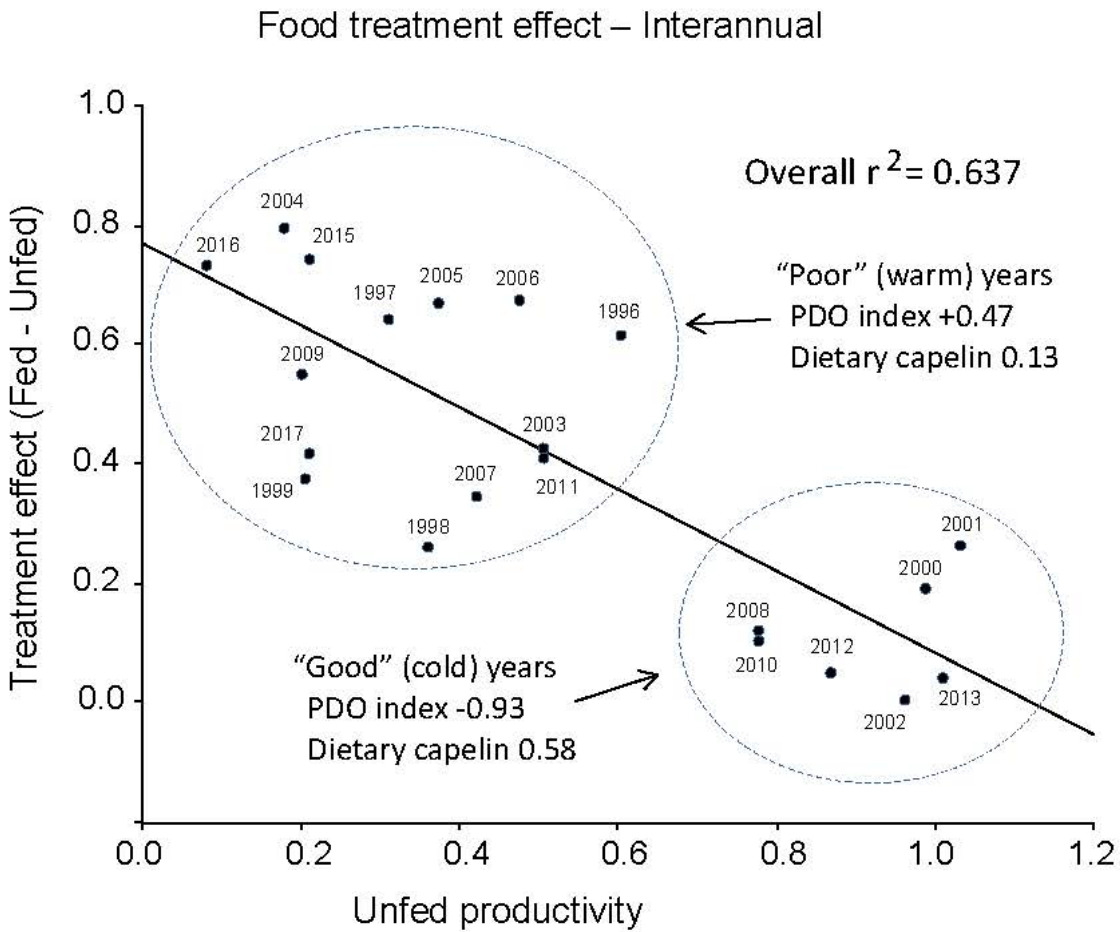


Fig. 12. Effect of supplemental food treatment on kittiwake breeding performance on Middleton Island in 21 years since 1996. Productivity of unfed pairs is a proxy for quality of the foraging environment. Treatment effect is the difference in productivity between supplementally fed and unfed pairs. “Poor” years are characterized by warm ocean conditions (PDO index June-August), a low proportion of capelin in the diet, and a marked effect of food treatment on kittiwake production. “Good” years have cool ocean conditions, a higher proportion of dietary capelin, and reduced or no difference in breeding performance of fed and unfed pairs.