NPAFC
Doc. 1848
Rev.

2018 Pink Salmon Harvest Forecast Models from Southeast Alaska Coastal Monitoring Surveys

by

James M. Murphy[1], Alex C. Wertheimer[1], Emily Fergusson[1], Andrew Piston[2], Steve Heinl[2],
Charles Waters[1], Jordan Watson[1], and Andrew Gray[1]

[1]National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center, Auke Bay Laboratories
17109 Point Lena Loop Road, Juneau, AK 99801 USA

[2]Alaska Department of Fish and Game, Division of Commercial Fisheries
2030 Sea Level Drive, Suite 205, Ketchikan, AK 99901 USA

Submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

United States of America

April 2019

THIS PAPER MAY BE CITED IN THE FOLLOWING MANNER:
Murphy, J.M., A.C. Wertheimer, E. Fergusson, A. Piston, S. Heinl, C. Waters, J. Watson, and A. Gray. 2019. 2018 pink salmon harvest forecast models from Southeast Alaska coastal monitoring surveys. NPAFC Doc. 1848. 19 pp. National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center, Auke Bay Laboratories, and Alaska Department of Fish and Game (Available at https://npafc.org).

2018 Pink Salmon Harvest Forecast Models from Southeast Alaska Coastal Monitoring Surveys

Keywords: Southeast Alaska, pink salmon, forecast models, juvenile salmon, ecosystem indicators

Abstract

Juvenile abundance indices from the Southeast Coastal Monitoring survey and ecosystem indicators are used to forecast harvests of Southeast Alaska (SEAK) pink salmon (*Oncorhynchus gorbuscha*). We describe the 2018 harvest forecast models and review the performance of the 2017 harvest forecast models. Goodness-of-fit statistics (AIC and AICc) and jackknife prediction errors were used to select the 2018 forecast models. Forecasts models were developed for the total harvest of pink salmon in SEAK and for the northern region of Southeast Alaska (NSEAK). Bootstrap confidence intervals (80%) of the model prediction were used as the forecast range. Two indices of juvenile abundance were considered in the 2018 harvest forecast models: $CPUE_{cal\_loc}$ (catch-per-unit-effort calibrated for sampling vessel and adjusted to balance sampling effort across transects or locations) and $CPUE_{ttd\_loc}$ (catch-per-distance-trawled adjusted to balance sampling effort across transects or locations). The model selected for total SEAK pink salmon harvest included the $CPUE_{cal\_loc}$ and the Icy Strait Temperature Index, and projected a harvest range from 10 M to 23 M with a point estimate of 13 M in 2018. The NSEAK pink salmon harvest model only included $CPUE_{cal\_loc}$, and projected harvest range of 0–3 M with a point estimate of zero in 2018.

Introduction

Southeast Alaska Coastal Monitoring (SECM) surveys have provided information on the status of juvenile salmon (*Oncorhynchus* spp.) and marine ecosystems in northern region of Southeast Alaska (SEAK) annually since 1997. The surveys support research on the marine ecology and production dynamics of SEAK salmon stocks and are used in forecast models of SEAK pink salmon harvests (Orsi et al. 2016; Wertheimer et al. 2018). Critical periods in the natural mortality of salmon are integral to the development of forecast models of abundance and harvest. The initial marine period of juvenile pink salmon (*O. gorbuscha*) is believed to be the primary determinant of year-class strength (Parker 1968; Mortensen et al. 2000; Willette et al. 2001; Wertheimer and Thrower 2007) due to the high and variable mortality that occurs during this life-history stage. SECM surveys provide unique insight into the relative importance of the initial and later marine stages of salmon to their overall survival by sampling juveniles after the initial marine entry stage (Murphy et al. 1999; Fergusson et al. 2018).

Pink salmon are primarily harvested in purse seine fisheries within the southern, northern-inside, and northern-outside sub-regions of SEAK. Purse seine fisheries account for an average 77% of the salmon harvested in SEAK and are managed primarily to target pink salmon (Clark et al. 2006; Conrad and Gray 2018). Annual ex-vessel value of the SEAK pink salmon fishery is variable due to large year-to-year variation in adult returns, fluctuating from approximately 16 to 124 million dollars over the recent decade 2007–2016 (ADF&G, 2018). Pink salmon spawn in over 2,000 streams throughout the SEAK region (Baker et al. 1996), and wild stocks comprise 97% of harvests (Piston and Heinl 2017). Pink salmon harvest and escapement (spawner abundance) is monitored and managed by the Alaska Department of Fish and Game (Clark et al. 2006; Piston and Heinl 2014). Spawner abundance is monitored in index streams throughout SEAK from aerial surveys during their primary spawning period. An index of spawner abundance (escapement) is constructed from peak counts of pink salmon within these index streams.

Juvenile abundance is uniquely informative to pink salmon. Due to their short, two-year life cycle, the adult population consists of a single age class that returns in the same year, and therefore adult sibling data cannot be used to provide insight into cohort strength. Uncertainty in spawner abundance and highly variable marine survival (Heard 1991; Haeseker et al. 2005) limit the utility of spawner/recruit models to project future abundance of pink salmon. As a result, simple or “naïve" models often outperform more complex spawner/recruit models (Haeseker et al. 2005). Wertheimer et al. (2006) documented a highly significant relationship between annual peak juvenile pink salmon catch-per-unit-effort (CPUE) from SECM surveys conducted in June or July and the SEAK harvest of adults in the following year. CPUE data have been supplemented with ecosystem indicators (Orsi et al. 2016; Wertheimer et al. 2018) and used as auxiliary data to improve exponential smoothing models used by the Alaska Department of Fish and Game (ADF&G) to generate pink salmon harvest forecasts (Piston and Heinl 2017). The use of ecosystem indicators to model natural mortality processes is becoming more common in stock assessment (Hollowed et al. 2011) and salmon production models (Miller et al. 2013; Orsi et al. 2016).

Methods

Data on juvenile pink salmon abundance, size, and growth, and associated ecosystem indicators have been collected by the SECM project annually since 1997; descriptions of the sampling locations and data collections have been reported in annual NPAFC documents (Fergusson et al. 2018). The survey data used in the forecast models stem from eight stations along two transects (IS=Icy Strait and UC=Upper Chatham) within Icy Strait in the northern region of SEAK. These stations were sampled monthly from May to August 1997–2016 (Figure 1).

Pink Salmon Harvest Data

Landed pink salmon harvest (weight) from individual commercial fishermen are recorded on fish tickets, and catch in units of total weight are converted into units of fish numbers by estimates of average weight. Fish ticket data are entered into the ADF&G Fish Ticket Database System, and the total weight and the estimated total number of commercially harvested salmon is available in electronic format to biologists in various time and spatial summaries for all years since 1975 (ADF&G, 2018).

Juvenile Pink Salmon Abundance

We considered two approaches for standardizing trawl catch for fishing effort and estimating juvenile pink salmon CPUE. $CPUE_{cal}$ uses vessel calibration factors to account for differences in vessel fishing power (Wertheimer et al. 2010), and all catches are standardized to a trawl duration of 20 minutes. $CPUE_{ttd}$ corrects for fishing effort by the distance trawled (trawl-track-distance, ttd) during each trawl haul (Wertheimer et al. 2018). Both indices are based on peak-month log-transformed peak catch-per-unit-effort ln (CPUE+1) in June or July, with the peak-month defined as the month with the highest average in a given year.

SECM surveys have sampled the two transects in Icy Strait with balanced and unbalanced sampling effort (Appendix 1–4). We decided to balance the sampling effort across the IS and UC transects by averaging the transect means rather than taking the overall average of all stations sampled within a given month. This decision was due to the large differences in mean catch rate by transect that was present in 2017 and the unbalanced sampling effort. The modified indices were identified as $CPUE_{cal\_loc}$ and $CPUE_{ttd\_loc}$ (Table 1).

Ecosystem Indicators

We evaluated the utility of six indicators to improve harvest forecast models based on juvenile abundance alone (Table 2). Indicators included the size and condition of juvenile pink salmon, which have an ecological connection to natural mortality, and four ecosystem indicators. We only considered indicators that were available during the fall to allow forecast models to be developed well in advance of the fishing season. The indicator of juvenile size was the weighted average length (mm, fork length) adjusted to a standard date (July24Size) based on juvenile growth rates between June and July. The overall average growth rate between June and July was used when juvenile size was not available in June or July. The juvenile condition indicator (Condition) was the average annual residuals derived from the regression of all paired Ln (weights) and Ln (lengths) for pink salmon collected during SECM sampling since 1997 (Wertheimer et al. 2018). Ecosystem indicators included one local index, the Icy Strait Temperature Index (ISTI), and three basin-scale indices: the winter and summer Pacific Decadal Oscillation (PDO_{win} and PDO_{sum}) Index, and the winter Multivariate El-Nino Southern Oscillation Index (MEI_{win}). ISTI was the average 20-m integrated water column temperature at the IS and UC stations sampled during the SECM surveys in May, June, July and August each year. The PDO is the first principal component of water temperatures from a broad array of sites in the North Pacific that has been linked to year-class strength of juvenile salmon during their first year at sea (Mantua et al. 1997). PDO_{win} was the average November to March PDO during the winter prior to juvenile pink salmon seaward migration, and PDO_{sum} was the average PDO in June, July, and August during their seaward migration. The winter (November to March) Multivariate El Niño Southern Oscillation (ENSO) Index (MEI, NCDC 2007) measures conditions in the equatorial Pacific Ocean that reach Alaska during the subsequent summer. Therefore the MEI_{win} reflects equatorial forcing of climate conditions experienced by juvenile salmon during their seaward migration.

Forecast Models

Juvenile abundance and ecosystem indicators were combined in a multivariate linear regression model, and Akaike Information Criterion (AIC) was used to select the most parsimonious forecast model of harvest using a backward and forward stepwise model selection approach in R (R core team, 2017). AIC values corrected for small sample sizes (AIC_c; Shono 2000) were then used to test if simpler models were more appropriate given the sample size of the regression model. Jackknife model prediction errors were used to select the final model based on the mean absolute prediction error (MAPE) and median absolute prediction error (MEAPE). The forecast range was based on 80% confidence interval from bootstrap resampling models of the individual trawl catches. Harvest forecast models were constructed for total pink salmon harvest in SEAK and harvest within the northern region of SEAK. Juvenile catch rates are significantly correlated with pink salmon harvest at both the regional (total SEAK) and local (northern region of SEAK) spatial scale. Although the primary interest and focus is on the regional harvest, we hope to be able to gain insight into the model structure and parameters by forecasting harvest on both spatial scales.

The regression model was defined as:

$$\text{Harvest} = \alpha + \beta(Y) + \gamma_1 X_1 + \ldots + \gamma_n X_n + \varepsilon,$$

Where Y is Ln (CPUE+1), γ_n is the coefficient for ecosystem indicator X_n, and $\mathcal{E}$ the normally distributed error term. $CPUE_{cal\_loc}$ and $CPUE_{ttd\_loc}$ were evaluated as potential forecast models for pink salmon harvest in 2018. $CPUE_{cal}$ and $CPUE_{ttd}$ were included for comparison purposes. Models were constructed for harvest and not total run; therefore, difference between harvest and total run is included in the error term of the forecast model. Forecast model performance for the 2017 harvest (Werthiemer et al. 2018) is also reviewed.

Results

2018 Forecast

Model performance and harvest projections for the selected 2018 forecast models are included in Table 3. We included model selection for the standard CPUE indices and the CPUE indices adjusted for unbalanced sampling but limited the final model selection to adjusted CPUE indices due to the unbalanced sampling in 2017. A two parameter model ($CPUE_{cal\_loc}$ and ISTI) was selected for total SEAK pink salmon harvest. The model had the lowest AICc, MAPE, and MAPE values of the adjusted CPUE indices and accounted for 67% (Adjusted R^2) of the variability in harvest data (Figure 2, Table 3). The harvest forecast for SEAK was 10–23 M fish, with a point estimate of 13 M. A single parameter model ($CPUE_{cal\_loc}$) was selected for pink salmon harvest in NSEAK. This model had the lowest AICc, MAPE, and MAEPE values of the adjusted CPUE indices and accounted for 59% (Adjusted R^2) of the variability in harvest data (Figure 3, Table 3). The harvest forecast for NSEAK was truncated at zero, resulting in projected harvest of 0–3 M fish, with a point estimate of zero.

2017 Forecast Performance

The 2017 forecast included a review of ecosystem indicators and their interaction with juvenile CPUE indices in harvest forecast models. Two indices of juvenile abundance ($CPUE_{cal}$ and $CPUE_{ttd}$) as well as the average rank of ecosystem indicators were evaluated for forecast efficacy. The forecast model selected for 2017 included two parameters, the $CPUE_{cal}$ juvenile abundance index and the ISTI index. This model had the lowest jackknife prediction error, was intermediate in the range of forecasts in relation to forecasts from the alternative abundance parameters, and provided a good statistical fit to the harvest data. The 2017 forecast for SEAK pink salmon harvest from this model was 46.2 M with an 80% bootstrap prediction interval of 28–64 M fish. Actual harvest in 2017 was 34.3 M and was within the expected range.

Discussion

Multiple factors contribute to differences between predicted and observed harvest (Figures 2 and 3). Several factors, such as error in estimates of juvenile abundance and offshore mortality, are inherent in the underlying design of the SECM survey. Although offshore habitats have been sampled by the survey in the past, the survey is principally designed to sample marine habitats in inside waters of SEAK, which limits its ability to address mortality processes that occur in the offshore habitats in the Gulf of Alaska (GOA). The use of an abundance index based on peak monthly CPUE rather than actual abundance has an inherent error due to migratory patterns of juveniles. This not only contributes to random error, but it may also alter how the abundance index is related to true abundance. If the proportion of SEAK juvenile pink salmon that utilize the northern corridor (Icy Strait) varies between warm and cold years, the significance of temperature (ISTI) in the forecast model could reflect juvenile migratory patterns rather than survival. Alternatively, these two ecological processes could be confounded within the forecast error.

Although forecast models that include ecosystem indicators tend to outperform models that are based on juvenile abundance alone (Wertheimer et al. 2018), it can be difficult to interpret how ecosystem indicators contribute to a forecast model due to the complex and dynamic nature of ecosystem-level processes. This is particularly true if more than one indicator is used. Overwinter mortality in marine ecosystems is believed to be an important component in the production dynamics of Pacific salmon (Beamish and Mahnken 2001; Moss et al. 2005). Offshore ecosystem processes and overwinter mortality are not explicitly part of our forecast models, but they could become more important in the future. The Gulf of Alaska (GOA) experienced unprecedented warm climate conditions with the advent of the marine heatwave known as "The Blob" in 2014 (Bond et al. 2015). The Blob is believed to have amplified the warming effect of the 2015–2016 El Niño, resulting in record high temperatures in the GOA (DiLorenzo and Mantua 2016) during 2015 and 2016. Surface temperatures in the GOA have returned back to near average, but marine heatwaves in the North Pacific and GOA are expected to become more frequent in the future due to the loss of sea ice and warming in the Arctic (DiLorenzo and Mantua 2016). However, an improved understanding of how and why temperatures in inside waters of SEAK contribute to the forecast model performance will be needed before we can account for mortality processes in offshore habitats of the GOA.

Acknowledgments

We thank the vessel captains and crews and the many biologists, students, contractors, and volunteers who have contributed to SECM sampling over the past 21 years. We also thank the Northern Fund of the Pacific Salmon Commission and the Alaska Sustainable Salmon Fund for providing funding support for SECM surveys. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of the National Oceanic and Atmospheric Administration, or the U.S. Department of Commerce.

Literature Cited

ADF&G. 2017. Commercial Salmon Catch, Effort, and Value. Alaska Department Fish and Game Commercial Fisheries Division.

Baker, T. T., A.C. Wertheimer, R. D. Burkett, R. Dunlap, D. M. Eggers, E. I. Fritts, A. J. Gharrett, R. A. Holmes, and R. L. Wilmot. 1996. Status of Pacific salmon and steelhead escapements in southeastern Alaska. Fisheries 21(10):6–19.

Beamish, R. J., and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49:423–437.

Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 anomaly in the NE Pacific. Geophysical Research Letters 42: 3414–3420.

Clark, J. H., A. McGregor, R. D. Mecum, P. Krasnowski, and A. M. Carroll. 2006. The commercial salmon fishery in Alaska. Alaska Fishery Research Bulletin 12:1–146.

Conrad, S., and D. Gray. 2018. Overview of the 2017 Southeast Alaska and Yakutat commercial, personal use, and subsistence salmon fisheries. Alaska Department of Fish and Game, Fishery Management Report No. 18-01, Anchorage.

Di Lorenzo, E. and N. Mantua. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change 6:1042.

Fergusson, E., J. Watson, A. Gray, and J. Murphy. 2018. Annual survey of juvenile salmon, ecologically-related species, and biophysical factors in the marine waters of southeastern Alaska, May–August 2016. NPAFC Doc. 1771. 66 pp. National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center, Auke Bay Laboratories, Ted Stevens Marine Research Institute (Available at https://npafc.org).

Haeseker, S. L., R. M. Peterman, Z. Su, and C. C. Wood. 2005. Retrospective evaluation of preseason forecasting models for pink salmon. North American Journal of Fisheries Management 25:897-918.

Heard, W. R. 1991. Life history of pink salmon (*Oncorhynchus gorbuscha*). pp. 119–230 In: C. Groot and L. Margolis (editors). Pacific Salmon Life Histories. Vancouver, B.C., Canada, UBC Press.

Hollowed, A. B., M. Barange, S.-i. Ito, S. Kim, H. Loeng, and M. A. Peck. 2011. Effects of climate change on fisheries: forecasting impacts, assessing ecosystem responses, and evaluating management strategies. ICES Journal Marine Science: Journal du Conseil 68: 984–985.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Journal of Climatology 8:241–253.

Miller, J. A., D. Teel, A. Baptista, and C. Morgan. 2013. Disentangling bottom-up and top-down effects on survival during early ocean residence in a population of Chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Science 70(4): 617–629.

Mortensen, D. G., A. C. Wertheimer, S. G. Taylor, and J. H. Landingham. 2000. The relation between early marine growth of pink salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fishery Bulletin 98:319–335.

Moss, J. H., D. A. Beauchamp, A. D. Cross, K. W. Myers, E. V. Farley, J. M. Murphy, and J. H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. Transactions of the American Fisheries Society 134:1313–1322.

Murphy, J. M., A. L. Brase, and J. A. Orsi. 1999. Survey of juvenile Pacific salmon in the northern region of southeastern Alaska, May–October 1997. U. S. Dept. of Commer. NOAA Tech. Memo NMFS-AFSC-105, 40p.

NCDC. 2007. Multivariate ENSO index. NOAA Climate Data Center. www.cdc.noaa.gov/people/klaus.wolter/MEI/mei.html

Orsi, J.A., E.A. Fergusson, A.C. Wertheimer, E.V. Farley, and P.R. Mundy. 2016. Forecasting pink salmon production in Southeast Alaska using ecosystem indicators in times of climate change N. Pac. Anadr. Fish Comm. Bull. 6:483–499.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. Journal Fisheries Research Board Canada 25:757–794.

Piston, A. W., and S. C. Heinl. 2014. Pink salmon stock status and escapement goals in Southeast Alaska. Alaska Department of Fish and Game, Special Publication No. 14-14, Anchorage.

Piston, A., and S. Heinl. 2017. Forecast area Southeast Alaska, species pink salmon. Pp. 49-54. In: R. E. Brenner and A. R. Munro (eds.), Run forecasts and harvests projections for 2017 Alaska salmon fisheries and a review of the 2016 season. Alaska Department Fish and Game Special Publication 17–08.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Shono, H. 2000. Efficiency of the finite correction of Akaike's information criteria. Fisheries Science 66:608–610.

Wertheimer A. C., J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson. 2006. Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters. pp. 65–72 In: H. Geiger (Rapporteur) (ed.), Proceedings of the 22nd Northeast Pacific Pink and Chum Workshop. Pacific Salmon Commission, Vancouver, British Columbia.

Wertheimer, A. C., and F. P. Thrower. 2007. Mortality rates of chum salmon during their initial marine residency. American Fisheries Society Symposium Series 57:233–247.

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2010. Calibration of Juvenile Salmon Catches using Paired Comparisons between Two Research Vessels Fishing Nordic 264 Surface Trawls in Southeast Alaska, July 2009. (NPAFC Doc. 1277). Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 19 pp. (Available at https://npafc.org).

Wertheimer, A. C., J. A. Orsi, and E. A. Fergusson. 2018. Forecasting pink salmon harvest in southeast Alaska from juvenile salmon abundance and associated biophysical parameters: 2016 returns and 2017 forecast. Auke Bay Laboratory Manuscript, Alaska Fisheries Science Center, NOAA, NMFS. 25 pp. (Available at https://npafc.org).

Willette, T. M., R. T. Cooney, V. Patrick, D. M. Mason, G. L. Thomas, and D. Scheel. 2001. Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fisheries Oceanography 10(1):14–41.

Table 1. Adult pink salmon harvests in Southeast Alaska (SEAK) and in the northern region of Southeast Alaska (NSEAK) and catch-per-unit-effort (CPUE) indices of juvenile pink salmon abundance used in 2018 pink salmon harvest forecast models. $CPUE_{cal}$ is an index calibrated for surface trawl fishing power differences between vessels, and $CPUE_{cal\_loc}$ is adjusted to balance sampling effort between the two primary sampling transects. $CPUE_{ttd}$ is catch-per-distance-trawled, and $CPUE_{ttd\_loc}$ is adjusted to balance sampling effort between the two primary sampling transects.

Juvenile Year	SEAK Harvest (M)	NSEAK Harvest (M)	$CPUE_{cal}$	$CPUE_{ttd}$	$CPUE_{cal\_loc}$	$CPUE_{ttd\_loc}$
1997	42.5	18.70	2.48	2.48	2.22	2.22
1998	77.8	38.96	5.62	5.62	5.32	5.32
1999	20.2	7.87	1.60	1.60	1.39	1.39
2000	67.0	15.01	3.73	3.61	3.34	3.23
2001	45.3	22.00	2.87	2.87	2.64	2.64
2002	52.5	23.19	2.78	2.74	2.48	2.43
2003	45.3	24.39	3.08	3.08	2.74	2.74
2004	59.1	30.26	3.90	3.79	3.39	3.28
2005	11.6	8.34	2.04	2.01	1.72	1.68
2006	44.8	13.02	2.58	2.35	2.27	2.05
2007	15.9	2.27	1.17	1.12	0.97	0.93
2008	38.0	11.60	2.49	2.38	2.18	2.08
2009	23.4	10.34	2.09	2.04	2.68	2.61
2010	59.0	47.67	3.67	3.52	5.01	4.89
2011	21.3	2.69	1.35	1.40	1.64	1.69
2012	94.7	41.10	3.15	2.94	4.26	3.95
2013	37.2	4.00	1.91	1.78	2.61	2.42
2014	35.0	22.70	3.40	3.42	4.62	4.65
2015	18.4	2.04	2.19	2.13	2.85	2.76
2016	34.3	24.70	3.89	3.89	5.31	5.32
2017	TBD	TBD	0.31	0.58	0.36	0.68
Average	**42.19**	**18.54**	**2.68**	**2.64**	**2.86**	**2.81**

Table 2. Annual ecosystem indices considered in pink salmon harvest forecast models. July24Size and Condition (unitless) are juvenile pink salmon indices. ISTI is a regional temperature index in Icy Strait. PDOsum, PDOwin, and MEIwin are large-scale climate indices of the North Pacific Ocean.

Juvenile Year	July24Size (mm)	Condition	ISTI (°C)	PDOsum	PDOwin	MEIwin
1997	133.67	0.026	9.48	-0.22	0.24	2.63
1998	132.09	-0.002	9.57	2.59	1.24	0.05
1999	115.27	-0.033	8.97	-1.01	-0.45	-0.97
2000	126.57	-0.016	9.04	-1.01	-1.24	-0.76
2001	116.97	0.000	9.44	-0.51	0.27	-0.85
2002	113.19	-0.050	8.56	0.00	-0.60	-0.02
2003	120.87	-0.022	9.78	0.94	1.79	0.84
2004	128.74	0.010	9.66	0.32	0.47	0.44
2005	130.20	0.025	10.26	0.72	0.36	0.69
2006	118.90	-0.011	8.88	-0.49	0.09	0.25
2007	124.70	-0.028	9.31	0.65	-0.08	0.46
2008	108.79	-0.015	8.29	-1.20	-0.83	-1.57
2009	123.06	0.007	9.61	-0.59	-1.33	-0.25
2010	124.55	-0.016	9.62	1.20	0.35	-0.85
2011	115.33	-0.023	8.90	-1.56	-0.89	-1.43
2012	119.32	0.014	8.73	-0.65	-1.48	-1.44
2013	129.58	0.002	9.16	0.05	-0.45	-1.02
2014	127.52	-0.019	9.37	-0.08	0.23	0.73
2015	153.24	0.041	9.86	0.63	2.20	1.65
2016	145.13	0.029	10.56	2.15	1.51	1.27
2017	120.69	0.018	8.93	0.04	0.33	1.05
Average	**125.16**	**0.000**	**9.3**	**0.09**	**0.08**	**0.04**

Table 3. Selected 2018 pink salmon harvest forecast model summaries for the total Southeast Alaska (SEAK) and northern Southeast Alaska (NSEAK) harvest regions. Model variables include juvenile catch-per-unit-effort ($CPUE_{cal}$ and $CPUE_{cal\_loc}$) and the Icy Strait Temperature Index (ISTI). Model estimates and bootstrap confidence intervals (LCI80 and UCI80) are included (in millions). Model performance statistics include: R^2 and $AdjR^2$ (model coefficients of determination), *AIC and AICc* (Akaike Information Criteria), and *MAPE* and *MEAPE (*mean and median absolute prediction errors).

Region	**Model**	**Estimate**	**LCI80**	**UCI80**	R^2	$AdjR^2$	***AIC***	***AICc***	***MAPE***	***MEAPE***
SEAK	$CPUE_{cal}$+ISTI	7	5	18	0.74	0.71	160	162	21%	17%
	$CPUE_{cal\_loc}$+ISTI	13	10	23	0.71	0.67	162	165	22%	17%
NSEAK	$CPUE_{cal}$	0	0	1	0.63	0.61	146	147	54%	57%
	$CPUE_{cal\_loc}$	0	0	3	0.61	0.59	147	148	53%	58%

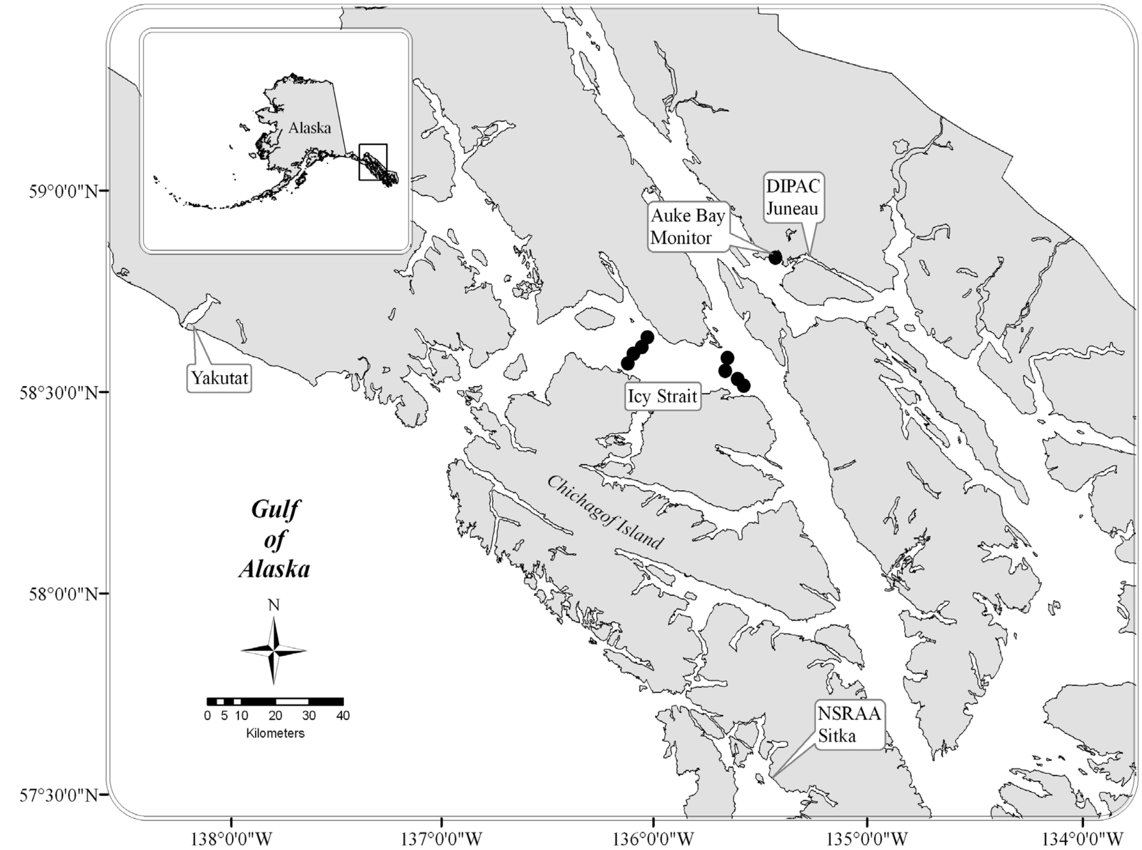

Figure 1. Southeast Coastal Monitoring stations in the northern region of Southeast Alaska during used in pink salmon harvest forecast models. Data include monthly temperature data from May to August, and surface trawl catch data during June and July, 1997–2017.

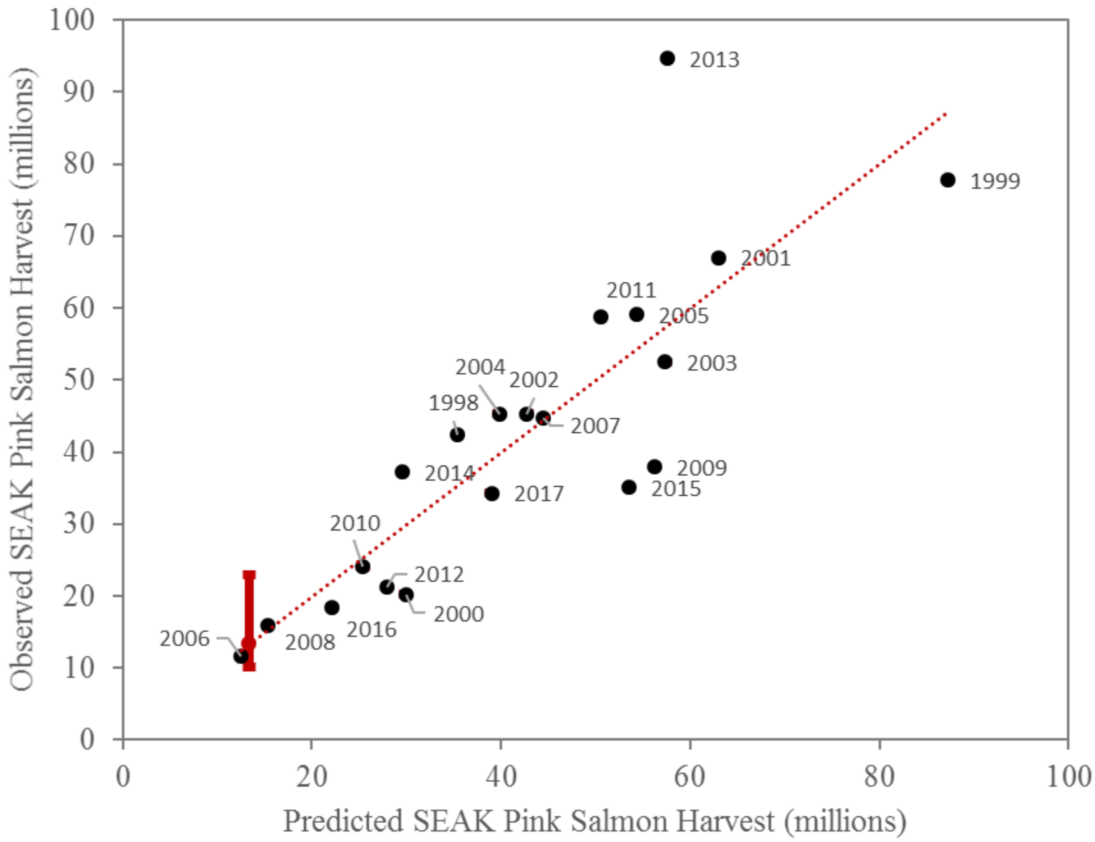

Figure 2. Forecast model fit for total Southeast Alaska (SEAK) pink salmon harvest. Data labels indicate the forecast year. The 2018 forecast range is shown as a red bar.

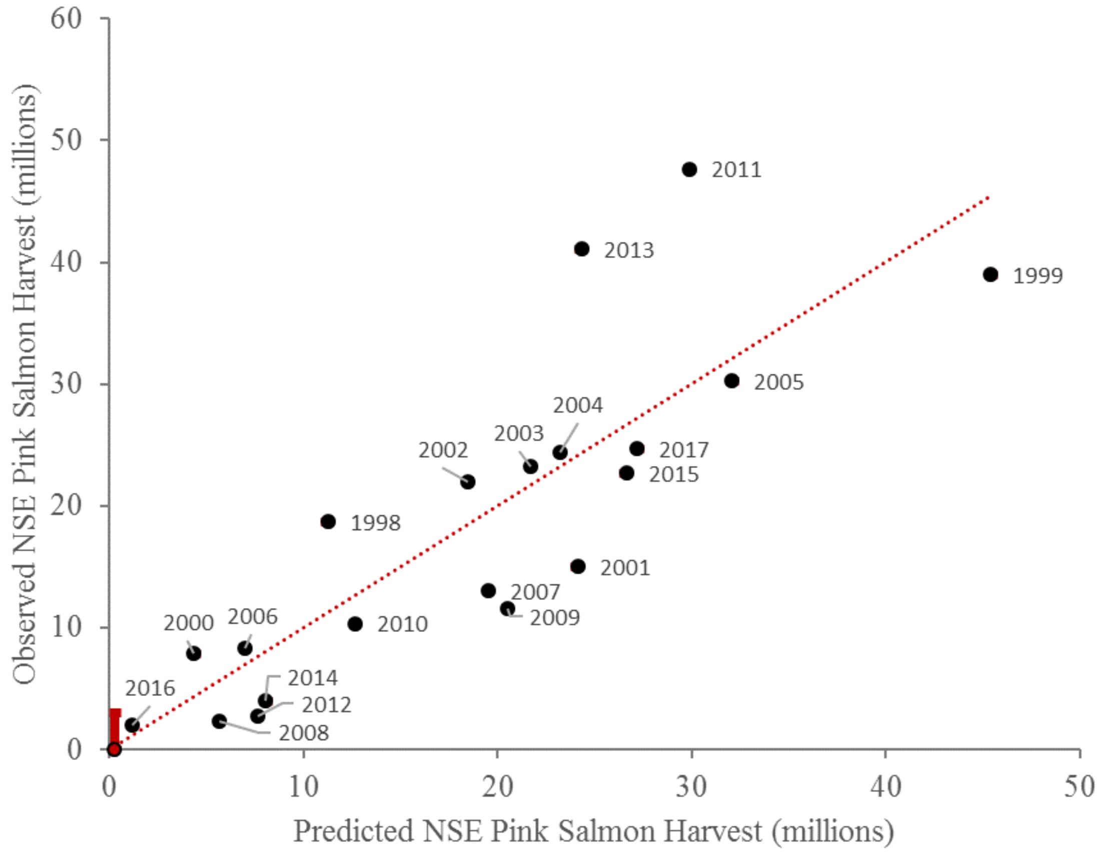

Figure 3. Forecast model fit for Northern Southeast Alaska (NSEAK) pink salmon harvest. Data labels indicate the forecast year. The 2018 forecast range is shown as a red bar.

Appendix 1. Juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$) values by year, vessel, and peak month for the Icy Strait stations, 1997–2017 (NWEx = *F/V Northwest Explorer*).

Year	Month	Vessel	ISA1	ISB1	ISC1	ISD1	ISA2	ISB2	ISC2	ISD2	ISA3	ISB3	ISC3	ISD3	ISA4	ISB4	ISC4	ISD4
1997	7	Cobb	0	0	68	206	--	--	--	--	--	--	--	--	--	--	--	--
1998	6	Cobb	1	1262	363	511	--	--	--	--	--	--	--	--	--	--	--	--
1999	7	Cobb	0	14	151	155	--	--	--	--	--	--	--	--	--	--	--	--
2000	7	Cobb	3	70	217	42	--	--	61	592	--	--	--	--	--	--	--	--
2001	7	Cobb	24	14	36	10	0	110	75	63	--	--	--	--	--	--	--	--
2002	7	Cobb	10	198	84	351	30	31	449	7	0	0	0	--	--	--	--	--
2003	7	Cobb	18	0	23	73	10	2	9	39	--	--	--	--	--	--	--	--
2004	6	Cobb	4	32	20	21	28	641	901	166	--	--	--	--	--	--	--	--
2005	6	Cobb	0	2	0	39	2	97	27	157	24	56	0	0	--	--	--	--
2006	6	Cobb	465	73	37	17	1	60	72	46	46	12	24	10	--	--	--	--
2007	7	Cobb	0	1	0	46	1	4	1	12	8	1	8	2	27	0	5	8
2008	7	Steller	0	1.1	303.2	55.1	0	4.2	33.9	810.9	1.1	61.5	71	189.7	0	163.2	141	17
2009	7	Chellissa	0	3.3	28.9	8.2	0.6	4.7	12	58.2	7.8	14.8	8	26.5	22.7	6.9	14.7	23.5
2010	7	NWEx	200.49	138.99	59.98	145.56	114.4	111.21	137.66	144.76	37.76	72.69	90.57	37.96	--	--	--	--
2011	7	NWEx	0	21.29	20.08	14.18	1.49	0	16.21	4.42	0.58	0	0	0	1.06	2.94	0	0
2012	7	NWEx	80.6	123.71	257.49	152.28	20.62	111.5	10.56	144.26	49.94	40.5	188.7	210.54	11.11	127.43	55.98	204.37
2013	7	NWEx	0	7.12	37.96	0.58	1.49	6.44	23.23	15.45	18.84	87.42	28.64	27.71	25.46	51.49	36.26	19.12
2014	7	NWEx	10.56	43.7	14.51	32.51	32.29	48.38	18.84	156.21	0	20.76	14.66	100.68	--	--	35.54	100.8
2015	6	NWEx	0	80.4	12.35	1.89	4.14	46.78	7.56	3.26	14.51	12	7.78	7.34	32.18	24.98	82.88	26.18
2016	6	NWEx	10.19	39.24	102.24	112.35	13.7	62.08	133.72	186.15	22.72	45.35	84.94	46.34	--	18.7	--	--
2017	7	NWEx	0	0	0	0	0	0	0.58	0	0	0	0	0	--	--	--	--

Appendix 2. Juvenile pink salmon catch-per-unit-effort ($CPUE_{cal}$) values by year, vessel, and peak month for the Upper Chatham stations, 1997–2017 (NWEx = *F/V Northwest Explorer*).

Year	Month	Vessel	UCA1	UCB1	UCC1	UCD1	UCA2	UCB2	UCC2	UCD2	UCA3	UCB3	UCC3	UCD3
1997	7	Cobb	45	102	1	2	--	--	--	--	--	--	--	--
1998	6	Cobb	732	819	371	324	--	--	--	--	--	--	--	--
1999	7	Cobb	0	0	0	0	--	--	--	--	--	--	--	--
2000	7	Cobb	18	8	34	26	--	--	--	--	--	--	--	--
2001	7	Cobb	0	244	215	136	5	0	0	23	--	--	--	--
2002	7	Cobb	7	4	65	51	0	3	4	147	--	--	--	--
2003	7	Cobb	129	50	57	92	5	124	203	0	--	--	--	--
2004	6	Cobb	139	18	40	8	--	--	--	--	--	--	--	--
2005	6	Cobb	2	2	9	2	1	7	8	60	--	--	--	--
2006	6	Cobb	14	5	0	1	0	2	1	13	--	--	--	--
2007	7	Cobb	0	0	1	1	0	1	0	1	21	24	0	0
2008	7	Steller	79.5	4.2	24.4	8.5	3.2	0	0	13.8	21.2	2.1	0	0
2009	7	Chellissa	29.9	12.9	3.6	6	0.6	5.2	2.9	1.1	5.7	3.6	13	1.5
2010	7	NWEx	10.56	24.36	14.66	4.96	12.69	24.36	11.65	0	--	--	--	--
2011	7	NWEx	2.94	0	3.26	42.02	2.94	2.61	17.84	6.67	0	1.06	18.84	19.12
2012	7	NWEx	3.56	10	9.61	1.49	0	7.12	1.49	2.26	0	2.26	12.18	19.39
2013	7	NWEx	7.34	0	4.14	1.49	12.18	0	1.49	0.58	4.96	0	0	0
2014	7	NWEx	23.49	45.44	15.91	8.62	22.47	56.22	56.38	101.94	--	33.46	--	--
2015	6	NWEx	0.58	9.42	14.35	1.49	6.9	42.77	10.75	29.99	0	6.2	0	0
2016	6	NWEx	65.14	55.57	49.86	49.08	108.5	27.83	13.7	62.39	--	--	--	--
2017	7	NWEx	4.42	9.42	0.58	0	--	--	--	--	--	--	--	--

Appendix 3. Juvenile pink salmon catch-per-unit-effort ($CPUE_{ttd}$) values by year, vessel, and peak month for the Icy Strait stations, 1997–2017 (NWEx = *F/V Northwest Explorer*).

Year	Month	Vessel	ISA1	ISB1	ISC1	ISD1	ISA2	ISB2	ISC2	ISD2	ISA3	ISB3	ISC3	ISD3	ISA4	ISB4	ISC4	ISD4
1997	7	Cobb	0.0	0.0	41.5	134.6	--	--	--	--	--	--	--	--	--	--	--	--
1998	6	Cobb	0.7	876.4	225.5	433.1	--	--	--	--	--	--	--	--	--	--	--	--
1999	7	Cobb	0.0	8.9	79.1	85.2	--	--	--	--	--	--	--	--	--	--	--	--
2000	7	Cobb	2.0	42.9	147.6	29.0	--	--	35.9	348.2	--	--	--	--	--	--	--	--
2001	7	Cobb	16.7	10.3	35.3	6.6	0.0	80.3	53.6	47.0	--	--	--	--	--	--	--	--
2002	7	Cobb	8.2	110.6	70.6	225.0	16.1	17.4	327.7	5.3	0.0	0.0	0.0	--	--	--	--	--
2003	7	Cobb	14.2	0.0	14.0	52.1	7.0	1.4	6.3	26.2	--	--	--	--	--	--	--	--
2004	6	Cobb	2.5	16.7	11.4	12.7	14.4	419.0	549.4	96.5	--	--	--	--	--	--	--	--
2005	6	Cobb	0.0	1.6	0.0	24.4	1.4	66.9	17.3	97.5	14.5	29.9	0.0	0.0	--	--	--	--
2006	6	Cobb	267.2	102.8	24.7	9.5	0.4	34.9	45.9	33.3	31.3	7.8	14.8	6.2	--	--	--	--
2007	7	Cobb	0.0	0.6	0.0	29.5	0.7	2.6	0.8	8.7	5.3	0.6	4.2	1.3	22.1	0.0	3.1	5.2
2008	7	Steller	0.0	0.6	169.2	35.4	0.0	2.9	20.3	500.0	0.8	46.8	46.2	127.0	0.0	113.2	9.1	54.5
2009	7	Chellissa	0.0	4.6	95.0	16.9	0.7	7.4	25.4	265.2	14.3	35.5	15.3	84.9	69.5	15.1	35.0	69.8
2010	7	NWEx	1134.8	1917.0	286.5	5084.2	1292.3	1355.8	1741.2	2336.6	243.8	764.0	946.0	274.5	--	--	--	--
2011	7	NWEx	0.0	67.9	59.4	34.7	1.7	0.0	41.6	6.6	0.6	0.0	0.0	0.0	0.7	3.7	0.0	0.0
2012	7	NWEx	575.4	969.2	3219.0	2553.1	58.0	680.5	48.8	1253.9	349.5	163.2	1436.2	4112.2	29.5	794.5	464.6	3358.3
2013	7	NWEx	0.0	14.9	169.7	0.5	1.8	11.8	91.2	36.5	49.7	567.7	127.8	120.0	97.3	298.5	170.9	69.6
2014	7	NWEx	23.8	136.5	38.0	112.6	132.7	169.7	54.4	1404.6	0.0	53.8	35.0	641.0	--	--	105.4	587.8
2015	6	NWEx	0.0	527.3	25.8	2.3	5.1	186.2	14.5	4.8	37.7	27.4	14.9	14.1	106.9	72.8	552.0	74.5
2016	6	NWEx	23.3	154.0	548.3	714.8	31.7	288.7	790.7	1450.8	59.6	168.0	469.4	183.6	--	46.0	--	--
2017	7	NWEx	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	--	--	--	--

Appendix 4. Juvenile pink salmon catch-per-unit-effort ($CPUE_{ttd}$) values by year, vessel, and peak month for the Upper Chatham stations, 1997–2017 (NWEx = *F/V Northwest Explorer*).

Year	Month	Vessel	UCA1	UCB1	UCC1	UCD1	UCA2	UCB2	UCC2	UCD2	UCA3	UCB3	UCC3	UCD3
1997	7	Cobb	27.4	62.6	0.8	1.8	--	--	--	--	--	--	--	--
1998	6	Cobb	449.1	535.3	294.4	297.2	--	--	--	--	--	--	--	--
1999	7	Cobb	0.0	0.0	0.0	0.0	--	--	--	--	--	--	--	--
2000	7	Cobb	14.1	6.3	19.1	18.7	--	--	--	--	--	--	--	--
2001	7	Cobb	0.0	179.4	180.7	85.0	3.4	0.0	0.0	15.2	--	--	--	--
2002	7	Cobb	4.2	2.5	48.1	27.0	0.0	1.8	2.6	96.7	--	--	--	--
2003	7	Cobb	80.1	30.7	42.2	46.9	3.1	77.0	147.1	0.0	--	--	--	--
2004	6	Cobb	73.5	9.4	32.5	4.3	--	--	--	--	--	--	--	--
2005	6	Cobb	1.3	1.4	5.2	1.1	0.6	4.1	4.3	32.6	--	--	--	--
2006	6	Cobb	8.3	3.8	0.0	0.7	0.0	1.2	0.7	9.5	--	--	--	--
2007	7	Cobb	0.0	0.0	0.6	0.8	0.0	0.6	0.0	0.6	14.0	16.3	0.0	0.0
2008	7	Steller	50.0	2.6	13.5	5.1	2.0	0.0	0.0	9.6	16.0	1.5	0.0	0.0
2009	7	Chellissa	100.6	29.4	4.9	10.5	0.5	8.5	4.0	1.1	10.1	5.1	28.4	1.6
2010	7	NWEx	42.6	163.4	80.0	8.2	57.8	132.7	54.1	0.0	--	--	--	--
2011	7	NWEx	4.5	0.0	3.6	149.3	3.6	3.4	54.1	9.4	0.0	1.0	70.8	40.0
2012	7	NWEx	4.8	22.3	18.2	1.1	0.0	13.1	1.6	2.7	0.0	2.5	17.1	54.9
2013	7	NWEx	17.3	0.0	5.7	1.7	33.6	0.0	1.9	0.7	10.2	0.0	0.0	0.0
2014	7	NWEx	83.6	218.8	43.1	15.1	73.0	277.2	223.6	614.1	--	107.0	--	--
2015	6	NWEx	0.5	18.8	30.7	1.8	10.4	145.3	25.3	93.3	0.0	9.5	0.0	0.0
2016	6	NWEx	354.0	228.6	569.1	164.3	646.4	82.7	33.1	278.9	--	--	--	--
2017	7	NWEx	7.0	16.1	0.5	0.0	--	--	--	--	--	--	--	--