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Southeast Alaska Pink Salmon Forecasting Models

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Alaska Department of Fish and Game **Divisions of Commercial Fisheries**

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	′
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	″
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

Pink salmon *Oncorhynchus gorbuscha* runs are notoriously difficult to forecast due to the species' propensity to respond dramatically to changes in the marine environment, cycles of abundance that fluctuate between odd and even years, and the fact that only one age class exists in the fishery each year. In an attempt to improve upon the standard forecast model, which incorporates juvenile pink salmon abundance (catch per unit effort [CPUE]) and temperature data (Icy Strait Temperature Index [ISTI]) from the National Oceanic and Atmospheric Administration (NOAA) Southeast Alaska Coastal Monitoring project, models with a different temperature index (satellite sea surface temperature [SST] data) along with a model-averaging approach were explored. To determine if one of these new approaches should be applied to the 2023 Southeast Alaska preseason pink salmon harvest forecast, the performance of the inverse-variance weighted model-averaged forecast, the equally weighted model-averaged forecast, and the individual regression models with satellite SST data or ISTI were compared for the last 5 and 10 years using only the data available at the time of the forecast. Based on the 5- and 10-year one-step-ahead mean absolute percent error (MAPE), the models that included juvenile pink salmon abundance (CPUE) and a spring and summer temperature index based on northern Southeast Alaska satellite SST data performed better than either of the model-averaged forecasts and better than the standard model with the biophysical variables CPUE and ISTI.

Keywords: pink salmon, model average, forecasting, *Oncorhynchus gorbuscha,* satellite sea surface temperature data, Southeast Alaska, forecast performance, juvenile pink salmon abundance, inverse-variance, CPUE, ISTI

INTRODUCTION

Pink salmon *Oncorhynchus gorbuscha* runs in Southeast Alaska support a valuable commercial fishery (Clark et al. 2006), although annual abundance varies tremendously. An average of 33 million pink salmon per year were harvested in Southeast Alaska in the last 10 years (2012–2021), with a range of 8 million (2018 and 2020) to 95 million (2013) fish. Although the inseason management of these stocks is focused on monitoring daily harvest and fishing effort, and using aerial survey counts to assess whether adequate numbers of pink salmon are present to meet escapement goals (Piston and Heinl 2020), the fishing industry benefits from meaningful preseason forecasts in order to plan appropriately for the harvest, processing, transportation, and marketing of these fish. Pink salmon runs are notoriously difficult to forecast (Adkison 2002; Haeseker et al. 2005; Shevlyakov and Koval 2012; Radchenko 2020) due to the species' propensity to respond dramatically to changes in the marine environment (Farley et al. 2020), the odd- and even-year cycles of abundance (Heard 1991; Ruggerone et al. 2003; Krkošek et al. 2011), and the fact that there is only one cohort (i.e., only one age class) in the fishery each year (Heard 1991). With only a 2-year life cycle, information about cohort strength is not available from jacks or siblings as with other species of salmon (Adkison and Peterman 2000; Haeseker et al. 2007); sibling recruit modeling is not possible with pink salmon. Beginning in the late 1960s, the Alaska Department of Fish and Game (ADF&G) implemented programs to improve pink salmon stock assessment but met with limited success in forecasting pink salmon runs (see Appendix A). Forecast accuracy (i.e., absolute percent error) from 1981 through 2006 was 57% (Appendix B). Past forecasts relied primarily on measures of pink salmon spawning abundance or success (Jones and Hofmeister 1985; Hofmeister and Jones 1989; Hofmeister and Blick 1993), both of which are poorly known and explain little of the variation in annual recruitment, which is largely determined in the early marine environment (Parker 1968; Mortensen et al. 2000; Willette et al. 2001).

NOAA Alaska Fisheries Science Center, Auke Bay Laboratories (National Oceanic and Atmospheric Administration [NOAA]) initiated the Southeast Alaska Coastal Monitoring (SECM) project in 1997 (Orsi et al. 1997; Murphy et al. 1999) to identify relationships between the year-class strength of juvenile salmon and the biophysical parameters influencing their growth and survival, their prey and predator interactions, their habitat utilization, and their stock interactions in marine waters (Orsi et al. 2000, 2005, 2009). Through this project, standardized monthly sampling and trawl surveys have been conducted annually from May to August (the August survey was dropped in 2020) to collect ecosystem (oceanographic data such as temperature and salinity profiles of the water column, surface water samples, and zooplankton samples) and catch per unit effort (CPUE) data associated with juvenile salmon at 8 stations in Icy Strait, a major migration corridor in northern Southeast Alaska (Orsi et al. 2001, 2006, 2012). The environmental and oceanographic data provided through the SECM project has become one of the longest continuous time series of its kind for the North Pacific. A major finding of the SECM survey is that relative abundance of juvenile pink salmon in June and July was highly correlated to harvest of adults in the subsequent year. As a result, NOAA used peak juvenile pink salmon CPUE and environmental information collected during SECM surveys to forecast the Southeast Alaska pink salmon harvest starting in 2004 (Murphy et al. 1999; Wertheimer et al. 2009a, 2010a, 2011–2015, 2017, 2018; Murphy et al. 2019b).

In the past, ADF&G and NOAA produced separate Southeast Alaska preseason pink salmon forecasts. In 2007, ADF&G began adjusting their simple trend forecasts with juvenile pink salmon abundance data from the SECM survey (Heinl et al. 2007; Piston and Heinl 2014, 2017; Appendix A). Forecast accuracy (i.e., absolute percent error) improved from 57% (1981 to 2006 preseason forecasts) to 31% (2007 through 2017 preseason forecasts; the 2018 preseason forecast was based on the average of 5 recent even-year harvests and did not use juvenile abundance indices from the SECM survey; Appendix B). The largest absolute percent error between the forecast and the actual harvest occurred in the 1987, 1988, 2006, and 2018 forecasts. In 2018, ADF&G and NOAA scientists collaborated to create a joint preseason forecast for 2019 (Piston et al. 2021a). The SECM project and Southeast Alaska pink salmon harvest forecasts are now conducted cooperatively by NOAA and ADF&G using the ADF&G research vessel (R/V) *Medeia* (Piston et al. 2021a, 2022). The current method (2019 to 2022 preseason forecasts) is to forecast the adult pink salmon harvest in a multiple linear regression model with peak monthly (June or July) juvenile pink salmon CPUE and a temperature index (Piston et al. 2019, 2020, 2021a, 2022). The temperature index is based on the overall average 20 m integrated water column temperature recorded during May–July or May–August at 8 stations in Icy Strait as part of the annual SECM survey (Icy Strait Temperature Index [ISTI]; Murphy et al. 2019a). Together, both agencies continue to examine alternative variables and statistical methods to improve annual forecasts.

The potential use of satellite sea surface temperature (SST) data (available from the NOAA National Environmental Satellite Data and Information Service; Huang et al. 2017) was explored in forecasts of pink salmon harvests in 2021 and 2022 (Piston et al. 2021a, 2022). Satellite data allow for averaging of temperature readings over an almost infinite variety of temporal and geographic units and could potentially be a better predictor of pink salmon runs as compared to temperature data collected during the SECM survey. In addition, a model-averaging approach, as opposed to a ‘one best’ model approach, is being considered. Model-averaging in this report is based on model-averaging the predictions from a set of candidate models (Cade 2015). This report explores the possible methods that performed the best forecasts for 2021 and thus would be applied to forecast the 2023 adult pink salmon harvest.

OBJECTIVES

1. Provide an overview of the history of the Southeast Alaska pink salmon forecasting models.
2. Forecast the 2022 adult pink salmon preseason harvest in Southeast Alaska using a model-averaged approach and with individual, multiple regression models that incorporate juvenile pink salmon abundance data (CPUE) and satellite SST data, and compare these forecasts to the current method applied to forecast the 2022 adult pink salmon harvest.
3. Evaluate alternative approaches for incorporating temperature data into the adult pink salmon forecast model (e.g., model-averaged approach, individual models) along with alternative temperature variables (i.e., ISTI, satellite SST data).

ADF&G FORECAST HISTORY

Pink salmon forecasting in Southeast Alaska began in the mid-1960s and has evolved over the years. To predict returning adult pink salmon populations in Southeast Alaska, ADF&G started a pre-emergent fry indexing program in spring of 1963 (Hoffman 1965). For this program, a pump with a hose was used to inject water and air into selected stream beds, forcing the salmon eggs and pre-emergent fry loose. A collection net placed downstream would catch the loose debris, and the number of dead and live eggs and alevins (i.e., fry density index measured as the number of fry per meter) were counted (Smedley et al. 1968). The justification for the relationship between fry and the resultant adult return was based on pink salmon predictions in Prince William Sound (Noerenberg 1961, 1963, 1964). Early predictions of southern and northern Southeast Alaska pink salmon runs, based on a weighted forecast of the escapement-return relationship and the pre-emergent fry indices, were not very accurate (Hoffman 1965, 1966; Smedley and Siebel 1967; Smedley et al. 1968). Throughout the 1970s, separate forecasts were developed for pink salmon runs in northern Southeast and southern Southeast Alaska due to regional differences in migration routes and run timing (Nakatani et al. 1975; Alexandersdottir 1987). Those forecasts were based on the relationship between fry abundance and adult returns (e.g., Valentine et al. 1969; Durley 1971, 1972). Starting with the 1974 forecasts, environmental variables such as seawater temperature and air temperature were added to forecast regressions (Durley 1973c; Kingsbury and Larson 1975; Jones and Hofmeister 1983a, 1983b). Pre-emergent fry indices were no longer available starting with the 1988 forecast (Jones and Hofmeister 1988); forecasts based on the fry abundance index were replaced by multiple linear regression forecasts of escapement indices, environmental variables, and fry data collected in the early marine program in Tenakee Inlet in the late 1980s to 1990s (e.g., Hofmeister 1990; Hofmeister and Blick 1991, 1992).

The 1993 forecast (Appendices A and B) was the first time that separate forecasts for northern and southern Southeast Alaska were not made, the result of cutting ADF&G pink salmon stock assessment programs, including the pre-emergent and early marine fry programs in 1992 (Hofmeister and Blick 1993). Early marine fry surveys were completely discontinued in 1997 (Geiger and Hart 1999). The 1994 to 2003 forecasts were a subjective combination of statistical forecast models, anecdotal fry abundance data, historical average harvests, environmental variables, and expert opinion (Willette 2000; Zadina 2002, 2003). This subjective method was replaced by a simple exponential smoothing model for the 2004 to 2006 harvest forecasts (Heinl et al. 2004, 2005, 2006). Starting with the 2007 forecast, the exponential smooth forecasts were adjusted with the NOAA June–July pink salmon fry data (Heinl et al. 2007; Piston and Heinl 2014, 2017). Recent harvest forecasts (2019–2022) have been based on a multiple linear regression model with juvenile pink salmon abundance indices collected by the SECM project in northern Southeast Alaska inside waters during June and July along with a temperature index, and are produced by the combined efforts of NOAA and ADF&G (Piston et al. 2021a; Appendix A).

METHODS

Biophysical variables based on data from Southeast Alaska were used to forecast the harvest of adult pink salmon in Southeast Alaska, a year in advance, using multiple linear regression in a model-averaging framework and based on individual models. Pink salmon harvest was the response variable. The potential predictive biophysical variables in the models were 1) April through July satellite-derived SST data, 2) overall average 20 m integrated water column temperature during (May–July) at the 8 stations in Icy Strait collected as part of the annual SECM surveys (ISTI; Murphy et al. 2019a), and 3) SECM survey juvenile abundance data (CPUE). Juvenile abundance data were the peak SECM CPUE in either June or July at the 8 stations in Icy and Chatham Straits. See the section 'Individual, Multiple Linear Regression Models' for details about the models.

Two comparisons were made. The first comparison was among the 2022 preseason forecasts from the 18 individual (bias-corrected) multiple linear regression models (one of which was the official forecast model) and the 2022 preseason forecast from a model-averaging approach (either the inverse-variance weighted model-averaged forecast or the equally weighted model-averaged forecast). Model-averaging in this report was defined as model-averaging the predictions from a set of candidate models. The actual (documented) preseason forecast (Piston et al. 2022) was based on one of the 18 multiple linear regression models with juvenile pink salmon abundance indices (CPUE) along with a temperature index. The second comparison was among the past performance of each of the 18 individual (bias-corrected) multiple linear regression models, the past performance of the inverse-variance weighted model-averaged forecast, and the past performance of the equally weighted model-averaged forecast, for the last 5 years (2017–2021) and for the last 10 years (2012–2021), using only the data available at the time of the forecasts. This comparison was done to determine if one of the multiple linear regression models or the model-averaging approach should be applied to the 2023 (and possibly future) preseason forecast.

BIOPHYSICAL PREDICTOR VARIABLES

Satellite-Derived SST Data

Monthly satellite-derived SST data (°C) from April 1997 through July 2021 were pulled from the NOAA National Environmental Satellite Data and Information Service (Huang et al. 2017) and matched to predetermined coordinates from 4 spatial regions to use as potential predictor variables in forecast models. The Icy Strait region encompasses waters of Icy Strait from the east end of Lemesurier Island east to a line from Point Couverden south to Point Augusta (Figure 1). The Chatham Strait region encompasses waters of Chatham and Icy Straits east of Lemesurier Island to Point Couverden, south to the approximate latitude of 56.025 degrees north (roughly at Cape Decision, Kuiu Island; Table 1; Figure 2). The northern Southeast Alaska region encompasses northern Southeast Alaska inside waters from 59.475 to 56.075 degrees north latitude (approximately ADF&G Management Districts 9–15, and District 13 inside area only; Figure 3); this area is defined as the northern Southeast Inside subregion for Southeast Alaska for pink salmon stock assessment (Piston and Heinl 2020). The Southeast Alaska region encompasses Southeast Alaska inside waters from 59.475 to 54.725 degrees north latitude (Figure 4). Satellite SST data, by spatial region, were then summarized by time period; e.g., average May SST, average SST over the months of May through July (MJJ), average SST over the months of April through June (AMJ), and average SST over the months of April through July (AMJJ). The monthly data for July 2021 were not available, so daily data for July 2021 were summarized by month and region, then combined with monthly data from April 1997 through June 2021 to create the SST dataset (April 1997 through July 2021; NOAA Coral Reef Watch 2021b). These 16 variables (4 regions and 4 temporal variables per region; Figure 5) were then used as potential predictor variables in the pink salmon forecast models.

Southeast Coastal Monitoring Project Survey Data

Since 1997, the SECM project has been conducted annually to evaluate the status of the pelagic ecosystem, including juvenile pink salmon, in the northern region of Southeast Alaska (Orsi et al. 1997; Murphy et al. 1999). Survey sampling occurs in Icy Strait, along the primary seaward migration corridor of salmon in Southeast Alaska; samples collected during the SECM surveys include fish (salmon and other pelagic species), zooplankton, and oceanographic data (physical profile data of the water column and surface water samples; Orsi et al. 2001, 2006, 2012). Although methodology has varied slightly over the years (e.g., different research vessels, surveys used to occur May–August), current methodology is to sample from June–July at 12 principal stations in northern Southeast Alaska with transects in Upper Chatham Strait, Icy Strait, and Stephens Passage using the ADF&G research vessel (R/V) *Medeia* (Piston et al. 2021b). Additional oceanography sampling occurs at these stations in May using the NOAA Fisheries vessel *Sashin*. Surface trawl hauls conducted in June and July, using a Nordic 264 rope trawl to sample fish, are 60 minutes long in Stephens Passage and 20 minutes long on the upper Chatham and Icy Strait transects (Piston et al. 2021b). The Icy Strait and Upper Chatham transects include 8 sampling stations (stations ISA, ISB, ISC, ISD, UCA, UCB, UCC, UCD). Data from these surveys are summarized annually and provide information to forecast pink salmon harvest. Only data from the Upper Chatham and Icy Straits transects in May–July are used for pink salmon forecasting.

Vessel-Based Temperature Data (Icy Strait Temperature Index; ISTI)

Survey temperature (°C) data were summarized by year (1997–2021) and month (average over the months of May, June, and July) for the 20 m integrated water column in the Icy Strait and Upper Chatham transects combined (Table 2; Figure 6). This variable (ISTI) was then used as a potential predictor variable in the pink salmon forecast models.

Index of Juvenile Abundance (CPUE)

Catch rate or catchability (also known as catch per unit effort or CPUE) is commonly used in fisheries science as a relative index of population abundance of a species, with an assumption that there is a direct proportion between CPUE and abundance that is captured in the average CPUE over the years. This assumption relies on the belief that other influences that may change over time (sources of variation; e.g., temporal, spatial, fish behavior) do not affect CPUE (Hilborn and Walters 1992; Arreguin-Sanchez 1996). The index of juvenile pink salmon abundance is the predictor variable 'CPUE' in the pink salmon forecast models. The CPUE data are the natural log transformed juvenile pink salmon catches (ln CPUE+1) by haul, standardized to a 20-minute trawl set. The CPUE was then multiplied by a pooled-species vessel calibration coefficient, based on calibration of the fishing power of various vessels used in the SECM project to the fishing power of the NOAA ship *John N. Cobb*, the vessel used for the initial 11 years of the project (Wertheimer et al. 2008, 2009b, and 2010b). The CPUE values were averaged over all 8 stations by month; data from whichever month (June or July) had the highest log transformed CPUE is then used as the juvenile abundance index for that particular year (Table 2).

RESPONSE VARIABLE: HARVEST DATA

Harvest data (natural log transformed) was used as the response variable in the forecast models. Time series of annual Southeast Alaska adult pink salmon harvest data are obtained from the ADF&G Fish Ticket Database System in millions of fish. The data include total pink salmon harvest from all gear and harvest types (harvest code in parentheses): state managed fisheries (11), hatchery terminal area fisheries (12), spring troll fisheries (13), Annette Island fisheries (nonstate authorized; 17), confiscated fish (18), private hatchery fisheries (21, 22), commercial sale/sportfish derby (31), discarded catch (33), educational permit (35), and test fisheries (41, 42, 43). Harvest data are restricted to ADF&G Management Districts 101–116, 150, 152, 154, 156, and 157 in Southeast Alaska, and exclude the small numbers of pink salmon harvested in the Yakutat Management Area.

INDIVIDUAL, MULTIPLE LINEAR REGRESSION MODELS

Biophysical variables based on data from Southeast Alaska were used to forecast the harvest of adult pink salmon in Southeast Alaska, 1 year in advance, using individual, multiple linear regression models (models m1–m18; Table 3). The simplest regression model (model m1) consisted of only the predictor variable juvenile pink salmon CPUE (X_1), whereas the other 17 regression models consisted of the predictor variable juvenile pink salmon CPUE and a temperature index (X_2),

$$\hat{E}(Y_i) = \hat{\alpha}_i + \hat{\beta}_{1_i} X_1 + \hat{\beta}_{2_i} X_2. \quad (1)$$

The temperature index was either the SECM survey ISTI temperature data (Murphy et al. 2019a; Table 2) or one of the 16 satellite-derived SST data (Huang et al. 2017; Table 1). Although the simplest model only contained CPUE, including temperature data with CPUE is probably a more accurate measure of juvenile abundance if temperature affects the proportion of juveniles that migrate through Icy Strait in a given year (Murphy et al. 2019a). The response variable (*Y*; Southeast Alaska adult pink salmon harvest in millions) and CPUE data were natural log transformed in the model, but temperature data were not. The forecast ($\hat{Y}_i$) and 80% prediction intervals (based on output from program R[1]) from the 18 regression models were exponentiated and bias-corrected (Miller 1984),

$$\hat{F}_i = \exp\left(\hat{Y}_i + \frac{\sigma_i^2}{2}\right), \quad (2)$$

where $\hat{F}_i$ is the preseason forecast (for each model *i*) in millions of fish, and σ_i is the variance (for each model *i*).

MODEL AVERAGING (MULTI-MODEL INFERENCE)

Model averaging is defined as calculating a weighted average of the predictions from the specified candidate models. In this case, the model-averaged approach was based on the weighted average of the predictions from the 18 individual, multiple regression models (*i* = 1, 2,…, 18 candidate

[1] R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

models) with juvenile pink salmon CPUE and a temperature index. Two methods of weighting were investigated. The first method weighted each model by the one-step-ahead inverse-variance (model m19) and the second method weighted each model equally (model m20) among the 18 different models (Table 3).

Model Weighting

One Step-Ahead Inverse-Variance Weights

The first method to weight each of the candidate models in the model-averaged preseason forecast for 2022 is as follows:

1. Calculate the model-predicted adult pink salmon harvest for 2022 ($\hat{Y}_i$) from each of the *i* regression models (18 models in the candidate model set) in natural log space (equation 1). This results in 18 separate preseason forecasts for 2022.

2. Calculate the model-averaged forecast ($\tilde{Y}$) in log space by weighting each of the 18 model forecasts ($\hat{Y}_i$) by the one-step-ahead inverse-variance weight (w_i),

$$\tilde{Y} = \sum_{i=1}^{18} w_i \hat{Y}_i. \tag{3}$$

The weights are normalized to sum to 1. To normalize the inverse-variance weights to sum to 1 ($\sum w_i = 1$), each individual weight δ_i is divided by the sum of all the model weights,

$$w_i = \frac{\delta_i}{\sum_{i=1}^{18} \delta_i}, \tag{4}$$

where the one-step-ahead inverse-variance (from the last 5 years of predictions) weight, δ_i, of each model *i* is defined as,

$$\delta_i = 1/\left(\frac{\sum_{t=1}^{n}(Y_t - \hat{Y}_t)^2}{n-1}\right). \tag{5}$$

In equation 5, Y_t is the natural log of the observed values (i.e., observed Southeast Alaska adult pink salmon harvest) and $\hat{Y}_t$ are the predicted values (i.e., predicted Southeast Alaska adult pink salmon harvest in log space) from model *i* using data up to time *t*-1 in the last 5 years of the time series. In equation 5, *n* = 5 since the last 5 years are forecasted in the time series. The process, in detail, for calculating the inverse-variance (one-step-ahead inverse-variance weight) weight δ_i for each model *i* is as follows:

a. Estimate the regression parameters at time *t*-1 from data up to time *t*-1 for model *i*.
b. Make a prediction of $\hat{Y}_t$ at time *t* based on the predictor variables at time *t* and the estimate of the regression parameters at time *t*-1 for model *i* (i.e., the fitted regression equation).
c. Calculate the inverse-variance weight (equation 5) based on the prediction of $\hat{Y}_t$ at time *t* and the observed value of Y_t at time *t*.
d. Repeat these steps for data up through year 2016 (e.g., data up through year 2016 is *t*−1 and the forecast is for year 2017; *t*), data up through year 2017: data up through year 2017 is *t*−1 and the forecast is for year 2018; *t*, data up through year 2018 to forecast 2019, data up through year 2019 to forecast 2020, and data up through year 2020 to forecast 2021. For example, based on the CPUE-only regression model (model m1; Table 3), and using data through 2016 (i.e., *t*-1; $\hat{Y}_t = 2.45 + 0.41X_1$), the predicted

harvest in 2017 (i.e., year t; X_1 = 4.35) is 4.23 (68.4 million fish) and $(Y_t - \hat{Y}_t)^2$ = (3.55 - 4.23)^2 = 0.46; using data through 2017, the predicted harvest in 2018 is 2.67 (14.4 million fish) and $(Y_t - \hat{Y}_t)^2$ = (2.09 - 2.67)^2 = 0.33; using data through 2018, the predicted harvest in 2019 is 2.86 (17.5 million fish) and $(Y_t - \hat{Y}_t)^2$ = (3.05 - 2.86)^2 = 0.04; using data through 2019, the predicted harvest in 2020 is 2.87 (17.7 million fish) and $(Y_t - \hat{Y}_t)^2$ = (2.09 - 2.87)^2 = 0.61; and using data through 2020, the predicted harvest in 2021 is 3.23 (25.3 million fish) and $(Y_t - \hat{Y}_t)^2$ = (3.88 - 3.23)^2 = 0.43. Then the sum of 0.46 + 0.33 + 0.04 + 0.61 + 0.43 divided by 4 (i.e., n – 1) is 0.47. Finally, one divided by 0.47 is 2.14. This value (2.14) is then the inverse-variance weight of the CPUE-only model for the 2022 forecast. To normalize this value (equation 4), δ_{m1} = 2.14 is divided by the sum of the 18 individual model weights (i.e., 2.14/65.85 = 0.03) and w_{m1}= 0.03 is the one-step-ahead inverse-variance weight for the CPUE-only model (model m1; Table 3). This value is then used in equation 3 as w_i for model m1.

The process to calculate the confidence interval around the model-averaged forecast is as follows. Calculate the standard error of the model-averaged forecast (i.e., the square root of the unconditional variance estimator; equation 9 in Buckland et al. 1997; derivation in Burnham and Anderson 2002:159–162) as

$$\widehat{\text{se}}(\tilde{Y}) = \sum_{i=1}^{18} w_i \sqrt{\widehat{\text{var}}(\hat{Y}_i) + \gamma_i^2}, \tag{6}$$

where $\tilde{Y}$ is the model-averaged forecast (in log space; assumed unbiased), $\hat{Y}_i$ is the individual model i forecast for 2022 (in log space), and γ_i (i.e., the misspecification bias of model i) is computed as $\gamma_i = \hat{Y}_i - \tilde{Y}$. To calculate $\widehat{\text{var}}(\hat{Y}_i)$, an estimate of s, the estimate of the standard error of the predicted mean, is squared $(\text{i.e.}, (s\sqrt{d})^2$; where d is the individual model with i degrees of freedom. An estimate of s is output from the statistical program R[1]. The confidence interval is then calculated as,

$$\tilde{Y} \pm z_{1-\alpha/2}\, \widehat{\text{se}}\, (\tilde{Y}), \tag{7}$$

where $z_{1-\alpha/2} = 1.28$ for an 80% confidence interval. The model-averaged forecast, the upper confidence interval, and the lower confidence intervals are then exponentiated,

$$\hat{F} = \exp(\tilde{Y}). \tag{8}$$

The one-step-ahead inverse-variance weighted preseason forecast is not bias-corrected (Miller 1984; Haeseker et al. 2007) due to the nature of the equations used. Although the model-averaged forecast $\tilde{Y}$ is in log space, to transform the forecast would require a model-averaged σ^2, the variance of the residuals estimated from fitting the model (e.g., $\hat{F}_i = \exp\left(\hat{Y}_i + \frac{\sigma_i^2}{2}\right)$; equation 2); each of the 18 models has an individual σ^2 associated with it, but the model-averaged preseason forecast does not have an σ^2 associated with it. This is probably not an issue because the maximum difference between the bias-corrected and non-bias-corrected forecasts for 2022, for example, from the 18 individual models was only 1.5 million fish. This is well within the prediction intervals of the individual models.

Equal Weights

The second method to weight each of the candidate models in the model-averaged preseason forecast for 2022, as was implemented in the 2008 pink salmon harvest forecast (Heinl 2008), is to weight the models equally (equation 3; each model is weighted by w_i = 1/18 = 0.06 because there are 18 models). Two potential methods to calculate the confidence interval of the model-averaged forecast based on equal-weighting of the models are based on (1) producing hindcast predictions for the last 5 years (2017–2021), then estimating the sample standard deviation from the sum of the squared errors of the log of the observed values minus the log of the predicted values (hindcast method); or (2) using equation 6 above based on Buckland et al. (1997). The 80% confidence interval is then calculated as equation 7. The model-averaged preseason forecast and upper and lower confidence intervals are then exponentiated as in equation 8. Similar to the reasoning for the one step-ahead inverse-variance weighting, the equally weighted model-averaged preseason forecast is not bias-corrected (Miller 1984; Haeseker et al. 2007).

The detailed methods to calculate the confidence interval based on the hindcast method are as follows:

1. Create hindcast predictions for the last 5 years in the data series for each of the 18 models using all the data in the time series (18 hindcast predictions for each year for 5 years; 2017–2021). For example, the CPUE-only regression model (2.33 + 0.43X_1), based on the entire available time series, would be used to create predictions for years 2017–2021 by replacing X_1 with the observed CPUE in that year (e.g., replacing X_1 with the observed CPUE in 2017 (0.35) to predict the harvest in 2018 (12 million fish)).
2. Produce a model-averaged forecast $\tilde{Y}$ for each of the last 5 years by weighting the 18 models equally, within each year, using equation 3 and w_i = 0.06 (one model-averaged forecast per year).
3. Estimate the sample standard deviation from the sum of the squared errors of the natural log of the observed values (i.e., the observed harvest for that year) minus the natural log of the predicted values for the 5 forecasts (i.e., the equally weighted model-averaged forecasts for years 2017 through 2021),

$$\widehat{\text{se}}\left(\tilde{Y}\right) = \sum_{t=1}^{n}(Y_t - \tilde{Y}_t)^2. \tag{9}$$

   In equation 9, Y_t is the natural log of the observed values (i.e., observed Southeast Alaska adult pink salmon harvest) and $\tilde{Y}_t$ are the predicted values (i.e., equally weighted, model-averaged predictions of the Southeast Alaska adult pink salmon harvest) in the last 5 years of the time series. In equation 9, n = 5 since the last 5 years are forecasted in the time series. For example, the equally weighted, model-averaged forecast for 2017 (in log space) is 3.66. Using equation 9, $(3.55\text{-}3.66)^2 = 0.01$. This is repeated for the 2018–2021 forecasts, and these values are summed (e.g., the summed value is 0.92).
4. Use the summed value (0.92) as the variable $\widehat{\text{se}}\,(\tilde{Y})$ in equation 7 to create 80% confidence intervals around the forecast.

2022 PRESEASON FORECAST COMPARISON

The first comparison was between the 2022 preseason forecasts from the 18 individual (bias-corrected) multiple linear regression models (Table 3), and the 2022 preseason forecasts from a model-averaging approach (inverse-variance weighted model-averaged preseason forecast or the equally weighted model-averaged preseason forecast; Table 3). The official 2022 preseason forecast (15.6 million fish rounded to 16 million fish; 80% prediction interval 10–24 million fish; Piston et al. 2022; model m2) was based on one multiple linear regression model with juvenile pink salmon abundance indices (CPUE) collected by the SECM project in northern Southeast Alaska inside waters during June and July along with a temperature index. The temperature index was based on the overall average 20 m integrated water column temperature during (May–July) at the 8 stations in Icy Strait collected as part of the annual SECM surveys (Murphy et al. 2019a).

PAST PERFORMANCE COMPARISON (2012–2021 AND 2017–2021)

To determine if these new methods should be applied to the 2023 preseason forecast of adult pink salmon harvest in Southeast Alaska, the past performance of the 18 individual (bias-corrected) multiple linear regression models, the past performance of the one step-ahead inverse-variance weighting of the 18 models (i.e., model-averaged forecast), and the past performance of the equal weighting of the 18 models (i.e., model-averaged forecast) were compared for the last 5 years (2017–2021) and for the last 10 years (2012–2021) using only the available data at the time of the forecast. For the 20 models (m1 through m20), the forecast performance metric one-step-ahead mean absolute percent error (MAPE) was calculated as follows.

1. Estimate the regression parameters at time *t*-1 from data up to time *t*-1.
2. Make a prediction of $\hat{Y}_t$ at time *t* based on the predictor variables at time *t* and the estimate of the regression parameters at time *t*-1 (i.e., the fitted regression equation).
3. Calculate the MAPE based on the prediction of $\hat{Y}_t$ at time *t* and the observed value of Y_t at time *t*,

$$\text{MAPE} = \left|\frac{\exp(Y_t) - \exp(\hat{Y}_t + \frac{\sigma_t^2}{2})}{\exp(Y_t)}\right|. \tag{10}$$

4. For each individual model, average the MAPEs calculated from the forecasts,

$$\frac{1}{n}\sum_{t=1}^{n}\left|\frac{\exp(Y_t) - \exp(\hat{Y}_t + \frac{\sigma_t^2}{2})}{\exp(Y_t)}\right|. \tag{11}$$

For example, to calculate the 5 year one-step-ahead MAPE for model m1, use data up through year 2016 (e.g., data up through year 2016 is *t*-1 and the forecast is for *t*, or year 2017). Then, calculate a MAPE based on the 2017 forecast and the observed pink salmon harvest in 2017 using equation 10. Next, use data up through year 2017 (e.g., data up through year 2017 is *t*-1 and the forecast is for year 2018; *t*) and calculate a MAPE based on the 2018 forecast and the observed pink salmon harvest in 2018 using equation 10. Repeat this process for each subsequent year through year 2020 to forecast 2021. Finally, average the 5 MAPEs to calculate a 5 year one-step-ahead MAPE for model m1. For the 10-year one-step-ahead MAPE for model m1, the process would be repeated, but the first forecast year would be 2012.

For the 2 model-averaged forecasts (model m19 and model m20), the performance metrics 5-year and 10-year one-step-ahead MAPE were calculated using the same 4 steps outlined above (and the methods under the section Model Weighting), but equation 10 was replaced by

$$\text{MAPE} = \left|\frac{\exp(Y_t) - \exp(\tilde{Y})}{\exp(Y_t)}\right|. \tag{12}$$

and equation 11 was replaced by

$$\frac{1}{n}\sum_{t=1}^{n}\left|\frac{\exp\left(Y_t\right)-\exp\left(\tilde{Y}\right)}{\exp\left(Y_t\right)}\right|. \tag{13}$$

RESULTS

2022 Forecast Comparison

The 2022 preseason forecasts from the individual multiple regression models varied little from a low of 13.0 million fish (model m18) to a high of 16.5 million fish (model m1; Table 3). The forecasts based on a model-averaged approach, weighting the models by either the inverse-variance weighting or equally, were roughly the same (13.6 million fish, based on the one step-ahead inverse-variance weighting with an 80% CI of 6.5–28.3, based on Buckland et al. 1997; and 13.6 million fish based on equally weighting with an 80% CI of 4.2–44.4, based on the hindcast method or with an 80% CI of 6.5–28.6, based on Buckland et al. 1997). The model-averaged forecasts are roughly 2 million fish less than the official 2022 forecast that was based on the biophysical predictor variables CPUE and ISTI (model m2 in Table 3; 15.6 million fish rounded to 16 million fish; Piston et al. 2022).

Past Performance Comparison (Single-Year MAPE, 5-Year MAPE, 10-Year MAPE)

The best models for each year, based on the one-step-ahead MAPE, are found in Tables 4 through 11. Based on the one-step-ahead MAPE, by year, the best models for 2012 were m9 and m18 (MAPE was <1%), the best model for 2013 was m2, the best model for 2014 was m3, the best model for 2015 was m11, the best model for 2016 was m9, the best model for 2017 was m14, the best model for 2018 was m11, the best model for 2019 was m1, the best model for 2020 was m14, and the best model for 2021 was m2. For the 2012 (m1, m3–m12, m14–m20), 2014 (m3, m7, m11, m13), 2016 (m7, m9, m14, m18–m20), 2017 (m5, m6, m7, m10, m13, m14, m17–m20), and 2019 (m1) forecasts, one or more models had a MAPE that was 10% or less (models stated in parentheses), whereas for the 2013, 2015, 2018, 2020, and 2021 forecasts, none of the models had a MAPE that was 10% or less. Across the last 5 years (2017–2021) of forecasts, models m5, m11, m13, m14, and m17 had the lowest one-step-ahead MAPE (28–31%). Across the last 10 years (2012–2021) of forecasts, models m3, m7, m9, m11, m13, m14, and m19 had the lowest one-step-ahead MAPE (24–27%). Based on the one-step-ahead MAPE in the last 5 and 10 years, the best models were m11, m13, and m14. These models included CPUE and a northern Southeast Alaska (NSEAK) satellite SST index for May (m11), April through June (m13), or April through July (m14).

Standard Forecast Model

The standard preseason forecast model used from 2019 to 2022 (Piston et al. 2019, 2020, 2021a, 2022) was a multiple linear regression model with peak monthly (June or July) juvenile pink salmon CPUE and the ISTI temperature index (Murphy et al. 2019a). This model, model m2, ranked 16/20 (average one-step-ahead MAPE of 40%) and 17/20 (average one-step-ahead MAPE of 37%) based on the average one-step-ahead MAPE in the last 5 and 10 years, respectively.

DISCUSSION

Model averaging (or ensemble modeling; Burnham and Anderson 2002) incorporates the uncertainty inherent in model structure and in parameter values into the analysis results (i.e., forecast) by weighting individual candidate models to create one prediction (Madigan and Raftery 1994; Wintle et al. 2003; Dormann et al. 2018). Some studies have suggested that this method outperforms choosing one single best model (Haeseker et al. 2005; Araújo and New 2006; Anderson et al. 2017) because predictions from alternative models can be highly variable. Based on the past performance comparison using the one-step-ahead MAPE in the last 5 and 10 years in this study, though, the individual models consistently performed better than the model-averaged predictions (i.e., model-averaging the predictions from the set of candidate models; Cade 2015). The best models for forecasting pink salmon harvests in Southeast Alaska (SEAK) were the individual models, not the forecasts from either of the model-averaged approaches. Individual models that included CPUE and an NSEAK satellite SST index for May (m11), April through June (m13), or April through July (m14) performed the best.

The model-averaging approach has been explored in historical forecasts of adult pink salmon returns (Heinl 2008) and in exploratory analyses of alternative methods of forecasting this stock (Adkison 2002). "Equal-weight" model averaging was applied to the 2008 forecast of adult pink salmon harvest; due to concerns that the 2007 June–July pink salmon fry CPUE index from the SECM project was low and outside the range of historical data, the exponential smooth estimate and the CPUE-error-adjusted estimate were averaged to produce the 2008 forecast (Heinl 2008). The "equal-weight" approach was again applied in this study as a comparison to the one-step-ahead inverse-variance from the last 5 years of predictions. Bayesian model averaging (Bayesian model weights; Adkison 2002) was also investigated as an alternative approach to the traditional statistical forecast models implemented at the time (Willette 2000; Geiger and McNair 2001; Zadina 2002). Spawner-recruit models that included environmental variables (Quinn and Deriso 1999) such as average upwelling anomalies, growth information from fish scales, average Gulf of Alaska SST anomaly, and average Southeast Alaska air temperature anomaly from September to August with and without density-dependent effects, were weighted by the posterior probability of each model and its parameter combination. To implement this method, the joint posterior probability distributions of the parameters of the full Bayesian model (with the environmental predictors included) was first computed. The posterior distribution was then sampled for model parameters and a stochastic forecast was drawn from each sample creating a Bayesian posterior predictive distribution of the 2002 pink salmon forecast for each competing model (Adkison 2002). The Adkison (2002) approach is an example of the Bayesian approach (Patterson 1999), whereas the approach implemented in this report is a frequentist approach to model averaging (Burnham and Anderson 2002).

There are various approaches to estimating the model-averaged weights, including fixed equal weights, Bayesian model weights, information-theoretic framework based on the Kullback-Leibler divergence (e.g., Akaike's Information Criterion; Akaike 1973; Burnham and Anderson 2002), and cross-validation (Dormann et al. 2018). Because our goal was to reduce prediction error in the forecast, one of our model weighting methods was based on the one-step-ahead inverse-variance from the last 5 years of predictions (model m19 in this analysis). This weighting method aims to adjust the average (i.e., improved inference) so that better performing models receive more weight than poorly fit models. The other method, equal weights, was considered a naïve approach to forecasting (model m20 in this analysis). Both methods produced identical forecasts for 2022 (13.6

million fish), although this was mainly due to the fact that the 18 individual models produced similar forecasts (range 13.0–16.5 million fish) and that there were a large number of candidate models. If there was more variability among the individual forecasts, or only a few of the models were considered candidate models, the difference between the model-averaged forecasts based on the one-step-ahead inverse-variance or the equal weights approach would likely have been greater.

The standard error of the model-averaged forecast (i.e., the square root of the unconditional variance estimator) was based on equation 9 in Buckland et al. (1997). This method assumes that the average point estimate $\tilde{Y}$ is unbiased and, thus, the average point estimate can be used to compute the bias of the individual predictions. In addition, the method by Buckland et al. (1997) assumes that predictions from different models are perfectly correlated (i.e., covariance term is large) and, as a result, the variance estimation is more conservative (Dormann et al. 2018). Although the Buckland et al. (1997) estimator has been criticized (Hjort and Claeskens 2003; Claeskens and Hjort 2008), this method has proved to work adequately in simulations (Lukacs et al. 2010; Fletcher and Dillingham 2011) and thus was used as one approach to calculate confidence intervals in this study.

Forecasting in recent years is moving toward more computationally intensive, nontraditional methods utilizing techniques such as artificial neural networks (Zhou 2003; McCormick and Falcy 2015), ridge regression (McCormick and Falcy 2015), least absolute shrinkage and selection operator (Lasso; McCormick and Falcy 2015), elastic net (McCormick and Falcy 2015), principal component regression (Burke et al. 2013; McCormick and Falcy 2015), and machine learning within ensemble models (Ovando et al. 2022). For example, recent efforts to improve forecasting of Bristol Bay sockeye salmon *O. nerka* included machine learning techniques to identify correlations in returns across multiple river systems and age classes. Compared to the preseason forecasts provided annually by the Fisheries Research Institute at the University of Washington and ADF&G, the ensemble modeling approach that incorporated machine learning was able to reduce the forecast error by an average of 13% in 5 of the 7 river systems, although the forecast error increased for the remaining 2 river systems (Ovando et al. 2022). In the past, NOAA explored a more complicated forecasting model that incorporated 6 ecosystem metrics (that were significantly correlated with the Southeast Alaska pink salmon harvest) and their average rank scores into an ecosystem indicators rank index (Wertheimer et al. 2015; Orsi et al. 2016; Wertheimer et al. 2017). This parameter was used as an alternative to CPUE in the forecasting models. Although the ecosystem model seemed to perform well in the first 2 years it was used (2014 and 2015 preseason forecasts; Wertheimer et al. 2015; Orsi et al. 2016), the 2-parameter model (i.e., vessel-calibrated peak June or July juvenile pink salmon CPUE and the Icy Strait temperature index) has been the selected forecast model in recent years (Piston et al. 2019, 2020, 2021a, 2022). As Adkison (2002) pointed out, "reducing the uncertainty in forecasts of pink salmon harvests will likely require direct measures of a cohort's abundance in coastal or marine waters." This is precisely the objective of the annual SECM surveys: to annually sample coastal ocean metrics and juvenile salmon along their primary seaward migration corridor in Southeast Alaska, to create a long-term time series. Although more complex models may one day be developed that provide clear improvements to our pink salmon forecast (e.g., model-averaged approach, machine learning), currently, the simple individual regression models using the SECM survey juvenile CPUE data and the spring/summer satellite-derived SST data provide the best forecast performance with the lowest forecast error.

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TABLES AND FIGURES

Table 1.–Satellite sea surface temperature data (°C) from the Icy Strait region, Chatham Strait region, northern Southeast Alaska region, and Southeast Alaska region for May, May through July (MJJ), April through June (AMJ), and April through July (AMJJ).

	Icy Strait				Chatham Strait				Northern Southeast Alaska				Southeast Alaska			
Year	MJJ	May	AMJJ	AMJ	MJJ	May	AMJJ	AMJ	MJJ	May	AMJJ	AMJ	MJJ	May	AMJJ	AMJ
1997	10.30	7.01	8.83	7.30	10.08	7.48	8.83	7.59	10.02	7.35	8.71	7.40	10.47	8.00	9.20	7.99
1998	9.97	7.34	8.85	7.56	9.85	7.83	8.91	7.88	9.89	7.65	8.85	7.71	10.36	8.37	9.38	8.37
1999	9.08	6.17	8.02	6.78	8.90	6.84	8.05	7.12	8.93	6.70	7.98	6.95	9.30	7.23	8.40	7.43
2000	9.94	7.02	8.67	7.35	9.70	7.34	8.62	7.52	9.70	7.23	8.57	7.39	10.02	7.71	8.95	7.86
2001	9.57	6.48	8.40	7.08	9.15	6.74	8.18	7.12	9.22	6.66	8.17	7.01	9.51	7.10	8.52	7.45
2002	9.34	6.26	8.02	6.60	8.97	6.39	7.85	6.64	9.05	6.39	7.88	6.61	9.44	6.92	8.33	7.14
2003	10.08	7.29	8.88	7.53	9.92	7.71	8.90	7.85	9.86	7.57	8.76	7.60	10.32	8.17	9.25	8.16
2004	10.68	7.53	9.25	7.69	10.43	7.94	9.22	7.96	10.38	7.89	9.09	7.79	10.98	8.58	9.74	8.51
2005	11.16	8.40	9.64	8.26	10.67	8.51	9.48	8.44	10.63	8.42	9.35	8.26	11.06	8.92	9.83	8.82
2006	10.19	6.84	8.86	7.49	9.78	7.16	8.68	7.58	9.72	6.98	8.55	7.36	10.19	7.63	9.07	7.96
2007	9.49	6.55	8.16	6.87	9.52	7.04	8.41	7.27	9.44	6.90	8.24	7.03	9.99	7.51	8.82	7.64
2008	8.85	6.43	7.72	6.68	8.65	6.77	7.69	6.83	8.65	6.64	7.63	6.74	9.18	7.22	8.17	7.28
2009	9.94	7.19	8.47	7.22	9.75	7.30	8.46	7.35	9.77	7.32	8.40	7.24	10.20	7.76	8.85	7.73
2010	9.87	7.71	8.68	7.81	9.65	7.97	8.66	7.93	9.62	7.76	8.54	7.72	10.09	8.28	9.05	8.23
2011	9.84	6.81	8.47	7.18	9.59	7.31	8.49	7.55	9.67	7.25	8.44	7.44	10.05	7.74	8.88	7.92
2012	9.23	6.92	8.10	7.07	9.17	7.07	8.18	7.22	9.14	6.95	8.09	7.10	9.68	7.47	8.63	7.61
2013	9.88	6.37	8.45	6.97	9.66	6.74	8.44	7.21	9.67	6.59	8.36	7.04	10.39	7.51	9.10	7.85
2014	10.23	7.90	8.81	7.62	9.98	8.17	8.76	7.77	10.03	8.15	8.70	7.64	10.57	8.62	9.26	8.17
2015	10.73	8.34	9.43	8.29	10.62	8.87	9.55	8.73	10.81	8.92	9.56	8.65	11.43	9.64	10.21	9.32
2016	11.65	8.81	10.37	9.14	11.04	8.92	10.03	9.07	11.18	8.92	10.05	9.00	11.67	9.61	10.59	9.59
2017	9.82	7.22	8.66	7.51	9.65	7.65	8.70	7.76	9.82	7.75	8.77	7.78	10.31	8.25	9.28	8.29
2018	9.99	6.92	8.74	7.43	9.87	7.40	8.75	7.61	10.11	7.53	8.86	7.63	10.79	8.28	9.54	8.30
2019	10.74	7.79	9.51	8.10	10.47	8.24	9.46	8.35	10.87	8.42	9.65	8.44	11.46	9.01	10.25	9.05
2020	10.40	7.83	9.05	7.86	9.99	8.09	8.84	7.86	10.23	8.26	8.98	7.94	10.70	8.90	9.52	8.53
2021	10.26	6.91	8.91	7.47	10.06	7.25	8.90	7.63	10.23	7.29	8.96	7.65	10.82	7.97	9.58	8.31

Table 2.–Annual adult pink salmon harvest data from Southeast Alaska (millions of fish), 1998–2022, compared to ISTI temperature (°C) and juvenile pink salmon CPUE data collected from the SECM project in the prior year, 1997–2021. The ISTI variable is the Icy Strait temperature index.

Year	ISTI	CPUE	Year	Harvest
1997	9.28	2.48	1998	42.4
1998	9.4	5.62	1999	77.8
1999	8.56	1.6	2000	20.2
2000	8.77	3.73	2001	67
2001	9.03	2.87	2002	45.3
2002	8.2	2.78	2003	52.5
2003	9.31	3.08	2004	45.3
2004	9.33	3.9	2005	59.1
2005	10.21	2.04	2006	11.6
2006	8.75	2.58	2007	44.8
2007	8.94	1.17	2008	15.9
2008	7.91	2.32	2009	38
2009	9.36	2.33	2010	24.1
2010	9.35	4.11	2011	58.9
2011	8.65	1.51	2012	21.3
2012	8.48	3.52	2013	94.7
2013	8.83	2.14	2014	37.2
2014	9.12	3.8	2015	35.1
2015	9.61	2.45	2016	18.4
2016	10.2	4.35	2017	34.7
2017	8.56	0.35	2018	8.1
2018	8.92	1.17	2019	21.1
2019	9.91	1.14	2020	8.1
2020	8.89	2.15	2021	48.5
2021	8.89	0.88	2022	NA

Table 3.–Summary of model outputs including adjusted R-squared, one-step-ahead mean absolute percent error (MAPE; based on the last 5 and 10 years), inverse variance weighting (scaled to sum to one), equal weighting (scaled to sum to one), and the 2022 Southeast Alaska pink salmon harvest forecast. The biophysical variables (terms) included SECM survey juvenile abundance data (CPUE) and temperature index data (Icy Strait temperature index [ISTI]) from 8 stations in Icy and Chatham Straits, and May through July satellite-derived sea surface temperature (SST) data summarized across 4 geographical areas and 4 time strata.

Model	Terms (letters in parentheses represent consecutive spring/summer months)	Adjusted R^2	One-step-ahead MAPE based on the last 5 years	One-step-ahead MAPE based on the last 10 years	Inverse variance weighting (scaled to sum to one)	Equal-weighting (scaled to sum to one)	2022 forecast (bias-corrected) with 80% prediction interval in parentheses (millions of fish)
m1	CPUE	0.59	79%	63%	0.03	0.06	16.5 (9.1–30.2)
m2	CPUE, ISTI	0.81	40%	37%	0.07	0.06	15.6 (10.3–23.6)
m3	CPUE, Chatham SST (May)	0.79	33%	25%	0.05	0.06	16.4 (10.6–25.4)
m4	CPUE, Chatham SST (MJJ)	0.74	44%	37%	0.06	0.06	13.3 (8.2–21.7)
m5	CPUE, Chatham SST (AMJ)	0.79	30%	28%	0.07	0.06	14.9 (9.7–22.9)
m6	CPUE, Chatham SST (AMJJ)	0.77	34%	30%	0.07	0.06	13.4 (8.5–21.1)
m7	CPUE, Icy Strait SST (May)	0.77	33%	24%	0.05	0.06	15.9 (10.1–25.0)
m8	CPUE, Icy Strait SST (MJJ)	0.73	42%	37%	0.05	0.06	13.8 (8.4–22.6)
m9	CPUE, Icy Strait SST (AMJ)	0.76	34%	27%	0.05	0.06	14.4 (9.0–22.8)
m10	CPUE, Icy Strait SST (AMJJ)	0.75	34%	32%	0.06	0.06	13.6 (8.4–22.0)
m11	CPUE, NSEAK SST (May)	0.78	31%	24%	0.05	0.06	16.3 (10.4–25.4)
m12	CPUE, NSEAK SST (MJJ)	0.75	37%	31%	0.05	0.06	13.2 (8.1–21.3)
m13	CPUE, NSEAK SST (AMJ)	0.78	28%	27%	0.06	0.06	14.3 (9.2–22.3)
m14	CPUE, NSEAK SST (AMJJ)	0.77	29%	27%	0.06	0.06	13.2 (8.3–20.9)
m15	CPUE, SEAK SST (May)	0.76	34%	28%	0.04	0.06	15.7 (9.9–25.0)
m16	CPUE, SEAK SST (MJJ)	0.73	41%	34%	0.05	0.06	13.1 (8.0–21.5)
m17	CPUE, SEAK SST (AMJ)	0.77	30%	30%	0.06	0.06	13.9 (8.8–22.0)
m18	CPUE, SEAK SST (AMJJ)	0.75	33%	29%	0.06	0.06	13.0 (8.1–21.0)
m19	inverse-variance weighted model-averaged forecast	ND	32%	27%	ND	ND	13.6 (6.5–28.3)[ab]
m20	equally weighted model-averaged forecast	ND	33%	28%	ND	ND	13.6 (6.5–28.6)[ab]

Note: ND = no data

[a] 80% confidence interval

[b] not bias-corrected

Table 4.–Forecast performance of the individual multiple regression models based on juvenile pink salmon CPUE and a temperature index (models m1 through m3). Observed harvest is the Southeast Alaska pink salmon harvest (millions of fish). Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m1	21.28	22.87	7%	1.59	7%
2013	m1	94.72	51.46	-46%	43.26	46%
2014	m1	37.17	30.42	-18%	6.76	18%
2015	m1	35.09	62.37	78%	27.28	78%
2016	m1	18.37	34.80	89%	16.43	89%
2017	m1	34.73	73.44	111%	38.71	111%
2018	m1	8.07	15.55	93%	7.49	93%
2019	m1	21.14	18.93	-10%	2.21	10%
2020	m1	8.06	19.08	137%	11.02	137%
2021	m1	48.50	27.54	-43%	20.96	43%
2012	m2	21.28	24.51	15%	3.23	15%
2013	m2	94.72	64.99	-31%	29.73	31%
2014	m2	37.17	30.36	-18%	6.81	18%
2015	m2	35.09	58.84	68%	23.75	68%
2016	m2	18.37	24.24	32%	5.86	32%
2017	m2	34.73	41.11	18%	6.38	18%
2018	m2	8.07	15.64	94%	7.57	94%
2019	m2	21.14	16.76	-21%	4.38	21%
2020	m2	8.06	10.18	26%	2.11	26%
2021	m2	48.50	28.13	-42%	20.37	42%
2012	m3	21.28	20.14	-5%	1.14	5%
2013	m3	94.72	60.03	-37%	34.69	37%
2014	m3	37.17	37.03	0%	0.15	0%
2015	m3	35.09	43.62	24%	8.52	24%
2016	m3	18.37	14.92	-19%	3.45	19%
2017	m3	34.73	40.79	17%	6.06	17%
2018	m3	8.07	10.08	25%	2.01	25%
2019	m3	21.14	16.28	-23%	4.86	23%
2020	m3	8.06	11.15	38%	3.08	38%
2021	m3	48.50	19.00	-61%	29.51	61%

Table 5.–Forecast performance of the individual multiple regression models based on juvenile pink salmon CPUE and a temperature index (models m4 through m6). Observed harvest is the Southeast Alaska pink salmon harvest (millions of fish). Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m4	21.28	21.80	2%	0.52	2%
2013	m4	94.72	60.19	-36%	34.53	36%
2014	m4	37.17	28.66	-23%	8.51	23%
2015	m4	35.09	55.82	59%	20.72	59%
2016	m4	18.37	23.23	26%	4.86	26%
2017	m4	34.73	43.45	25%	8.71	25%
2018	m4	8.07	13.11	62%	5.04	62%
2019	m4	21.14	15.66	-26%	5.48	26%
2020	m4	8.06	12.45	54%	4.39	54%
2021	m4	48.50	23.56	-51%	24.95	51%
2012	m5	21.28	19.67	-8%	1.60	8%
2013	m5	94.72	60.53	-36%	34.19	36%
2014	m5	37.17	32.77	-12%	4.40	12%
2015	m5	35.09	55.64	59%	20.55	59%
2016	m5	18.37	16.35	-11%	2.02	11%
2017	m5	34.73	35.44	2%	0.70	2%
2018	m5	8.07	10.70	33%	2.63	33%
2019	m5	21.14	16.15	-24%	4.99	24%
2020	m5	8.06	11.22	39%	3.15	39%
2021	m5	48.50	22.85	-53%	25.65	53%
2012	m6	21.28	21.42	1%	0.14	1%
2013	m6	94.72	61.26	-35%	33.46	35%
2014	m6	37.17	29.95	-19%	7.22	19%
2015	m6	35.09	58.20	66%	23.11	66%
2016	m6	18.37	20.67	12%	2.29	12%
2017	m6	34.73	38.25	10%	3.52	10%
2018	m6	8.07	11.62	44%	3.56	44%
2019	m6	21.14	15.46	-27%	5.68	27%
2020	m6	8.06	11.17	38%	3.10	38%
2021	m6	48.50	23.95	-51%	24.56	51%

Table 6.–Forecast performance of the individual multiple regression models based on juvenile pink salmon CPUE and a temperature index (models m7 through m9). Observed harvest is the Southeast Alaska pink salmon harvest (millions of fish). Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m7	21.28	21.65	2%	0.37	2%
2013	m7	94.72	54.84	-42%	39.88	42%
2014	m7	37.17	36.51	-2%	0.66	2%
2015	m7	35.09	44.37	26%	9.27	26%
2016	m7	18.37	17.69	-4%	0.69	4%
2017	m7	34.73	38.09	10%	3.36	10%
2018	m7	8.07	10.29	28%	2.22	28%
2019	m7	21.14	17.00	-20%	4.14	20%
2020	m7	8.06	11.59	44%	3.52	44%
2021	m7	48.50	18.22	-62%	30.28	62%
2012	m8	21.28	21.95	3%	0.68	3%
2013	m8	94.72	61.88	-35%	32.84	35%
2014	m8	37.17	29.01	-22%	8.16	22%
2015	m8	35.09	55.95	59%	20.85	59%
2016	m8	18.37	25.21	37%	6.83	37%
2017	m8	34.73	39.06	12%	4.33	12%
2018	m8	8.07	13.46	67%	5.39	67%
2019	m8	21.14	16.54	-22%	4.61	22%
2020	m8	8.06	12.59	56%	4.53	56%
2021	m8	48.50	22.04	-55%	26.46	55%
2012	m9	21.28	21.31	0%	0.03	0%
2013	m9	94.72	59.19	-38%	35.53	38%
2014	m9	37.17	33.15	-11%	4.02	11%
2015	m9	35.09	54.55	55%	19.45	55%
2016	m9	18.37	18.39	0%	0.01	0%
2017	m9	34.73	29.26	-16%	5.48	16%
2018	m9	8.07	10.41	29%	2.35	29%
2019	m9	21.14	15.47	-27%	5.67	27%
2020	m9	8.06	11.33	40%	3.26	40%
2021	m9	48.50	20.30	-58%	28.21	58%

Table 7.–Forecast performance of the individual multiple regression models based on juvenile pink salmon CPUE and a temperature index (models m10 through m12). Observed harvest is the Southeast Alaska pink salmon harvest (millions of fish). Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m10	21.28	21.97	3%	0.70	3%
2013	m10	94.72	62.67	-34%	32.05	34%
2014	m10	37.17	30.15	-19%	7.02	19%
2015	m10	35.09	58.18	66%	23.09	66%
2016	m10	18.37	22.95	25%	4.58	25%
2017	m10	34.73	34.07	-2%	0.67	2%
2018	m10	8.07	11.89	47%	3.82	47%
2019	m10	21.14	15.66	-26%	5.48	26%
2020	m10	8.06	11.32	40%	3.25	40%
2021	m10	48.50	21.96	-55%	26.55	55%
2012	m11	21.28	19.78	-7%	1.50	7%
2013	m11	94.72	60.26	-36%	34.46	36%
2014	m11	37.17	38.14	3%	0.97	3%
2015	m11	35.09	41.22	17%	6.12	17%
2016	m11	18.37	13.76	-25%	4.62	25%
2017	m11	34.73	39.53	14%	4.79	14%
2018	m11	8.07	9.44	17%	1.38	17%
2019	m11	21.14	15.04	-29%	6.10	29%
2020	m11	8.06	10.48	30%	2.42	30%
2021	m11	48.50	17.56	-64%	30.94	64%
2012	m12	21.28	20.95	-2%	0.33	2%
2013	m12	94.72	61.66	-35%	33.06	35%
2014	m12	37.17	28.30	-24%	8.87	24%
2015	m12	35.09	54.11	54%	19.02	54%
2016	m12	18.37	20.60	12%	2.22	12%
2017	m12	34.73	40.06	15%	5.33	15%
2018	m12	8.07	12.06	50%	3.99	50%
2019	m12	21.14	14.13	-33%	7.02	33%
2020	m12	8.06	10.75	33%	2.69	33%
2021	m12	48.50	21.70	-55%	26.80	55%

Table 8.–Forecast performance of the individual multiple regression models based on juvenile pink salmon CPUE and a temperature index (models m13 through m15). Observed harvest is the Southeast Alaska pink salmon harvest (millions of fish). Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m13	21.28	18.73	-12%	2.55	12%
2013	m13	94.72	60.49	-36%	34.23	36%
2014	m13	37.17	33.39	-10%	3.79	10%
2015	m13	35.09	54.10	54%	19.01	54%
2016	m13	18.37	14.24	-22%	4.13	22%
2017	m13	34.73	32.89	-5%	1.85	5%
2018	m13	8.07	9.69	20%	1.62	20%
2019	m13	21.14	14.94	-29%	6.21	29%
2020	m13	8.06	10.20	27%	2.14	27%
2021	m13	48.50	20.66	-57%	27.84	57%
2012	m14	21.28	20.84	-2%	0.44	2%
2013	m14	94.72	62.63	-34%	32.09	34%
2014	m14	37.17	29.80	-20%	7.37	20%
2015	m14	35.09	57.27	63%	22.18	63%
2016	m14	18.37	18.59	1%	0.22	1%
2017	m14	34.73	35.25	1%	0.52	1%
2018	m14	8.07	10.60	31%	2.53	31%
2019	m14	21.14	14.06	-33%	7.08	33%
2020	m14	8.06	10.01	24%	1.95	24%
2021	m14	48.50	21.86	-55%	26.65	55%
2012	m15	21.28	20.31	-5%	0.97	5%
2013	m15	94.72	61.34	-35%	33.38	35%
2014	m15	37.17	31.65	-15%	5.53	15%
2015	m15	35.09	44.42	27%	9.33	27%
2016	m15	18.37	13.04	-29%	5.33	29%
2017	m15	34.73	39.39	13%	4.65	13%
2018	m15	8.07	9.96	23%	1.89	23%
2019	m15	21.14	13.99	-34%	7.15	34%
2020	m15	8.06	10.91	35%	2.84	35%
2021	m15	48.50	17.68	-64%	30.82	64%

Table 9.–Forecast performance of the individual multiple regression models based on juvenile pink salmon CPUE and a temperature index (models m16 through m18). Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m16	21.28	21.46	1%	0.19	1%
2013	m16	94.72	59.25	-37%	35.47	37%
2014	m16	37.17	25.68	-31%	11.50	31%
2015	m16	35.09	53.92	54%	18.83	54%
2016	m16	18.37	20.84	13%	2.46	13%
2017	m16	34.73	42.85	23%	8.11	23%
2018	m16	8.07	12.27	52%	4.20	52%
2019	m16	21.14	13.33	-37%	7.81	37%
2020	m16	8.06	11.17	39%	3.11	39%
2021	m16	48.50	22.53	-54%	25.97	54%
2012	m17	21.28	19.49	-8%	1.79	8%
2013	m17	94.72	61.35	-35%	33.37	35%
2014	m17	37.17	28.42	-24%	8.76	24%
2015	m17	35.09	56.22	60%	21.12	60%
2016	m17	18.37	14.70	-20%	3.67	20%
2017	m17	34.73	35.44	2%	0.71	2%
2018	m17	8.07	10.21	27%	2.14	27%
2019	m17	21.14	14.26	-33%	6.88	33%
2020	m17	8.06	10.51	30%	2.45	30%
2021	m17	48.50	20.90	-57%	27.60	57%
2012	m18	21.28	21.28	0%	0.01	0%
2013	m18	94.72	60.61	-36%	34.11	36%
2014	m18	37.17	26.43	-29%	10.75	29%
2015	m18	35.09	56.67	61%	21.58	61%
2016	m18	18.37	18.77	2%	0.40	2%
2017	m18	34.73	38.12	10%	3.38	10%
2018	m18	8.07	10.95	36%	2.88	36%
2019	m18	21.14	13.28	-37%	7.86	37%
2020	m18	8.06	10.45	30%	2.39	30%
2021	m18	48.50	22.26	-54%	26.24	54%

Table 10.–Forecast performance of the model-averaged approach, based on 18 multiple regression models with juvenile pink salmon CPUE and a temperature index, and weighted by the one step-ahead inverse-variance. Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are not bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m19	21.28	20.23	-5%	1.05	5%
2013	m19	94.72	57.91	-39%	36.81	39%
2014	m19	37.17	29.66	-20%	7.51	20%
2015	m19	35.09	50.72	45%	15.63	45%
2016	m19	18.37	17.37	-5%	1.00	5%
2017	m19	34.73	36.80	6%	2.06	6%
2018	m19	8.07	10.73	33%	2.66	33%
2019	m19	21.14	14.88	-30%	6.26	30%
2020	m19	8.06	10.73	33%	2.67	33%
2021	m19	48.50	20.31	-58%	28.19	58%

Table 11.–Forecast performance of the model-averaged approach, based on 18 multiple regression models with juvenile pink salmon CPUE and a temperature index, and weighting the models equally. Forecast performance (2012–2021) is expressed as the percent deviation from the observed Southeast Alaska harvest. Positive values indicate the forecast was higher than actual and negative values indicate the forecast was lower than actual. Forecasts are not bias-corrected. The performance metric MAPE is the one-step-ahead mean absolute percent error.

Year	Model	Harvest (observed)	Forecast	Forecast performance	Absolute deviation	MAPE
2012	m20	21.28	20.25	-5%	1.03	5%
2013	m20	94.72	58.00	-39%	36.72	39%
2014	m20	37.17	29.64	-20%	7.53	20%
2015	m20	35.09	51.14	46%	16.04	46%
2016	m20	18.37	18.20	-1%	0.17	1%
2017	m20	34.73	37.48	8%	2.74	8%
2018	m20	8.07	10.97	36%	2.91	36%
2019	m20	21.14	14.72	-30%	6.42	30%
2020	m20	8.06	10.89	35%	2.83	35%
2021	m20	48.50	20.77	-57%	27.74	57%

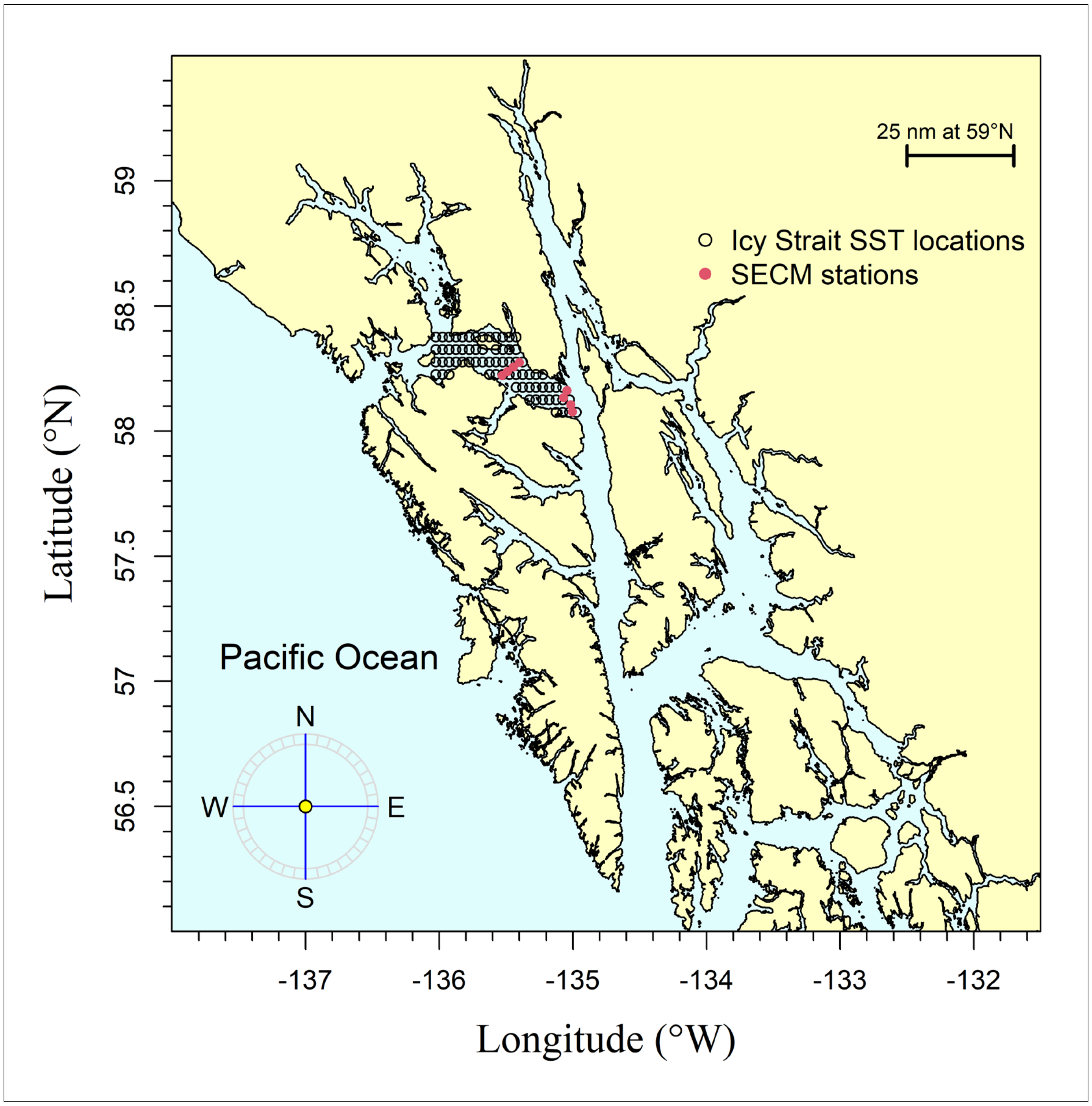

Figure 1.–The Icy Strait region encompasses waters of Icy Strait from the east side of Lemesurier Island east to a line from Point Couverden south to Point Augusta in northern Southeast Alaska. The Southeast Coastal Monitoring (SECM) project transects in Upper Chatham and Icy Straits are shown as red points for comparison to the 70 satellite data points (black circles) in the Icy Strait region.

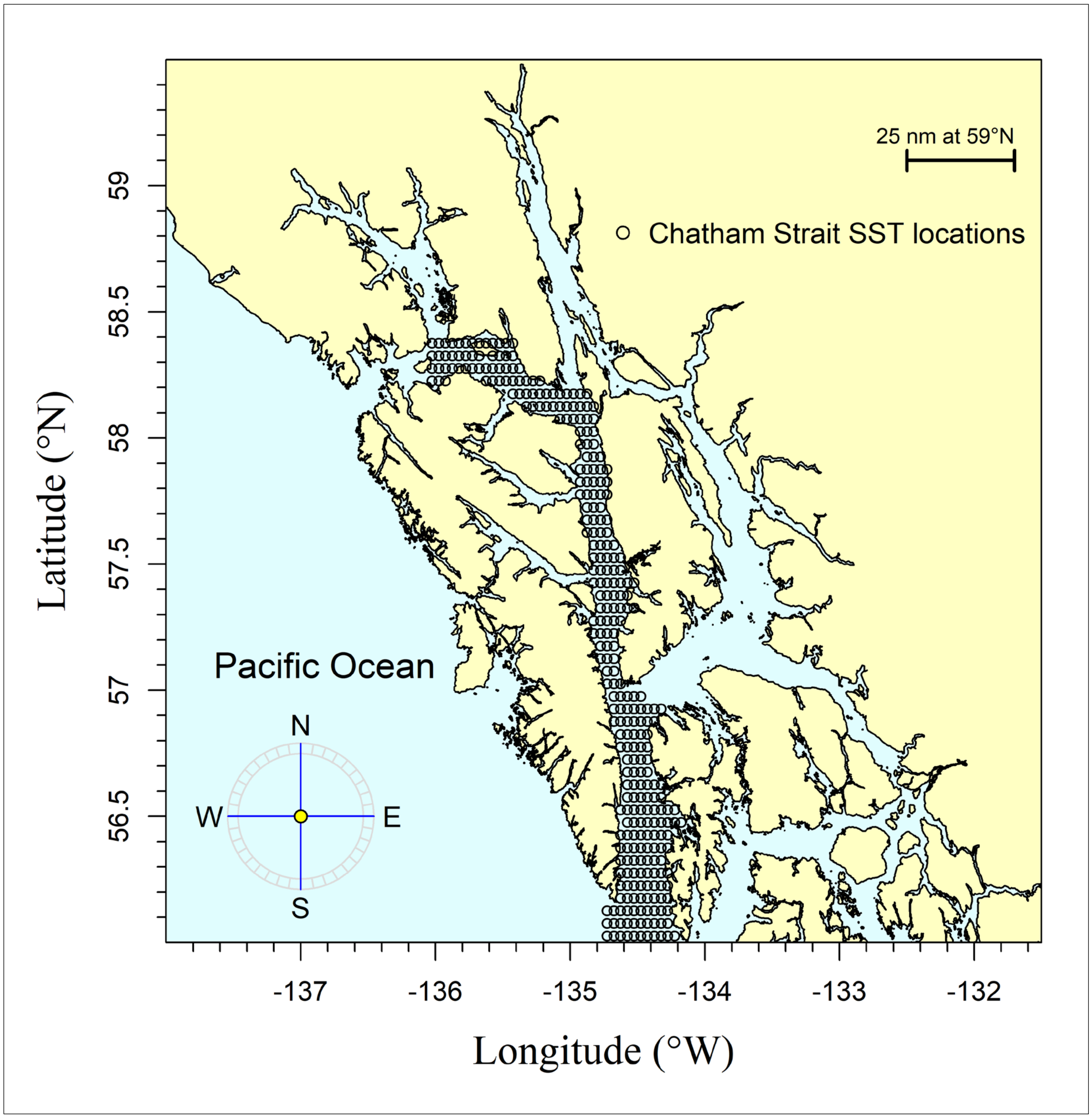

Figure 2.–The Chatham region encompasses waters of Chatham and Icy Straits from the easternmost point of Lemesurier Island east to Admiralty Island, and south to the approximate latitude of 56.025° N (roughly Cape Decision, Kuiu Island) in Southeast Alaska. There are 313 satellite data points (black circles) in the Chatham region.

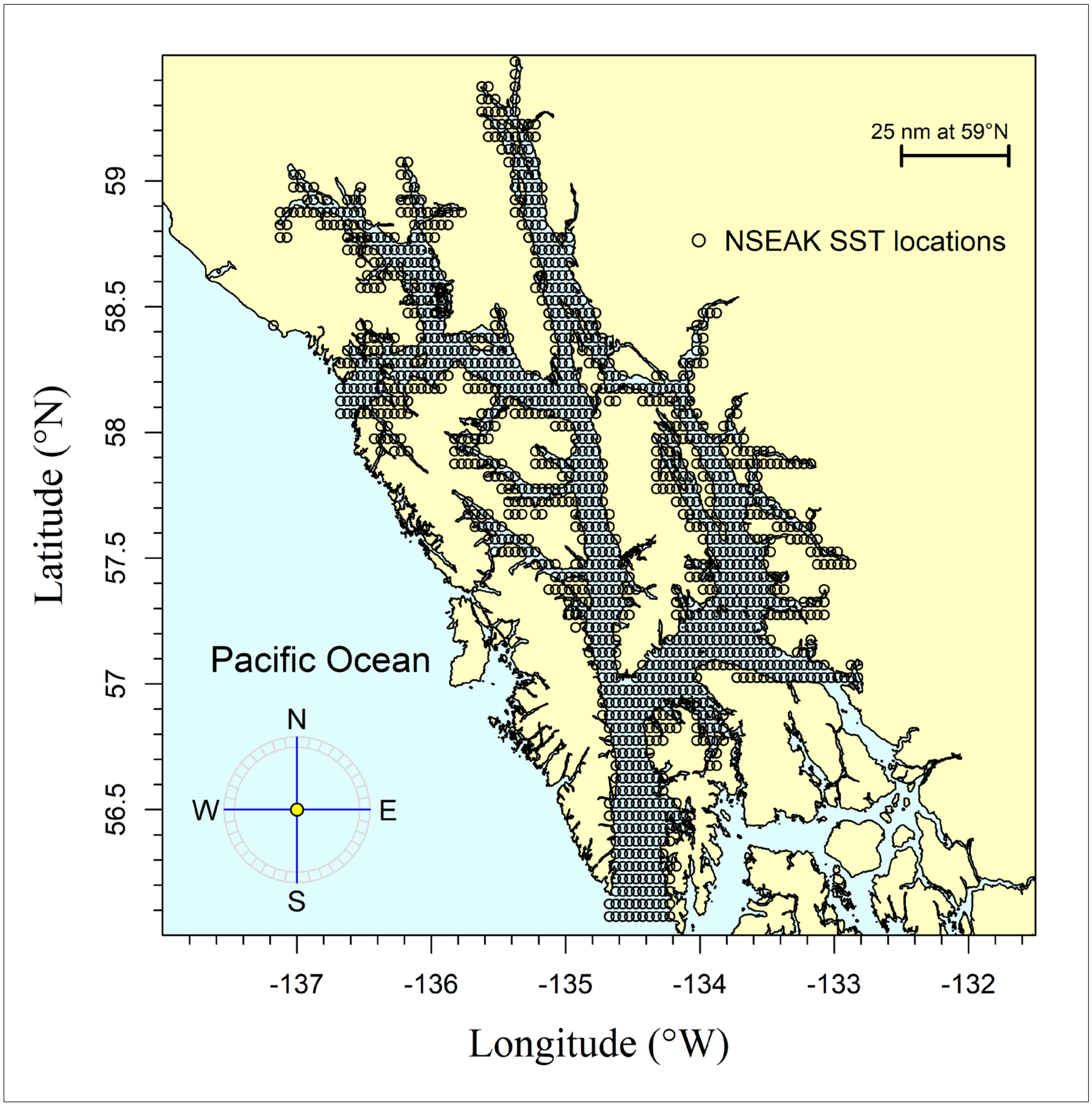

Figure 3.–The northern Southeast Alaska (NSEAK) region encompasses northern Southeast Alaska inside waters from 59.475 to 56.075° north latitude and from -137.175 to -132.825° west longitude. There are 1,344 satellite data points (black circles) in the NSEAK region.

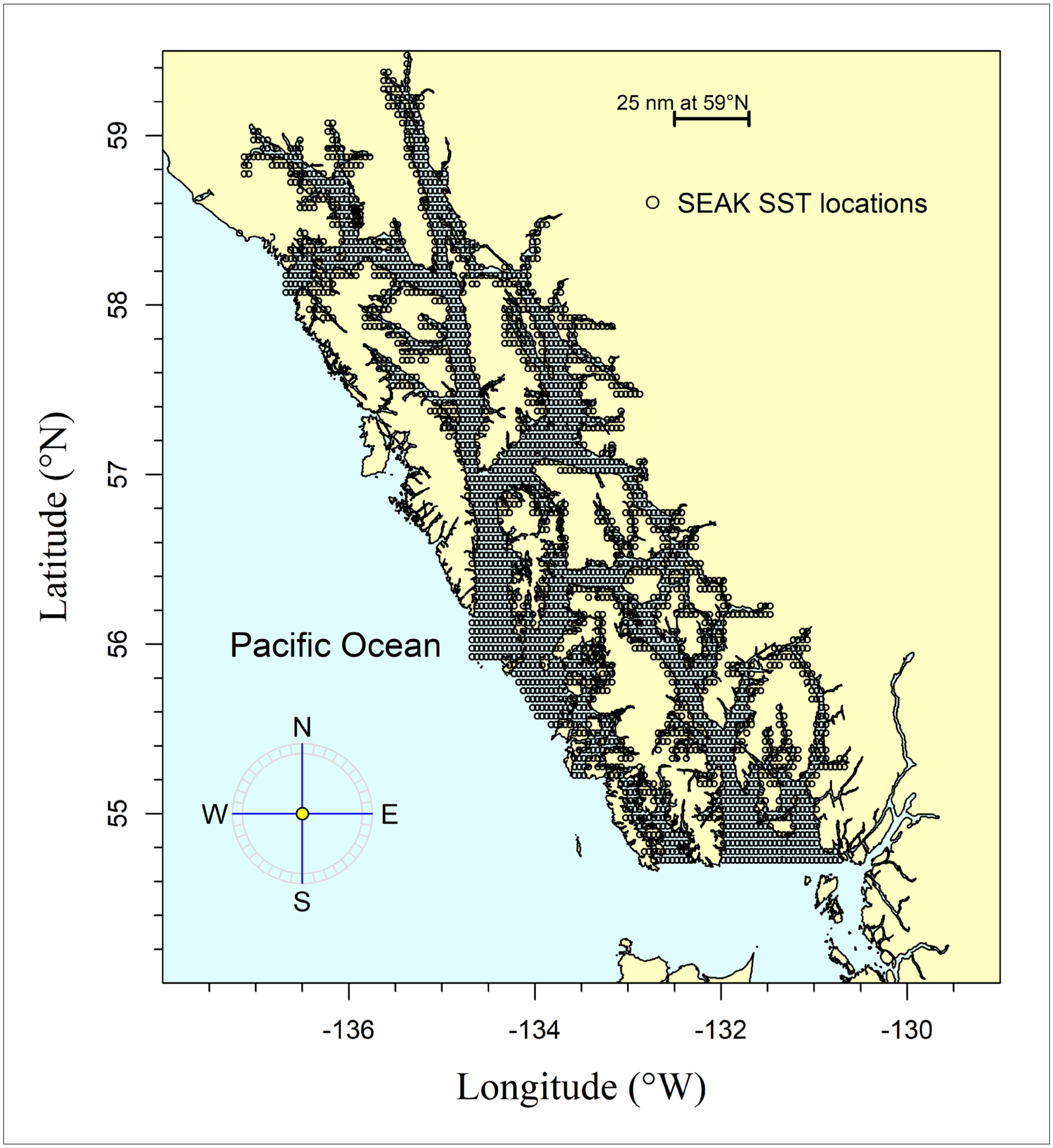

Figure 4.–The Southeast Alaska (SEAK) region encompasses Southeast Alaska inside waters from 59.475 to 54.725° north latitude and from -137.175 to -130.675° west longitude. There are 2,669 satellite stations (black circles) in the SEAK region.

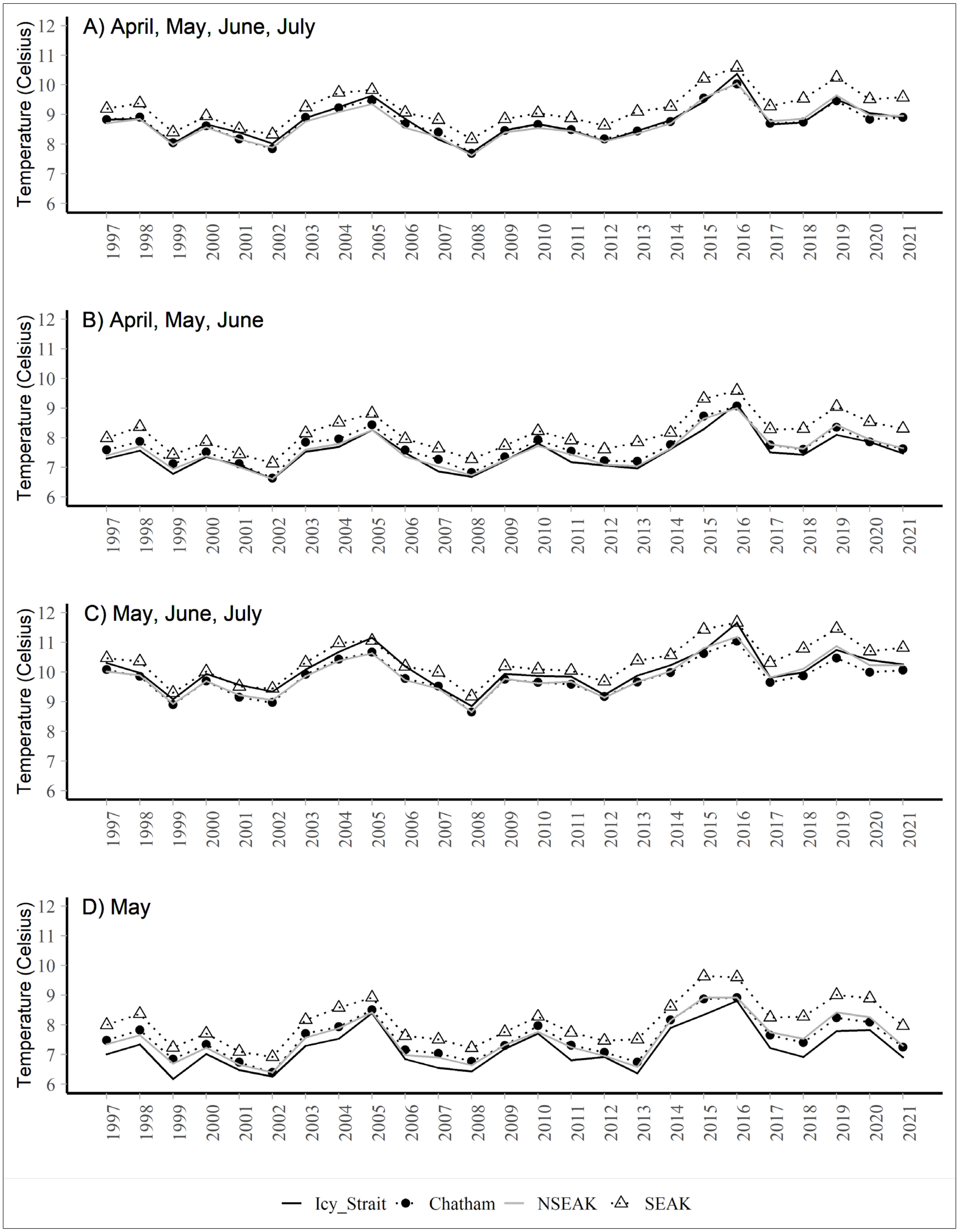

Figure 5.–Satellite sea surface temperature (°C) averaged over 5 time strata and the 4 regions Icy Strait, Chatham, northern Southeast Alaska (NSEAK), and Southeast Alaska (SEAK), from 1997 through 2021.

Figure 6.–Average temperature (°C) at 20 m depth during May, June, and July at 8 SECM project monitoring stations in Icy Strait (Icy Strait and Upper Chatham transects; Icy Strait temperature index) from 1997 through 2021.

APPENDICES

Appendix A.–Methodology used by ADF&G to forecast adult pink salmon returns or harvest in Southeast Alaska (1970–2021). Separate forecasts for northern and southern Southeast Alaska were made from 1970 through 1992, after which harvest forecasts were made for the entire Southeast Alaska region.

Forecast year	Method – Southern Southeast Alaska (SSEAK)	Method – Northern Southeast Alaska (NSEAK)	Response variable	Reference
1970	Simple linear regression of observed pre-emergent fry index and subsequent even-year total adult return.	Simple linear regression of escapement-weighted pre-emergent fry index and subsequent total adult return.	returns	Valentine et al. 1969; Valentine et al. 1970
1971	Simple linear regression of observed pre-emergent fry index and subsequent total adult return.	Simple linear regression of escapement-weighted pre-emergent fry index and subsequent total adult return.	returns	Gwartney et al. 1970
1972	Simple linear regression of escapement-weighted pre-emergent fry index and subsequent total adult return.	Simple linear regression of escapement-weighted pre-emergent fry index and subsequent total adult return.	returns	Durley 1971; Durley and Seibel 1972
1973	Simple linear regression of escapement index-weighted pre-emergent fry index and total adult return.	Simple linear regression of escapement-weighted pre-emergent fry index and total adult return. Forecast adjusted down due to colder than average marine water temps.	returns	Durley 1972; Durley 1973a
1974	Multiple linear regression of unweighted pre-emergent fry abundance, spring (Mar.–May) seawater temperature at Ketchikan, and total adult return.	Multiple linear regression of escapement-weighted pre-emergent fry index, spring (Mar.–May) estuary seawater temperature at Juneau-Sitka, and total adult return.	returns	Durley 1973b; Durley 1973c
1975	Simple linear regression of unweighted pre-emergent fry index and total adult return.	Multiple linear regression of escapement-weighted pre-emergent fry index, mean air temperature (Apr.–Aug.) at 7 locations in NSEAK, and total adult return.	returns	Kingsbury and Larson 1975
1976	Multiple linear regression of pre-emergent fry abundance, spring (Mar.–May) seawater temperature at Ketchikan, and total adult return.	Multiple linear regression of escapement-weighted pre-emergent fry index, air temp (Apr.–Aug.) at 7 locations in NSEAK, and total adult return.	returns	Kingsbury and Larson 1976a, 1976b
1977	Multiple linear regression of pre-emergent fry index, spring (Mar.–May) seawater temperature at Ketchikan, and total adult return.	Multiple linear regression of escapement-weighted pre-emergent fry index, air temp (Apr.–Aug.) at 7 locations in NSEAK, and total adult return.	returns	Kingsbury and Larson 1977

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Forecast year	Method – Southern Southeast Alaska (SSEAK)	Method – Northern Southeast Alaska (NSEAK)	Response variable	Reference
1978	Multiple linear regression of parent-year escapements, winter air temperatures, and adult returns.	Parent-year escapements and spawner return ratios.	returns	Kingsbury 1978
1979	Multiple linear regression of unweighted pre-emergent fry index, average annual air temperature at 15 stations located throughout Southeast Alaska, and index of fry fitness.	Multiple linear regression of pre-emergent fry index and average annual air temperature at 15 stations located throughout Southeast Alaska.	returns	Jones 1979
1980	Multiple linear regression of pre-emergent fry index, average January-February air temperature at several stations in SSEAK, and parent-year escapements.	Multiple linear regression of pre-emergent fry index and average annual air temperature at 15 stations located throughout Southeast Alaska.	returns	Jones and Hofmeister 1980
1981	Multiple linear regression of escapement, and August, November–February, and spring air temperatures for several stations in SSEAK.	Multiple linear regression of pre-emergent fry index and index of spring environmental conditions in NSEAK.	returns	Jones and Hofmeister 1981
1982	Multiple linear regression of escapement, and August, November–February, and spring air temperatures for several stations in SSEAK.	Multiple linear regression of escapement, winter precipitation, and spring air temperatures.	returns	Jones and Hofmeister 1982
1983	Multiple linear regression with escapements, rainfall in the fall of the parent year, and winter air temperatures.	Multiple linear regression of pre-emergent fry index and spring air temperatures.	returns	Jones and Hofmeister 1983a
1984	Multiple linear regression that incorporated parent-year escapements, parent-year weight, and an adjustment for the increasing numbers of females in the escapements in recent years.	Multiple linear regression that incorporated pre-emergent fry and spring air temperatures at 5 stations in NSEAK.	returns	Jones and Hofmeister 1983b
1985	Multiple linear regression of estimates of parent egg deposition and average winter air temps at several stations in SSEAK.	Multiple linear regression of parent-year escapement, pre-emergent fry index, and spring air temperatures at several stations in NSEAK.	returns	Jones and Hofmeister 1985
1986	Multiple linear regression of escapement index, average winter air temperature at several stations in SSEAK, and average CPUE of the last 2 weeks of the districts 103 and 104 seine fishery; latter variable is a measure of the quantity of females in the escapement.	Multiple linear regression of pre-emergent fry index and average regional air temperatures during the year fry emerge and outmigrate.	returns	Jones and Hofmeister 1986

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Forecast year	Method – Southern Southeast Alaska (SSEAK)	Method – Northern Southeast Alaska (NSEAK)	Response variable	Reference
1987	Multiple linear regression on 22 years of data to forecast survival (return/spawner). Variables included average minimum winter air temperatures in SSEAK, date of the coldest 15-day moving average over same time period, and a variable related to escapement sex ratios.	Multiple linear regression of pre-emergent fry index and index of marine conditions in the year that fry outmigrated.	returns	Jones and Hofmeister 1987
1988	Multiple linear regression of average minimum winter air temperature in SSEAK, date of coldest 15-day moving average over the same time period, and the brood year escapement index.	Multiple linear regression of average minimum winter air temperature in SSEAK, date of coldest 15-day moving average over the same time period, and brood year escapement index.	returns	Jones and Hofmeister 1988
1989	Multiple linear regression of brood year escapement index, average minimum winter air temperatures (1 Nov. through 28 Feb.), and the lowest average 50-day precipitation over the spawning period (15 July–30 Sept.).	Multiple linear regression of escapement indices weighted by the size of the parent-year adults and environmental conditions during the year of fry outmigration.	returns	Hofmeister and Jones 1989
1990	Multiple linear regression of brood year escapement index, and average daily minimum winter air temperatures from 5 stations in SSEAK (1 Nov.–28 Feb.)	Multiple linear regression of brood year escapement index and average length of fry collected during early marine program in Tenakee Inlet.	returns	Hofmeister 1990
1991	Variance-weighted nonlinear least-squares regression with a brood year escapement index, average daily minimum air temperatures for 5 stations in SSEAK (1 Nov.–28 Feb.), and a total escapement index from the 2 previous brood years (i.e., generalized 3-parameter Ricker model).	Multiple linear regression of brood year escapement index and average weight of fry collected in Tenakee Inlet (16–31 May).	returns	Hofmeister and Blick 1991
1992	Multiple linear regression with a brood year escapement index, average daily minimum air temperatures for 5 stations in SSEAK (1 Nov.–28 Feb.), and a total escapement index from the 2 previous brood years (i.e., generalized 3-parameter Ricker model).	Multiple linear regression of brood year escapement index and average weight of fry collected in Tenakee Inlet (16–31 May).	returns	Hofmeister and Blick 1992

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Forecast year	Method	Response variable	Reference
1993	Multiple linear regression of the brood year escapement index, average daily minimum winter air temperatures (1 Nov.–29 Feb.) from 9 NOAA weather stations throughout Southeast Alaska, and sum of previous 2 brood year escapement indices. Years 1987–1988 considered outliers and removed from the model.	harvest	Hofmeister and Blick 1993
1994	Multiple linear regression of the brood year escapement index, average daily minimum winter air temperatures (1 Nov.–29 Feb.) from 9 NOAA weather stations throughout Southeast Alaska, and sum of previous 2 brood year escapement indices. Years 1987–1988 considered outliers and removed from the model. Prediction based on a subjective weighting of multiple points as multiple linear regression analysis, aerial survey observations of fry abundance, and winter air temperatures.	harvest	Hofmeister and Blick 1994
1995	Multiple linear regression of the brood year escapement index, average daily minimum winter air temperatures (1 Nov.–29 Feb.) from 9 NOAA weather stations throughout Southeast Alaska, and sum of previous 2 brood year escapement indices. Years 1987–1988 considered outliers and removed from the model. Prediction based on a subjective weighting of multiple points as multiple linear regression analysis, fry abundance from a small-scale early marine program in 1994, and precipitation records.	harvest	Hofmeister and Blick 1995
1996	Prediction based on a subjective weighting of multiple points as statistical forecast models, historic average harvests, and expert opinion.	harvest	Geiger and Frenette 1996
1997	Multiple linear regression of the brood year escapement index, average daily minimum winter air temperatures (1 Nov.–29 Feb.) from 9 NOAA weather stations throughout Southeast Alaska, and sum of previous 2 brood year escapement indices. Years 1987–1988 considered outliers and removed from the model. Prediction based on a subjective weighting of multiple points as multiple linear regression analysis; anecdotal fry abundance information from fishers, biologists, and sonar studies; juvenile pink salmon CPUE data from the National Marine Fisheries Service (NMFS) trawl survey; historic harvests; and winter air temperatures.	harvest	Hofmeister and Blick 1997
1998	Prediction based on a subjective weighting of statistical forecast models (standard 2-parameter Ricker model including winter temperature and the sum of the 2 previous brood year escapement indices, and a 3-parameter Ricker model), early marine fry surveys, winter air temperature, and juvenile pink salmon CPUE data from the NMFS trawl survey.	harvest	Hofmeister and Blick 1998
1999	Prediction based on a subjective combination of statistical forecast models (Ricker spawner-recruit, "generalized" Ricker and Loess smooth), escapement index, and winter air temperature.	harvest	Zadina and Blick 1999
2000	Prediction based on a subjective combination of statistical forecast models (Ricker spawner-recruit, "generalized" Ricker, and Loess smooth), brood year escapements, and winter incubation (air) temperature.	returns	Willette 2000

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Forecast year	Method	Response variable	Reference
2001	Prediction based on a subjective combination of multiple regression analysis, using 40 years of escapement and return (catch + escapement) data, winter incubation (air) temperature data, anecdotal spring fry observations, and expert opinion.	harvest	Zadina 2001
2002	Prediction based on the spawner-recruit relationship, winter incubation (air) temperatures, and anecdotal spring fry observations.	harvest	Zadina 2002
2003	Predictions based on 2 statistical models (Ricker spawner-recruit relationship and a "generalized" Ricker fit), winter (air) incubation temperatures, and brood year escapements.	harvest	Zadina 2003
2004	Exponential smooth (weighted average) of harvests since 1960	harvest	Heinl et al. 2004
2005	Exponential smooth (weighted average) of harvests since 1960	harvest	Heinl et al. 2005
2006	Exponential smooth (weighted average) of harvests since 1960	harvest	Heinl et al. 2006
2007	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data.	harvest	Heinl et al. 2007
2008	Model average (equal weight) of the exponential smooth (weighted average) harvest estimate and the CPUE-error-adjusted estimate (adjusted using NOAA Auke Bay Lab June–July pink salmon fry data).	Harvest	Heinl 2008
2009	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data.	harvest	Heinl 2009
2010	Model average (equal weight) of the exponential smooth (weighted average) harvest estimate and the CPUE-error-adjusted estimate (adjusted using NOAA Auke Bay Lab June–July pink salmon fry data) using even-year data only.	harvest	Heinl et al. 2010
2011	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data and using odd-year data only.	harvest	Piston and Heinl 2011
2012	Model average (equal weight) of the exponential smooth (weighted average) harvest estimate and the CPUE-error-adjusted estimate (adjusted using NOAA Auke Bay Lab June–July pink salmon fry data) using even-year data only.	harvest	Piston and Heinl 2012
2013	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data and using odd-year data only.	harvest	Piston and Heinl 2013
2014	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data and using even-year data only.	harvest	Piston and Heinl 2014

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Forecast year	Method	Response variable	Reference
2015	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data.	harvest	Piston and Heinl 2015
2016	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data.	harvest	Piston and Heinl 2016
2017	Exponential smooth (weighted average) of harvests since 1960, adjusted using NOAA Auke Bay Lab June–July pink salmon fry data.	harvest	Piston and Heinl 2017
2018	5-year average of the even-year Southeast Alaska pink salmon harvests.	harvest	Piston and Heinl 2018
2019	Linear multiple regression model based on juvenile pink salmon abundance indices collected by the SECM project in northern Southeast Alaska inside waters during June and July and the Icy Strait temperature index (overall average 20 m integrated water column temperature was used to estimate the Icy Strait Temperature Index [ISTI], May–August).	harvest	Piston et al. 2019
2020	Linear multiple regression model based on juvenile pink salmon abundance indices collected by the SECM project in northern Southeast Alaska inside waters during June and July and the Icy Strait temperature index (overall average 20 m integrated water column temperature was used to estimate the Icy Strait Temperature Index [ISTI], May–July).	harvest	Piston et al. 2020
2021	Linear multiple regression model based on juvenile pink salmon abundance indices collected by the SECM project in northern Southeast Alaska inside waters during June and July and the Icy Strait temperature index (overall average 20 m integrated water column temperature was used to estimate the Icy Strait Temperature Index [ISTI], May–July).	harvest	Piston et al. 2021a
2022	Linear multiple regression model based on juvenile pink salmon abundance indices collected by the SECM project in northern Southeast Alaska inside waters during June and July and the Icy Strait temperature index (overall average 20 m integrated water column temperature was used to estimate the Icy Strait Temperature Index [ISTI], May–July).	harvest	Piston et al. 2022

Appendix B.–Annual adult pink salmon harvest data from Southeast Alaska (millions of fish), the official forecast for the year, and the absolute percent error between the observed harvest and the forecasted harvest, 1981–2021.

Year	Harvest	Forecast	Absolute percent error
1981	18.9	10.6	44%
1982	24.2	25.5	5%
1983	37.5	13.5	64%
1984	24.7	29.6	20%
1985	51.9	32.1	38%
1986	46.2	38.4	17%
1987	10.3	26.3	155%
1988	11.1	41.4	273%
1989	59.4	19.5	67%
1990	32.3	9.1	72%
1991	61.9	62.4	1%
1992	34.9	29.2	16%
1993	57.3	52.3	9%
1994	57.3	46.0	20%
1995	47.9	20.0	58%
1996	64.6	60.0	7%
1997	28.9	35.3	22%
1998	42.4	41.2	3%
1999	77.8	41.0	47%
2000	20.2	37.5	85%
2001	67.0	42.0	37%
2002	45.3	36.5	19%
2003	52.5	43.5	17%
2004	45.3	50.0	10%
2005	59.1	49.0	17%
2006	11.6	52.0	348%
2007	44.8	47.0	5%
2008	15.9	19.0	19%
2009	38.0	41.0	8%
2010	24.1	19.0	21%
2011	58.9	55.0	7%
2012	21.3	17.0	20%
2013	94.7	54.0	43%
2014	37.2	22.0	41%
2015	35.1	58.0	65%
2016	18.4	34.0	85%
2017	34.7	43.0	24%
2018	8.1	23.0	185%
2019	21.1	18.0	15%
2020	8.1	12.0	49%
2021	48.5	28.0	42%