

# **Temperature/depth data collections on Bering Sea groundfish vessels to reduce bycatch**

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## **Abstract**

Currently, sea floor and water column temperature information comes mainly from NMFS trawl surveys covering the summer months and a limited number of slope and shelf temperature buoys maintained by NOAA. This project focused on expanding the temporal coverage of existing data and providing finer spatial resolution of temperature data than was available from existing sources. Seasonally, the broader fishery-dependent temperature collections could also prove valuable for evaluating the development and evolution of the Bering Sea cold pool before and after the trawl surveys. Pollock vessel operators were asked to volunteer to deploy scientific-grade temperature at depth (TDR) recorders on their nets over several pollock seasons. Coupled with survey bottom-temperature data and scientific observer data, we were able to compare bycatch rates against a variety of factors to determine which of them appear to have the biggest impact. Results from three seasons of temperature data indicate that some potential exists for using temperature data to reduce Chinook salmon bycatch. However, the relationship between temperature-at-depth and salmon bycatch rates appears to be only one of the important factors. Chinook bycatch appeared to be also related to conditions for a given year, season, and location; these factors should also be considered in addition to temperature. Separate analyses on Chum salmon bycatch also appeared to have a similar but generally weaker relationship with temperature. The feasibility of collecting temperature on fishing vessels in Alaska is considered in the context of the potential utility of the data for bycatch reduction and improvement of the understanding of ecosystem dynamics in the Bering Sea. Recommendations are made for improving and expanding temperature collections on Bering Sea fishing vessels based on our assessment of the utility of these data.

### **Key words:**

Eastern Bering Sea, bycatch management, fisheries management, bycatch rates, opportunistic data collection, temperature

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### Study Chronology

The table below provides the timeline of activities undertaken for this project.

	2007					2008												2009				
	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb to Dec	
Purchase TDR units and construction of cases	x	x																				
Hire and train Dutch Harbor technician		x																				
Summer/fall 2007 deployment of TDRs			x	x	x	x																
Periodic data downloads			x	x	x																	
In-field service (troubleshooting) on units with problems			x	x	x	x																
Rotations between vessels under sampling plan			x	x	x																	
Manufacturer services TDR (calibration and O'ring replace)							x	x														
Data base construction by Sea State (2007 data)						x	x															
Preliminary data analysis						x	x	x														
Initial workshops with fishers, hypothesis generation							x	x														
Presentations of preliminary results, feedback from fishers							x	x														
Winter/spring 2008 deployment of TDRs								x	x	x	x	x										
Periodic data downloads								x	x	x	x	x										
In-field service (troubleshooting) on units with problems								x	x	x	x	x										
Rotations between vessels under sampling plan								x	x	x	x	x										
Data base construction by Sea State (adding 2008 data)											x	x	x									
Full data analysis covering one year of data												x	x	x								
Presentations of preliminary results, feedback from fishers												x	x									
Drafting of projects reports (technical and fishery audience)													x	x	x							
Workshop with fishermen to explore/assess how to make data accessible (plotter program showing relationship of their fishing data to temperature)															x	x	x					
Finalization of project reports and implementation plan for plotter program development																x	x	x				
Presentation of results at Alaska Science Symposium																					x	
Final report to NPRB on project results																						x
Extension granted by NPRB																						x

## Introduction

The Alaska pollock (*Theragra chalcogramma*) fishery is one of the largest fisheries in the world and represents a major component of all commercial Alaskan fisheries (Hiatt et al. 2009). Compared to most fisheries, the relative bycatch of all other species is low representing only about 1.2% of the total removals by weight due to the pollock fishery (24% of which is attributed to jellyfish while 63% of the bycatch consisted of other quota-managed target groundfish species; Ianelli et al. 2009). This compares with nation-wide estimates of over 20% (Harrington et al. 2005). Nonetheless, bycatch levels require careful monitoring and Pacific salmon (*Oncorhynchus* sp.) in particular are important since they are a vital resource to Alaska and to the countries surrounding the north Pacific.

Salmon bycatch management has been a part of the BSAI groundfish fisheries management plan since amendment 21b was passed and trigger closure areas were established (Fig. 1; Witherell et al. 2002). Salmon bycatch levels have varied considerably reaching peaks for Chinook salmon in 2007 and for chum salmon in 2005 (Table 1). The response to this has been to re-evaluate the bycatch patterns (Stram and Ianelli 2009) and develop new management approaches to reducing bycatch in the pollock fishery (NMFS 2009). In 2009 the Council recommended that NMFS move forward with a management system that would cap the maximum amount of Chinook salmon that could be taken as bycatch in the pollock fishery within a year. Vessel-level incentives to reduce bycatch were also a stated goal of the Council. As such, developing innovative ways for vessels to avoid bycatch are needed. This project was designed to develop a new tool for reducing salmon bycatch and learn more about factors that contribute to bycatch variability. Pollock vessel operators were asked to volunteer to deploy scientific-grade temperature at depth (TDR) recorders on their nets over several pollock seasons. Coupled with survey bottom-temperature data and scientific observer data, we use these temperatures to first determine if temperature data from these devices provide enough information to evaluate factors affecting bycatch. Secondly, we use a longer time series of bycatch information and temperature data to test as potential factors.

Salmon respond to temperature in a variety of ways. Crozier and Zabel (2006) found survival effects of temperature in near-shore habitats. Mueter et al. (2002) evaluated surface temperature effects on survival rates and found that responses occur at relatively local scales. Walker et al. (2000) showed from archival tag data (where temperature and depth are recorded by a device implanted in the fish) that chum salmon respond to temperatures and undertake diurnal migrations. Temperature regimes for the Bering Sea are the likely to affect the variability of salmon distribution relative to the pollock fishery operations. A summary of the relative distributions of summer pollock catches and the incidences of Chinook and chum salmon bycatch are shown in Figure 2.

## **Project Objectives**

Fine-scale temperature recordings collected on pollock vessels that volunteered to deploy the TDRs were to be evaluated against catch data from the pollock fishery. The relationships between temperature and catch rates for pollock, salmon, and other incidental species were to be investigated to assess the utility of temperature information for use by fishermen to reduce bycatch or otherwise increase efficiency. A related objective was to evaluate the feasibility of collecting temperature on fishing vessels in Alaska in the context of the potential utility of the data for bycatch reduction and improvement of the understanding of ecosystem dynamics in the Bering Sea. Depending on the specific findings from the analysis of the temperature data collected in our study, recommendations would be made for improving and expanding temperature collections on Bering Sea fishing vessels.

This report presents these findings and supplements presentations made at a series of workshops with fishermen and scientific meetings.

## **Methods**

### *Temperature Data Recorders*

Temperature-at-depth recording (TDR) devices were deployed on nets of commercial fishing boats: summer/fall 2007, winter 2008, and summer/fall 2008. Temperature-at-depth sensors were attached to trawl “codends” (aft end of the net where catch is collected) by crew members prior to each set and removed each time the net was retrieved. The trawl “codend” was selected in preference to the potentially more convenient “headrope” (floated upper portion of the mouth of the net) to place the temperature recorders closest to the fishing depth of the net. A brief training session was provided to all participating vessel captains and crews prior to each season to inform participants of the objectives of the project, handling procedures for the TDR units, instructions for returning the unit for periodic data downloads, and contact information for questions/comments. Written materials summarizing this information were also provided at the time of the briefings. Field coordination duties including briefings, data downloads, and delivery and retrieval of the TDR units were done via a technical services contract with a trawl gear supplier in Dutch Harbor, Alaska.

Maximizing spatial and seasonal coverage of the Bering Sea pollock fishery was the primary objective in selecting vessels to deploy the TDR units. Knowledge of past fishing patterns from a former pollock captain was used to stratify the pollock fleet by area and timing of fishing (i.e., differences in where different fishing cooperative vessels tend to fish as well as differences in timing for fishing operations). Once the fleet was divided into which vessels would likely cover different fishing grounds and portions of the season, selection of specific vessels was based on a combined assessment of willingness to deploy the

TDR units, commitment to project objectives and timing, and relative difficulty of attaching and removing the units on a tow by tow basis. Our judgment of the relative difficulty of deploying the units was based on amount of deck space on the vessel, whether the vessel fished with a forward or aft net reel, and other factors involving how catch is brought on board and dumped into holding tanks. In effect, this process tended to select larger pollock vessels simply because they tend to use forward net reels and have more room on deck to handle the TDR units.

The temperature at depth recorder deployed for this project was the SBE 39 manufactured by Seabird Electronics. This recorder is generally accepted to be highly accurate with additional features including an internal battery and non-volatile memory for deployment at depths up to 10,500 meters. All units deployed were equipped with the optional pressure recorder package. The SBE 39 unit is generally intended for moorings or other long-term, fixed-site applications but is also recommended by the manufacturer for shorter-term deployments on nets, towed vehicles, or ROVs. All units were deployed with protective cases made of UHMW plastic to help prevent damage to the units from normal handling conditions on fishing vessels. The SBE 39's thermal recording unit is recognized to provide accuracy and stability for scientific applications; drift is typically less than 0.002 °C per year, resolution is 0.001 and the clock accuracy drift is less than 5 seconds per month. The autonomous sampling mode for the SBE 39 was used for our project where sampling occurred at pre-programmed intervals of 120 seconds. This interval was selected to provide a useful sampling interval while conserving battery capacity so that units could record data a two to three month period of time (roughly the duration of an average pollock fishing season).

For the three seasons, operations from a total of 1,805 vessel-days were recorded. Some temperature recording devices failed during part or all of the seasonal deployments so the number of boats effectively involved ranged from 8 to 17 for the three seasons.

A matching database was developed to compare bycatch patterns with the temperature data. This required linking observer data to the area and times based on records from a GPS vessel monitoring system (VMS) system where vessels with temperature recording equipment were operated. Scientifically trained observers collected the species composition data. For salmon, the observers are instructed to sample all occurrences in the observed catch. For salmon caught by shore-based "catcher vessels" observers enumerate salmon bycatch at the plant where pollock are delivered. The shore-based values are assigned to tow locations recorded by observers. In all cases, observers identify salmon to species and sex and record measurements of weight and total length. Bycatch data (on numbers of salmon) are available since 1990. Further details on observer sampling protocols can be found at <http://www.afsc.noaa.gov/FMA/document.htm>.

To facilitate the matching of data, all TDR data were compiled by day and vessel. For the TDR data, fishing activity was identified by ensuring that the change in depth was less than 3 meters per minute and these records were used in computing the average temperature for that vessel and day. This allowed the observer data for that vessel and day to be easily compiled and temperature and catch records to be matched. For the three seasons covered, the number of vessel fishing days totaled 357 vessel-days with an average 331 temperature measurements over an average 3.13 tows per day. The numbers of measurements by all vessels at depth bins (below 10 m) and months are shown in Table 2.

*Modeling factors affecting bycatch rates*

The two different data sets evaluated include the raw TDR information coupled with observer catch estimates for the tows where the data were available and the extended time series (1991-2008) of bycatch information broken down by week and geographic area (but with only a single area synopsis of temperatures as measured by chartered vessel during the corresponding NMFS annual trawl survey). The advantage of the first data set is that temperature and bycatch data are matched for each day, and the effect of different vessels is retained. The disadvantage of this data set is that it spans only two years and lacks contrast of bycatch patterns over different areas and years. The second data set extends back to 1991 and covers a broader area since the entire observer data set is used. However, these data are limited since vessel-effects are aggregated and temperatures are only available in synoptic form from the NMFS summer bottom-trawl survey. The surveys are conducted primarily during June and July.

General Linear Models (GLMs) have been used to model bycatch in a number of different settings (e.g., Murawski 1996). Here, this approach was extended to use a mixed-effects Generalized Additive Model (GAMM) following methods detailed in Pinheiro and Bates (2000) and more extensively in Wood (2006). Generally, the model approach to evaluating factors affecting bycatch was

$$\ln(P_{ijk}) = \mu + \alpha_i + \beta_j + \gamma_k + \delta_{ij} + \epsilon_{ijk}$$

for the data set using daily observations from TDRs collected from this study (for both A and B seasons) and

$$\ln(P_{ijk}) = \mu + \alpha_i + \beta_j + \gamma_k + \delta_{ij} + \epsilon_{ijk}$$

is the model used for the temperature and fishery observations for the data set that extends from 1991-2008 (for the pollock summer/fall “ B-season” only). The index  $i$  represents year,  $j$  location, and  $k$  the time elapsed since June 10<sup>th</sup> (to capture the season effects. The term for the catch of the bycatch species of interest is  $u_{ijk}$ ,  $P_{ijk}$  is the amount of pollock caught in that location and period,  $t_j$  is the temperature

recorded in that year at the location by the NMFS bottom-trawl survey,  $W_{ij}$  is the week when the bycatch occurred,  $V_j$  is the vessel factor,  $Y_{ij}$  is the year factor, and  $X_{ij}^{longlat}$  are the coordinates for longitude and latitude, respectively. The non-parametric smooth functions  $f(\cdot)$  employed are based on “thin-plate spline regressions” described in Wood (2006). Since bycatch numbers are typically relatively rare events, the model was specified to follow a Poisson distribution and fit within the *R* statistical software version 2.10.1 with package *mgcv* version 1.6-1<sup>1</sup>. Experimentations of different sets of random effects (e.g., location) provided similar results.

#### *Extending existing temperature data series*

Data were also used to evaluate the evolution of the “cold pool” subsequent to the NMFS summer survey bottom temperatures. These were derived by computing the averages for  $1 \times 1^\circ$  degree cells from the TDR data by 5-day periods.

## **Results**

#### *Device deployment details*

While data was collected from the TDR units and analyzed here for patterns and trends, the number of vessels volunteering to and successfully deploying the units was somewhat lower than was hoped and the failure rate for units that were deployed as described in the methods section above was somewhat higher than expected. The objective was to successfully deploy and collect data on 18 pollock vessels per season starting in fall 2007 and through both pollock seasons in 2008. The number of successful deployments ranged from 8 to 17 over the three pollock seasons with winter 2008 being the lowest number of successful deployments. The inability to attain this objective was due to a combination of the factors associated with the difficulty of deploying the units according to the instructions provided to fishermen for this project and the relative robustness of the units for the conditions on the decks of pollock fishing vessels, particularly during the winter months. A separate section (see Discussion section on feasibility) is included which describes the challenges for handling and deploying the units and the nature of the TDR unit difficulties and suggestions for improving upon this in future studies. Results described below are using the TDR data as collected and the spatial and temporal coverage of those results.

The spatial and resolution of the different seasons in aggregate indicates that the coverage for the 2007 B-season and 2008 A-season was good and dropped off in B-season 2008 (Fig. 3). The temporal coverage of the TDR data relative to the fishery can be gauged by examining the relative concentrations of TDR

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<sup>1</sup> <http://cran.r-project.org/>

data and observed pollock fishing operations. For 2008 the A-season (winter) fishery had a similar pattern of coverage but the B season coverage was generally missing the months of June and July and for 2007 was highly concentrated in September (Fig. 4). This indicates that the TDR coverage was different than the temporal patterns of the fishery. However, since bycatch generally occurs later in the season, the data may still provide insights on relative bycatch patterns.

#### *TDRs and water column information*

The data collected from TDRs on board fishing vessels can provide indications of water column properties from specific areas over time. For example, a subset of the 2008 A-season data specific to the area near Unimak Islands (a  $1 \times 1^\circ$  cell centered on  $164^\circ\text{W } 56^\circ\text{N}$ ) shows that temperature at depth is nearly constant but varies markedly as the season progresses (Fig. 5). This is in contrast to the 2007 B-season TDR data that shows a large thermocline (for two  $1 \times 1^\circ$  cells centered on  $177^\circ\text{W } 60^\circ\text{N}$  and  $178^\circ\text{W } 60^\circ\text{N}$ ) followed by a slight temperature inversion with depth but only slight seasonal change (Fig. 6).

#### *Observer catch data versus temperature records*

Computing the daily mean temperature from fishing vessel TDRs and comparing with the Chinook salmon bycatch rates for these vessels showed a general increase in rates as temperature increased (Fig. 7). The relationship with chum salmon was much less pronounced (Fig. 8). Conditioning for the other factors with a model was applied and the data support a model with terms temperature, time of year (here expressed as days since Jan 20<sup>th</sup>, the annual start date of the pollock fishery), area, and vessel (as a factor; Fig. 9; Table 3). As with the raw data, higher temperatures appear to affect Chinook salmon bycatch (Fig. 9a). Time of year was most significant for the TDR data (Fig. 9b) followed by location (Fig. 9c). The vessel effect was significant, but the confidence bands for the bycatch effect overlapped considerably between vessels (Fig. 9d).

For the chum salmon and individual vessel TDR measurements, applying a model confirmed that the data provide little support for establishing a relationship with temperature, time of year (here expressed as days since Jan 20<sup>th</sup>), area, and vessel (as a factor; Fig. 10). The estimated temperature effect were not significant for chum salmon bycatch (Fig. 10a) neither was time of year from the TDR data (Fig. 10b). The term in the model for estimated locations for higher chum bycatch was significant (Fig. 10c) and the estimated vessel effect was significant, but again had confidence bands that overlapped considerably between vessels (Fig. 10d).

#### *Broader scale examination of factors affecting bycatch rates*

For the non-zero cells of salmon bycatch, the relationship of bycatch to tons of pollock caught within 5-day periods and  $42 \times 42$  km grids was highly variable from 1991-2008 (Fig. 11). To show patterns in the

bycatch data, conditioning on the amount of pollock catch is standard practice. For Chinook salmon, the distribution of the logged-catch rates appears to follow a normal distribution and some noisy relationship with temperature (Fig. 12). The annual trends for Chinook salmon show variability with the lowest rates apparent in 1999 and 2001 and highest in 1997 and 2007 (upper panel, Fig. 13). The data also confirm that Chinook bycatch rates increase later in the summer (lower panel, Fig. 13).

For chum salmon bycatch, the highest rates appeared in 1993 and in 2004 and 2005 (upper panel, Fig. 14). The within-season rates for the data are variable, but show an increase in August and a general leveling out (lower panel, Fig. 14). From these data, the model with all terms included (i.e., the year, the amount of pollock caught within a grid cell/5-day period, the within season date, the bottom temperature at that locale, and the location) clearly reveals these patterns.

For Chinook salmon, bycatch increases significantly with temperature from 2-4°C with some suggestion that in warmer bottom conditions, the Chinook bycatch level drops off (Fig. 15a). Conditioned on the other factors, the increase in Chinook salmon bycatch as the season progresses is very pronounced (Fig. 15b). The spatial locations of higher bycatch rates are consistent with the data and indicate highest rates around the slope break near Pribilof Islands and also close to Unimak Island (Fig. 15c). Interestingly, weighing the other factors the annual effect of bycatch levels reveal that 2007 was the highest, but not markedly so (Fig. 15d). This latter effect suggests that the abundance of Chinook salmon was high in 2007 or that the spatial overlap between Chinook distribution and the pollock fishery increased. However, the other factors such as the location and time of fishing contributed to the high levels of Chinook bycatch in 2007. The year 2007 represents a major focal point in terms of attention to the issue of Chinook salmon in the pollock fishery by managers and the interested public as it was a record high in annual bycatch of Chinook by the pollock fleet.

The model results for chum salmon the bycatch also apparently increases with temperature from 2-3°C, levels off some then increases from 3.5-4°C (Fig. 16a). Conditioned on the other factors, chum salmon bycatch as the season progresses is earlier and reaches a plateau by mid-August (Fig. 16b). The modeled spatial locations of chum salmon bycatch levels are consistent with the data and indicate highest bycatch rates in the area northeast of Unimak Island and north of the “horseshoe” (Fig. 16c). The annual effect of chum bycatch levels show that 2005 was the highest and that the levels from 2004, 2006 and 2007 were also quite high (Fig. 16d).

#### *Extending existing temperature data series*

The TDR data collected in this study can also supplement information on how bottom temperatures change over time. The available data (averaged by 1x1° cell and 5-day period) suggests that there is

nearly a 1° increase in bottom temperature during the month from Aug 20<sup>th</sup> to Sept 20<sup>th</sup> for grid cells centered on 177°W 60°N and 178°W 60°N (Fig. 17). For the cell centered on 168°W 56°N, the change in bottom temperature was more gradual and extended into October whereas other cells appeared to decline in temperature in October (Fig. 17). If such fine-scale information on how rapidly the bottom temperatures change in different years were available on a consistent basis, it may help to understand how spatial overlaps between species are affected and by extension, processes that affect bycatch patterns. This could augment the collective understanding of conditions that lead to higher or lower bycatch rates in the pollock fishery and possibly eventually be useful to efforts to reduce salmon bycatch provided such patterns are borne out over a greater time series of the finer-scale temperature data.

*Examining catch rates of pollock and other species*

The catch-per-unit of effort (CPUE) of pollock by factors such as time of year, area, and temperature is also of interest since such information could be useful to increasing the efficiency of pollock fishing and perhaps reducing salmon bycatch by simply reducing the number of fishing hours in a given year or season. This type of information would also be useful for comparing the trade-off with avoiding bycatch weighed against potentially lower pollock CPUE (and perhaps other unforeseen consequences). However, information on the changes in the pollock fishery net dimensions is unavailable because these data are not routinely collected and therefore there is no way to control for the extent to which CPUE is affected by the use of bigger nets or increased horsepower over time. Also, in order to standardize effort accurate tow duration estimates are required. Presently, revisions to NMFS database have created some apparent inconsistencies that need to be resolved before standardized CPUE measures can be used. For the observer data that matched the TDR vessel-days, the relationship between pollock catch per tow and temperature was poor (Fig. 18). Given the acknowledged problems with CPUE in the NMFS data system at present, the objective of evaluating how temperature is related to pollock catch rates could not be as rigorously evaluated as was envisioned at the outset of this project.

A separate dataset from the observer database was compiled that covered bycatch of squid. The total catch of squid (in t) from the NMFS observer database by season is shown in the following table:

	A season	B season	Total
1991	124	323	447
1992	136	324	461
1993	201	223	424
1994	23	181	205
1995	23	248	271
1996	56	537	593
1997	273	819	1,092
1998	203	743	946
1999	205	170	375
2000	334	30	364
2001	185	1,260	1,445
2002	236	1,304	1,540
2003	279	755	1,035
2004	201	529	730
2005	305	614	918
2006	495	610	1,105
2007	745	347	1,092
2008	209	788	997
2009	89	88	177

For the vessels with TDR devices, the bycatch of squid was rare and small since out of the 357 vessel-days of TDR data and bycatch only 33 days recorded more than 100 kg of squid as bycatch. Nonetheless,

the non-zero days of squid bycatch relative to pollock indicate that the highest days of squid bycatch were generally in warmer conditions (Fig. 19).

## **Discussion**

The ability to characterize environmental conditions with direct catch observations, for example simple temperature measurements as related to bycatch levels, will play an increasing role as managers and fishers alike face increasing demands for more sophisticated conservation goals. The data collected for this project is a prime example of how industry can provide sound scientific data that can in turn be used to fine-tune fishing operations to minimize bycatch.

### *Utility of temperature data in characterizing bycatch*

Murawski (1996) examined a wide variety of factors affecting bycatch in a large multi-species groundfish fishery similar to the study presented here. However, his study examined patterns and was limited only to data typically collected by observers and/or recorded in logbooks. The factors investigated here include extra data collected on board fishing vessels and also data from fishery-independent surveys (on temperature). Similar to his results, year-effects (as a proxy for abundance) had a large effect on bycatch levels.

Specific to Chinook salmon, the year-effect from the extended analysis was high for 2007 indicating that either the overlap between Chinook and the pollock fishery was greater than normal or that the abundance of Chinook salmon was higher. A survey of juvenile Chinook salmon indicated high abundances in 2004 compared to the previous 2 years (NPAFC 2004). This may have contributed to the annual factor showing high bycatch levels in 2007 (when these juveniles may have become more vulnerable to bycatch in the pollock fishery).

For chum salmon, the TDR data collected for this project failed to reveal a strong relationship with temperature but the evaluation using an extended time series of temperature and bycatch data established a significant relationship with temperature. This is consistent with studies on chum salmon migration routes that followed oceanographic temperature patterns (Friedland et al. 2001). While chum salmon migration is linked to temperature patterns, age-specific and stock specific linkage to temperature is not well known. Studies are limited on the stock composition of chum salmon bycatch in the pollock fishery in recent years, however several studies of bycatch in the 1994, 1995 and 1996 fisheries all indicated high variability in stock composition estimates depending upon temporal and spatial variability of capture in the fishery (Patton et al., 1998; Wilmot et al., 1998; Seeb et al., 2004). A separate scale pattern analysis was used to age chum salmon from bycatch in the during that year and indicated stratification of chum salmon stocks in the Bering Sea by age with variability depending upon the month and area in which they

were caught (Myers et al., 1994). This leads to speculation that if there are age-specific differences in temperature preference by chum salmon, how fishers respond to temperatures may affect both the age and the stock composition of the bycatch.

The North Pacific Fishery Management Council (Council) has developed alternative measures for management of incidentally caught salmon species (NMFS 2009). This EIS includes detailed analysis of Chinook salmon bycatch patterns and the potential impacts of alternative management measures focusing in on the years from 2003-2007. Results presented from this study confirm many of the findings in the EIS (e.g., that bycatch rates for Chinook are higher during September and October than earlier in the B season). Our study also benefited from a full evaluation of temperature patterns and used a model to evaluate the relative importance of different factors. The ability to use this type of information explicitly will become more important, particularly as economic factors are considered (e.g., Larsen et al. 1998).

Stram and Ianelli (2009) examined bycatch patterns for both Chinook and chum salmon with an examination of rates by time of day, sector, spatial concentrations, and size- and gender-specific patterns observed in the pollock fishery. They noted the high inter-annual variability of bycatch (CVs of 63% for Chinook and 125% for chum salmon). This is consistent with the significance of the year-effects for the models examined from this study.

This study did not examine the effect of time of day on bycatch rates—a factor considered important based on findings in Stram and Ianelli (2009). It may be that the fishery could reduce salmon bycatch by taking advantage of the diurnal behavior patterns of salmon (Walker et al. 2000, Ishida et al. 2001). For example, Ishida et al. notes that chum salmon spent 48% of the day and 85% of the night in the upper 10 m of the water column. This was consistent with patterns identified in Stram and Ianelli (2009). As a longer time series of temperature data are accumulated, accounting for time of day may provide an additional factor that should be considered.

#### *Feasibility of deploying TDRs on Alaska fishing vessels and suggestions for future temperature data collections*

Noting that temperature data collections on fishing vessels could supplement many of the above analyses, gaining experience from and improving the effectiveness and feasibility of voluntary temperature data collections on fishing vessels was one of the objectives of this project. In this regard, the workshops held with the pollock industry were very valuable for learning what worked and what could be improved.

As was described previously, the failure rate for units was higher than expected and the main problem was that, despite the UHMW protective casing, the batteries became detached from their connection points probably as a result of the units occasionally banging on the deck or stern ramp during setting and

retrieving the net. After the fall 2007 season, a correction from the manufacturer was undertaken to help prevent this problem but the correction did not prove to be effective.

Given the number of failures of TDR units over the three seasons, potential measures for improvements were discussed at the workshops. The focus of these discussions included how to improve the effectiveness of collections at the scale of this project and how to expand the effort to other fisheries beyond pollock. More reliable performance is likely best attained from using an alternative TDR device that is more resilient to the conditions on fishing vessels rather than using different training and deployment instructions which would only likely result in small marginal reductions in the failure rate for the TDR devices used for this study. Expanding to other fisheries would involve an expansion of the temporal and spatial extent of collections as these fisheries use different fishing grounds and extend fishing into parts of the year beyond that covered by pollock fishing.

The workshops delved into the relative difficulty of deploying TDR devices on Alaska groundfish fishing vessels as it related to improving the Alaska fishing industry's participation in the temperature collections. Fishermen pointed out that the placement of the TDR units on net codends required that the devices be removed following each haulback due to relative fragility of the devices despite the protective cases. The concern here was that haulback is a time when deck crews must focus intently on safely dumping the catch into the vessel's tanks. Catches per haul typically range from 60 to 120 metric tons in the Bering Sea pollock fishery and removing the TDR from the codend under inclement weather conditions when the codend can quickly shift across the trawl alley presents inherent challenges. Some captains felt that having the crew concentrate on extra tasks at that time may not lead to maximum safety on deck, especially in bad weather conditions. In conjunction with the workshops, study participants inquired whether there is an alternative device that could be used. Participants noted that it would be better to either deploy a small unit which is robust enough to be rolled onto the net reel or a device that is small enough to be placed on the vessel's net sounder suitcase that is removed each haul prior to bringing the net on deck.

Increased data storage and battery capacity sufficient to allow for an entire season of data collection without necessitating downloading were also suggested as an improvement for a TDR device in any future efforts. Mid-season downloads were needed in our project during the 2007 B season when fishing extended beyond the reliable battery capacity of the TDR units. Greater data storage capacity would be optimal as downloads would only be needed twice a year which would decrease inconvenience and costs. Ease of downloading was also discussed with suggestions including a technician in Dutch Harbor who might be able to download the data via a wireless connection during a short visit to the vessel.

Following discussions at the first workshop, some research was done on alternative TDR devices. This focused on using a small archival “fish tag” style device that is designed to record temperature/depth when attached to fish that are released back to the sea. These fish tag devices apparently collect scientific-grade information (probably not to the same specifications as the devices used) and are of a size that would likely work for attaching to the headrope sounder or fitting into the short tube that could be rolled up on the net reel without damage.

“Fish tag” style TDR units have sufficient memory to be able to collect approximately 80 days of data which is roughly equivalent to a typical pollock season. Given the lower cost per unit of this type of TDR, vessels could potentially be outfitted with two units such that the second one could be started and deployed if fishing continues beyond the average battery life of the first unit. Sampling pressure and temperature would probably need to be set at a 5 minute intervals with the fish tag devices which is roughly twice the interval used for this project but probably within the range of what would be useful particularly if these lower cost and more convenient devices could be feasibly deployed on a larger number of vessels. Archival fish tags are individually calibrated and verified using a 9 point calibration (3 pressures over 3 temperatures) and are advertised to be highly stable over the specified ranges. The price per unit has been estimated to be under \$300 per tag based on orders of approximately 50 units. There are some other software costs for wireless downloading but these are expected to be minimal.

## **Conclusions**

Our study shows that temperature-at-depth data can be feasibly collected and with some relatively minor adjustments to the procedures for deploying TDRs and perhaps a smaller more robust TRD unit used for the temperature collections. Matching direct temperature recordings with actual onboard bycatch rates proved that temperature is an important factor affecting Chinook salmon bycatch. For chum salmon there appeared to be too little contrast to establish meaningful relationships between temperature and bycatch levels using the TDR data collected for this project. However, The TDR data proved useful to evaluate the vertical structure of the EBS in different locations over the course of the season and also provided some insight on how temperatures evolved in the Bering Sea as the cold pool contracts during the summer and early fall.

Extending the available bycatch data for the period 1991-2008 and contrasting this with bottom temperatures collected during the B-season (as supplemented by the NMFS summer bottom-trawl survey data) allowed tests for factors affecting bycatch over a broad range of years and conditions. This analysis indicated that Chinook salmon bycatch rates are affected by temperatures but that other factors also play important roles. Chief among these was the year effect, followed by the time of year, then temperature.

Results from three seasons of temperature data indicate that some potential exists for using temperature data to reduce Chinook salmon bycatch. However, the relationship between temperature-at-depth and salmon bycatch rates appears to be only one of the important factors. Chinook bycatch appeared to be also related to conditions for a given year, season, and location; these factors should also be considered in addition to temperature. Separate analyses on chum salmon bycatch also appeared to have a similar relationship with temperatures. The temperature and chum salmon bycatch pattern from the extended data set provided the additional power needed to establish this relationship. This contrasts with the TDR data collected for this project which was limited in the ability to reveal a pattern between bycatch and temperature.

#### *Next steps*

Lessons learned from this study included: 1) more fishing vessels would be required to obtain better coverage over the fishing grounds; 2) adjustments in deployment procedures and more robust temperature recording devices are needed; and 3) a longer time series of data is needed since our supplemental study linking historical bycatch rates to traditional temperature records indicated year-to-year variability was substantially higher than temperature effects.

Based on outreach workshops done as part of this project, support for expanding temperature collections using a small “fish tag” temperature-at-depth recorder is broad. Such units are relatively inexpensive and would provide the additional data required to better understand bycatch in these complex fisheries. Results from this project should be viewed in the context of “process advice” rather than “operational advice” for bycatch avoidance despite initial goals being their utility for direct application as bycatch avoidance tools. Had the relationship between temperature and salmon bycatch shown a stronger signal and been more direct, it was originally envisioned that the end product would have been a plan to collect and utilize the temperature data “in-season” so it could be used in a plotter application on pollock vessels to augment the pollock industry’s efforts to avoid salmon bycatch hotspots during the season. At this point it is clear that more data and analysis of those data would be needed to determine whether that plotter application would someday be worthwhile.

Future work will be done through outreach to render model results to the degree possible into simple scenario management situations that would be most useful for vessel operators to make plans to reduce bycatch. One possibility currently under evaluation is a set of “almanac-style” catalogues (electronic or hard-copy) based on model results which would begin to provide vessel operators with valuable new information for making decisions on the various trade-offs on potential bycatch outcomes.

If collections of fine-scale temperature data on Alaska fishing vessels can be continued in the future to obtain a longer time series as well as extending this effort to the other fishing grounds used by other Bering Sea fisheries, the potential clearly exists for a new and effective tool for reducing salmon and other bycatch in Alaska's groundfish fisheries.

## **Publications**

In addition to materials made available at outreach events, the results from these analyses are presently being prepared for publication in a peer-reviewed scientific journal.

## **Outreach**

### *Conference presentations*

Alaska Marine Science Symposium 2009

Alaska Marine Science Symposium 2010

### *Workshops*

Leif Ericson Hall workshop with pollock fishermen and other interested public May 10, 2008

Leif Ericson Hall workshop with pollock fishermen and other interested public April 23, 2009

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## Tables

Table 1. Bycatch of salmon species by BSAI pollock fisheries 1992-2009. Source: NMFS Regional Office Catch Accounting. A-season is from Jan 20<sup>th</sup> through April or March and the “B-season” is from June 10<sup>th</sup> through October (though the season periods have changed some over time).

Year	Chinook salmon			Chum salmon		
	A season	B season	Total	A season	B season	Total
1992	25,691	10,259	35,950			
1993	17,264	21,252	38,516			
1994	28,451	4,686	33,137	3,991	88,681	92,672
1995	10,579	4,405	14,984	1,708	17,556	19,264
1996	36,068	19,554	55,622	222	77,014	77,236
1997	10,935	33,973	44,908	2,083	63,904	65,987
1998	15,193	36,130	51,323	4,002	60,040	64,042
1999	6,352	5,627	11,979	362	44,810	45,172
2000	3,422	1,539	4,961	213	58,358	58,571
2001	18,484	14,961	33,445	2,386	54,621	57,007
2002	21,794	12,701	34,495	1,377	79,404	80,781
2003	33,808	13,185	46,993	3,834	185,350	189,184
2004	23,093	28,603	51,696	422	440,050	440,472
2005	27,346	40,017	67,363	595	703,995	704,590
2006	58,391	24,256	82,647	1,332	308,311	309,643
2007	69,408	52,230	121,638	8,523	85,137	93,660
2008	15,698	4,861	20,559	319	14,852	15,171
2009	10,725	1,076	11,801	47	29,410	29,457

Table 2. Distribution of TDR recordings by month and 10 m depth bins.

Depth	2007				2008			
	Aug	Sep	Oct	Jan	Feb	Mar	Aug	Sep
10	240	425	159	85	329	49	55	17
20	420	739	279	136	803	366	83	26
30	440	607	228	244	1,032	341	61	20
40	635	595	262	326	1,508	505	39	21
50	548	659	247	327	1,268	272	52	10
60	513	740	234	468	1,060	411	67	15
70	1,850	2,488	198	378	1,373	250	82	34
80	3,483	3,899	277	1,911	4,110	556	100	52
90	3,028	7,826	937	2,094	5,580	532	386	148
100	1,601	6,458	3,696	1,219	1,772	214	710	967
110	2,717	7,582	3,551	331	403	296	2,890	1,228
120	4,286	7,531	2,208	128	77	6	3,735	1,944
130	7,102	9,778	2,241	16	16	8	828	612
140	3,666	5,264	1,400		19	5	3	106
150	577	2,618	1,247		17	5	6	
160	306	1,558	592		16	3	20	
170	177	1,304	821		11	5	27	
180	92	1,630	1,201		18	6	51	
190	136	1,748	1,376		26	3	39	
200	123	1,898	1,163		24	1	54	
210	66	1,494	1,520		27	5	97	
220	99	1,229	1,233		40	6	67	
230	141	1,148	1,476		45	4	99	
240	215	953	1,200		28	2	232	
250	344	742	931		47	5	123	
260	186	708	598		52	3	80	
270	208	446	253		43	5	130	
280	97	459	155		47	7	17	
290	97	496	238		32	2		
300	37	281	68		35	4		
310	47	341	3		52	4		
320	23	231	1		37	5		
330	14	253	2		63	3		
340	5	381	2		42	6		
350	5	169	9		32	2		
>350	5	85	22	0	2,677	1,587		
Total	33,529	74,768	30,028	7,663	22,761	5,484	10,133	5,200

Table 3. Summary table showing significance levels of the GAMM output for the TDR recordings and **Chinook** salmon bycatch.

Family: poisson      Link function: log

	Estimate	Std. Error	t value	Pr(> t )
(Intcpt)	-10.2835	1.26659	-8.119	9.98E-15 ***
ln(poll)	0.90905	0.09721	9.351	< 2e-16 ***
vess1	0.76782	0.46224	1.661	0.09767.
vess2	1.16693	0.50349	2.318	0.02109*
vess3	0.23166	0.58414	0.397	0.69194
vess4	1.1343	0.50029	2.267	0.02403*
vess5	0.48727	0.51473	0.947	0.34452
vess6	0.14539	0.57059	0.255	0.79904
vess7	0.62847	0.44592	1.409	0.15968
vess8	1.07506	0.51916	2.071	0.03917*
vess9	1.59322	0.68323	2.332	0.02032*
vess10	2.14991	0.71723	2.998	0.00293**
vess11	1.2939	0.49093	2.636	0.00880**

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(time of year)	3.726	3.726	24.432	< 2e-16 ***
s(temperature)	1.237	1.237	8.886	0.00155 **
s(longitude,latitude)	15.833	15.833	7.496	7.43e-15 ***

R-sq.(adj) = 0.787    Scale est. = 6.5441    n = 357

Table 4. Summary table showing significance levels of the GAMM output for the TDR recordings and **chum** salmon bycatch.

Family: poisson		Link function: log		
	Estimate	Std. Error	t value	Pr(> t )
(Intcpt)	-15.4126	2.48537	-6.201	1.74E-09***
ln(poll)	1.37501	0.19757	6.959	1.95E-11***
vess1	0.24905	0.38939	0.640	0.522901
vess2	-0.18834	0.56951	-0.331	0.741089
vess3	0.43006	2.53932	0.169	0.865620
vess4	0.38269	0.62137	0.616	0.538420
vess5	-0.04032	0.38138	-0.106	0.915865
vess6	-0.06842	0.4273	-0.160	0.872884
vess7	-0.59652	0.37628	-1.585	0.113887
vess8	-1.99505	0.8332	-2.394	0.017224*
vess9	0.98872	1.05764	0.935	0.350582
vess10	2.90167	0.74124	3.915	0.000111***
vess11	0.26068	0.4948	0.527	0.598669

Signif. codes: 0 '\*\*\*' 0.001 '\*\*' 0.01 '\*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value	
s(toy)	3.802	3.802	5.501	0.000354	***
s(t)	7.495	7.495	4.085	0.000177	***
s(lon,lat)	14.300	14.300	3.546	1.64e-05	***

## Figures

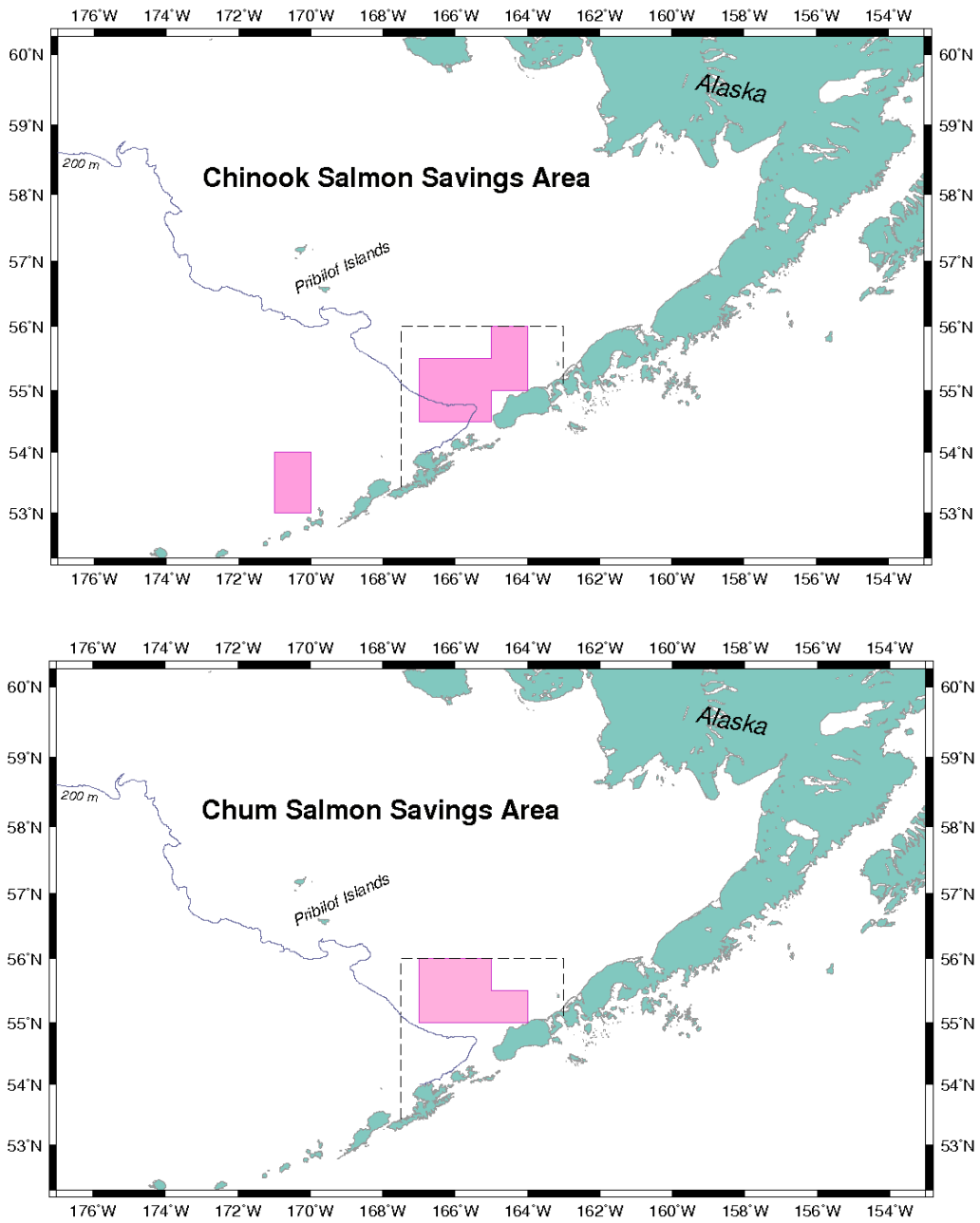


Figure 1. NMFS regulatory areas for Chinook salmon (top) and chum salmon (bottom) established in 1996. The dashed outline represents the catcher-vessel operational area (CVOA) management area.

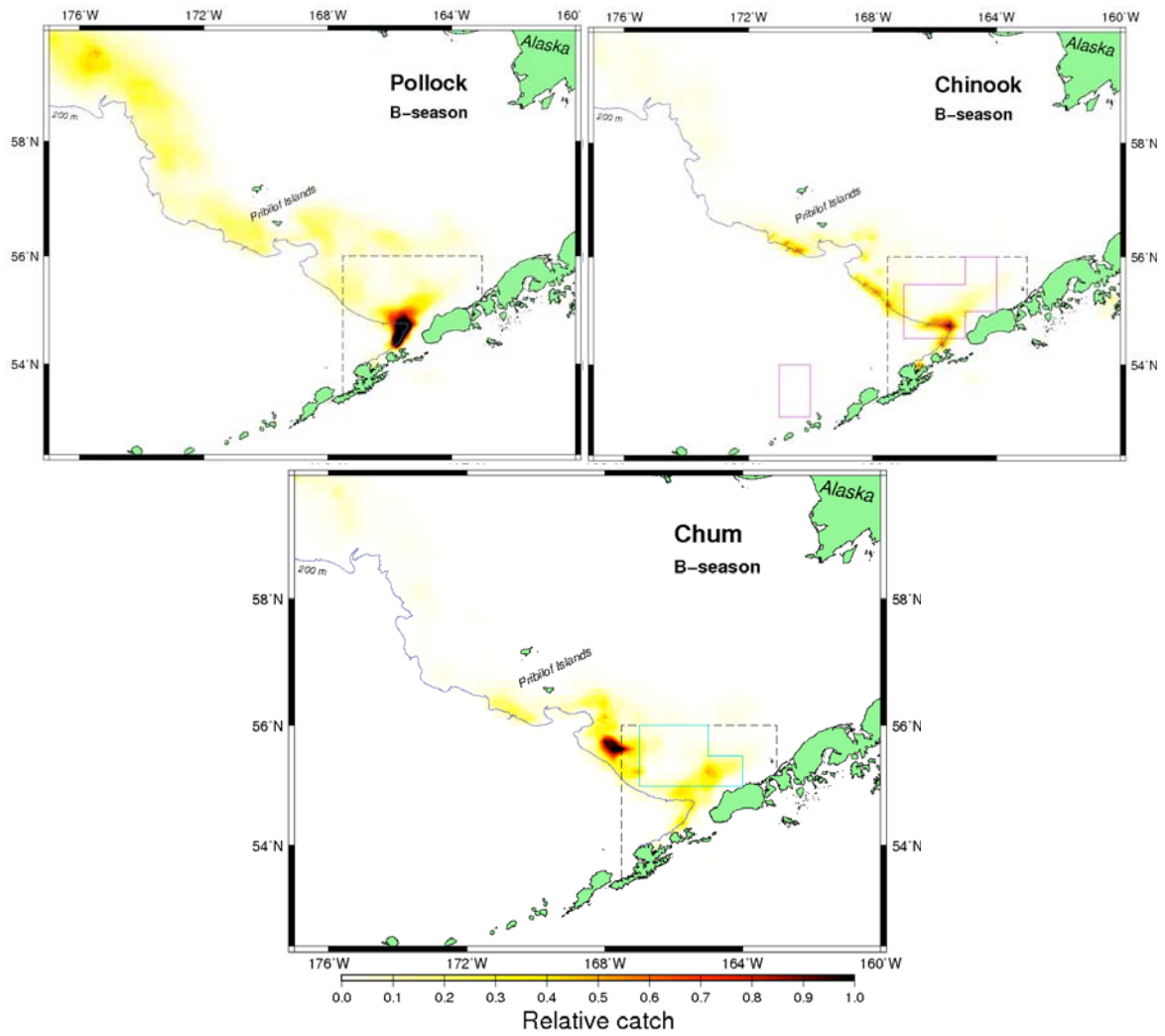


Figure 2. The average spatial patterns of pollock, Chinook and chum salmon catch during the B-season (June–Dec) from 2000–2008 NMFS observer data. (From Stram and Ianelli 2009).

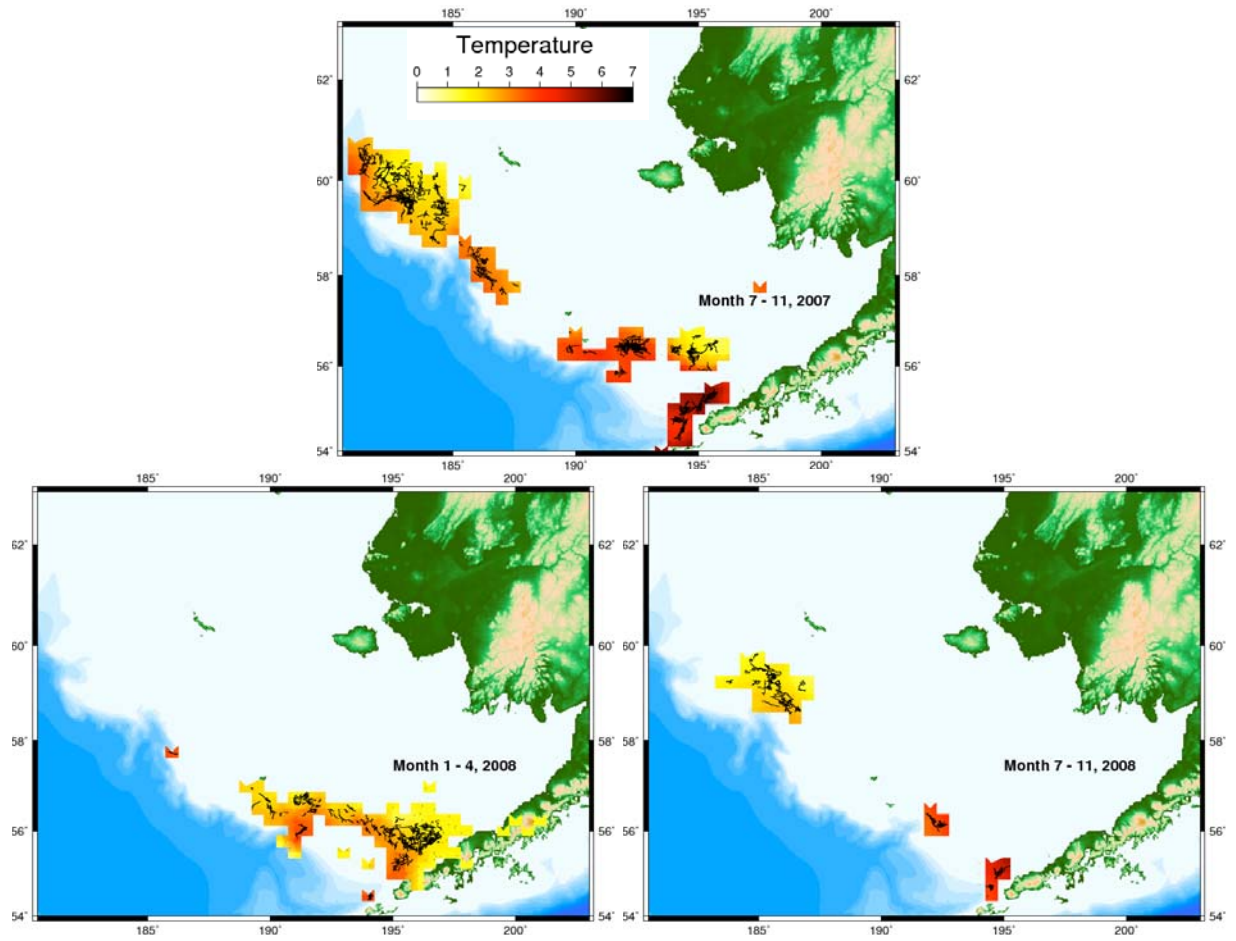


Figure 3. The spatial extent of temperature-depth data collections by season for 2007 and 2008. Shaded contours indicate the bottom temperatures from the TDR deployments of this project. Temperature units are in °C.

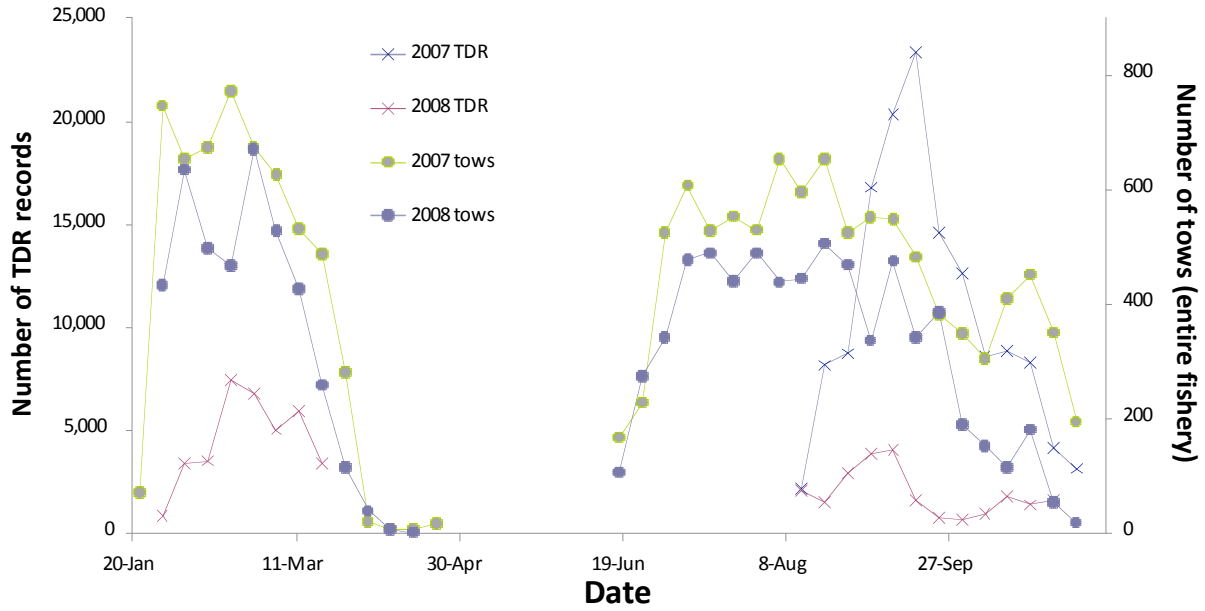


Figure 4. The temporal extent of temperature-depth data collections for 2007 and 2008 as indicated by the number of TDR points collected compared to the number of tows recorded in the NMFS observer database for the EBS pollock fishery. Points represent weekly totals.

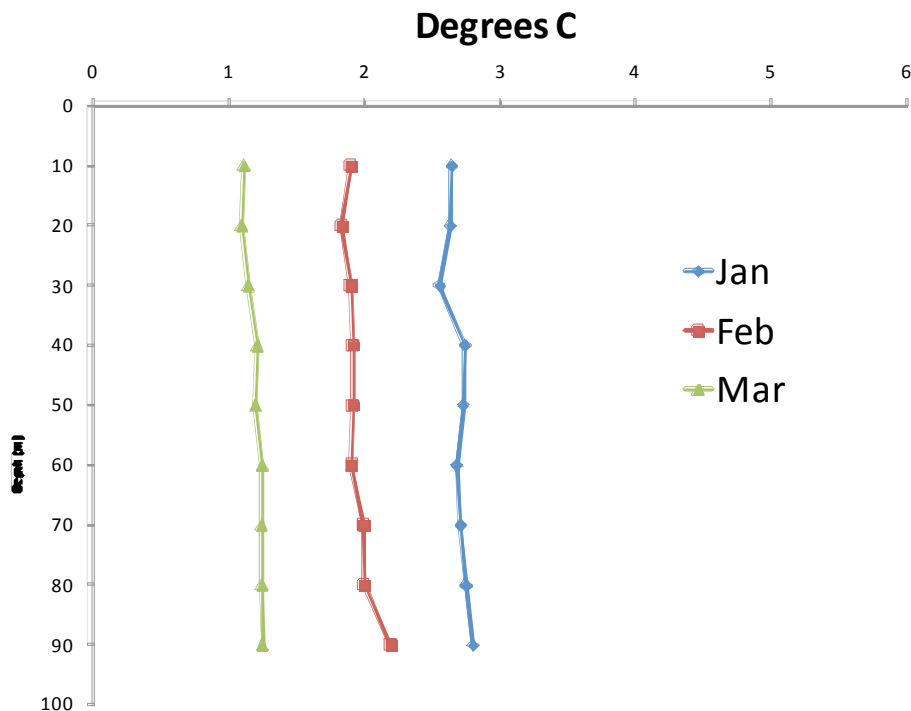


Figure 5. Temperature at depth profiles for the winter 2008 fishery averaged by month for the 1x1° cell centered on 164°W 56°N.

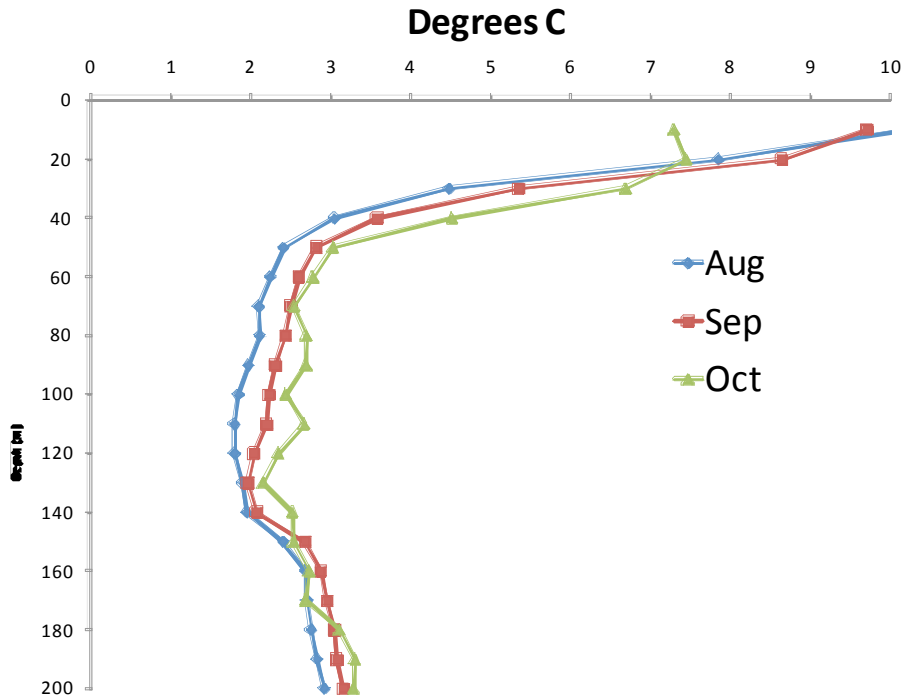


Figure 6. Temperature at depth profiles for the summer-fall 2007 fishery averaged by month for the 1x1° cells centered on 177°W 60°N and 178°W 60°N.

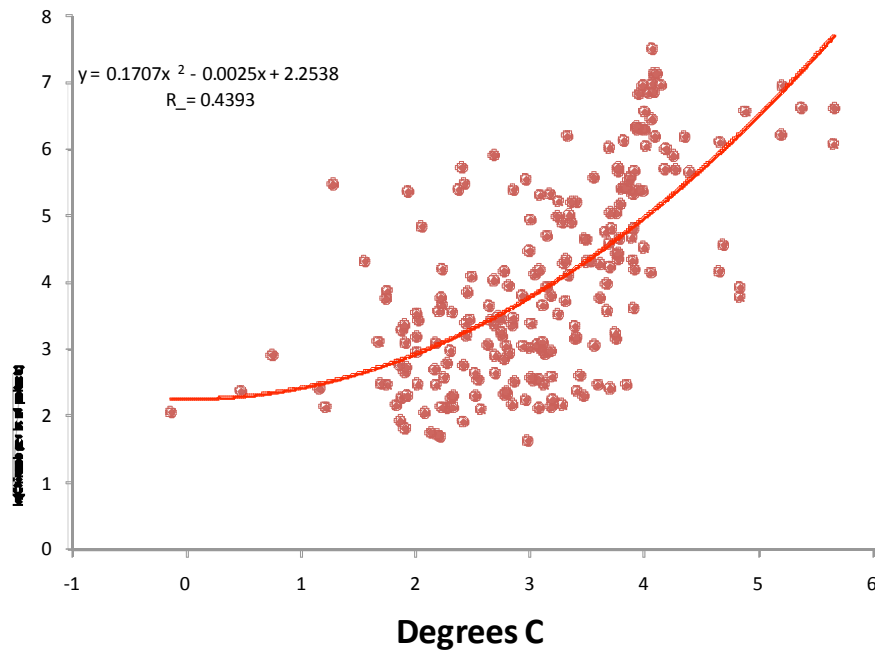


Figure 7. Scatterplot of daily **Chinook** salmon bycatch per kt of pollock versus recorded TDR temperatures during the 2007 and 2008 B-seasons and the 2008 A-seasons of the EBS pollock fishery. The line and equation shown is a polynomial fit.

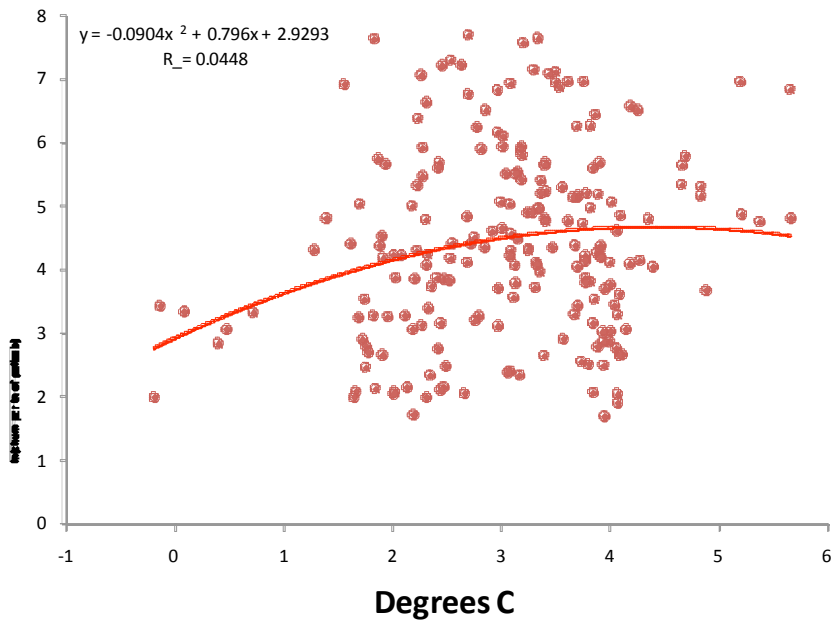


Figure 8. Scatterplot of daily **chum** salmon bycatch per kt of pollock versus recorded TDR temperatures during the 2007 and 2008 B-seasons and the 2008 A-seasons of the EBS pollock fishery. The line and equation shown is a polynomial fit.

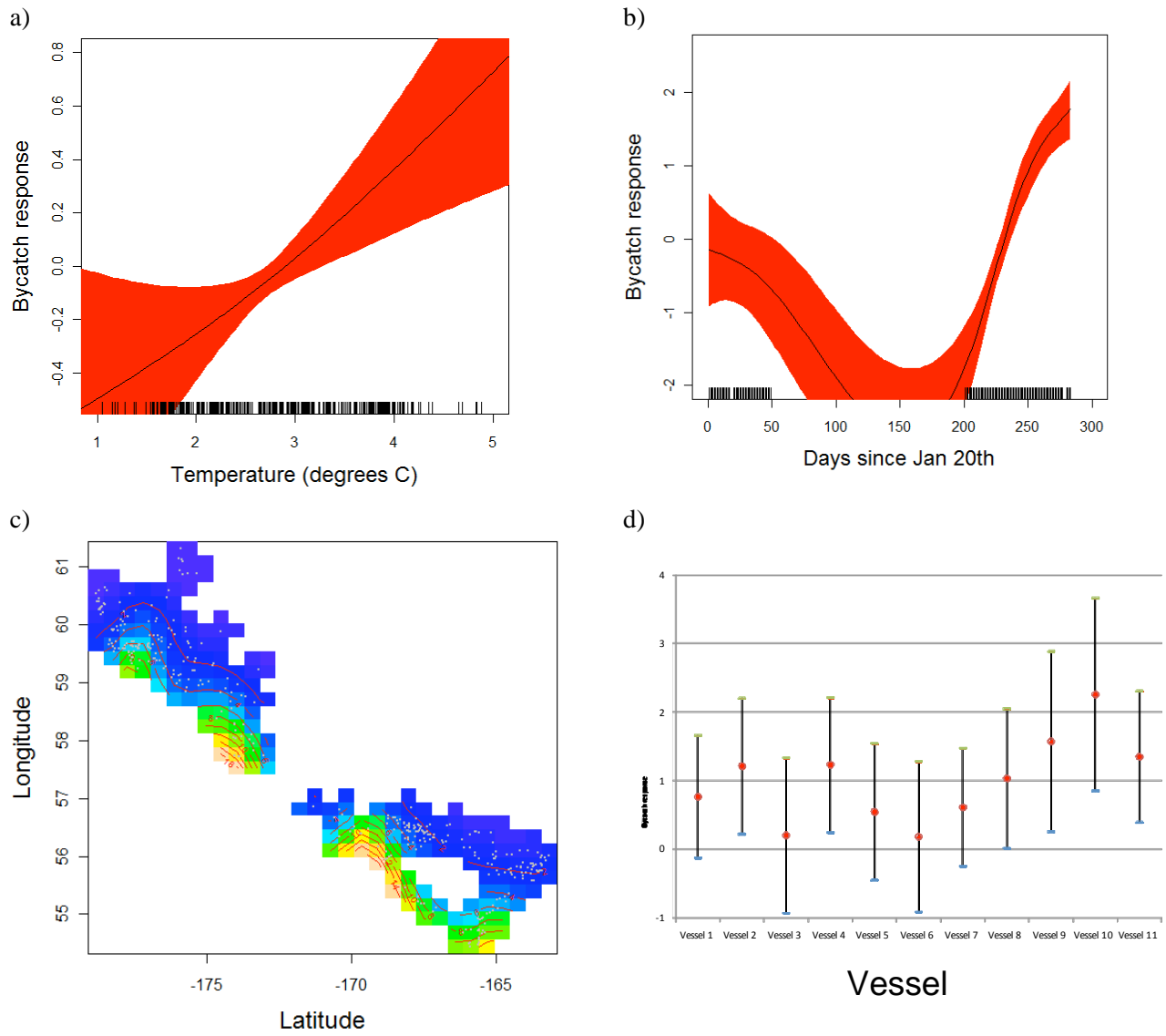


Figure 9. Chinook full model with main factors affecting bycatch modeled for **the TDR data**. Panel a) shows the response of Chinook bycatch to a) temperature, b) day since Jan 20<sup>th</sup>, c) to location, and d) to the relative vessel-effect.

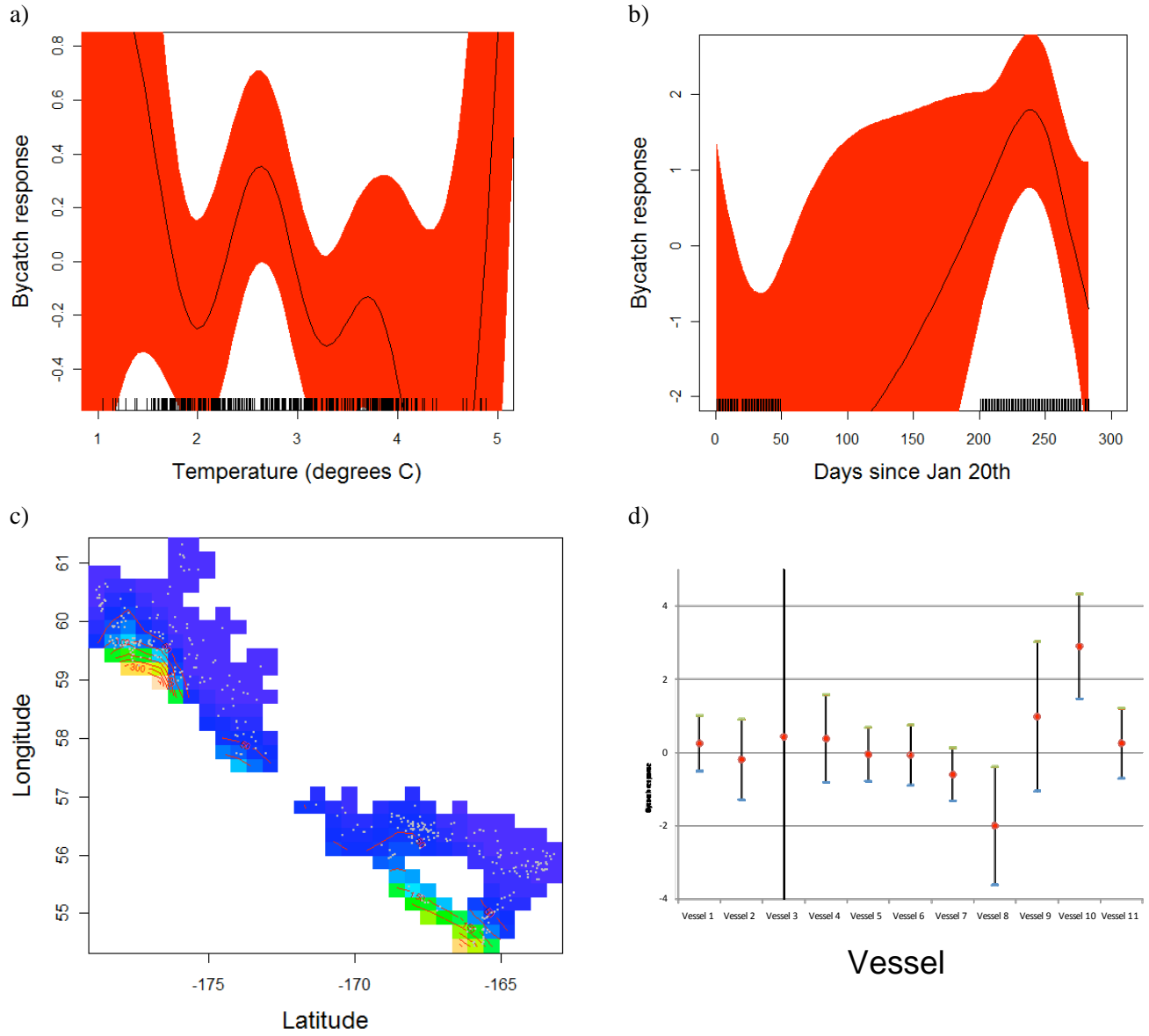


Figure 10. Chum full model with main factors affecting bycatch modeled for **the TDR data**. Panel a) shows the response of chum bycatch to a) temperature, b) day since Jan 20<sup>th</sup>, c) to location, and d) to the relative vessel-effect.

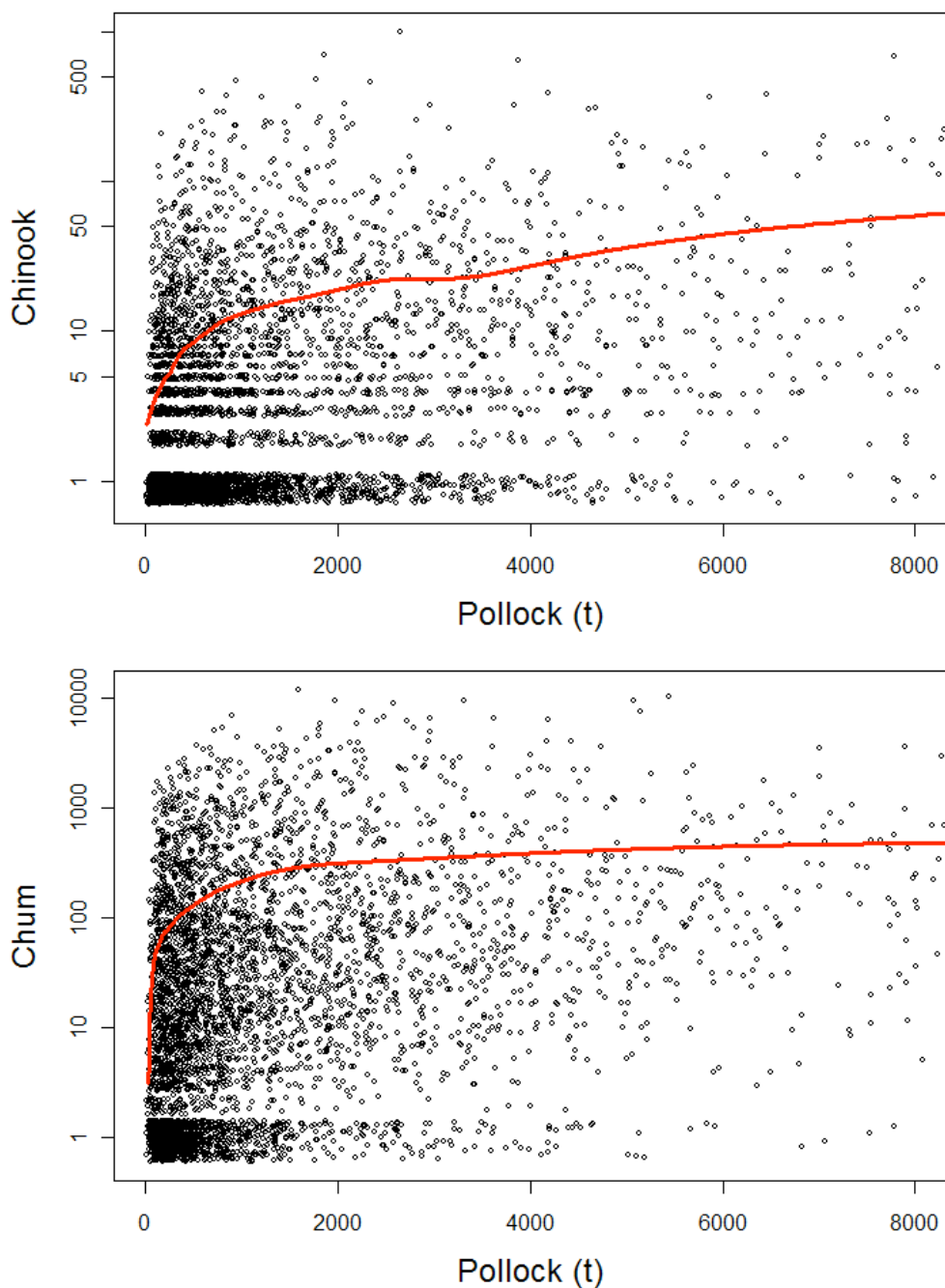


Figure 11. Scatter plots of Chinook salmon (top) and chum salmon bycatch numbers in the pollock fishery as a function of the amount of pollock caught (each dot represents a 5-day period after June 10<sup>th</sup> within a 42x42 km grid, 1991-2008 from observer data only). Line is a smooth fit through the data. Points were jittered slightly to better show point concentrations.

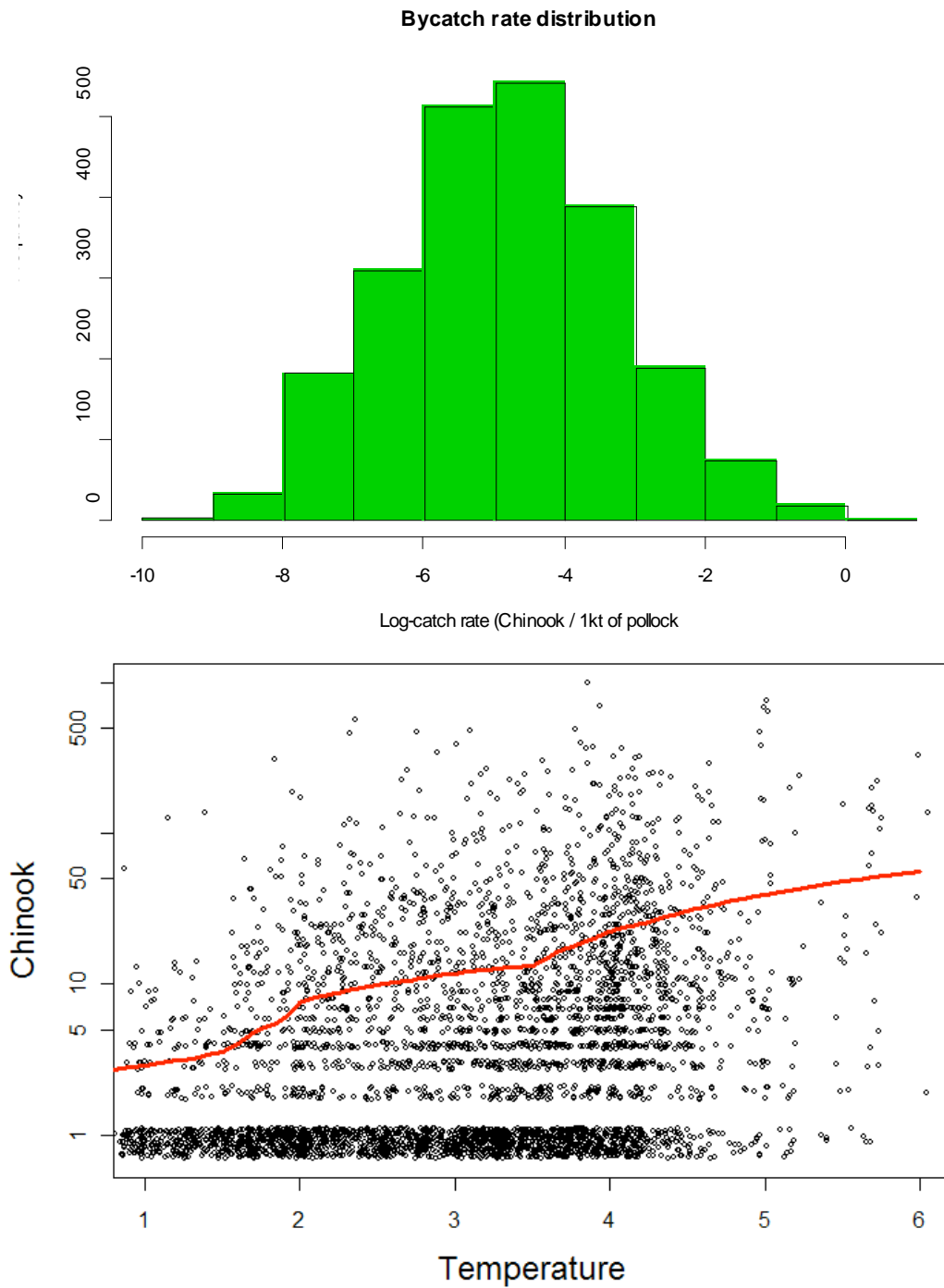


Figure 12. Bycatch rate (logged) frequency histogram (top) and distribution by temperature (bottom; line is a smooth fit through the data and points were jittered slightly to better show point concentrations) for **Chinook** salmon in the EBS pollock fishery.

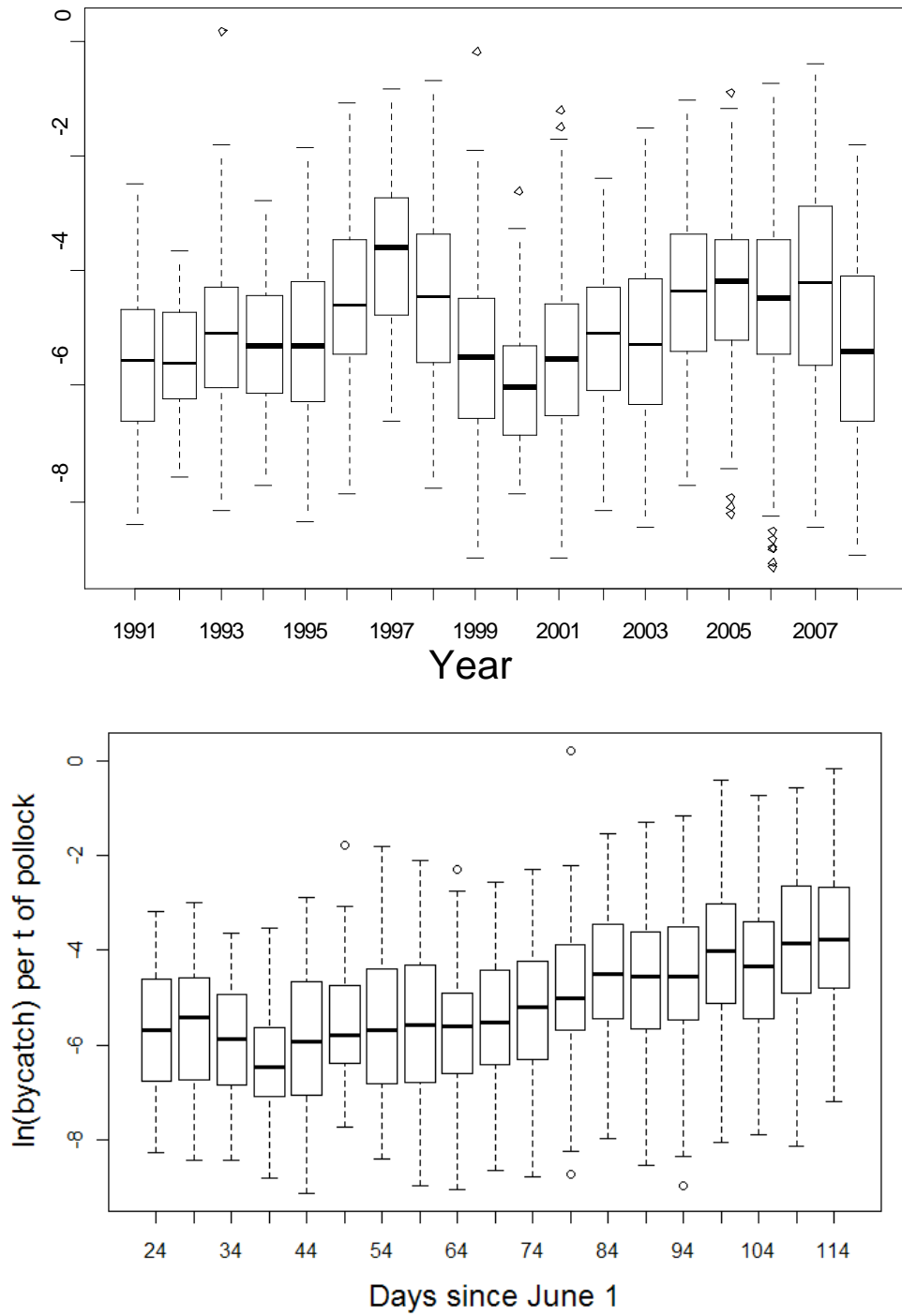


Figure 13. **Chinook** salmon bycatch rate (logged) by year (top) and by 5-day period since June 1<sup>st</sup> (bottom) in the EBS pollock fishery.

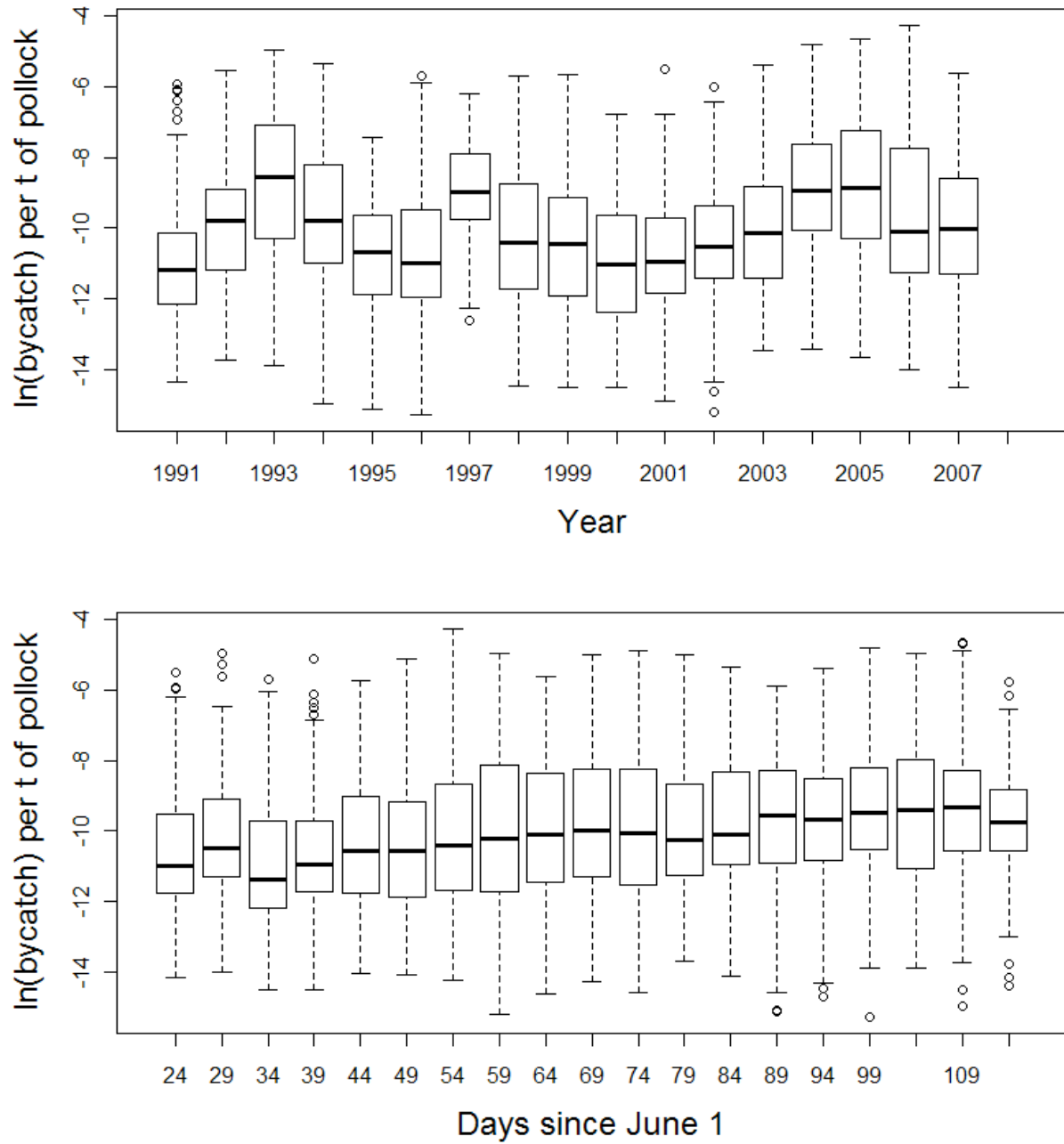


Figure 14. **Chum** salmon bycatch rate (logged) by year (top) and by 5-day period since June 1<sup>st</sup> (bottom) in the EBS pollock fishery.

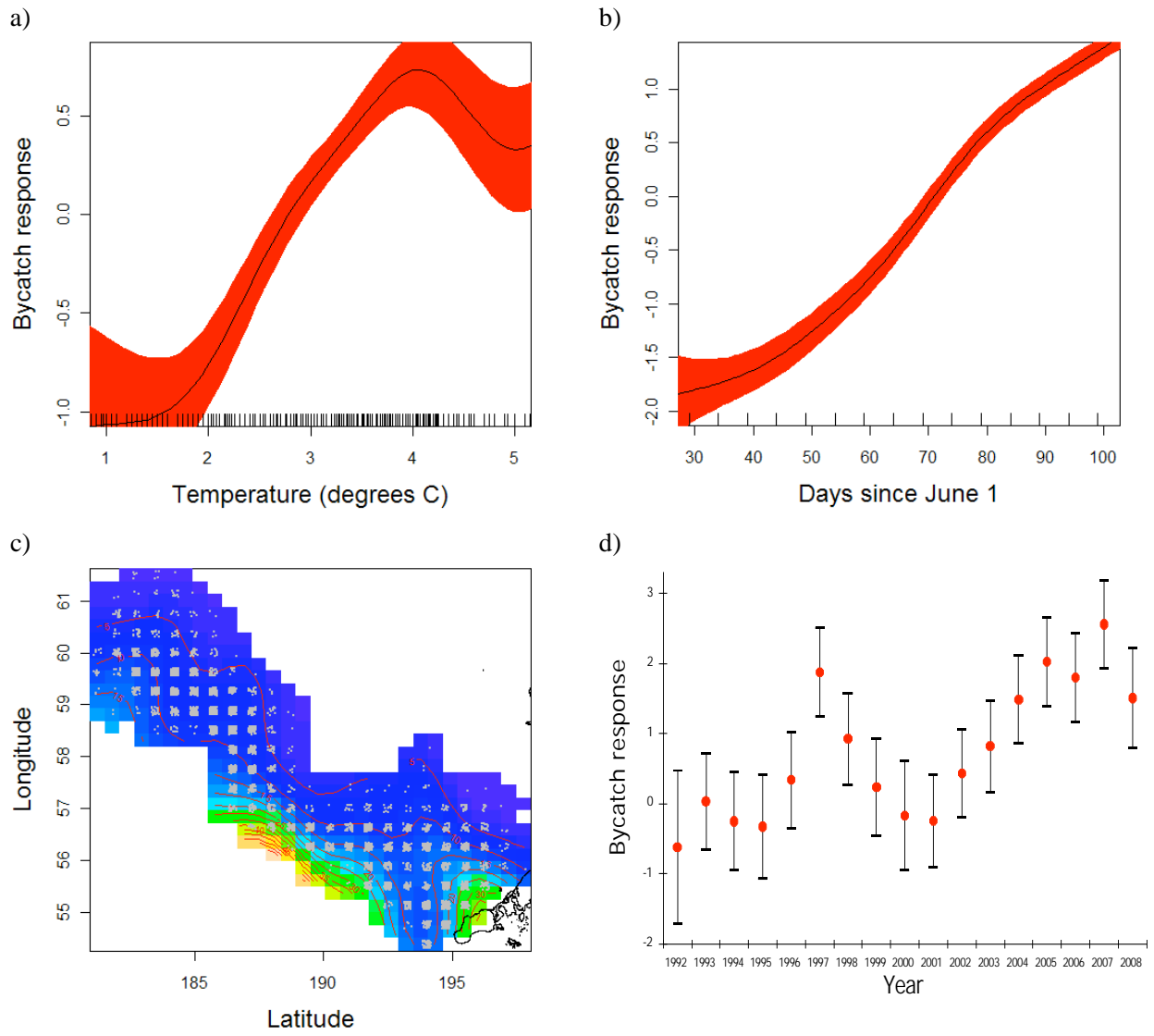


Figure 15. Chinook full model with main factors affecting bycatch modeled for the long time-series.. Panel a) shows the response of Chinook bycatch to a) temperature, b) day since June 1<sup>st</sup>, c) to location, and d) to the relative year-effect.

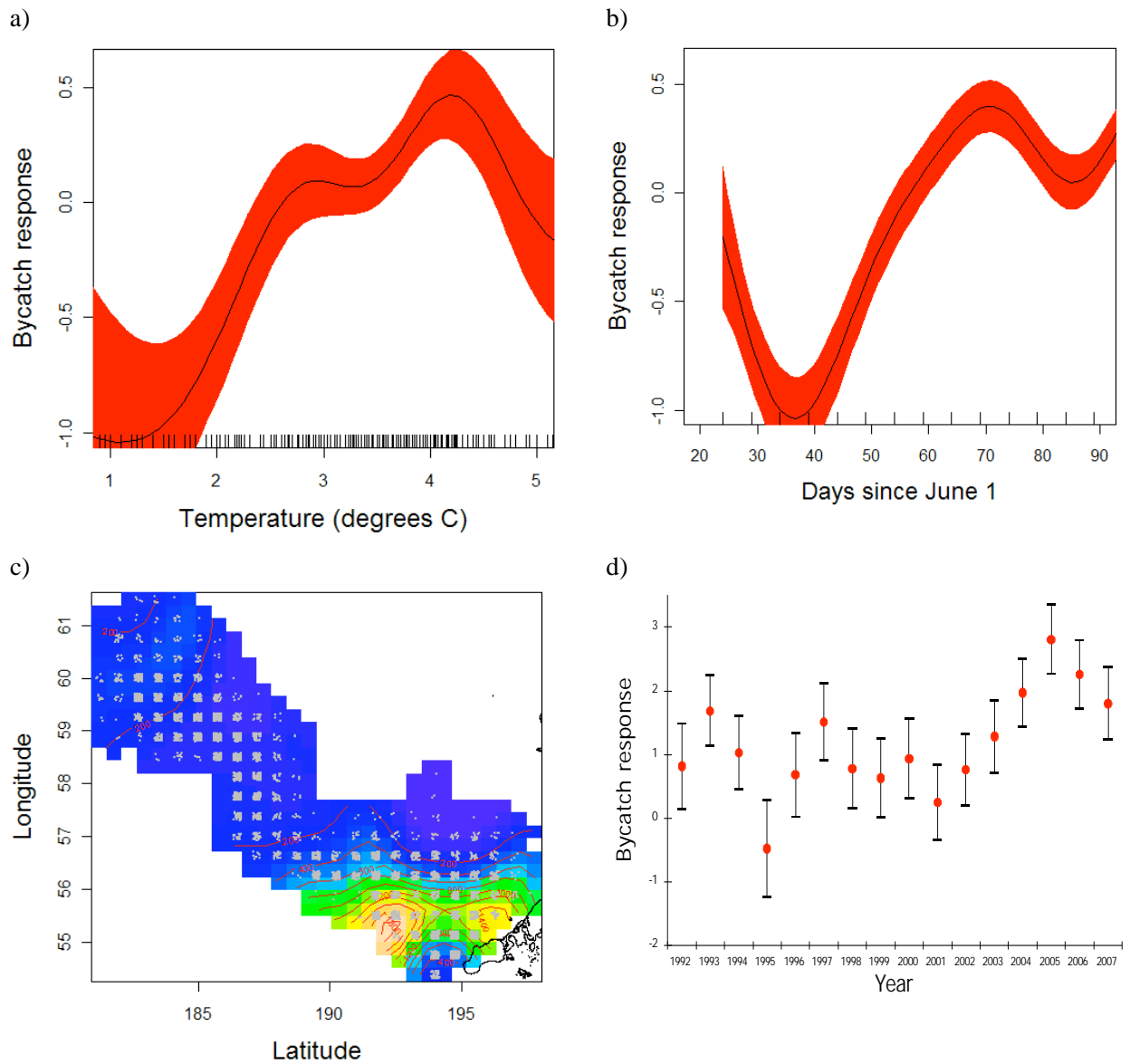


Figure 16. Chum full model with main factors affecting bycatch modeled for the long time-series. Panel a) shows the response of chum bycatch to temperature, b) day since June 1<sup>st</sup>, c) to location (with data points shown as grey dots per grid area), and d) to the relative year-effect.

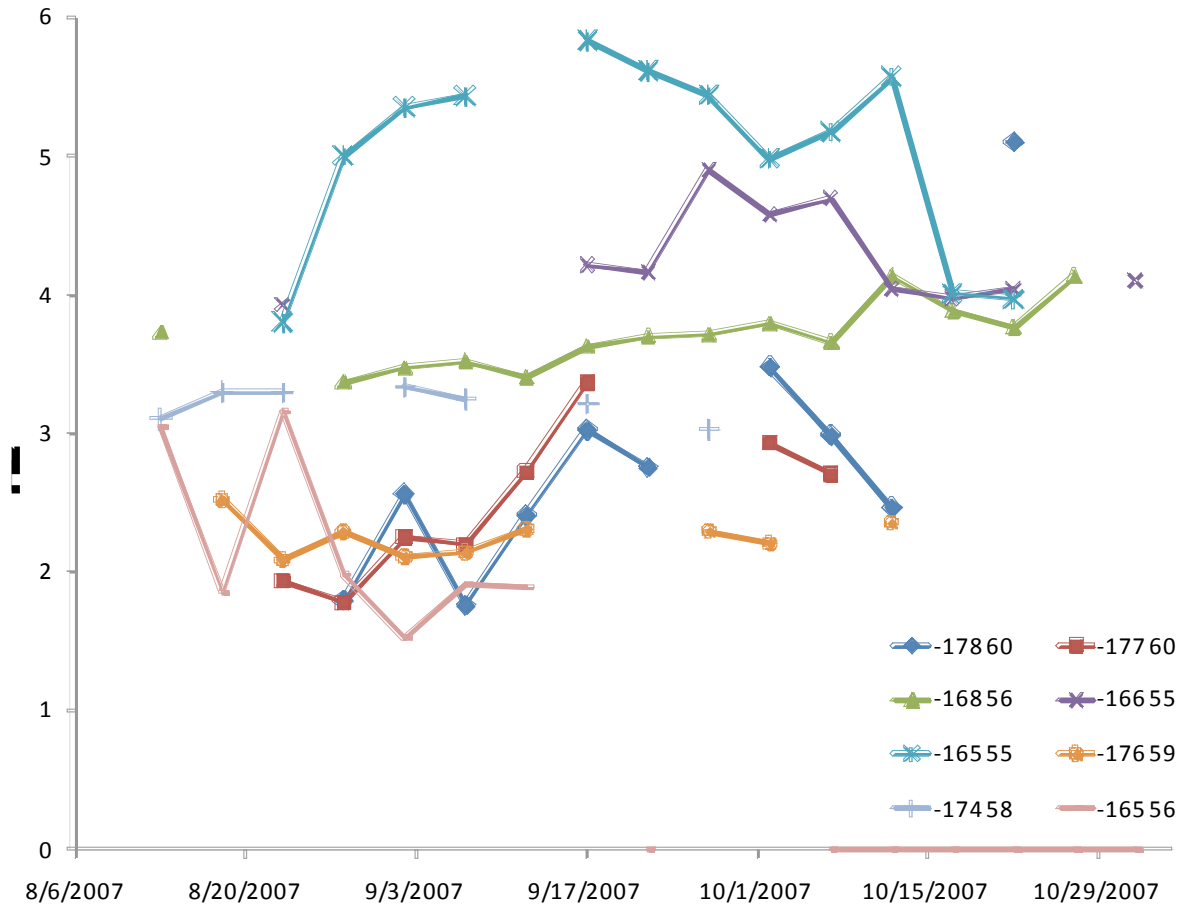


Figure 17. Mean bottom temperatures for the 2007 fishery TDR data averaged by 5-day period and plotted for 1x1° cells (where “-178 60” implies 178°W 60°N). Cells were selected based on having the most observations.

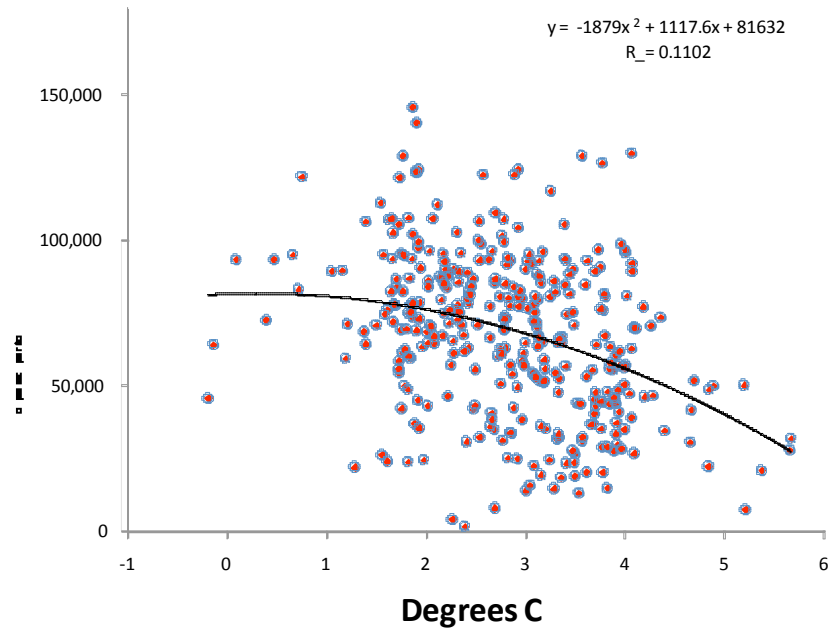


Figure 18. Pollock catch per tow versus mean daily temperatures as collected on board cooperating vessels with TDR devices. The trend line represents 2<sup>nd</sup>-order polynomial fit to these data.

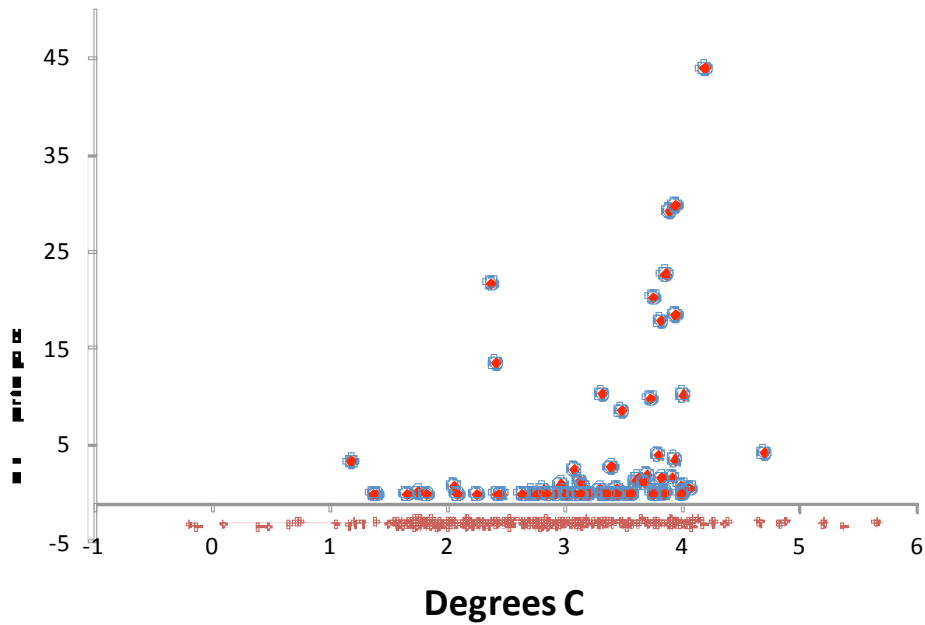


Figure 19. Squid bycatch rate versus mean daily temperatures as collected on board cooperating vessels with TDR devices. Note that the “+” symbol below the horizontal line represents the measured temperatures for vessel days where no squid were observed.

## Attachments

### Summaries from Workshops with the pollock fishery and interested public

#### Workshop 1: Leif Ericson Hall workshop with pollock fishermen and other interested public May 10, 2008

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June 11, 2008

## *Workshop Summary*

### *How does seafloor temperature affect Pollock fishing & Salmon bycatch?*

The workshop on May 10, 2008 was an opportunity for the pollock industry to learn about the NPRB funded Temperature Depth Sensor Project to reduce bycatch in the pollock industry. Feedback from fishermen was also sought as to the utility of the data to their fishing and bycatch avoidance efforts as well as ways to facilitate the work they have to do to collect the temperature data. Twenty-seven fishermen and representatives of the North Pacific pollock industry gathered to discuss the findings. The workshop included presentations by co-principal investigators John Gauvin on behalf of the Marine Conservation Alliance Foundation, John Gruver for United Catcher Boats, Dr. Jim Ianelli of the NMFS Alaska Fisheries Science Center, and Dr. Phyllis Stabeno of NOAA through a presentation of the analysis of Dr. Ianelli.

#### **Background**

In 2007 over 120,000 Chinook salmon were taken as bycatch in the Alaska North Pacific pollock fishery, the largest fishery in the United States. This record high catch was preceded by several years of increasing bycatch. In response to the increased bycatch, the NPFMC is considering invoking a salmon bycatch hard cap for the pollock fishery. The decrease in pollock catch rates in 2007 resulted in 20% longer towing times for fishermen. This may be a factor in the increased bycatch, but does

not account for the threefold increase in Chinook bycatch in the Bering Sea. This suggests that salmon abundance may have increased or that the overlap of Chinook salmon with the pollock fishing grounds may have increased.

### **NPRB Project**

Part of the motivation for looking into the relationship between fine-scale temperature and bycatch rates for salmon came from an Alaska Sea Grant publication entitled “Temperature Directed Fishing”. The paper claimed that differences in preference for temperature gradients could be successfully used to locate high catch rate areas for target species as well as areas where bycatch rates for incidental species would be expected to be high. The paper specifically referenced salmon and pollock as species where temperature preferences could be used to reduce bycatch of salmon. This in part led John Gauvin and John Gruver to look at the possibilities of using this data to help reduce salmon bycatch.

In the 2007 Pollock B Season, temperature devices were attached to the headrope and codend of pollock trawl nets of over twenty different catcher vessel and catcher processor vessels during a three month period. The data was given to Dr. Ianelli with NMFS, who analyzed it in comparison to bycatch data provided by Karl Haflinger. The temperature data was linked with pooled observer data from vessels fishing in each area, not data from individual boats carrying the temperature devices.

### **Project Results**

Based on his knowledge of the species, Dr. Ianelli described how the pollock prefer areas with bottom temperatures in the 2 and 4 degrees Celsius range and avoid areas with zero degree water which includes water under the ice pack. The initial analysis shows that there is an area near the Aleutian Peninsula where bycatch rates for salmon in the pollock fishery were high and where relatively warmer water was located in the fall of 2007. But there is also an area up in the headlands of Bering Sea canyons north west of the Pribilof Islands with colder water but with high bycatch as well. The analysis is preliminary and further study of the data is needed. Dr. Stabeno stated that the northern and southern pollock fishing areas are warm for different reasons, the area near the Aleutians is warm due to currents through Unimak Pass. She suggested looking at how much flow comes through Unimak pass and a strategy would be to have vessels skirt the warm water intrusion. Another attendee suggested looking into salmon migration patterns to help determine how to avoid salmon, although Dr. Ianelli was skeptical that data to evaluate migration routes could be found.

### **Is temperature the thing to study?**

Although other study methods are available, temperature is the cheapest and easiest physical feature of water habitat to study and is the best place to start. The Bering Sea Integrated Ecosystem Program will be studying other relevant issues. One theory is that salmon are coming in to forage on juvenile larval and post-larval pollock. Another is that in years where the food is not broadly distributed, the result is greater overlap between pollock and salmon stocks. Dr. Ianelli explained that based on data from some comparisons of catch rates in the pollock fishery, night fishing accounts for a slightly lower salmon catch rate but this difference would likely not be practical in terms of taking the pollock TAC in the allotted season if only night fishing were done. He also reported that tests under the ice shelf showed that the zero degree Celsius water on the bottom effects the distribution of

pollock and pushes them out from under the ice pack so they can stay in warmer water. Dr. Ianelli has a theory since salmon follow mixed depth, it is more important to look at the change in temperature rather than the actual temperature. Looking at where the temperature is changing the fastest might show us a front where salmon concentrate to orient themselves towards river systems. Dr. Stabeno wants to focus on large temperature changes since small changes will be inconsequential from an ecosystem perspective.

### **Temperature Devices**

Dr. Stabeno stated that the U.S. Navy is using a new ruggedized sensor that might do well for this project and future temperature testing using nets. The device used on the research vessel ALDEBARAN is not sufficiently rugged for this type of work. An attendee suggested using equipment manufactured by Simrad which is currently used by the fleet. According to Dr. Stabeno, the problem with the devices used for commercial fishing is that the data has a significant amount of drift and is not particularly constant. The mini-temperature recorder (MTR) temperature devices furnished by PMEL appear to work well and are much less expensive, but are tedious to download since they must be taken apart.

### **Where to attach the temperature devices?**

Dr. Stabeno found that devices on the codend and headrope gave the same temperature data. John Gauvin mentioned that the MTR units are less expensive and can be calibrated to scientific instrument standards. The problem is that the MTRs used last fall were in canisters without effective attachment points. This required that they be deployed in mesh bags which resulted in a relatively high loss rates for the MTR units. Calibration is easy, with a second unit added to verify the data collected from the first. One attendee had temperature devices attached to both headrope and codend without problem.

### **Did the study miss any areas or vessel types that should have been included?**

It was agreed that the study area looked complete, but it should be compared to the data that Karl Haflinger and Jim Ianelli possess. Dr. Ianelli mentioned that there is a lot of redundant data from vessels conducting multiple tows in the same area. Ideally more boats would be used to capture a larger spatial area, instead of having many downloads from one boat in the same area.

### **Logistics: Downloading Temp Data at Net Systems**

It was agreed that downloading the device data in Dutch Harbor at Net Systems worked well and should be continued in future efforts.

### **Real time temp data, is it the future?**

Dr. Stabeno knows of instruments that transmit data automatically to a box that could be downloaded every day. The price would be a consideration relative to the expected benefits to fishermen. At this point, it appears that fishermen cannot gauge the potential benefits of the temperature data in real time until a more in-depth analysis of the relationship between temperature and catch rates is completed. It is hoped that Dr. Ianelli will be able to do such an analysis once he finishes with some of the salmon bycatch analysis he is doing for the issue in front of the North Pacific Council this spring/summer.

This report was prepared by the MCA Foundation with funding provided by the North Pacific Research Board under agreement number 731 of award number NA05NMF4721198 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, or the North Pacific Research Board.

**Workshop 2: Leif Ericson Hall workshop with pollock fishermen and other interested public April 23, 2009**

June 10, 2009

## ***Workshop Summary***

### ***Temperature Data to Reduce Salmon Bycatch***

*Results from the April 23, 2009 temperature data workshop in Seattle, Washington at the Leif Ericson Hall.*

#### **Summary of findings from the Workshop**

The objective of this project was to engage the pollock industry in collecting temperature data on their pollock nets with the expectation that salmon bycatch is somehow correlated with differences in water temperature across the pollock fishing grounds. Because the Bering Sea pollock fishery has encountered high levels of salmon abundance, the project was intended to develop a new tool for reducing salmon bycatch and to learn about the conditions that are associated with it. Based on the results of Dr. Ianelli's analysis of all three seasons of temperature data at the April workshop, it is clear that some potential for using temperature to better understand the expected magnitude of salmon bycatch exists. However, the relationship between temperature-at-depth and salmon bycatch rates appears to be only one of the important factors. Chinook bycatch appears to be also related to conditions for a given year, season, and location. The role of temperature was found to be a potentially valuable provided other factors were also considered. Chum salmon bycatch also appeared to have a relationship with bottom temperatures in a similar way.

This study highlighted the potential value of temperature to help reduce salmon bycatch. For a more definitive relationship to use for predictions, data collections would need to be expanded spatially and temporally over a longer period. The pollock industry is now seeking ways to make the most of this tool for reducing salmon bycatch. Scientists are also keen to use these relatively inexpensive data to learn more about the Bering Sea ecosystem.

### **Cooperative research between MCAF, the Bering Sea pollock industry, and scientists/fishery managers involved with the fisheries in Alaska**

This NPRB funded project was coordinated by John Gauvin of the Marine Conservation Association Foundation with significant scientific and analytical assistance from Dr. James Ianelli of the Alaska Fisheries Science Center. The Pacific Marine Ecosystem Laboratory and the North Pacific Fishery Management Council also contributed technical assistance. A deployment strategy to help ensure the temperature data collection units were distributed across the pollock fishing grounds was undertaken by John Gruver of the United Catcher Boat Association. Mr. Gruver is a former pollock fishing captain who is currently the inter-cooperative manager for the pollock inshore and mothership pollock cooperatives.

The April 23, 2009 workshop began with a presentation by Dr. Ianelli on the technical results and specifically the question of how temperature could be used in the pollock industry's overall efforts to reduce salmon bycatch. Over fifty fishermen, scientists, and other interested members of the public gathered to review and discuss the findings and consider how temperature data collections could be improved.

For this project, temperature collection devices were attached to the codends and in some cases headropes of pollock trawl nets of catcher vessel and catcher processor vessels during 2007 and 2008. Over twenty pollock vessels volunteered for the project and deployed the temperature collection devices during some or all of the three separate seasons of deployments. Not all deployments resulted in useful data, however, due mostly to electrical connection failures of the temperature at depth recording (TDR) units. The main reason the unit failures were mainly due to faulty wiring connections

between the temperature recording devices and their battery source. This problem was partially solved after the first season but still suffered from gear failures.



*Barb Terada, Dutch Harbor field project manager, explains to a pollock captain how the temperature/depth recorder should be attached to a pollock net. The TDR is housed in a UHMW protective housing.*

To examine the degree to which the temperature collections covered the pollock fishing grounds overall, Dr. Ianelli's analysis first compared haul-specific temperature at depth observations with the overall spatial extent of fishing locations based on fishery observer data. For the Bering Sea pollock fishery, close to 80% of the catch is taken on vessels carrying NMFS-trained observers. Observer data is therefore a very good indication of where pollock fishing occurs. Additionally, Dr. Ianelli reviewed how well the temperature data from the project corresponded to other sources of temperature readings such as NMFS' summer trawl surveys and temperatures from PMEL's moorings on the Bering Sea shelf.

### **Major Project Findings**

In his analysis of the data, Dr. Ianelli framed the question of the utility of temperature-at-depth data for predicting salmon or other bycatch in the Alaska pollock fishery in terms of its potential for providing

either “operational advice” versus “process advice”. Operational advice would be useful for avoiding bycatch hotspot locations during the fishing season, something that was originally hoped for in terms of development of a new tool to assist the pollock fishery’s effort to reduce salmon bycatch.

An example of operational advice described at the workshop is the western Pacific longline fishery for tuna and swordfish. Dr. Ianelli explained that maps of temperature fronts are made available to tuna and swordfish longline fishermen in real time. These data are apparently currently used by fishermen to help avoid fishing in areas where 18° C surface temperature conditions prevail. Areas with those temperature conditions are apparently highly correlated with sea turtle locations (hence bycatch). This was determined from temperature recording tag devices placed on sea turtles – an innovative way to directly measure the relationship temperature and the bycatch species. Such an approach is unfortunately probably not feasible for tracking salmon abundance locations for the pollock fishery.

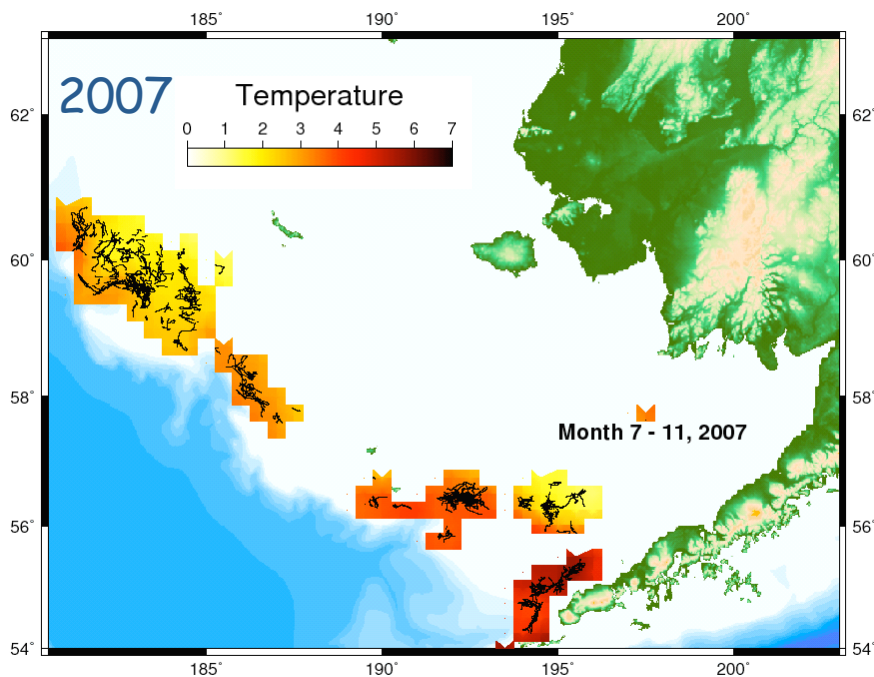
Where relationships between temperature and bycatch are weaker or more complex, process advice would be where temperature data collections are examined in statistical models that look at a wide set of factors. These models allow evaluation of multi-variate patterns in salmon bycatch rates over different time scales (week, month, season, year). Information about the general correlation between temperature and bycatch as “process advice” could then augment our understanding of the determinants of bycatch rates. But this advice would not be expected to be directly useful to predict bycatch hotspots in a stand-alone fashion during the fishing season. An example of process advice would be the case where temperature collections on the fishing grounds would improve bycatch predictions spatially and seasonally. For example, fishery bycatch mitigation efforts might, be increased or reduced for a given season as a result of advice developed from historical data. Likewise process advice tailored to conditions in a given year or season might make bycatch reduction efforts more efficient and cost effective.

Based on Dr. Ianelli’s analysis, temperature data collections in the pollock fishery appear most useful in the form of process advice. This was because of the short time frame and limited contrast between temperatures and bycatch levels. Evaluations of the available data shows the extent of temperature data collected compared to the overall spatial distribution of the fishing grounds. Broken out by seasons

and month, the analysis showed that the fall 2007 and winter 2008 seasons had the best “coverage” of the fishing grounds. An example of the spatial extent of tows where temperature data were collected relative to the overall area where fishing occurred is provided in Figure 1 below.

Differences in spatial coverage between seasons resulted from several factors including the number of boats that volunteered to deploy the units, the success/failure rates for the devices on boats that deployed them, and how well the deployment strategy was able to get the units out in the “field” across the different fishing areas. The deployment strategy was designed to place the units on vessels such that they would capture the expected differences in fishing location patterns for different components and sectors of the pollock fleet.

**Figure 1: Temperature data collections compared to overall spatial extent of the fishing grounds (spatial grids where observer data indicates fishing occurred) during the fall 2007 pollock fishery**



A set of nested generalized additive models (GAMs) were used to examine pollock bycatch rates (as log-transformed Chinook salmon catch per 1,000 t of pollock). These models tested for temperature effects of bycatch relative to other known factors (such as area and time of year). Given the narrow time

window and spatial extent of the NPRB temperature data collections, temperature data from the NMFS Bering Sea groundfish trawl surveys were used thus allowing the analysis to cover the period 1991-2008 coupled with observer data on bycatch. The bycatch data were spatially dis-aggregated into 42 km grids split into 5-day time intervals. The temperature data collected by the NMFS surveys were treated synoptically within these 42 km grids

Results from the GAMs showed the relative importance of year, season, week, temperature as explanatory variables for summer Chinook bycatch rates. A feature of GAMs is that relevant factors can be expressed in terms of non-parametric “response surfaces” with estimates of uncertainty of their role in predicting bycatch rates. A narrower “confidence band” of the response surface indicates a range where predictability is improved for explaining the bycatch rate of Chinook salmon in the pollock fishery (Figure 2). This analysis shows that while temperature appears to be related to Chinook bycatch, the other factors including year, month, week, and geographic location were important conditioning factors to modify the temperature relationship (Figure 3).

Overall, Dr. Ianelli’s analysis confirms the conclusion of the 2009 Environmental Impact Assessment for Chinook salmon bycatch. Specifically, annual differences in salmon bycatch are the predominant factor to explain differences bycatch rates. This likely indicates that the relative abundances of pollock and Chinook salmon varies between years (rather than being in a constant proportion. Also, time of year tends to be a significant factor for Chinook bycatch with higher bycatch rates occurring later in the season (October). To a lesser degree, combined with these factors the fishing area matters for the level of Chinook bycatch. This study adds to these prior findings by indicating that temperature is also a relevant factor, especially within the band of temperatures (between 2 to 4 degrees C) observed. This is consistent with temperature preferences for pollock and Chinook salmon from the scientific literature.

A similar analysis was applied to chum salmon data. Based on the same modeling approach, chum salmon bycatch rates appear to be more strongly correlated with temperature (Figure 3). As with the Chinook salmon analysis, the additional conditional factors are also important.

Figure Two shows Chinook Bycatch in the Bering Sea pollock fishery compared with temperature data, Figure Three adds the three primary bycatch factors into the model.

## Chinook Salmon Models

Below are two graphs showing the Chinook Salmon Bycatch rate in the Bering Sea pollock fishery, taking into account specific factors as listed.

Figure Two: Chinook Bycatch Rate and Temperature

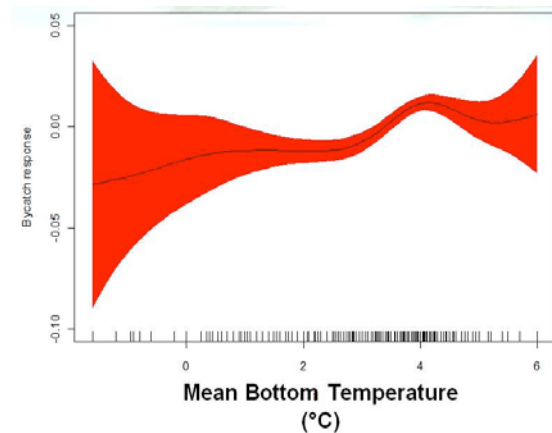
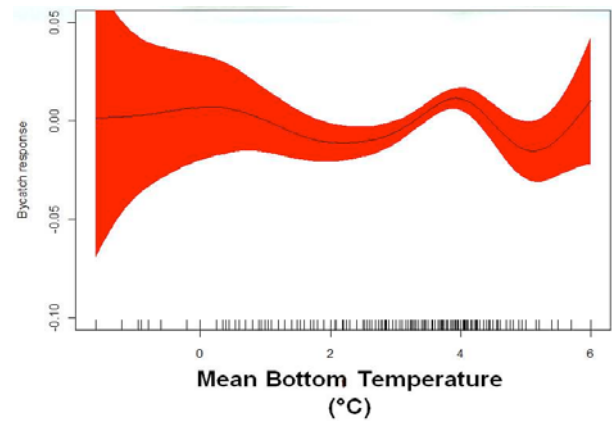


Figure Three: Chinook Bycatch Rate and Temperature, year, week, space (Lat-Long)



— Average Bycatch Rate

■ Rate of variation. The thinner areas indicate a high rate of confidence in the model's ability to explain the relationship between the factors of interest.

Finally, the relationship between temperature and simply pollock catch rates was examined.

Unfortunately, the tow duration data field in the observer data records is often incomplete for the time series that was examined. This means that catch quantity per tow was the only available measure of catch per unit of effort. Pollock fishermen attending the workshop pointed out that catch amount per tow is unlikely to be a relevant indicator of true catch rate differences within spatial grids. The American Fisheries Act resulted in a number of fleet behavior changes. Fishing cooperatives were established by this legislation and effectively ended the "race for fish." Catch quality considerations then became a major driver of catch amount per tow so changes over time could well have resulted from response to the AFA system. This major change in incentives in the fishery would be expected to confound

interpretation of the “annual” effect included in the model. However, the relationship with temperature catch rates (as catch-per-tow) should be viable.

### **Where do these findings leave us in terms of a role for temperature collections?**

The models clearly suggest that temperature data are valuable for understanding bycatch rates. Unfortunately, the ability to provide reliable operational advice for reducing salmon bycatch in the pollock fishery will require more extensive study and data. While limitations in using pollock catch-per-tow were expressed, the fine-scale temperature data appear to have some effect on pollock catch rates (i.e., catch/hour). Lower overall catch rates occurred at higher temperatures between 2° and 4° C. Given this information, this study should allow for more efficient fishery prosecution. That is, accounting for areas and time of year, the fishery should be able to focus on areas that were closer to 2° C since pollock catch rates are higher and bycatch rates (for both chum and Chinook) tend to be lower.

The project was originally designed to focus on how to make real-time data available to the pollock fleet. The appropriate format for incorporating temperature data into vessel plotter programs was considered. Also, confidentiality issues were raised since vessel-specific fishing positions potentially be made available and consequently put program participants at a disadvantage.

The workshop attendees from the fishing industry and scientific community concluded that there is considerable potential for temperature data collected on fishing vessels. The ability to learn more about the interplay between bycatch and ecosystem conditions was considered important and that the more information that is made available, the better. Developing this potential to expand the spatial and temporal coverage of the collections was noted as being desirable.

Adding other fleets would increase the spatial coverage beyond pollock fishing grounds. This expansion would help provide information about the shallower shelf areas where flatfish, crab, and other fisheries occur. Temperature trends in these areas may be important in how pollock and salmon are distributed and may provide insights on other important target and bycatch species. In addition to providing more

information to understand bycatch better, additional temperature data could supplement ecosystem models that are being used to increase our knowledge of the Bering Sea ecosystem.

Currently, sea floor and water column temperature information comes mainly from NMFS trawl surveys. These collections occur mainly in the summer and thereby may limit applicability later in the B season (and certainly for the A season). A limited number of slope and shelf temperature buoys deployed and maintained by the NOAA's Pacific Marine Ecosystem Lab (PMEL). Expanded and adapting these collections could be useful for getting finer scale resolution of temperature differences between buoys that are currently unavailable.

Expanding the fishery-dependent temperature collections in the pollock fishery and other fisheries would, for example, be useful for evaluating the development and evolution of the Bering Sea cold pool before and after the trawl surveys. The extent and migrations of the cold pool could help provide information to help models predict recruitment of key groundfish species as well its potential utility for reducing or learning more about the determinants of bycatch. Finally, if the data collections were expanded to other fisheries and gear types such as pot gear, there may be better means to collect water column temperatures in addition to near/seafloor and seafloor temperature. This information would be even more helpful for improving the understanding the dynamics of the Bering Sea ecosystem.

All of the potential uses for expanded temperature data from fishing vessels would require better coverage over the fishing grounds and more reliable performance for the temperature recording devices. For this reason, issues surrounding the relative convenience of deployment of the units were also discussed at the workshop. In these discussions, fishermen pointed out that the placement of the TDR units used for this project on net codends required that the devices be removed following each haulback due to relative fragility of the devices despite the protective cases. The concern here was that haulback is a time when deck crews must focus intently on safely dumping the catch into the vessel's tanks. Some captains felt that having the crew concentrate on extra tasks at that time may not lead to maximum safety on deck, especially in bad weather conditions.

The question arose whether alternative devices might be robust enough to be rolled onto the net reel. Another question was whether the device could be small enough to be placed on the vessel's net sounder suitcase that is removed each haul prior to bringing the net on deck.

**A strategy emerges for improving and expanding temperature data collections for process advice on salmon bycatch reduction and ecosystem information**

The TDR device deployment challenges discussed above were vetted at the workshop and it soon became clear that the key issues for expanding the coverage were coming up with a different TDR device. This alternate device would better withstand conditions in the Bering Sea on deck and be sufficiently accurate and allow for calibration to the degree needed for the science. Additional attributes of interest would be better data storage and battery capacity that would allow for an entire season of data collection without downloading. Having this greater capacity would be optimal because the data used as process advice does not require periodic downloads and increasing the interval to twice a year would decrease inconvenience and costs.

Likewise, ease of downloading was discussed such that a technician in Dutch Harbor might be able to download the data via a short visit to the vessel and the use of a wireless connection on the vessel deck. Further discussion centered on the idea of a small device that would be attachable to the vessel's net sounder headrope unit because the "suitcase" unit of a headrope sounder is removed as a matter of course prior to each net haulback.

As an alternative approach, it was discussed that a small device about the size of a shotgun shell could be placed in a resilient but relatively small metal tube. Because the unit and tube would still be relatively small it could be wound up onto the net reel without risking damage (it was felt that a short but stout tube would not be susceptible to bending when rolled up onto the net reel but this is yet to be determined).

Finally, the issue of cost was broached. For broader coverage, attendees felt that every vessel or at least a much greater percentage of the pollock vessels. This led to ideas for expanding the temperature collections to other fisheries but because participants in those fisheries were not well represented at the workshop, that idea was placed on hold for the time being.

Following this discussion of desirable attributes and ideas for expanding the temperature collections, Dr. Ianelli mentioned that he had been doing some investigation of small “fish tag” style devices that record temperature/depth when attached to fish that are released back to the sea. These fish tag devices apparently collect science-grade information and are of a size that would likely work for attachment to the headrope sounder or fitting into the short tube discussed before.

These fish tag units have sufficient memory to be able to collect approximately 80 days of data which is roughly about one typical pollock season. This duration is achieved when sampling pressure and temperature are set at a 5 minute interval. Archival fish tags are individually calibrated and verified using a 9 point calibration (3 pressures over 3 temperatures) and are advertised to be highly stable over the specified ranges. The price per unit has been estimated to be under \$300 per tag based on orders of approximately 50 units. There are some other software costs for wireless downloading but these are expected to be minimal.

### **The Plan**

Workshop attendees were definitely interested in expanding the data collections along the lines of the ideas described above. The modified project design to provide process advice and building a time series of temperature data for all the uses detailed above was thought to be the best course of action. The next step is coming up with detailed cost estimates for the new plan for temperature collections as a program. With the existing estimated cost for the new style of TDR devices, the key information to obtain now is how many units would be needed, what fisheries would be targeted for the data collections, and how much of a field manager’s time would be needed. A Dutch Harbor project manager is clearly needed to distribute the units and download data and switch out batteries. Logistics for meeting vessels participating in several different fisheries would likely be more challenging and the

different seasons for an expanded set of fisheries would likely require a Dutch Harbor project person to work for the project over a greater portion of the year.

All these issues will have to be worked out before approaching potential funding sources. Lead time for funding sources is also a consideration for which sources to target as is the different scientific and management objectives of different potential sources. In the end, some participants thought that looking into fishing industry based funding might be the best course because that might obviate some of the timing and funding source hurdles of public or private foundations. With these issues to resolve, the workshop concluded with the suggestion that the NPRB project organizers figure out how to “make it happen” from here.

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