Kolarctic ENPI CBC – Kolarctic salmon project (KO197) - Report XV

The linkage between changes in sea temperature and the timing of salmon catches

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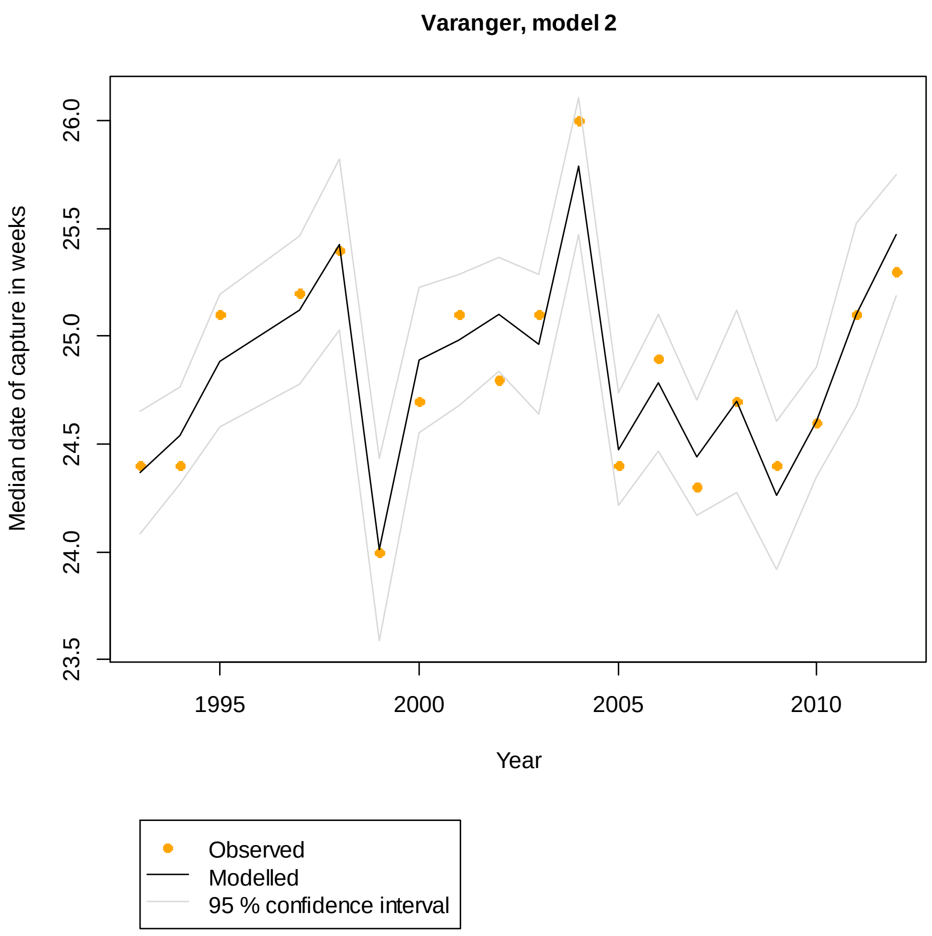

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Cover page figure: The fit of the model 2 to the observed median date of capture in Varanger. Explanatory variables in the model are the differences of the sea temperatures (0-50 m) between February and January, between April and March and between June and May in the Kola section.

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Abstract

The mean sea temperatures were measured in Fugløya-Bjørnøya section, Laksefjord, Varangerfjord and Kola section of the Barents Sea. After several modifications from the original measurements of sea temperature, altogether 92 original and modified explanatory variables were included in the analysis. The median date of capture was modeled in four locations, Alta, Hammerfest, Tana and Varangerfjord. The best models for median date of capture in Varangerfjord included the difference of the mean sea temperatures (0-50 m) between April and March in the Kola section, which accounts for around 53 % of the deviance. The effect of the difference of the sea temperatures (0-50 m) between June and May in the Kola section is almost linear and the differences of the mean sea temperatures in January, February and March has a part in the models. However interpreting the models for the median date of capture in Tana, Hammerfest and Alta is demanding. The set of explanatory variables might not include the essential variables.

1. Results

1.1 Sea temperatures

The sea temperatures were measured in Fugløya-Bjørnøya section, Laksefjord, Varangerfjord and Kola section. The sea temperatures of Fugløya-Bjørnøya section were from SJÖMIL (available in the Institute of Marine Research website, http://www.imr.no/sjomil/index.html). The sea temperatures in Laksefjord and Varangerfjord were also from IMR. The sea temperatures in Kola section were available in Polar Research Institute of Marine Fisheries and Oceanography, PINRO's website (http://www.pinro.ru/index_e.htm).

The original measurements are the means of sea temperature for each month (Table I). In Fugløya-Bjørnøya section the measurements were done in depth 50-200 m. Since 1977, the Fugløya-Bjørnøya section has been measured 6 times each year. From Kola section the means of sea temperatures in depth 0-50 m and 0-200 m were available for each month.

Table I. The original measurements and the variable names of the mean sea temperature for each month.

	Mean sea temperature of...				
Month	Fugløya-Bjørnøya	Laksefjord	Varangerfjord	Kola 0-50 m	Kola 0-200 m
January	seafb01	sealakse01	seavar01	seakola01	sea200_01
February	-	sealakse02	seavar02	seakola02	sea200_02
March	seafb03	sealakse03	seavar03	seakola03	sea200_03
April	seafb04	sealakse04	seavar04	seakola04	sea200_04
May	-	sealakse05	seavar05	seakola05	sea200_05
June	seafb06	sealakse06	seavar06	seakola06	sea200_06
July	-	sealakse07	seavar07	seakola07	sea200_07

Modifications from the original measurements of sea temperature were included in the analysis. For example differences between means of each month, means over 3 months, annual mean calculated for calendar year, annual mean calculated from September to August were calculated for Laksefjord, Varangerfjord, Kola section (depths 0-50 m and 0-200 m) and for Fugløya-Bjørnøya section when it was possible. Altogether 92 original and modified explanatory variables were included in the analysis.

1.2 GAM-models

From three to six sets of explanatory variables were included in generalized additive modeling (GAM) separately. The thin plate regression spline was used for smoothing. The spline smoothing was done for one explanatory variable in time for each explanatory variable in the set resulting up to five different GAM-models. The best model candidate was selected by multi model inference using Akaike information criterion (AIC). The selected model candidate was analyzed stepwise and the reduced models were evaluated using AIC again. In the end, from all different sets of explanatory variables the best models were evaluated using multi model inference and AIC. One or two models were selected for each location (Table II).

Table II. Summary of the explanatory variables included in the final GAM-models. The median date of capture (in weeks) was explained with different uncorrelated sets of variables. For each location, the models with minimum AIC are shown (ΔAIC > 2 for the compared model).

Location	Explanatory variables (smoothed variables in parenthesis)	Deviance explained (%)	AIC
Alta	dlakse0302 + s(seakola05)	88.9	11.1
Hammerfest[*)]	dfb0301+ seavar07	64.8	12.0
Tana	s(year) + dfb0301 + dkola0504	97.6	-12.8
Varanger, model 2	s(dkola0403) + dkola0605 + dkola0201	91.2	3.2
Varanger, model 6	s(dkola0403) + dfb0301 + dkola0605	90.4	3.9

[*)] In the year 2004 median date of capture is exceptional in Hammerfest. The single year has great influence on the model. Without observation from 2004 the results of the model are clearly different and explained deviance decrease approximately 10%. Also the correlation structure differs and the possible best set of explanatory variables is different.

Table III. Description of the explanatory variables in Table II.

Variable name	Description of the explanatory variable
year	calendar year
seakola05	May sea temperature (0-50 m) in the Kola section
seavar07	July sea temperature in Varangerfjord
dfb0301	Difference of the sea temperatures (50-200 m) between March and January in the Fugløya-Bjørnøya section
dkola0201	Difference of the sea temperatures (0-50 m) between February and January in the Kola section
dkola0403	Difference of the sea temperatures (0-50 m) between April and March in the Kola section
dkola0504	Difference of the sea temperatures (0-50 m) between May and April and in the Kola section
dkola0605	Difference of the sea temperatures (0-50 m) between June and May in the Kola section
dlakse0302	Difference of the sea temperatures between March and February in Laksefjord

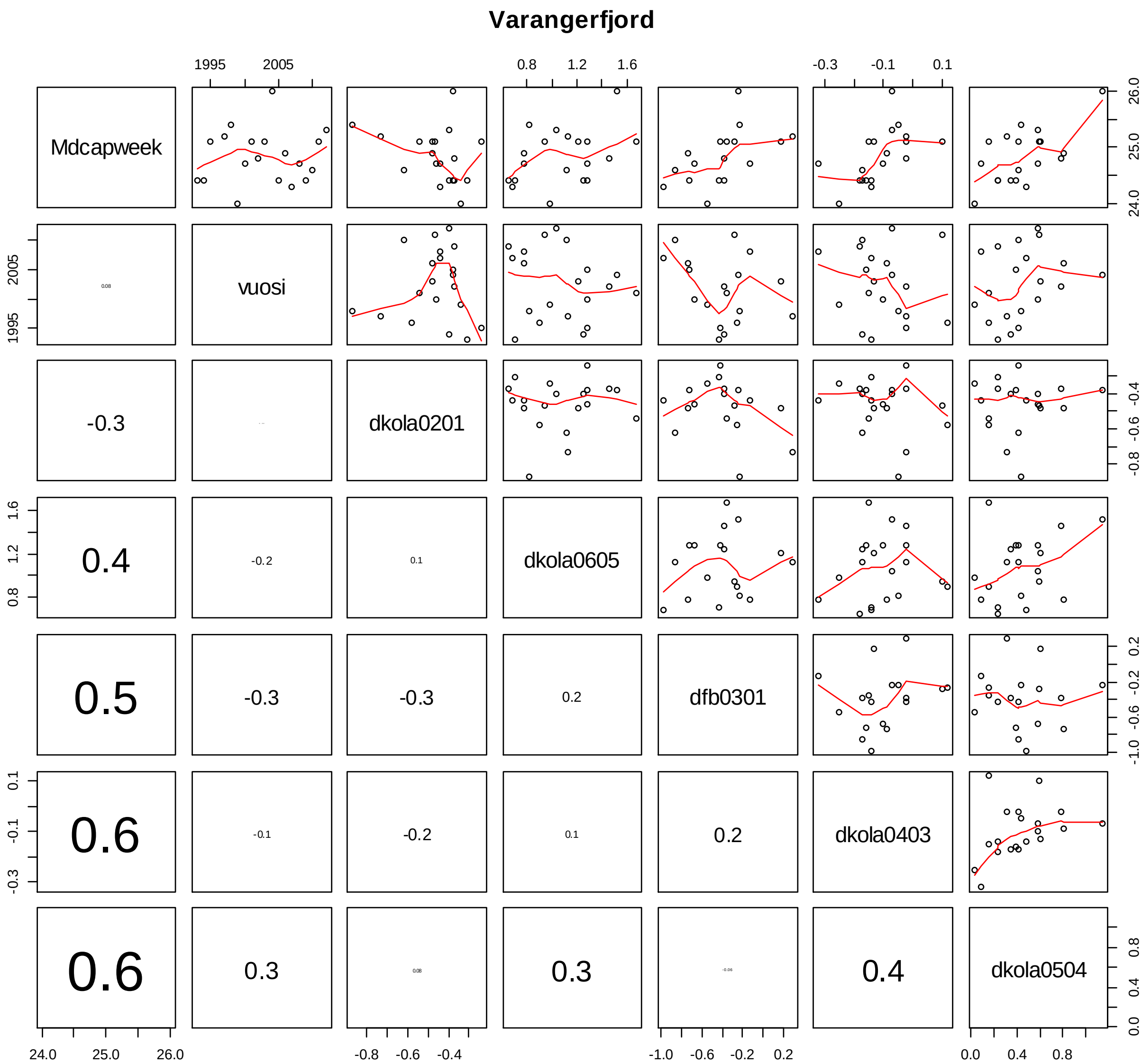

Figure 1. The pairwise correlation coefficients and scatter plots between all selected explanatory variables and the median date of capture in Varanger. (Variable vuosi is year.)

1.3 Results of the statistical models

In Varangerfjord, the best models highly explain the variation in median date of capture. Six different sets of possible explanatory variables were included in the models separately. The following results are common with both models 2 and 6 in Table I. The difference of the sea temperatures (0-50 m) between April and March in the Kola section has threshold value from -0.2 to (Figure 1). If the sea is cooling slightly (the difference is around -0.2) from March to April, the median date of capture is observed earlier, around week 24.5, but if there is no change (value is 0) in temperature of sea the median date of capture is observed slightly later, week 25.3. The previous difference between April and March alone accounts for around 53% of the deviance (Table IV, models d, e and f). The effect of the difference of the sea temperatures (0-50 m) between June and May in the Kola section, is almost linear - the more warming from May to June the later is the median date of capture observed (estimated difference is from 0.5 to 0.7 week per one degree). The difference of the sea temperatures between April and March accounts for 33 % of the deviance in model 2 and 7.4% of the deviance in model 6 (Table IV, comparison of the models b versus f and c versus d). The results rise a question does both differences tell the same story of late spring?

Table IV. Comparison of the models 2 and 6 for the median date of capture in Varanger. Observations from years 1996, 2009 and 2012 are excluded from all models due to missing observation in at least one of the models.

	Explanatory variables included, smoothed variables marked by s(x)						
Name of model	dkola0201	dkola0403	dkola0605	dfb0301	Deviance explained (%)	AIC	deltaAIC
GAM2 model a	**x**	**s(x)**	**x**		**93.2**	**1.15**	**-**
model b		s(x)	x		86.4	8.62	a vs b 7.5
GAM6 model c		**s(x)**	**x**	**x**	**90.4**	**3.99**	**-**
model d		s(x)		x	83.0	11.0	c vs d 7.01
model e				x	28.4	22.8	d vs e 11.8
model f		s(x)			53.1	20.6	d vs f 9.6 b vs f 12.0
model g			s(x)		13.9	25.9	-

In Varangerfjord additionally in model 2, the less cooling from January to February in the sea temperatures (0-50 m) in the Kola section, the earlier the median date of capture is observed (estimated difference is 0.7 week per one degree), and vice versa more cooling from January to February means later weeks for the median date of capture. The previous difference between January and February alone accounts for only 7 % of the deviance (Table IV, models a and b), but AIC difference clearly increase. The fit of the model 2 to the observed median date of capture in Varanger is shown in Figure 2. The model 2 explains 91.2 % of the deviance (Table I).

In the alternative model 6, the more cooling from January to March in the sea temperatures (50-200 m) in the Fugløya-Bjørnøya section, the earlier the median date of capture is observed (estimated difference is 0.5 week per one degree). The effect is almost linear. The previous difference between January and March alone accounts for around 29% of the deviance (Table IV, models e and f). The fit of the model 6 to the observed median date of capture in Varanger is shown in Figure 3. The model 6 explains 90.4 % of the deviance (Table I).

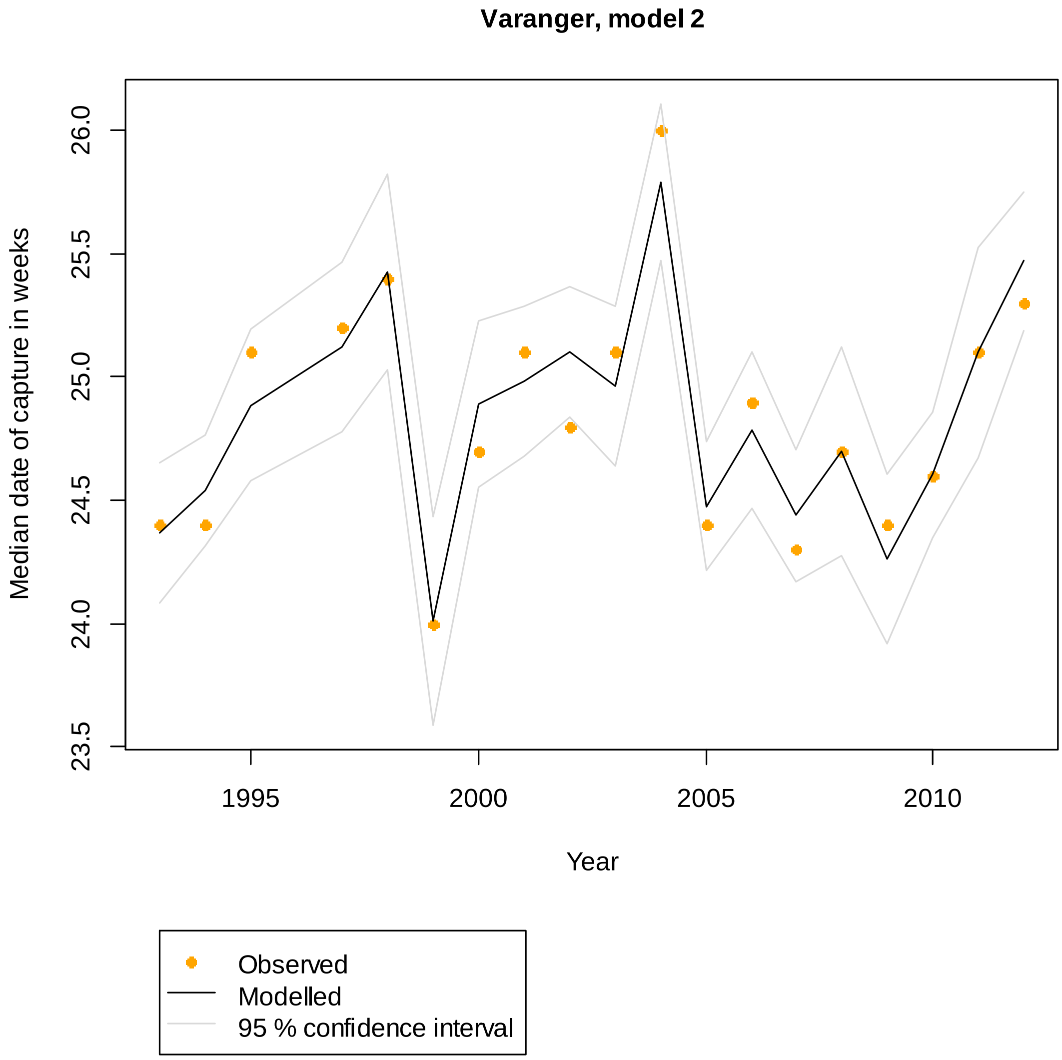

Figure 2. The fit of the model 2 to the observed median date of capture in Varanger. Explanatory variables in the model are the differences of the sea temperatures (0-50 m) between February and January, between April and March and between June and May in the Kola section.

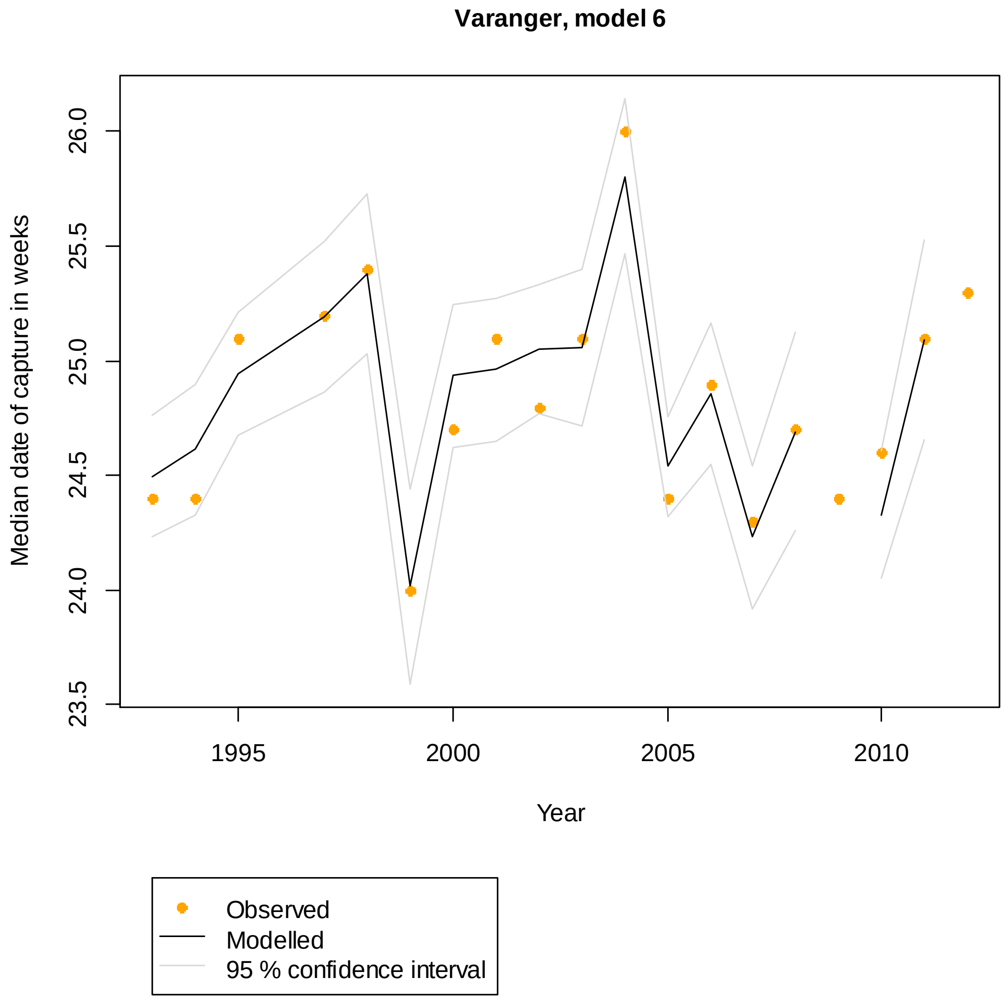

Figure 3. The fit of the model 6 to the observed median date of capture in Varanger. Explanatory variables in the model are the differences of the sea temperatures (0-50 m) between April and March and between June and May in the Kola section and between January and March in the Fugløya-Bjørnøya section. Missing observations are shown as missing lines in the figure.

In Tanafjord, the smoothed year is the most important explanatory variable. The year variable alone explains 64-80% of the deviance. The more warming from April to May in the sea temperatures (0-50 m) in the Kola section, the later the median date of capture is observed (estimated difference is 1.24 week per one degree). The previous difference in sea temperatures explains 18-26% of the deviance. Additionally, if in January and in March the mean sea temperatures (50-200 m) are the same in the Fugløya-Bjørnøya section, the later the median date of capture is observed (estimated difference is 0.54 week per one degree), which explains 2-7% of the deviance. However, the main focus is still in calendar year.

In Hammerfest, the median date of capture is exceptional in 2004. The single year has great influence on the model. Without observation from 2004 the results of the model are clearly different and explained deviance decrease approximately 10%. Also the correlation structure differs and the possible best set of explanatory variables is different. The model including the year 2004 explains only 68.4 % of the deviance (Table 1) indicating that important predictor variables are missing.

If the mean sea temperature in Laksefjord is cooling from February to March, the median date of capture will be slightly later in Alta than if the mean sea temperatures are the same in February and March. The estimated difference in the median date of capture is 0.34 week per one degree. The mean sea temperature in May in Kola section has a W-shaped smoothed curve which is related to the median date of capture in Alta.

Interpreting the models from Tana, Hammerfest and Alta is demanding. The set of explanatory variables might not include the essential variables. With additional work including sea temperatures from Ingøy, Gimsøy and Lopphavet, the models could give a different answer.

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Responsibilities in this report: Finnish Game and Fisheries Research Institute planned the report, produced graphs and statistical analysis. Institute of Marine Research and Polar Research Institute of Marine Fisheries and Oceanography delivered the temperature data.