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Some Aspects of a Time Series of Longline Catch-per-unit of Effort Data for Greenland Halibut (*Reinhardtius hippoglossoides*)

by

Åge Sigurd Høines and Knut Korsbrekke
Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway
e-mail:aageh@imr.no

Abstract

Data from a yearly longline survey (1992-2000) are analysed. The survey attempts to mimic commercial fishery. The catch per unit of effort has seen a large increase over the time period. This seems to be partly an artefact of a trend in the reported number of hooks used per setting and the change from targeting both cod and Greenland halibut to only target Greenland halibut at a larger depth. Controlling for these effects are difficult, but indicates a more modest increase in CPUE, which is comparable with CPUE data from a similar gill-netter survey. The changing depth coverage of the survey in combination with the change in number of hooks makes it difficult to interpret the trend.

Introduction

Greenland halibut (*Reinhardtius hippoglossoides,* Walbaum) is distributed in the Arctic and boreal waters in the North Atlantic and in the North Pacific (Fedorov, 1971; Godø and Haug, 1989; Bowering and Brodie, 1995; Bowering and Nedreaas, 2000). In the northeastern Atlantic the distribution is more or less continuous along the continental slope from the Faeroe Islands and Shetland to north of Spitsbergen (Whitehead *et al*., 1986; Godø and Haug, 1989), with the highest concentrations from 500 to 800 m depth between Norway and Bear Island, which is also regarded as the main spawning area (Godø and Haug, 1987; Albert *et al*., 2001b). Peak spawning occurs in December in the main spawning area, but also in nearby localities during summer (Albert *et al*., 2001b). Eggs and larvae drift northwards and the juveniles are distributed in the deeper parts of the Barents Sea and to the north and east of Spitsbergen, to the waters around Franz Josef Land (Godø and Haug, 1987; 1989; Albert *et al*., 2001a).

Before the mid 1960's the fishery for Northeast Arctic Greenland halibut was mainly a coastal longline fishery off the coasts of eastern Finnmark and Vesterålen in Norway. Following the introduction of international trawlers in the fishery in the mid 1960's, the total landings increased from a level of about 3,000 t to about 80,000 t in the early 1970's. The total landings decreased steadily to a level of about 20,000 t during the early 1980,s (ICES, 2001). The commercial trawl fishery was concentrated in the main distribution area for the adult stock. Based on the regular 0-group survey in the Barents Sea a drop in the year-class indices were observed during the late 1980's and beginning of the 1990's, and also a historic low spawning stock biomass was detected in the same period (Hylen and Nedreaas, 1995; Smirnov, 1995). There was also a reduction in the commercial catch per unit of effort (CPUE) and this lead to strong regulations from 1992, including a total fishing ban for Greenland halibut north of 71°30N. South of this limit the regulations rules allowed only a limited longline and gillnet fisheries by vessels smaller than 28 m to be directed for Greenland halibut. Trawl catches were limited to bycatch only.

When catches from the commercial fishery became reduced after 1992 it turned out to be very important to increase the research effort in order to confirm or invalidate the reduction in recruitment and the decrease in spawning stock. In order to continue the already established time series of commercial trawl CPUE data, and to improve biological sampling as a basis for stock assessment, commercial fishing vessels were contracted, i.e. trawlers, longliners and gillnetters. The vessels should perform commercial-scale fishing, but restricted to certain time periods and areas.

Scientific surveys using longline for stock monitoring and stock assessment purposes are not very common, but in a few cases there are surveys carried out regularly, e.g. Greenland (Simonsen *et al*., 2000) and northern Pacific (Trumble, 1998). When investigating CPUE the biases introduced by longline is generally in connection with saturation of the baited hooks and the process where the fish actively have to seek and find the baited hook, but also the behaviour of the people involved is of importance. Several investigations have been carried out on fish behaviour in connection with the catch process e.g.(Woll *et al*., 1998; Sigler, 1997; Godø *et al*., 1997; Løkkeborg, 1992), but knowledge on how the fishermen's choices influence the CPUE data is rather sparse. The present study therefore used data from the long line surveys and the objective was to describe how some of these choices could influence the CPUE.

Material and Methods

Surveys and sampling

Data were collected during several cruises using longline as sampling gear between Norway and Svalbard in autumn in the period 1992 – 2000 (Table 1, Fig. 1). The surveys were set up in a way attempting to mimic the commercial Greenland halibut fishery. Commercial fishing vessels were contracted to conduct regular fishing operations, but there were set some restrictions in the area where they were able to operate, i.e. between 70°N and 76°N.

The longliners used in most cases Mustad EZ-baiter hooks no. 12 with hook spacing of 1.4 m. During the time period each setting varied between 2700 and 6100 hooks (Table 1). The hooks were baited mechanically (Mustad Autoline System) mostly with sequences of squid and mackerel, but also other bait types were used occasionally. The soak time varied between 6 and 24 hours. Each setting was treated as one separate station.

The procedure for collecting individual samples unfortunately was not consistent throughout the time-series, but individual samples, when collected, was stratified both geographically and by depth. The inconsistency in sampling caused problems getting enough samples from different strata in some of the years, but most of the years weight and numbers of Greenland halibut for each separate station were recorded. Total length-frequency distributions (to the nearest cm below) were obtained, either by measuring the entire catch or from a random subsample.

Analyses

The catch per unit of effort (kg/100 hooks) was transformed using the natural logarithm. This Log CPUE was analysed using different generalised linear models (GLM). Year was used as a main effect in all models and the last year was chosen to be zero in order to make comparisons more easily. The first model was a traditional 2-way ANOVA with intercept, year and area effect (1):

$$\text{Log(CPUE)} = I + A_{year} + B_{area} + e \qquad (1)$$

Bottom depth (x) was included as a continuous variable (regression effect):

$$\text{Log(CPUE)} = I + A_{year} + B_{area} + \mathrm{g}(x) + e$$

The depth effect considered where 3 different non-linear functions. A second-degree polynomial (2), a second-degree polynomial with a plateau level (3) and third degree polynomial (4):

$$a \cdot x + b \cdot x^2 \tag{2}$$

$$a \cdot x + b \cdot x^2 \qquad \text{if} \;\; x < \frac{-a}{2b}$$

and

$$\frac{-a^2}{4b} \qquad \text{if} \;\; x \geq \frac{-a}{2b} \tag{3}$$

$$a \cdot x + b \cdot x^2 + c \cdot x^3 \tag{4}$$

The effect of treating the unit of effort as one setting (as if the number of hooks were constant) was studied by a similar model as (4) and this model was noted (4b).

More complex models involving using the number of hooks per setting as an explanatory variable was investigated, but due to the strong correlations the models did not produce parameter estimates that "made sense".

Results

Total catches of Greenland halibut and cod are shown in Fig. 2. The total survey catch of Greenland halibut has shown an increasing trend since the beginning of the time series in 1992 with the highest catch in 2000 (66 tonnes). Cod on the other hand has shown a decreasing trend starting at 38 tonnes in 1992 with a negligible catch in 2000 (0.3 tonnes). The survey effort has changed through the time series and the catch per unit of effort series (catch in kg per 100 hooks) shown in Fig. 3 is different. The reported catch per unit of effort (CPUE) for Greenland halibut shows a much stronger increase while CPUE numbers for cod seems to vary around a constant level until 1996 and has since then been on a low level.

The size composition has varied throughout the time series and a box (25-75 percentile) and whisker (10-90 percentile) plot with the median value is shown in Fig. 4. The median length shows a trend with increase from 1992 to 1995, then a decline until 1999 and an increase again in 2000. The upper 75th and 90th percentiles follows the same trend while the bottom 25^{th} and 10^{th} percentiles shows a slightly different pattern. The two years that differs most are 1995 and 1999 and the length distribution for these two years are visualized in Fig. 5.

A first step of analysing the data included the estimation of the correlation between a long series of variables (both the dependent variable and potential explanatory variables). The results are shown in Table 2. The most striking result is the very high correlation between the year and depth variable. All other variables are highly correlated (strong negative or strong positive correlation) with year. This is confirmed in Fig. 6 where the mean depth of the settings each year is plotted together with the mean number of hooks used per setting. The overall trend is a drastic increase in mean depth together with a decline in the number of hooks used per setting. The number of hooks used per setting seems to have increased somewhat in the last year.

The trend in the depth of the settings calls for caution when interpreting model results. All the models gave quite good fit to the data. The summary statistics are given in Table 3. The model (2), (3) and (4a) gave a better fit than the others. The best fit was achieved with model (4a), but only slightly better and not conclusive. The residuals were inspected and all models gave residuals with a distribution close to the normal distribution. The distributions were not symmetrical, but it was only the upper tail that was slightly shorter than the lower. This could be due to saturation of the longline. This is a moderate violation of the underlying assumption of normality and since all the P-values were well below the 0.05 level, the results were accepted.

The estimated area effect varied between 0.19 and 0.21 for all models except (4b) which showed a much weaker area effect (0.08). All models showed higher catches in the northern part of the survey area. The weaker area effect in model (4b), which is the model with CPUE per setting, is due to an overall use of fewer hooks per setting in the northern area.

The estimated year effects (parameter estimates) from the different models are compared in Fig. 7. All model results indicate an increase in abundance up to 1995-1996 where it seems to fluctuate. The largest increase is in model (1), which is the model without depth effect. The models give conflicting results for the years 1997-2000 and it is not possible to conclude if the stock is increasing, decreasing or stable. The models (2) and (4a) produced comparable year effects for the whole time series (Fig. 8).

The mean depth in a setting was used as a continuous explanatory variable (Fig. 9). The models indicated that the CPUE increased rapidly from around 400 meters to around 550 meters where it seemed to level out. There were only a few stations deeper than 650 meters all with quite high catches. Some of the model results in this end of the depth range are more dependent on the choice of model than data points.

Discussion

Earlier work have demonstrated that saturation of the longline may be a problem in connection with abundance estimations using catches from this gear type, i.e. the estimates are biased both by size of the target fish and from non-target fish attaching the hooks (Murphy, 1960; Fernø *et al*., 1986; Løkkeborg, 1994; da Silva and Menezes, 1996). In the first part of the investigated time series the results revealed that cod was a main component of the catches, which lead to a suspicion that the vessels also targeted cod in this period. The result of this was probably reduced Greenland halibut catches in comparison with a more directed fishery for this species. In the latest part of the time series more strict control, on which species the vessels were allowed to target, has been carried out. As a result, the catches of Greenland halibut in the latest part of the time series probably were a more correct picture of the catch level than the years before, and consequently the increase in CPUE in the first years would be overestimated.

A striking result in the analyses was the strong positive correlation between years and mean depth of the settings and the negative correlation between years and number of hooks. These factors suggest a methodical change in the performance of the experimental fishery throughout the period. The strong trend in the preferred depth for the longline settings shown in the results make it difficult to quantify how much of the increase in CPUE is due to an increase in fish abundance or a result of the change in depth distribution of the settings. The picture is further distorted by a reduction in the number of hooks used per setting, which may be caused due to erroneous reporting. It could also be an attempt to maximize the catch per hook by targeting a more exact depth range where it was believed that the concentration of Greenland halibut would be more desirable, hence reduce the number of settings, i.e. reduce the time at sea needed to catch their allotted research quota.

In order to use longline as tool for abundance estimation it is very important to standardize the survey design to reduce operational bias caused by the people involved. The survey area should reflect the distribution of the fishable stock to reduce inconsistency due to annual differences in distribution pattern in connection with small-scale differences in the physical environment, i.e. current conditions, temperature and salinity. It is also known that the effective fishing distance for longline is dependent on the current conditions since this has effect on the dispersion of the released attractants from the bait, i.e. transport and dispersion of bait odour to the environment. The longline catches may vary considerably with different circumstances independently of overall population abundance and structure (Engås and Løkkeborg, 1994). Despite these problems longline is used, and in many areas it's the only practicable gear to use, in order to collect data for abundance estimation for several species. Thus controlling of the survey design and research for improving knowledge about the behavior of Greenland halibut in connection with the catching process is needed before longline should be regarded as well suited gear for abundance estimation.

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TABLE 1. List of cruises from which data for this paper were collected. Hooks is number of hooks usually used in each station (setting). Number of samples, N denotes number of stations, N_L is number of stations with length sample and N_A is number of stations with age sampling.

Year	*Time period*	*Hooks*	*N*	N_L	N_A
1992	5.10 – 21.10	5400	85	84	28
1993	7.10 – 16.10	5400	41	40	15
1994	27.9 – 8.10	4000 & 6100	71	49	8
1995	22.9 – 3.10	3400 – 5000	58	41	4
1996	17.9 – 27.9	3400 & 5100	43	26	3
1997	17.9 – 29.9	2700 – 4200	67	34	0
1998	21.9 – 1.10	3000	58	27	3
1999	21.9 – 5.10	3000 & 4000	64	27	8
2000	21.9 – 3.10	4500	42	19	6

Table 2. Pearson Product-moment correlation for some variables.

	Year	*Depth*	*No of hooks*	*Log CPUE*
Year	1.00			
Depth	0.74	1.00		
No of hooks	-0.64	-0.48	1.00	
Log CPUE	0.70	0.64	-0.70	1.00
Log CPUE (Cod)	-0.62	-0.64	0.42	-0.40

Table 3. Summary statistics for models (1), (2), (3), (4) and (4b).

Model	*Source*	*df*	*SS*	*MS*	*F*	*P*	R^2
(1)	Model	9	153.9	17.11	71.93	<.0001	0.5527
	Error	524	124.6	0.2378			
(2)	Model	11	173.4	15.76	78.44	<.0001	0.6235
	Error	521	104.7	0.2009			
(3)	Model	11	174.6	15.87	79.95	<.0001	0.6280
	Error	521	103.4	0.1985			
(4a)	Model	12	175.8	14.65	74.57	<.0001	0.6324
	Error	520	102.2	0.1965			
(4b)	Model	12	94.55	7.880	46.11	<.0001	0.5155
	Error	520	88.85	0.1709			

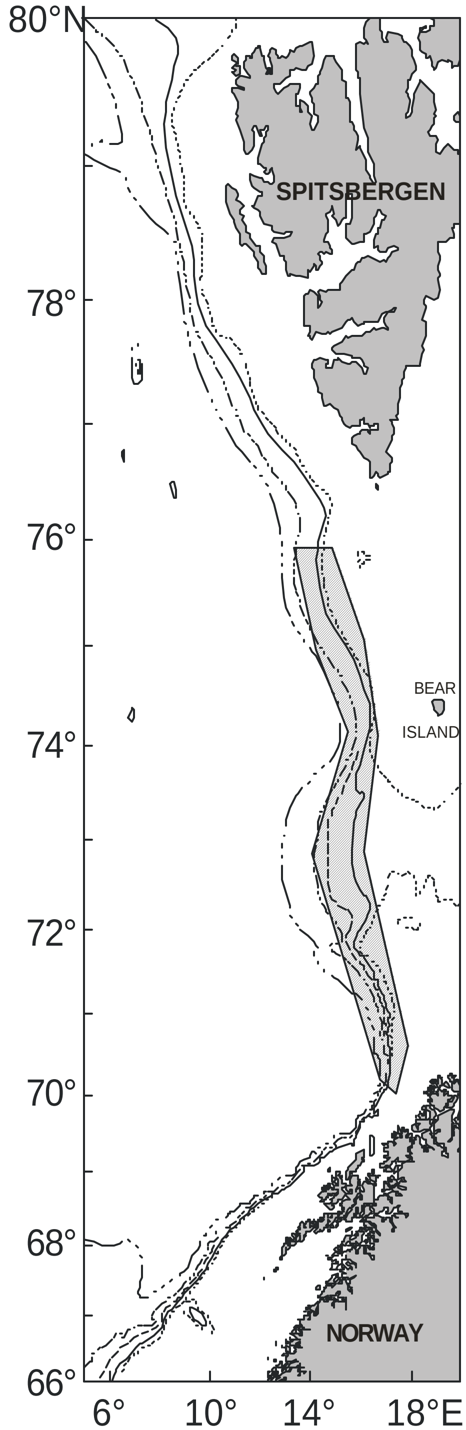

Figure 1. Experimental area (shaded), with depth contours 400, 500, 700, 1000 and 1500 m drawn.

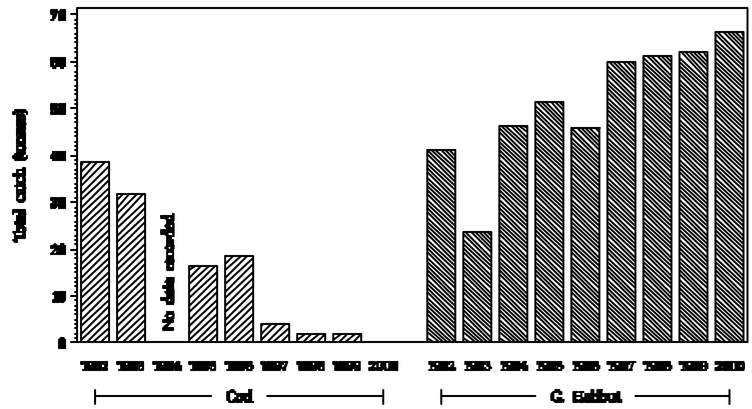

Figure 2. Total catch (in tonnes) of Greenland halibut and of cod in the years 1992-2000. Cod data was not recorded in 1994.

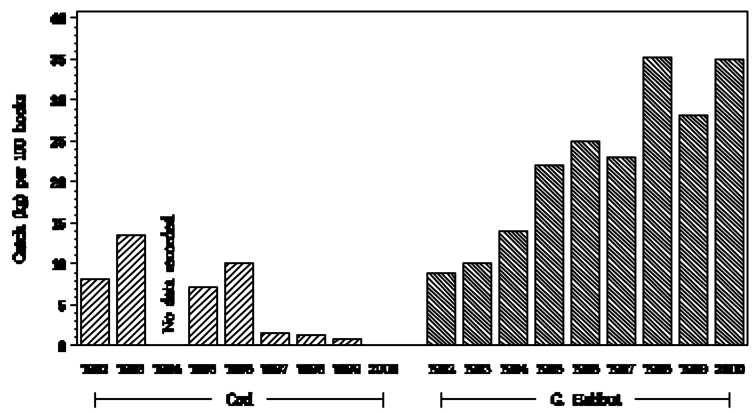

Figure 3. Catch per unit of effort (kg / 100 hooks) of Greenland halibut and of cod in the years 1992-2000. Cod data was not recorded in 1994.

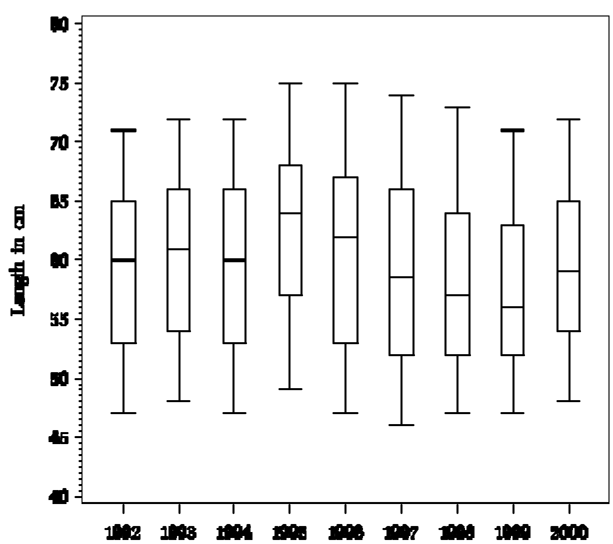

Figure 4. Box and whisker plot of the yearly length distributions. Together with the median the box covers the 25-75 percentiles while the whiskers represent the 10th or 90th percentile.

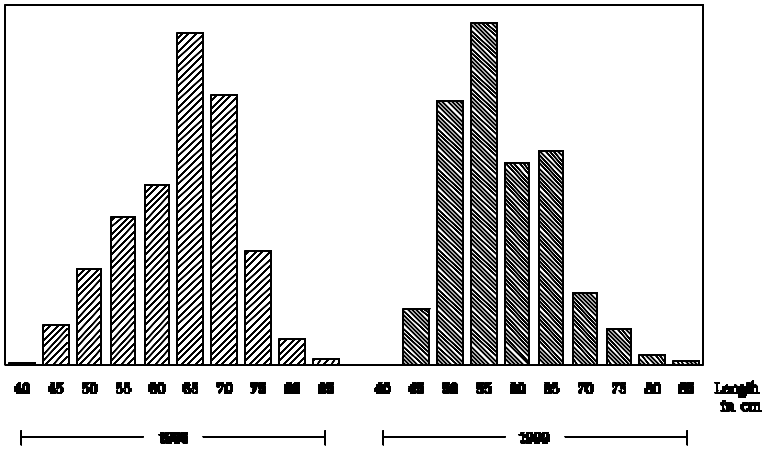

Figure 5. Observed length distributions from 1995 and 1999.

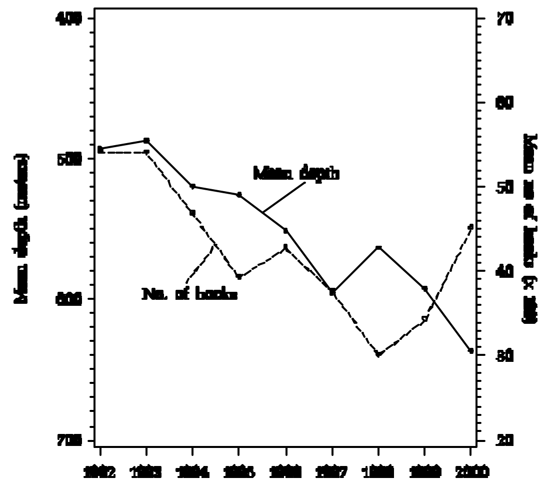

Figure 6. Mean depth and the mean number of hooks used per setting in the years 1992-2000.

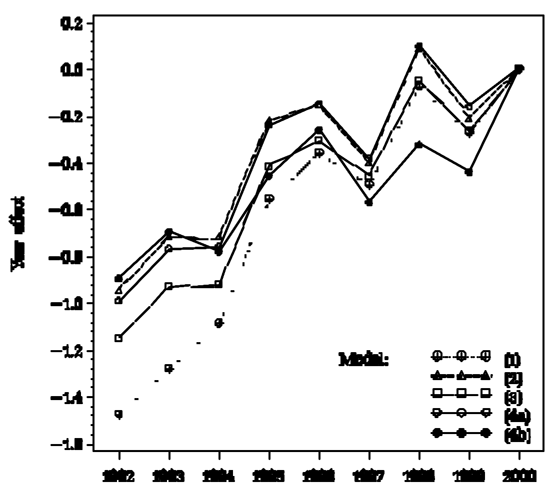

Figure 7. Plot of year effects (A_{year}) for the different models.

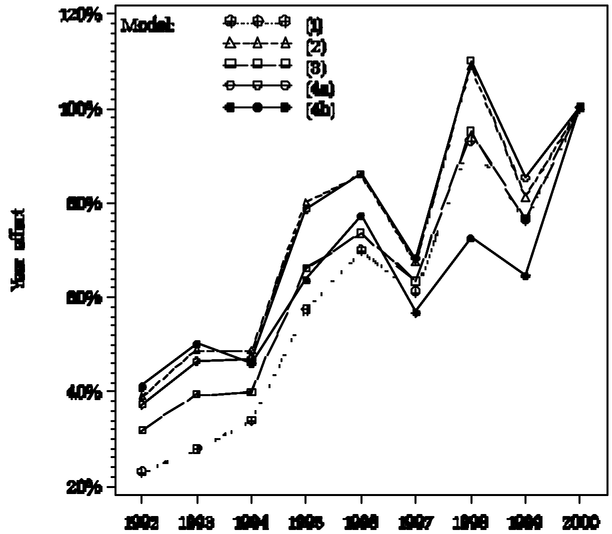

Figure 8. Plot of year effects for the different models on a percentage scale ($100 \cdot e^{A_{year}}$).

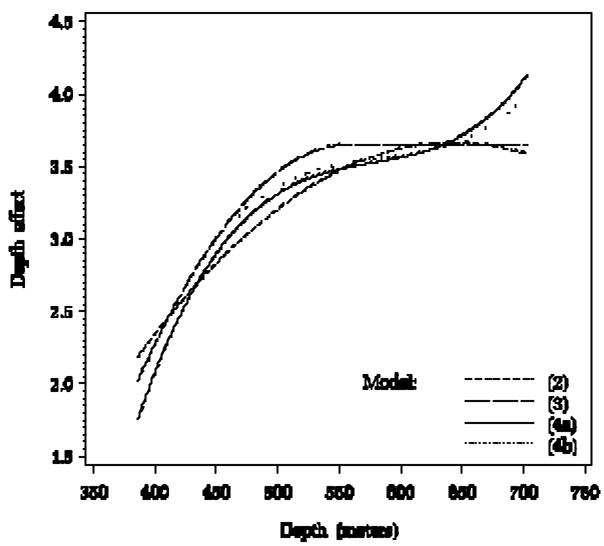

Figure 9. Plot of bottom depth effect (no depth effect in model 1).