STANDARDISATION OF JAPANESE LONGLINE CATCH RATES FOR YELLOWFIN TUNA IN THE INDIAN OCEAN USING GAM ANALYSES

Brent Wise[1], Adrian Bugg[1], David Barratt[1], Simon Barry[1],

Hiroshi Shono[2], Tom Nishida[2] and John Kalish[1]

[1] *BRS, PO Box 658 Canberra, ACT, Australia 2000*

[2] *NRIFSF, 7-1, 5-chrome Orido Shimizu-shi, Japan 424 8633*

ABSTRACT

Japanese longline catch rates for yellowfin tuna in the Indian Ocean were standardised for the years 1960 to 2000 using GAM analyses with temporal, spatial, gear and environmental variables. The presence/absence and abundance (CPUE) of yellowfin tuna were modelled separately. The terms used in these models included a combined year-month variable, the latitude and longitude, the number of hooks between floats and the sea surface temperature. GAM analyses were carried out using a logistic regression with a binomial response for the presence/absence data and a Gaussian response for the abundance data. The significance of the various model terms differed between the presence/absence and abundance models. The temporal trends estimated by the models suggest a decline in catch rates in the early years between 1960 and 1980, thereafter remaining relatively stable at these lower levels in the 1990s.

INTRODUCTION

Further to the work carried out by Shono *et al*. (2002) we present an alternative method for standardising Japanese longline catch rates for yellowfin tuna in the Indian Ocean using generalised additive models (GAMs) (Hastie & Tibshirani 1990). The temporal trend estimated using GAM analyses can be compared with the trend estimated by the Generalised Linear Model (GLM) analyses (Shono *et al*. 2002). GAM analysis is useful for determining the functional form of each term in the model. Subsequently, the functional form of the model terms can be approximated by low order polynomials in GLM analysis.

METHODS

Data

The Japanese longline yellowfin catch-effort data from 1960 to 2000 has been described by Shono *et al*. (2002). The catch was recorded as the number of yellowfin tuna and effort was the number of hooks (in 1000s). Catch rates (CPUE—catch per unit effort) were calculated as the number of yellowfin tuna per 1000 hooks. The catch-effort data by year and month was aggregated to 5-degree grid cells with a latitude and longitude reference for each of these grid cells. In this study, the year and month data were combined into a single year-month variable (YearMonth) by adjusting month into a proportion of year calculated on the median of each month. Additional fishery data available for these analyses were the number of hooks between floats (Gear). The environmental data available was the sea surface temperature (SST).

Models

GAM analyses were carried out using SPLUS (SPLUS 2001). Models were fitted firstly using a logistic regression with a binomial response for the presence/absence (PA) of yellowfin tuna involving all records (PA models) and secondly using a Gaussian response for the CPUE of yellowfin tuna for only those records where yellowfin tuna was caught (abundance models).

All explanatory model terms were treated as continuous variables with spline smoothers initially fitted to each term in the model (Table 1). Comparison of the addition of each term to the null model was carried out using the Cp statistic (SPLUS 2001). Selection of significant terms in the models using spline variables was carried out using backward stepwise regression and the AIC statistic. Multivariate loess smoothers were subsequently fitted to combinations of the model terms to investigate interaction effects (Table 1). Results from the various fitted models were graphed to enable visual inspection of the functions fitted and comparisons between models. Comparison between models was carried out using an F test (SPLUS 2001). Finally, the YearMonth additive term in the PA and abundance models were extracted and scaled to the base year (1960). These rescaled YearMonth terms were used to present the trends in PA and CPUE over the period and were compared with those estimated using GLM analysis (Shono *et al*. 2002).

Table 1. Models examined in the GAM analyses. PA–presence/absence models, Log(CPUE)–abundance models

Family	Model
binomial	PA~s(YearMonth)+ s(Lat)+s(Long)+ s(LogEffort)+s(Gear)+s(SST)
	PA~s(YearMonth)+ s(Lat)+s(Long)+s(LogEffort)+s(Gear)+s(SST)+lo(YearMonth,Latitude) +lo(YearMonth,Longitude)+ lo(Latitude,Longitude)+ lo(YearMonth,SST)
	PA~s(YearMonth)+ s(Lat)+s(Long)+s(LogEffort)+s(Gear)+s(SST)+lo(YearMonth,Latitude) +lo(YearMonth,Longitude)+ lo(Latitude,Longitude)+ lo(YearMonth,SST) +lo(YearMonth,Latitude,Longitude)
gaussian	Log(CPUE)~ s(YearMonth)+s(Lat)+s(Long)+s(Gear)+s(SST)
	Log(CPUE)~ s(YearMonth)+s(Lat)+s(Long)+s(Gear)+s(SST)+lo(YearMonth,Latitude) +lo(YearMonth,Longitude)+ lo(Latitude,Longitude)+ lo(YearMonth,SST)
	Log(CPUE)~ s(YearMonth)+s(Lat)+s(Long)+s(Gear)+s(SST)+lo(YearMonth,Latitude) +lo(YearMonth,Longitude)+ lo(Latitude,Longitude)+ lo(YearMonth,SST) ++lo(YearMonth,Latitude,Longitude)

RESULTS

Maps of the Japanese longline effort, yellowfin tuna catch and catch rate for the combined years 1960 to 2000 aggregated to 5-degree grid cells are presented in Figures 1 and 2. A surface fitted to the SST for all of the records in the Indian Ocean is also presented.

Catch rate standardisation using presence/absence data

The addition of either the SST or Latitude term to the null model reduced the Cp by greater than 6% while the Gear term reduced the Cp by less than 1% (Table 2), though the backward stepwise regression did not reduce the number of model terms. The model including multivariate loess terms differed significantly from the spline smoothers only model (Table 3). The temporal patterns estimated by these absence/presence models were similar and suggest a steady decline in the early years between 1960 and the mid 1980s. This was followed by a rapid decline to *ca* 30% of the 1960s catch rate in the mid 1990s and then remaining stable at these lower levels in the late 1990s (Figure 3). Figures 4-12 show the non-linearity of the various model terms and interactions between terms.

Table 2. Addition of each term to the null presence/absence model.

	SS	RSS	Cp	% of Cp
Null		41504.0	41506.0	
s(YearMonth)	1031.8	40472.2	40476.2	2.5
S(Latitude)	2861.8	38642.2	38646.2	6.9
s(Longitude)	307.9	41196.1	41200.1	0.7
s(logEffort)	946.1	40557.9	40561.9	2.3
s(Gear)	87.1	41416.9	41420.9	0.2
s(SST)	4446.0	37058.0	37062.0	10.7

Table 3. Comparison of presence/absence models.

Terms	Resid. Df	Resid. Dev	Change in Resid. Df	Change in Deviance	F Value	P value
Null	41503.0	26281.6				
+ terms[1]	41479.3	17746.2	23.7	8535.4	551.9	<0.001
+ terms[2]	41456.2	17317.2	23.0	429.0	28.6	<0.001
+ terms[3]	41447.1	17289.1	9.1	28.2	4.7	<0.001

[1]s(YearMonth)+ s(Latitude)+s(Longitude)+s(LogEffort)+s(Gear)+s(SST)
[2]lo(YearMonth,Latitude)+ lo(YearMonth,Longitude)+lo(Latitude,Longitude)+ lo(YearMonth,SST)
[3]lo(YearMonth,Latitude,Longitude)

Catch rate standardisation using abundance data

The addition of either the YearMonth or SST term to the null model reduced the Cp by greater than 8%, while the Gear term reduced the Cp by less than 1% (Table 4). Backward stepwise regression did not reduce the number of these model terms. The model including multivariate loess terms differed significantly from the spline smoothers only model (Table 5). The temporal patterns estimated by the abundance models suggest a large decline in the early years between 1960 and mid 1980s, then declining slightly during the late 1980s and 1990s to *ca* 20% of the 1960 catch rate (Figure 14). These results were similar to the relative temporal trend estimated by the GLM analysis (Shono *et al*. 2002), with the GAM analyses indicating slightly higher catch rates over time. The importance of interactions between terms is shown in Figures 15-24. The QQ-plots indicate the existence of bias in the fits (Figure 14-24).

Table 4. *Addition of each term to the null abundance (CPUE) model of catch rates.*

	SS	RSS	Cp	% of Null Cp
Null		77521.0	77525.1	
s(YearMonth)	6379.3	71141.7	71149.9	8.2
s(Latitude)	4484.0	73037.0	73045.3	5.8
s(Longitude)	2388.7	75132.3	75140.5	3.1
s(Gear)	809.5	76711.5	76719.7	1.0
s(SST)	8341.5	69179.5	69187.8	10.8

Table 5. *Comparison of abundance (CPUE) models.*

Terms	Resid. Df	Resid. Dev	Change in Resid. Df	Change in Deviance	F Value	P value
Null	37511.0	77521.0				
+ terms[1]	37491.0	50283.7	20.0	27237.4	1069.2	<0.001
+ terms[2]	37467.7	48042.5	23.3	2241.1	75.6	<0.001
+ terms[3]	37458.2	47662.7	9.5	379.9	31.2	<0.001

[1]s(YearMonth)+ s(Latitude)+s(Longitude)+s(Gear)+s(SST)
[2]lo(YearMonth,Latitude)+ lo(YearMonth,Longitude)+lo(Latitude,Longitude)+ lo(YearMonth,SST)
[3]lo(YearMonth,Latitude,Longitude)

DISCUSSION

The standardisation of Japanese longline catch rates for yellowfin tuna in the Indian Ocean using GAM and GLM (Shono *et al*. 2002) analyses give similar temporal trends. They suggest that the decline in catch rates during the period 1960 to 1980 appears to have slowed, and catch rates in the 1990s have remained stable at these lower levels.

The GAM analyses indicate that differing fishery and environmental conditions influence the presence/absence and the abundance (CPUE) data. The inclusion of both these data types into a single model requires careful consideration.

The catch–effort data were not obtained from a random sample and are aggregated to 5-degree grid cells so that bias in the data is expected. The large number of data records, and hence degrees of freedom, mean that too many significant effects (terms) may be detected. For these reasons, the statistical tests should be treated with caution and models with fewer terms and no interaction effects may actually provide a more parsimonious model.

Given that there are definite differences in the amount of variability explained by each model term, further analyses involving modified scale weighting factors should be investigated. In addition, the influence of the interactions between model terms requires further detailed analysis.

The analyses presented in this paper should be treated as preliminary, and further exploration of the data should be carried out to investigate some of the problems highlighted above. While GAM analysis provides functional forms of the model terms, subsequent GLM analyses using low order polynomial approximations should be undertaken to provide the year coefficients and the associated uncertainty.

Finally, whether these standardised catch rates should be considered as indices of abundance for use in stock assessments requires careful consideration. Further analyses need to be undertaken to assess the abundance and distribution of yellowfin tuna in regions not fished by the Japanese longline fleet, including an examination of any changes in technology over the 40 years and how this may be affecting catch rates.

ACKNOWLEDGEMENTS

Bob Forrester (BRS) kindly provided statistical support for the GAM analyses and Hiroaki Okamoto (NRIFSF) prepared the Japanese longline data.

REFERENCES

HASTIE, T.J. & TIBSHIRANI, R.J (1990). *Generalized Additive Models*. New York, Chapman & Hall.

SHONO, H., OKAMOTO, H. AND NISHIDA, T. (2002). Standardised CPUE for yellowfin tuna (*Thunnus albacares*) of the Japanese longline fishery in the Indian Ocean by generalised linear models (GLM) (1960-2000). *IOTC WWPT-02-12.*

SPLUS. (2001). *S-SPLUS 6 for Windows Guide to Statistics. Volume 1*. Insightful Corporation. Seattle, Washington.

ESRI. (1996). *ArcView Spatial Analyst. Advanced Spatial Analysis Using Raster and Vector Data*. Environmental Systems Research Institute Inc. New York.

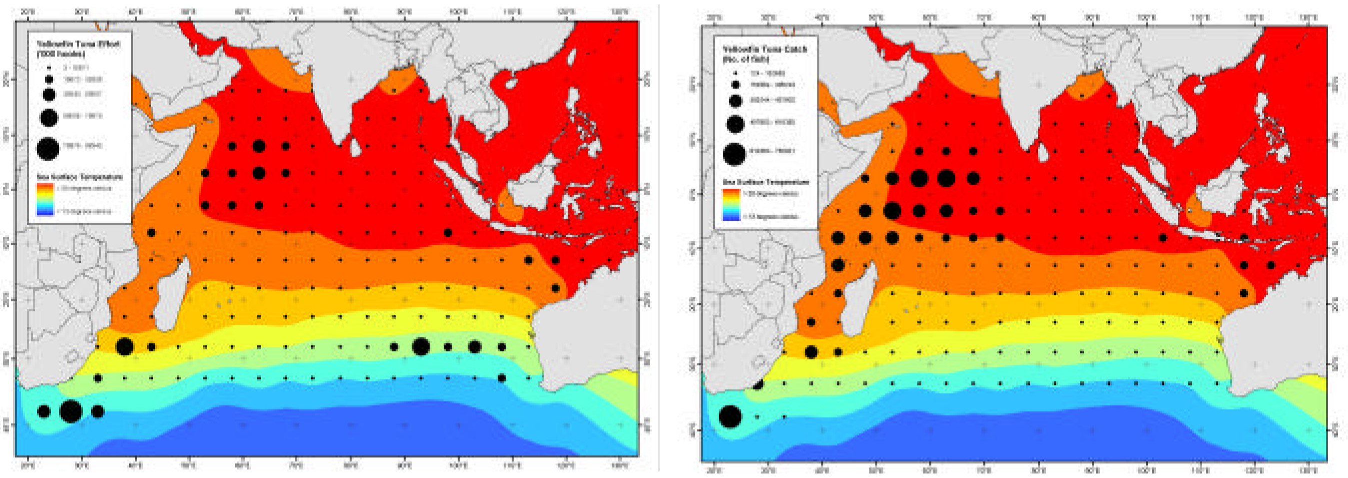


Figure 1. Japanese longline effort and yellowfin tuna catch, and SST in the Indian Ocean for the combined years 1960 to 2000. The SST (point) data were interpolated using a tension spline interpolation technique (ESRI 1996).

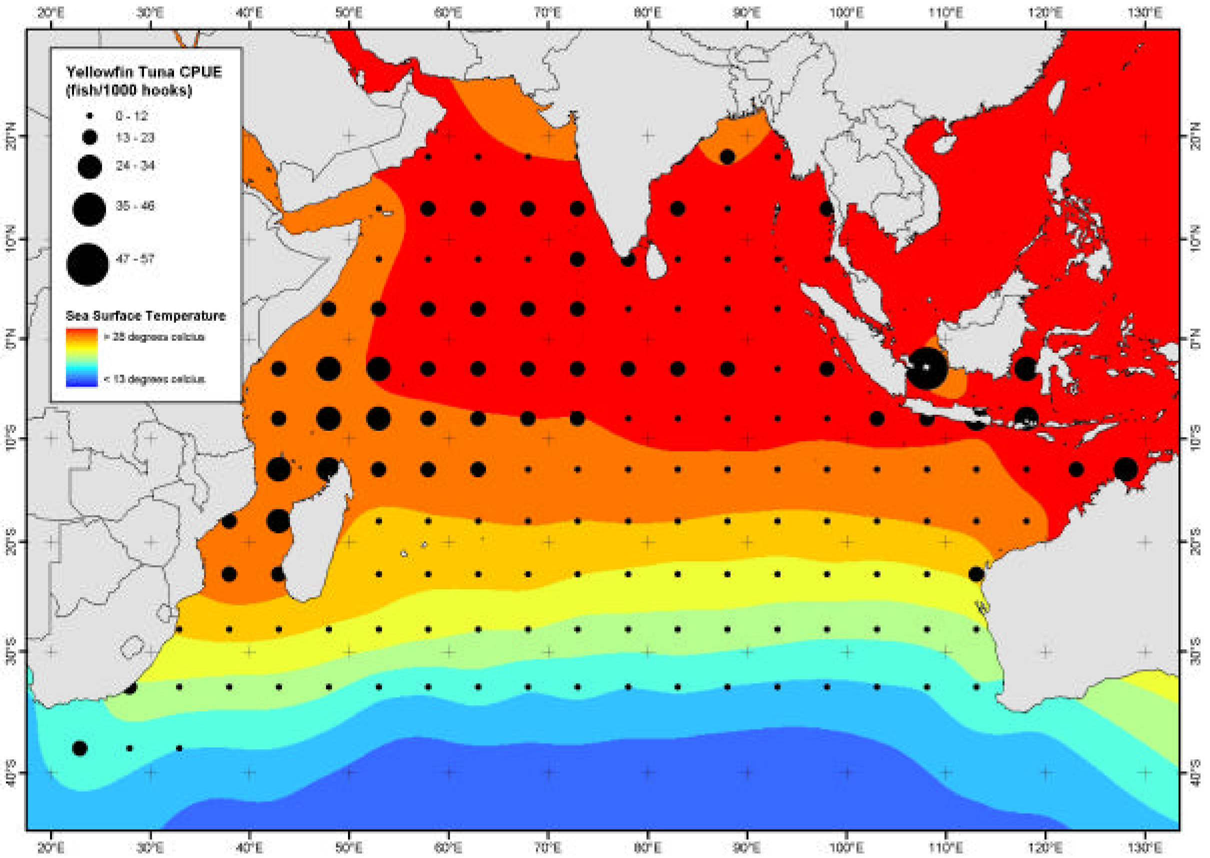
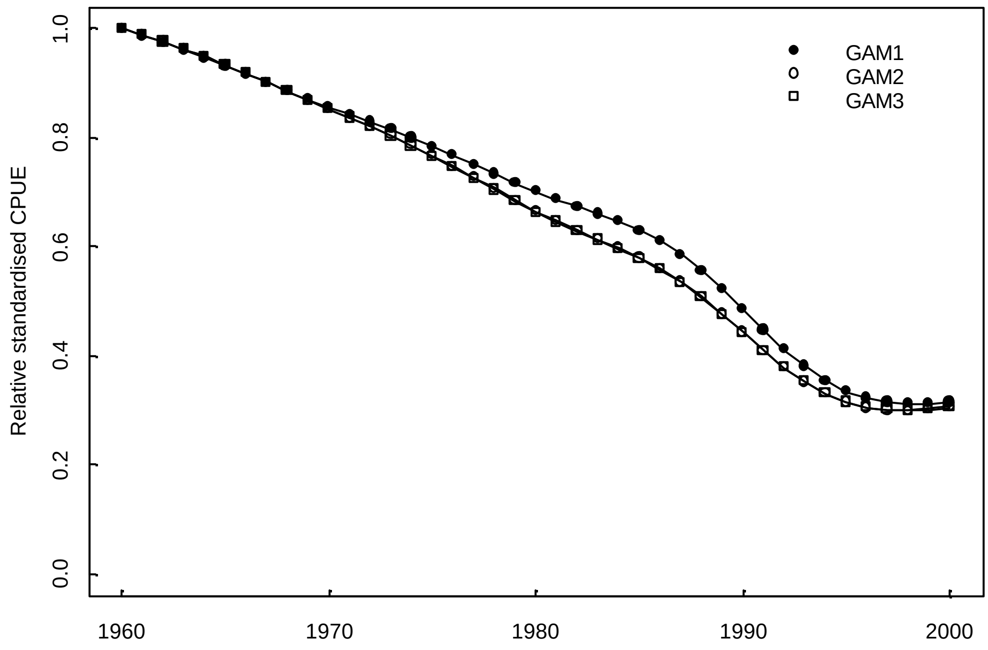


Figure 2. Japanese longline yellowfin tuna catch rates and SST in the Indian Ocean for the combined years 1960 to 2000. The SST (point) data were interpolated using a tension spline interpolation technique (ESRI 1996).



Gam1 PA~s(YearMonth)+ s(Latitude)+s(Longitude)+s(LogEffort)+s(Gear)+s(SST)
Gam2 PA~s(YearMonth)+s(Latitude)+s(Longitude)+s(LogEffort)+s(Gear)+s(SST)+lo(YearMonth,Latitude)+lo(YearMonth,Longitude) +lo(Latitude,Longitude)+lo(YearMonth,SST)
Gam3 PA~s(YearMonth)+s(Latitude)+s(Longitude)+s(LogEffort)+s(Gear)+s(SST)+lo(YearMonth,Latitude)+lo(YearMonth,Longitude) +lo(Latitude,Longitude)+lo(YearMonth,SST)+ lo(YearMonth,Latitude,Longitude)

Figure 3. . Comparison of temporal trends in catch rates between the presence/absence models produced using GAM analyses.

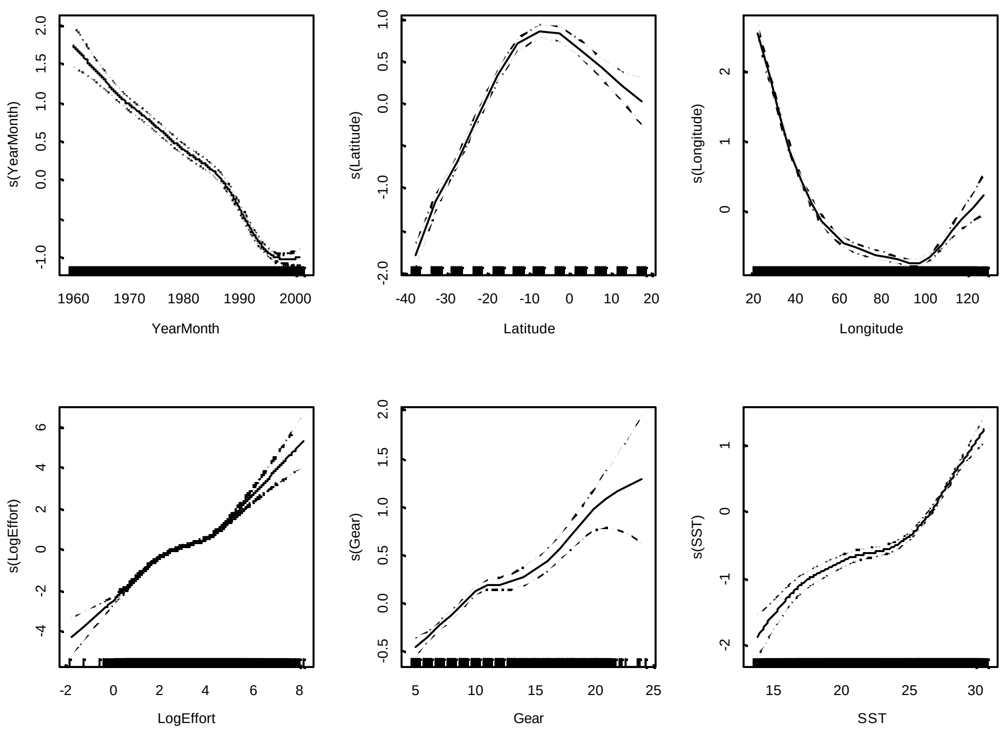


Figure 4. GAM model: PA~s(YearMonth)+ s(Latitude)+s(Longitude)+s(LogEffort)+s(Gear)+s(SST).

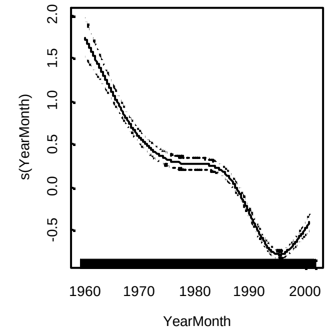


Figure 5. GAM presence/absence model: PA~s(YearMonth).

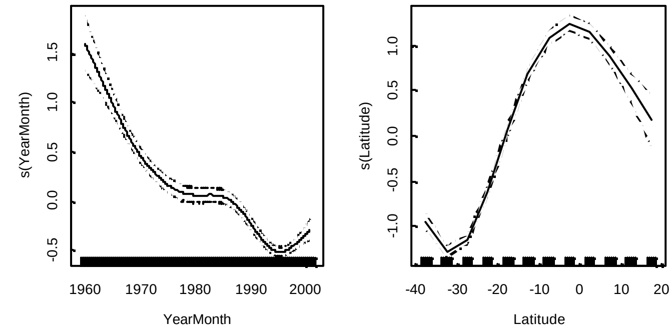


Figure 6. GAM presence/absence model: PA~s(YearMonth)+ s(Latitude).

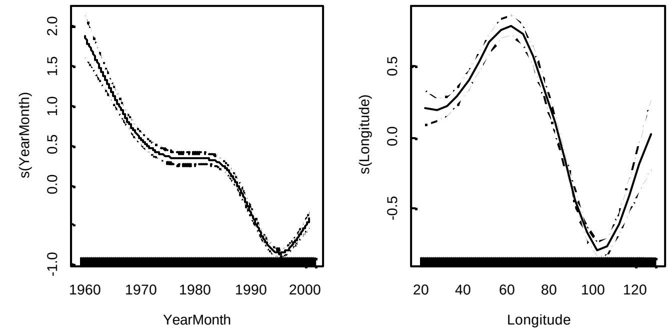


Figure 7. GAM presence/absence model: PA~s(YearMonth)+ s(Longitude).

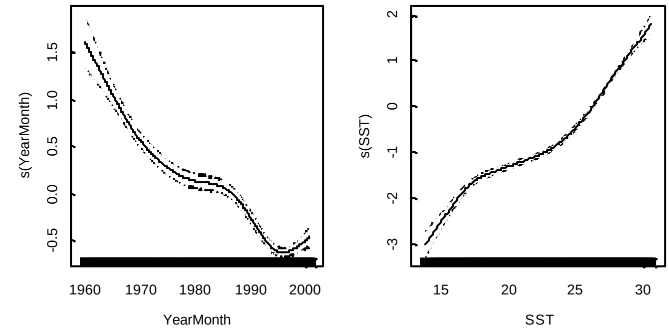


Figure 8. GAM presence/absence model: PA~s(YearMonth)+s(SST)

.

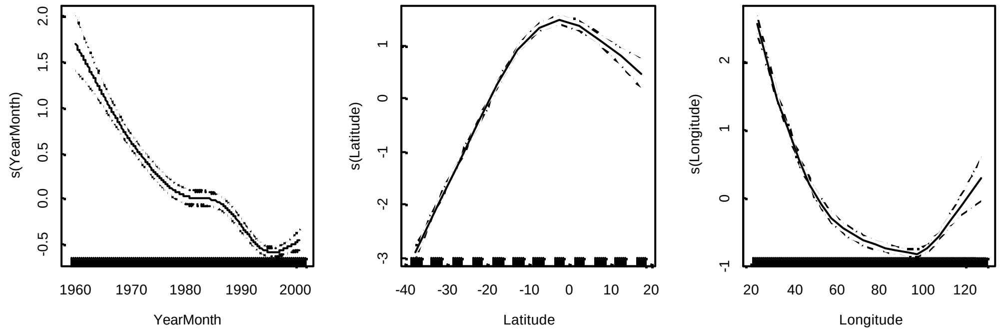


Figure 9. GAM presence/absence model: PA~s(YearMonth)+ s(Latitude)+s(Longitude).

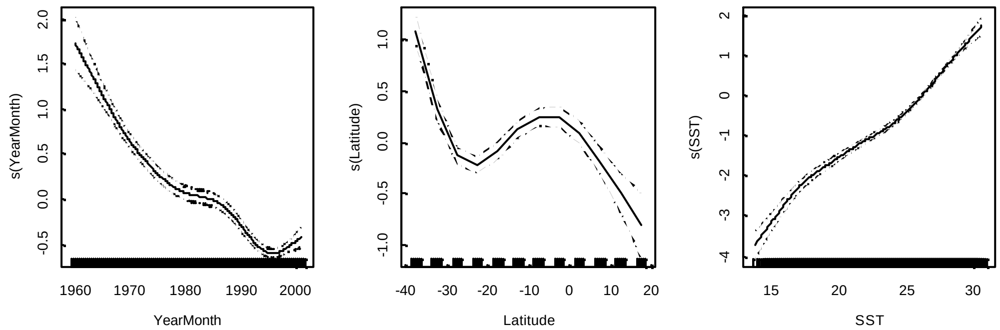


Figure 10. GAM presence/absence model: PA~s(YearMonth)+ s(Latitude)+s(SST).

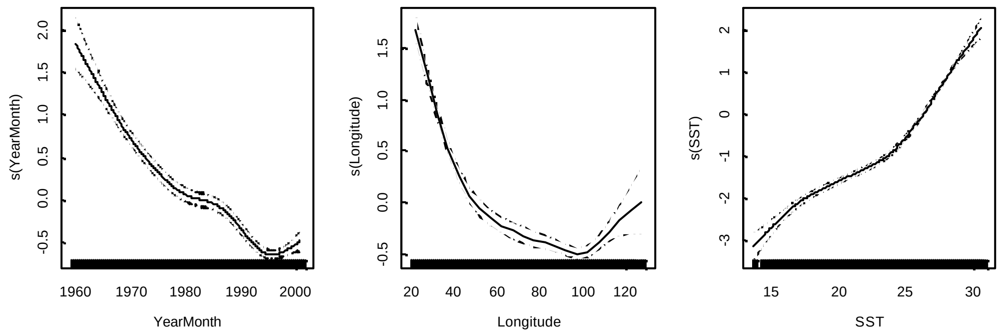


Figure 11. GAM presence/absence model: PA~s(YearMonth)+ s(Longitude)+s(SST).

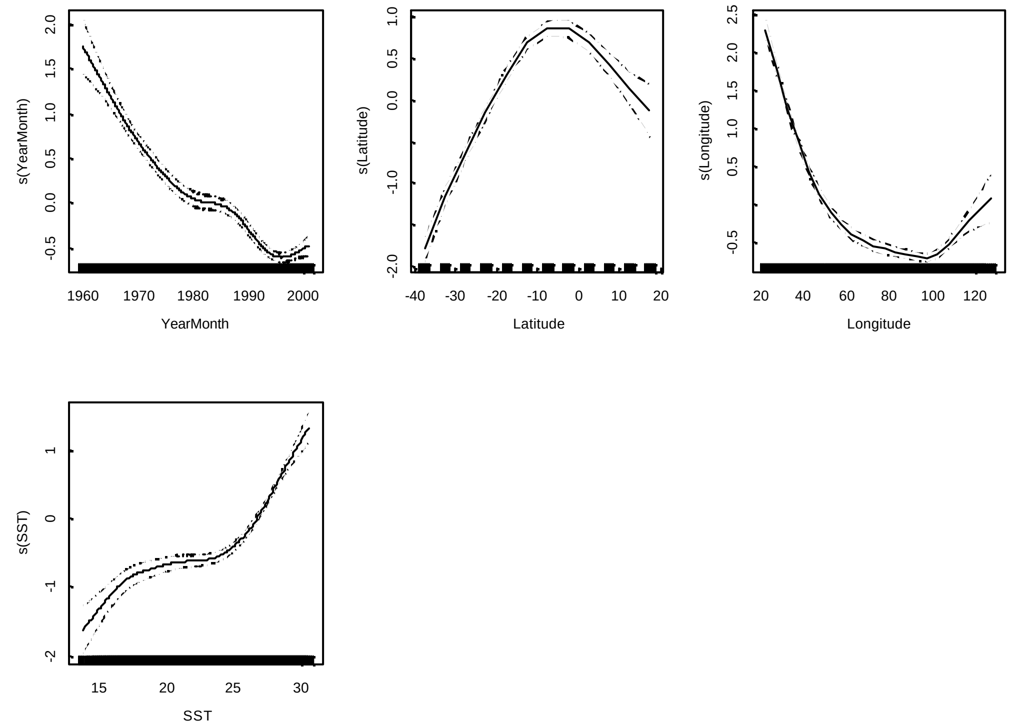
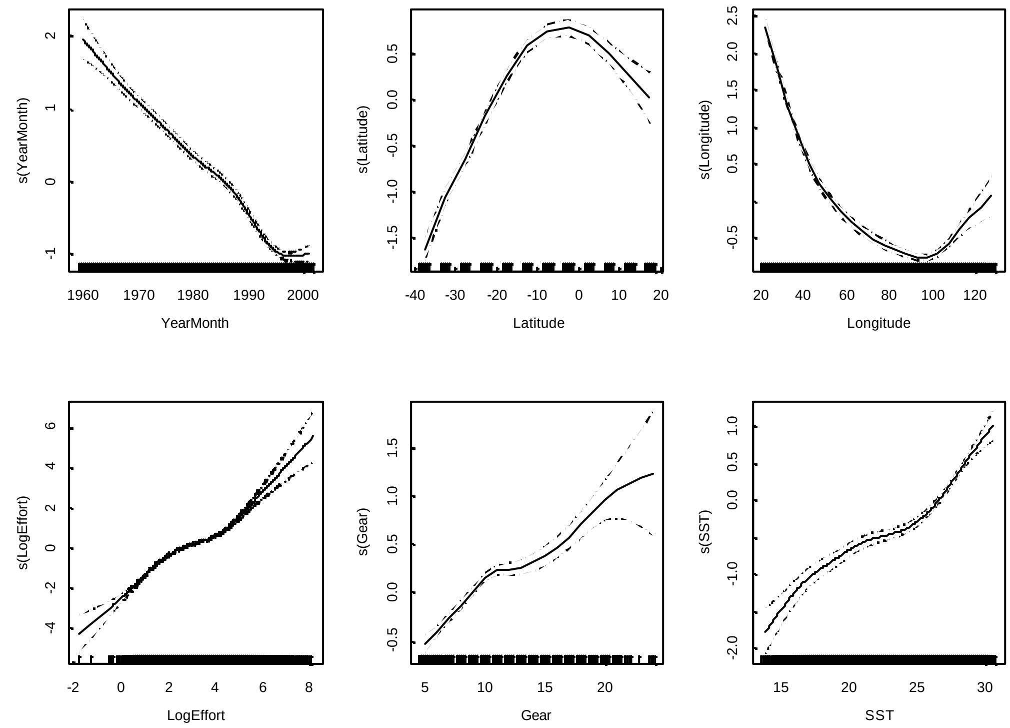


Figure 12. GAM presence/absence model: PA~s(YearMonth)+ s(Latitude)+s(Longitude)+s(SST).



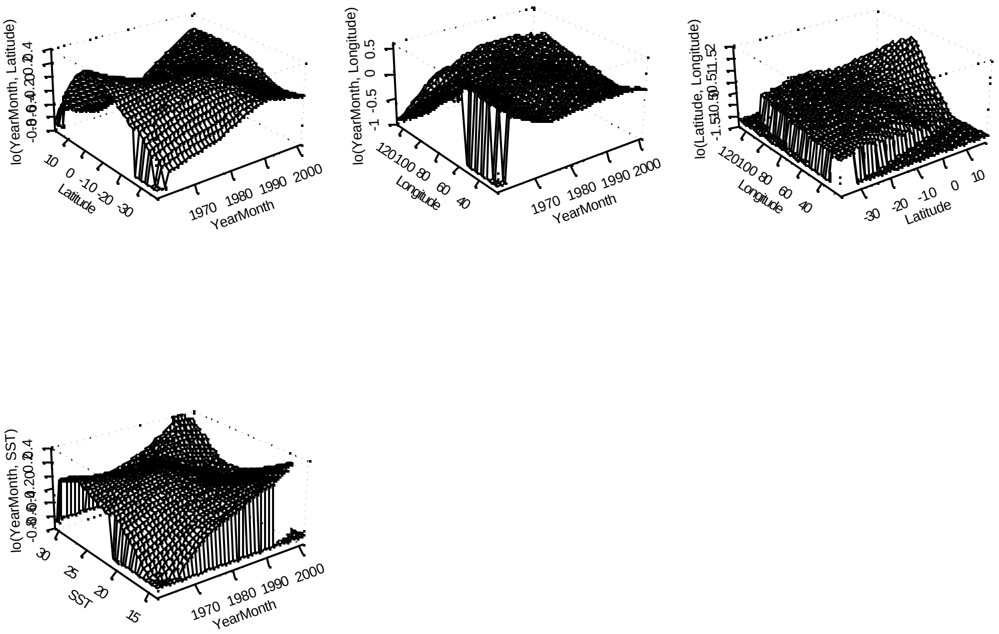
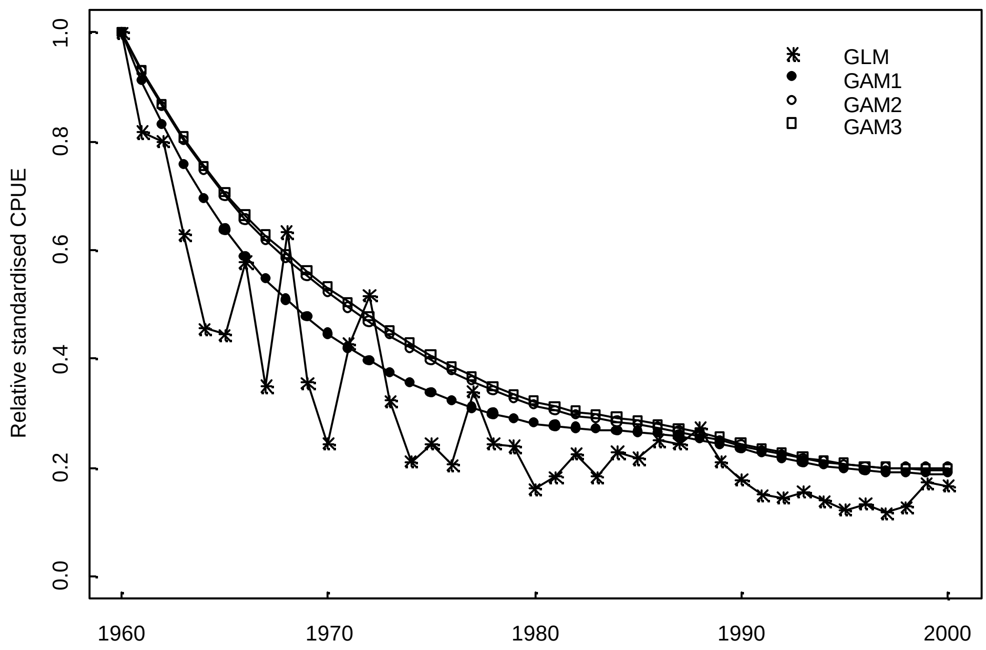


Figure 13. GAM presence/absence model: PA~s(YearMonth)+ s(Latitude)+s(Longitude)+s(LogEffort)+ s(Gear)+s(SST)+lo(YearMonth,Latitude)+lo(YearMonth,Longitude)+lo(Latitude,Longitude)+lo(YearMonth,SST).



GAM1 LogCPUE~s(YearMonth)+ s(Latitude)+s(Longitude)+s(Gear)+s(SST)
GAM2 LogCPUE~s(YearMonth)+s(Latitude)+s(Longitude)+s(Gear)+s(SST)+lo(YearMonth,Latitude)+lo(YearMonth,Longitude)
+lo(Latitude,Longitude)+lo(YearMonth,SST)
GAM3 LogCPUE~s(YearMonth)+s(Latitude)+s(Longitude)+s(Gear)+s(SST)+lo(YearMonth,Latitude)+lo(YearMonth,Longitude)
+lo(Latitude,Longitude)+lo(YearMonth,SST)+lo(YearMonth,Latitude,Longitude)

Figure 14. Comparison of temporal trends in catch rates between the abundance models produced using GAM and GLM analyses. Refer to (Shono et al. 2002) for details of the GLM analysis.

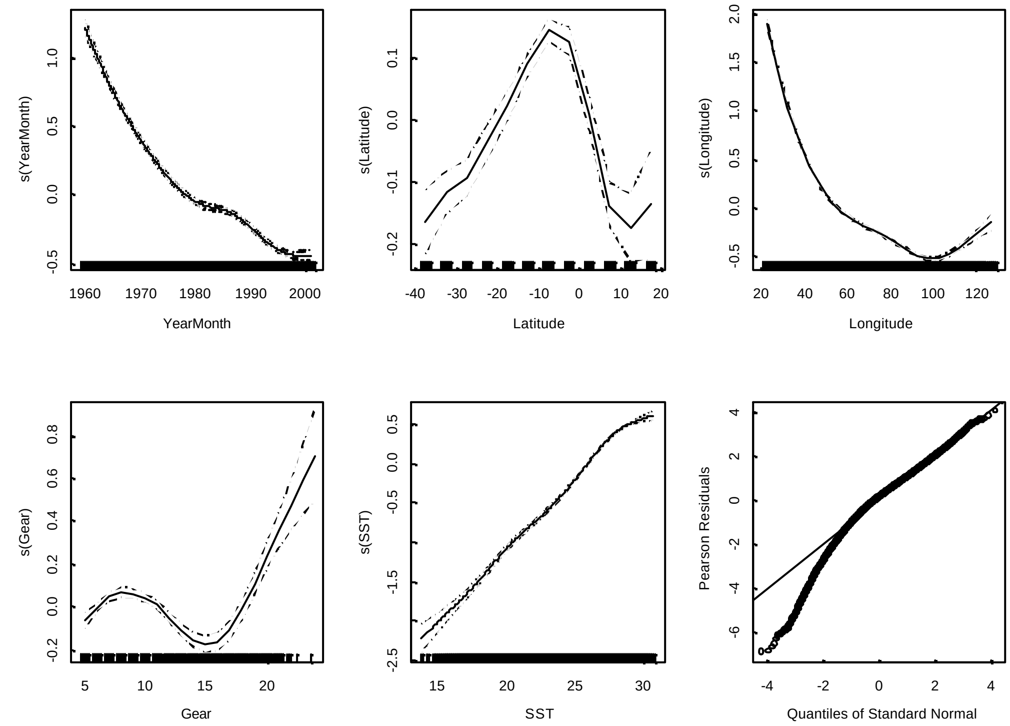


Figure 15. GAM abundance model: LogCPUE~s(YearMonth)+ s(Latitude)+s(Longitude)+s(Gear)+s(SST).

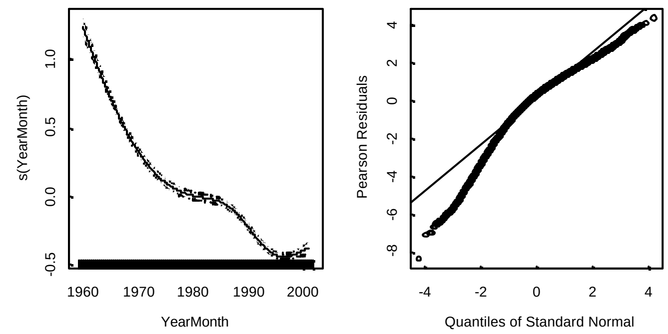


Figure 16. GAM abundance model: LogCPUE~s(YearMonth).

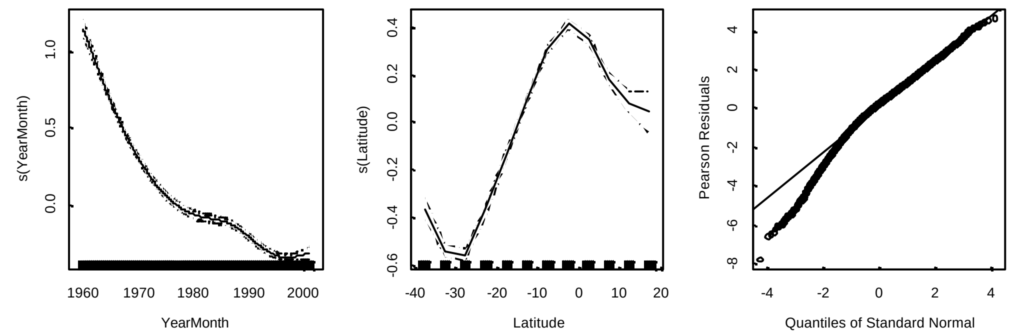


Figure 17. GAM abundance model: LogCPUE~s(YearMonth)+ s(Latitude).

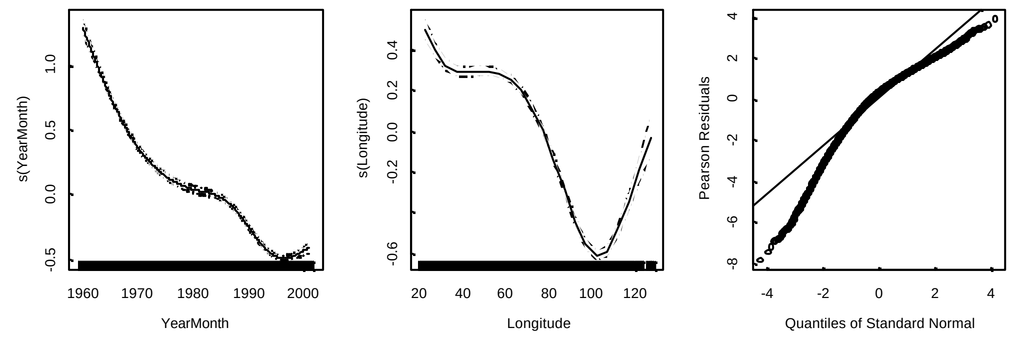


Figure 18. GAM abundance model: LogCPUE~s(YearMonth)+s(Longitude).

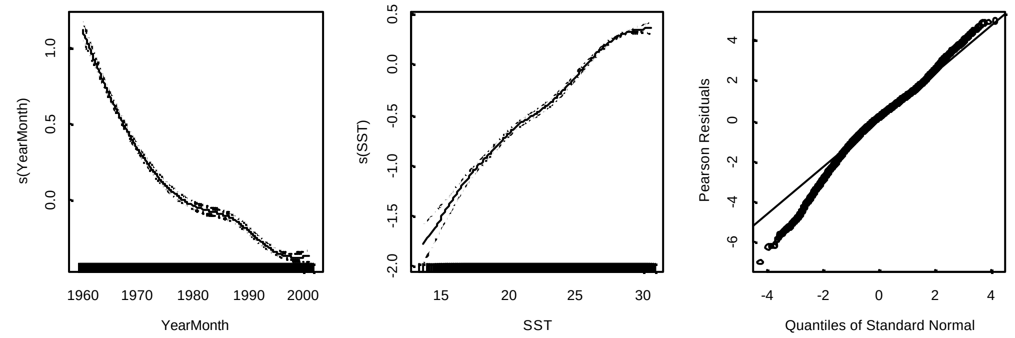


Figure 19. GAM abundance model: LogCPUE~s(YearMonth)+s(SST).

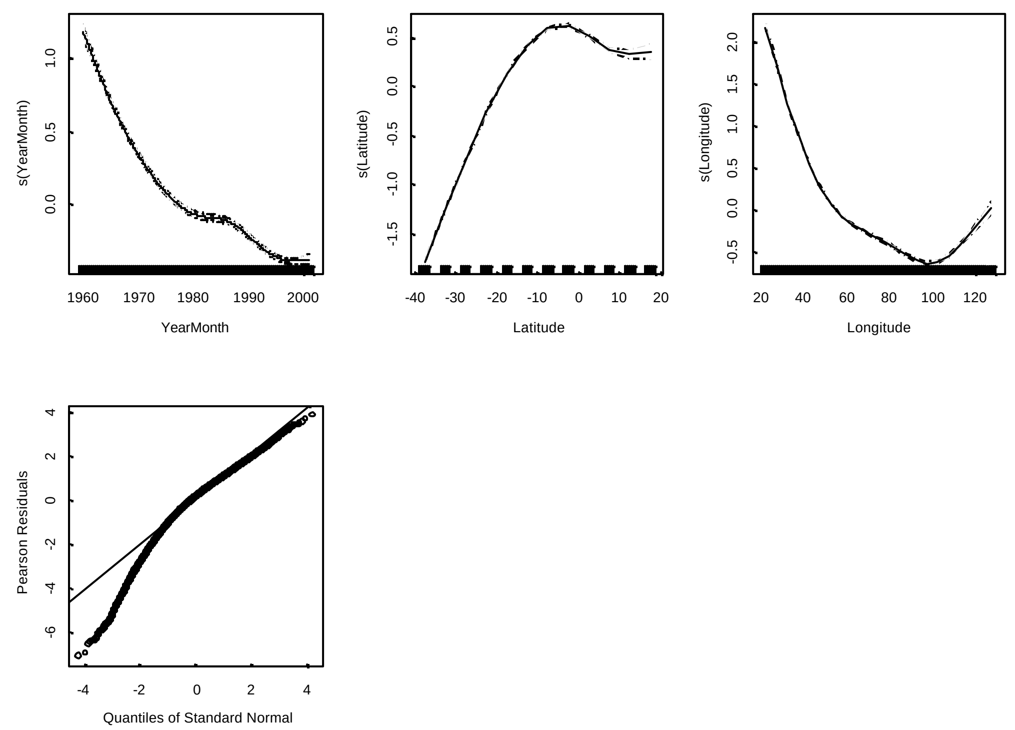


Figure 20. GAM abundance model: LogCPUE~s(YearMonth)+ s(Latitude)+s(Longitude).

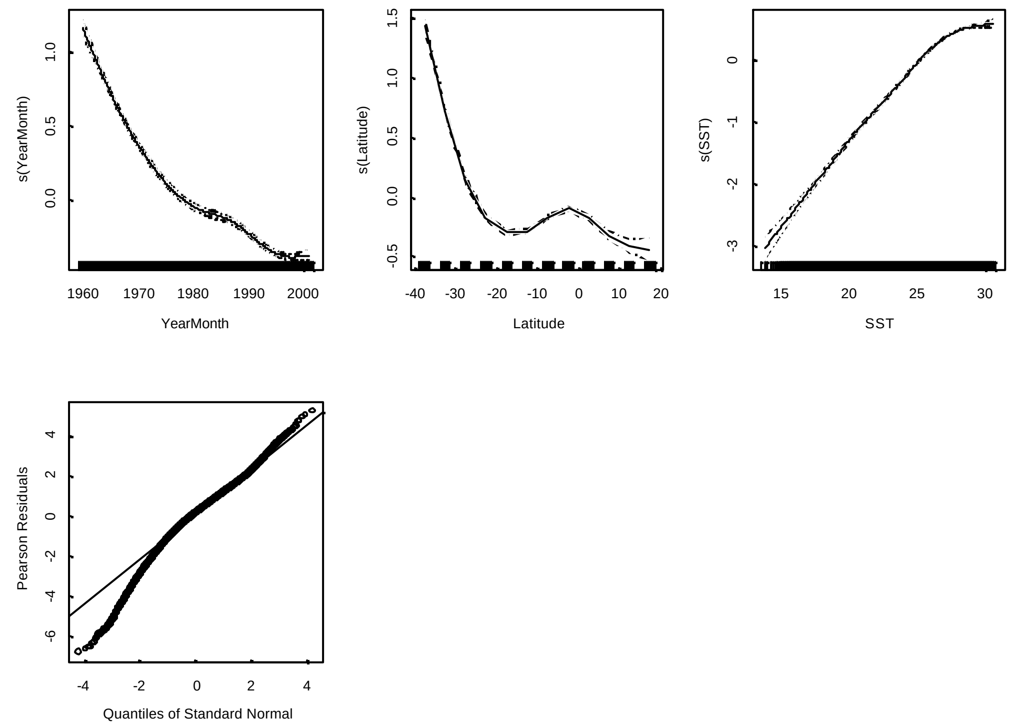


Figure 21. GAM abundance model: LogCPUE~s(YearMonth)+ s(Latitude)+s(SST)

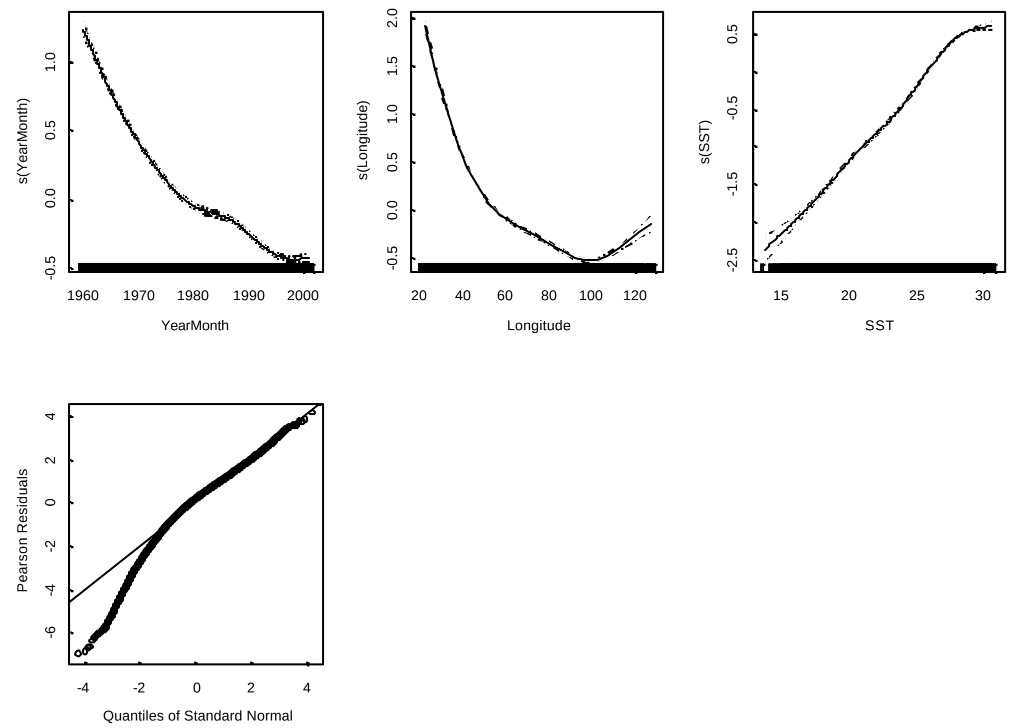


Figure 22. GAM abundance model: LogCPUE~s(Longitude)+ s(Longitude)+s(SST)

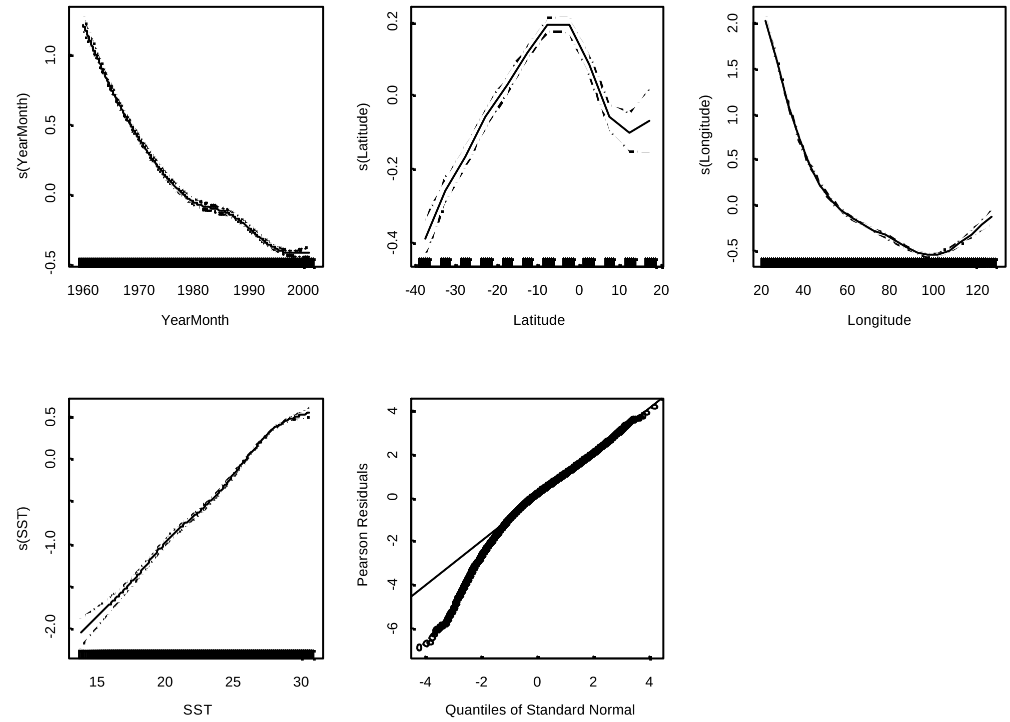
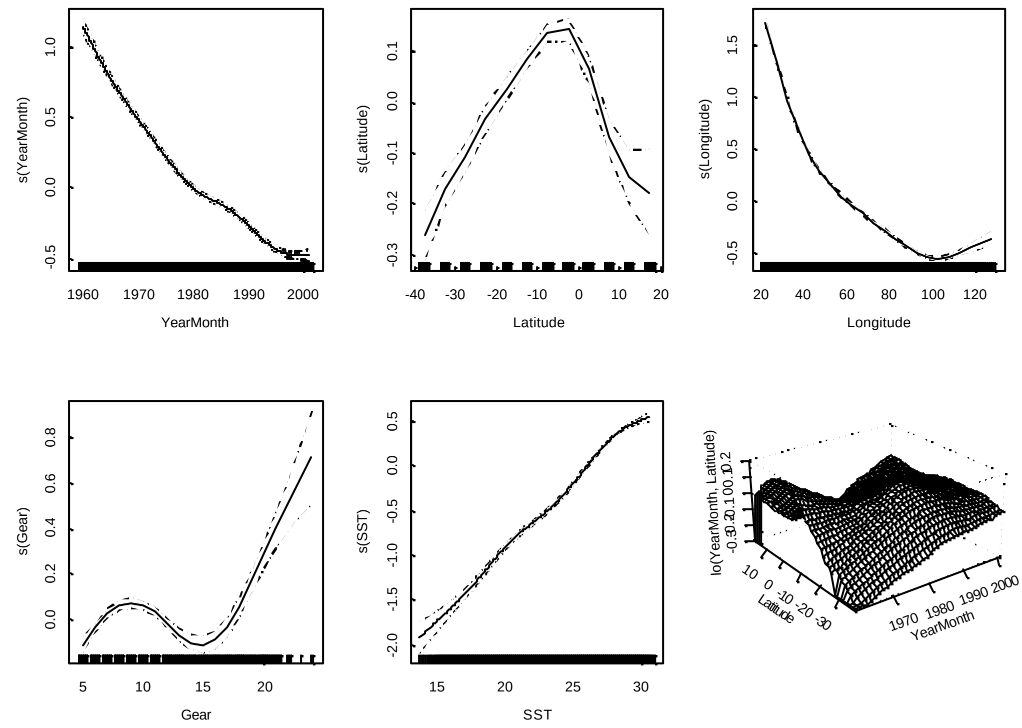


Figure 23. GAM abundance model: LogCPUE~s(YearMonth)+ s(Latitude)+s(Longitude)+s(SST)



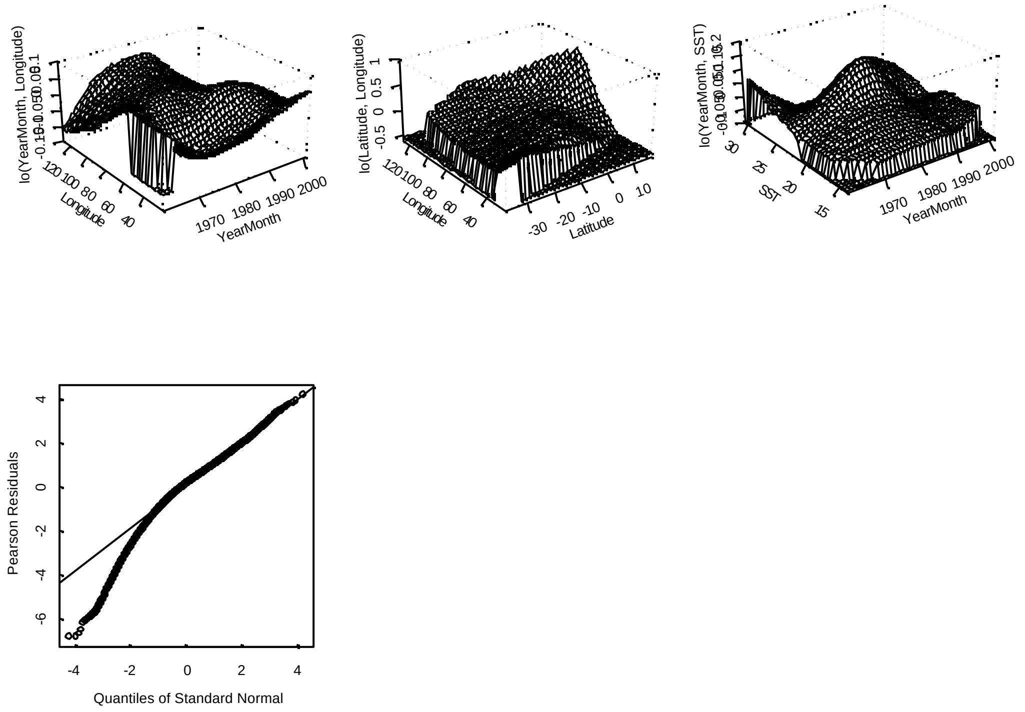


Figure 24. GAM abundance model: LogCPUE~s(YearMonth)+ s(Latitude)+s(Longitude)+s(Gear)+s(SST) +lo(YearMonth,Latitude)+lo(YearMonth,Longitude)+lo(Latitude,Longitude)+lo(YearMonth,SST).