Final standardised CPUE series for toothfish (*Dissostichus eleginoides*) in the Prince Edward Islands EEZ to be used as input for the assessment

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Abstract

GLMM standardisations of longline and trotline toothfish CPUE data are presented based on a "fishing" year rather than a calendar year. Possible relationships between average depth of sets and CPUE are investigated but no discernable differences in the trends of relative abundance indices are found.

Introduction

Brandão and Butterworth (2014a) presented results for some of the suggestions put forward by a task team to address two issues. One was the complications in analysing the toothfish CPUE data due to the fact that the vessel *Koryo Maru* that had been in operation was replaced by a new vessel with the same name in 2009 and only two sets were carried out by the old vessel that coincided with sets made by the new vessel in the same year. This resulted in estimates of post-2008 vessel effects that were too imprecise to be used. The second part of Brandão and Butterworth (2014a) showed results on a GLMM which includes different fixed month effects prior- and post-2000 (the year when cetacean depredation first became noticeable) rather than including the year-month interaction as a random effect, to provide a quantitative surrogate for the extent of cetacean depredation.

Based on the results presented, a decision was made by the working group that the option which assumes that the two *Koryo Maru* vessels are identical in terms of power (rendered reasonable by the fact that the same skipper operated on both vessels) together with the inclusion of a "split" month factor would be used to standardise the longline toothfish CPUE data. However, another decision made by the task team that was not implemented by Brandão and Butterworth (2014a), was to base future GLMM analyses and assessments using a “fishing” year rather than a calendar year, where a “fishing” year *y* is defined to be from 1 December of year *y*-1 to 30 November of year *y*. This is now addressed in this paper.

The GLMM standardisation of the trotline CPUE data is also updated in this paper to be based on a “fishing year”. The trotline CPUE data are also affected by the change of the *Koryo Maru* vessel in 2009 with no sets that coincide between the two *Koryo Maru* vessels for GLMMs based on calendar years, and only two sets that coincide for those based on “fishing” years. Based on the same rationale as for longlines, the two *Koryo Maru* vessels are treated as the same vessel in the analyses presented in this paper.

Further analyses are performed to investigate the effect of average depth (average of depth at the start of a set and the depth at the end of the set) on toothfish CPUE.

The Data

In previous CPUE standardisation analyses, which were based on calendar year, all fishing sets from 1996 were omitted from the analyses. With the definition of a “fishing” year, CPUE data from December 1996 now falls within the 1997 “fishing” year and has been incorporated in the present GLMM analyses. A total of 7 681 sets are available for analyses.

Methods

The changes to the General Linear Mixed Model (GLMM) of Brandão and Butterworth (2011) to standardise the longline (Spanish) and trotline CPUE data for toothfish in the Prince Edward Islands EEZ are detailed below.

The GLMM applied to the longline (and to trotline) CPUE data is of the form:

$$\ln(CPUE+\delta)=X\alpha+Z\beta+\varepsilon, \tag{2}$$

where

$CPUE$ is the longline/trotline catch per unit effort,

δ is a small constant (10% of the average of all CPUE data values = 0.0170 for longline and = 0.152 for trotline) added to the toothfish CPUE to allow for the occurrence of zero CPUE values,

α is the unknown vector of fixed effects parameters which includes:

$\mu + \kappa_{vessel} + \omega_{year} + \gamma_{month} + \lambda_{area}$, where

μ is the intercept,

vessel is a factor with 9 levels associated with each of the vessels that have operated in the longline fishery (to an appreciable extent):

Aquatic Pioneer
Arctic Fox
El Shaddai
Eldfisk
Isla Graciosa
Koryo Maru 11 (which represents the old and the new *Koryo Maru* vessels)
Ross Mar
South Princess
Suidor One

Where only two vessels have operated trotlines: the *Koryo Maru 11* (which also represents the old and the new *Koryo Maru* vessels) and the *El Shaddai,*

year is a factor with 17 levels associated with the years 1997–2013 for longlines or with 6 levels associated with the years 2008–2013 for trotlines,

month is a factor with 12 levels (January– December) for trotlines and 24 levels for longlines, reflecting the months prior to 2000 and the months on and after 2000,

area is a factor with 19 levels associated with the new spatially distinct fishing areas shown in Figure 1 of Brandão and Butterworth (2014b). Trotlines have been used in only 14 of these areas,

X is the design matrix for the fixed effects,

β is the unknown vector of random effects parameters which includes the following interaction terms:

$\eta_{year\times area}+\theta_{year\times month}+\phi_{month\times area}$, for trotline sets and

$\eta_{year\times area}+\phi_{month\times area}$, for longline sets, where

year×area	is the interaction between year and area (this allows for the possibility of different trends in abundance with time in the different areas),
year×month	is the interaction between year and month,
month×area	is the interaction between month and area,

Z is the design matrix for the random effects, and

ε is an error term assumed to be normally distributed and independent of the random effects.

It is assumed that both the random effects and the error term have zero mean, i.e. E(β) = E(ε) = 0, so that E($\ln(CPUE+\delta)$) = **X**α. The variance-covariance matrix for the residual errors (ε) is denoted by **R** and the variance-covariance matrix for the random effects (β) by **G**. In the analyses of this paper it is assumed that the residual errors as well as the random effects are homoscedastic and are uncorrelated, so that both **R** and **G** are diagonal matrices given by:

$$\mathbf{R}=\sigma_{\varepsilon}^{2}\mathbf{I}$$
$$\mathbf{G}=\sigma_{\beta}^{2}\mathbf{I}$$

where **I** denotes an identity matrix. Thus, in the mixed model, the variance-covariance matrix (**V**) for the response variable is given by:

$$\mathrm{Cov}(\ln(CPUE+\delta))=\mathbf{V}=\mathbf{ZGZ}^{\mathrm{T}}+\mathbf{R},$$

where $\mathbf{Z}^{\mathrm{T}}$ denotes the transpose of the matrix **Z**.

The estimation of the variance components (**R** and **G**), the fixed effects (α) and the random effects (β) parameters in GLMM requires two steps. First the variance components are estimated. Once estimates of **R** and **G** have been obtained, estimates for the fixed effects parameters (α) can be obtained as well as predictors for the random effects parameters (β). Variance component estimates are obtained by the method of residual maximum likelihood (REML) which produces unbiased estimates for the variance components as it takes the degrees of freedom used in estimating the fixed effects into account.

For GLMMs that investigate a quadratic relationship between average depth and CPUE, the function $\upsilon depth + \varsigma depth^2$ is added to the vector of fixed effects, where *depth* is the average depth of a set and υ and ς are the associated coefficients. When an other than quadratic (categorical) relationship is assumed, the term ξ_{depth} is added, where *depth* is a factor with 15 levels associated with longline average depths of 100 m (300 – 1700 m), and is a factor with 11 levels associated with trotline average depths of 100 m (700 – 1700 m). The first and last categories for the average depth include depths that fall below/above that category.

Results and Discussion

Table 1 and Figure 1 show the relative abundance indices for toothfish provided by the standardised commercial longline CPUE series for the Prince Edward Islands EEZ that considers the old and new *Koryo Maru* to be the same, includes split month factors prior and post-2000, and for which the year factor is based on a "fishing" year. The month and vessel effects for this GLMM are also shown, all with 95% confidence intervals. Figure 2 shows a comparison of this standardised CPUE series and one that has the year factor based on a calendar year. Apart from the 1999 index, the two series show almost identical trends in relative abundance for toothfish.

Figure 3 (and Table 1) show the relative abundance indices for toothfish provided by the standardised commercial trotline CPUE series for the Prince Edward Islands EEZ that considers the old and new *Koryo Maru* to be the same and for which the year factor is based on a "fishing" year. The month factors for this GLMM are also shown, all with 95% confidence intervals. Figure 4 shows a comparison of this standardised CPUE series and one that has the year factor based on a calendar year, as well as indices obtained by Brandão and Butterworth (2013) which uses the old fishing areas. All series show similar trends in relative abundance, especially over the last three years. The old area definition provides a series with higher indices for 2009 and 2010 compared to the other two series, and the series based on "fishing" year differs from that based on a calendar year with a lower index for 2009.

Figures 5 and 6 show comparisons of relative abundance indices for toothfish provided by standardised CPUE series that either include a relationship (either quadratic or categorical) between the average depth of sets and CPUE or no relationship, for longlines and trotlines respectively. For both longlines and trotlines there is no discernable relationship between the average depth of sets and CPUE.

References

Brandão, A. and Butterworth, D.S. 2013. Obtaining a standardised CPUE series for toothfish (*Dissostichus eleginoides*) in the Prince Edward Islands EEZ calibrated to incorporate both longline and trotline data over the period 1997-2013. DAFF Branch Fisheries document: FISHERIES/2013/OCT/SWG-DEM/57.

Brandão, A. and Butterworth, D.S. 2014a. Further results for the standardisation of the CPUE series for toothfish (*Dissostichus eleginoides*) in the Prince Edward Islands EEZ using finer scale fishing areas. DAFF Branch Fisheries document: FISHERIES/2014/JUL/SWG-DEM/28.

Brandão, A. and Butterworth, D.S. 2014b. Standardisation of the CPUE series for toothfish (*Dissostichus eleginoides*) in the Prince Edward Islands EEZ using finer scale fishing areas. DAFF Branch Fisheries document: FISHERIES/2014/JUN/SWG-DEM/17.

Table 1. Relative abundance indices for toothfish provided by the standardised commercial CPUE series for the Prince Edward Islands EEZ for the Spanish longline and for the trotline fisheries CPUE series.

Year	**GLMM *CPUE***	
	Longline fishery	**Trotline fishery**
1997	3.040	
1998	1.220	
1999	1.082	
2000	1.000	
2001	0.570	
2002	0.691	
2003	0.421	
2004	0.553	
2005	0.730	
2006	0.600	
2007	0.680	
2008	0.602	0.857
2009	0.657	0.995
2010	0.529	1.536
2011	0.168	1.000
2012	0.343	1.020
2013	0.347	0.928

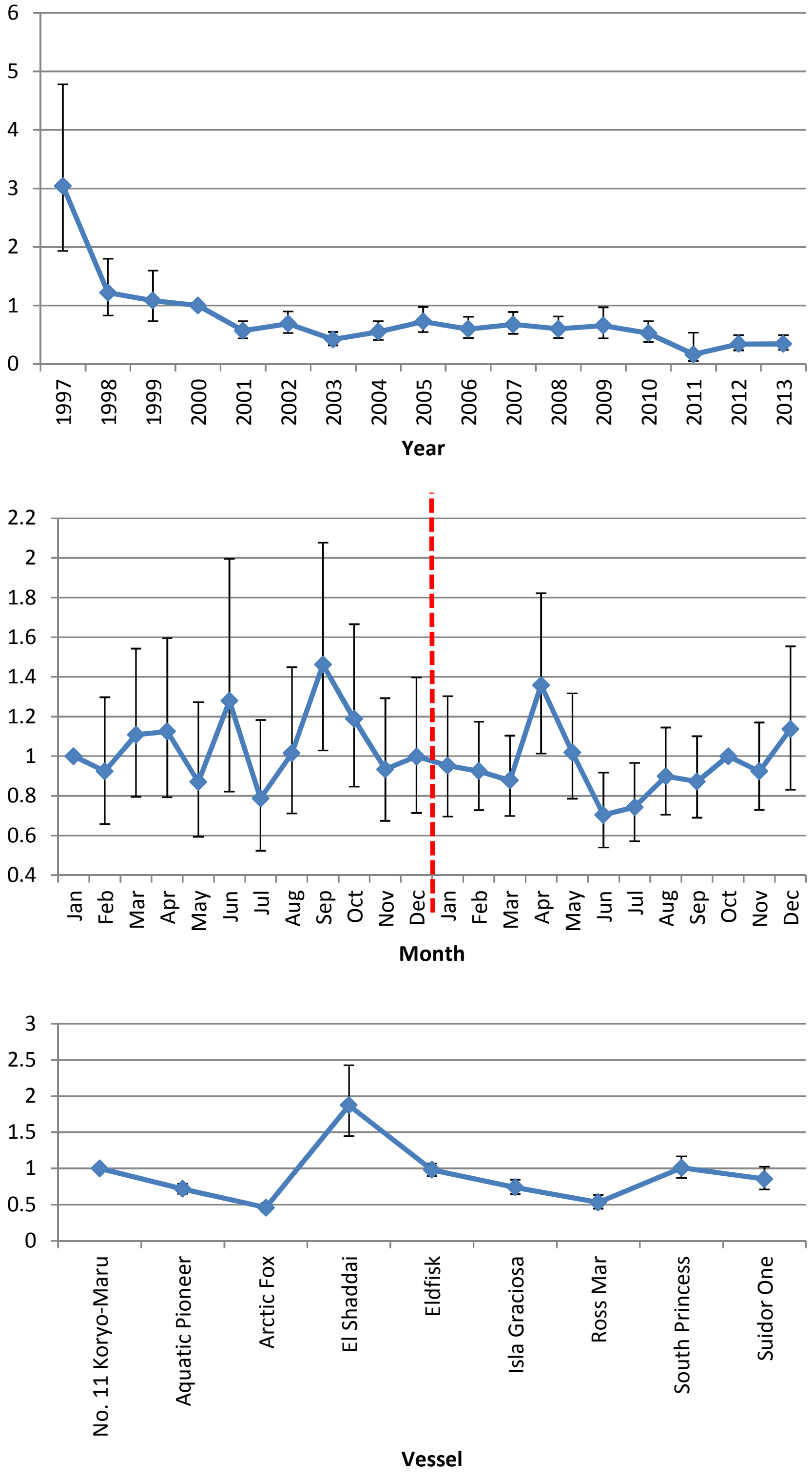

Figure 1. GLMM-standardised CPUE trends (top), month effects (middle) and vessel effects (bottom) together with 95% confidence intervals for the Spanish longline toothfish fisheries for the Prince Edward Islands EEZ when the old and new *Koryo Maru* are considered to be the same, the month factors are split prior and post-2000 (demarcated by the dashed vertical line), and the year factor relates to a "fishing" year. Note that CIs are given relative to 2000 for CPUE, post-2000 October (set at 1) for the month effect, and the *Koryo Maru* (set at 1) for the vessel effect.

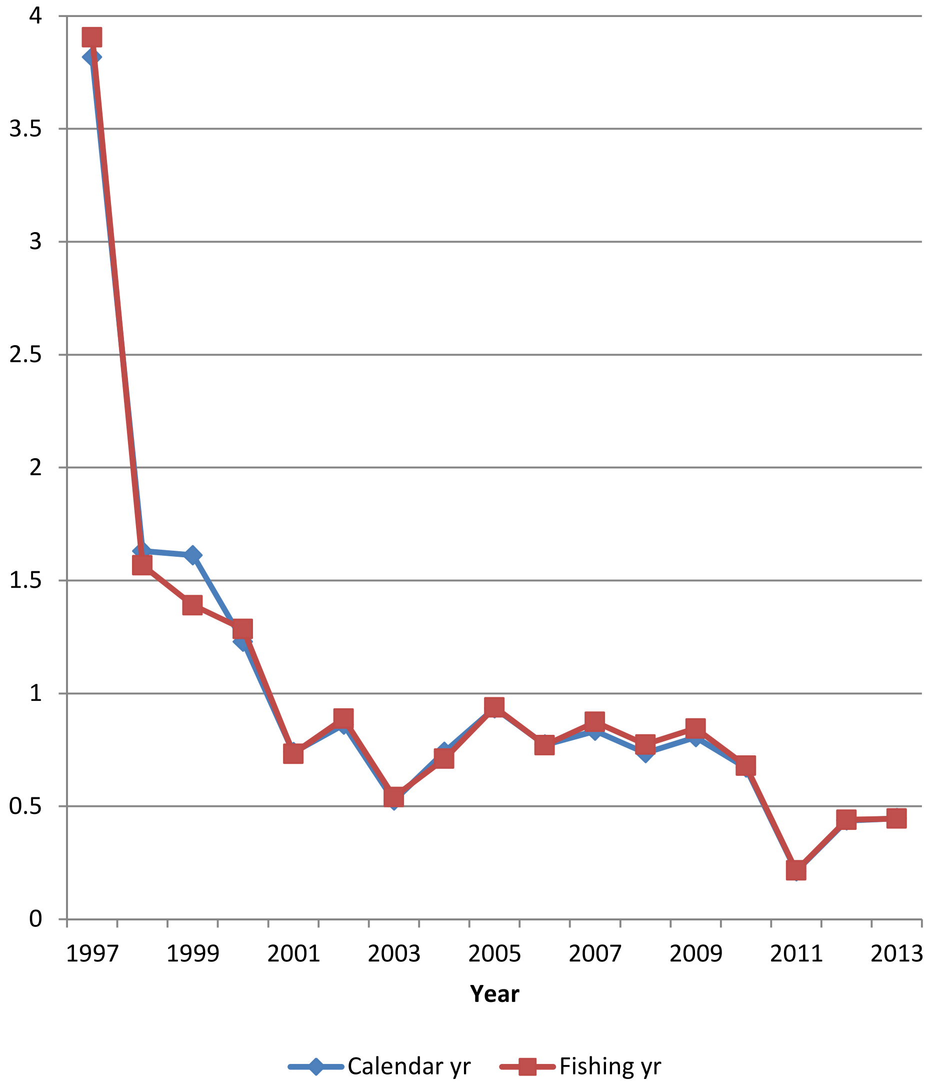

Figure 2. Comparison of the GLMM-standardised CPUE trends for the Spanish longline toothfish fisheries for the Prince Edward Islands EEZ between using calendar year and using "fishing" year (both normalised to their mean over the 2008 to 2013 period).

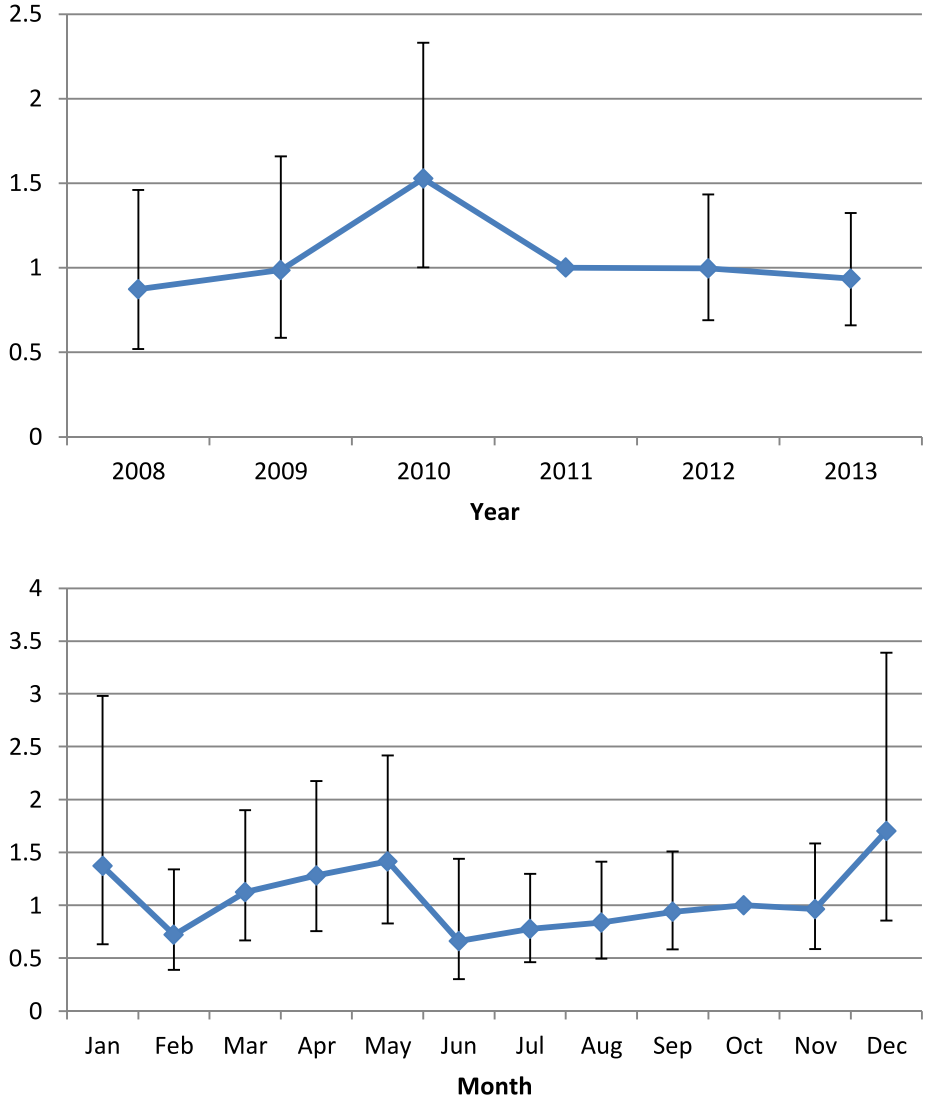

Figure 3. GLMM-standardised CPUE trends (top) and month effects (bottom) together with 95% confidence intervals for the trotline toothfish fisheries for the Prince Edward Islands EEZ when the old and new *Koryo Maru* are considered to be the same and the year factor relates to a "fishing" year. Note that CIs are given relative to 2011 for CPUE and October (set at 1) for the month effect.

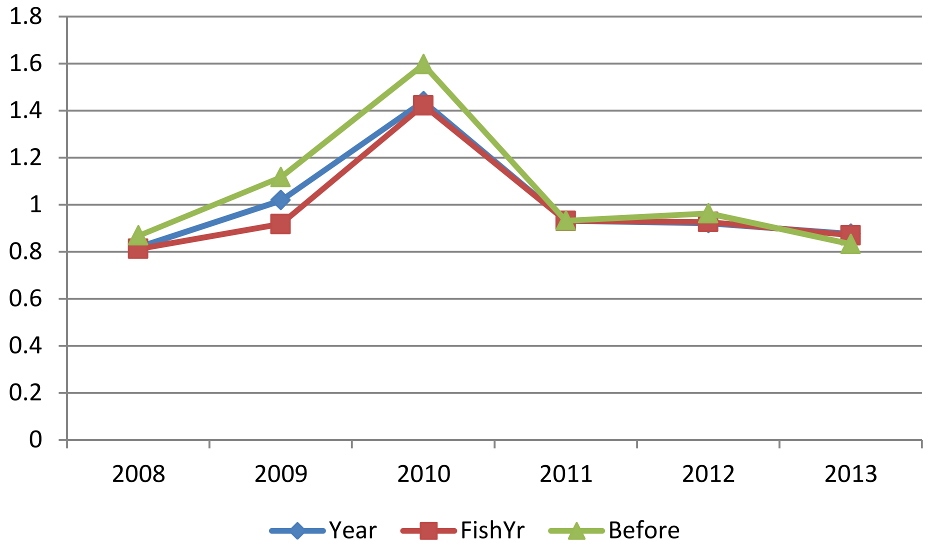

Figure 4. Comparison of the GLMM-standardised CPUE trends for the trotline toothfish fisheries for the Prince Edward Islands EEZ between using calendar year and using "fishing" year, as well as a comparison with the trend obtained by Brandão and Butterworth (2013) (the latter considers a calendar year and fishing areas at a coarser scale) (all are normalised to their means over the 2008 to 2013 period).

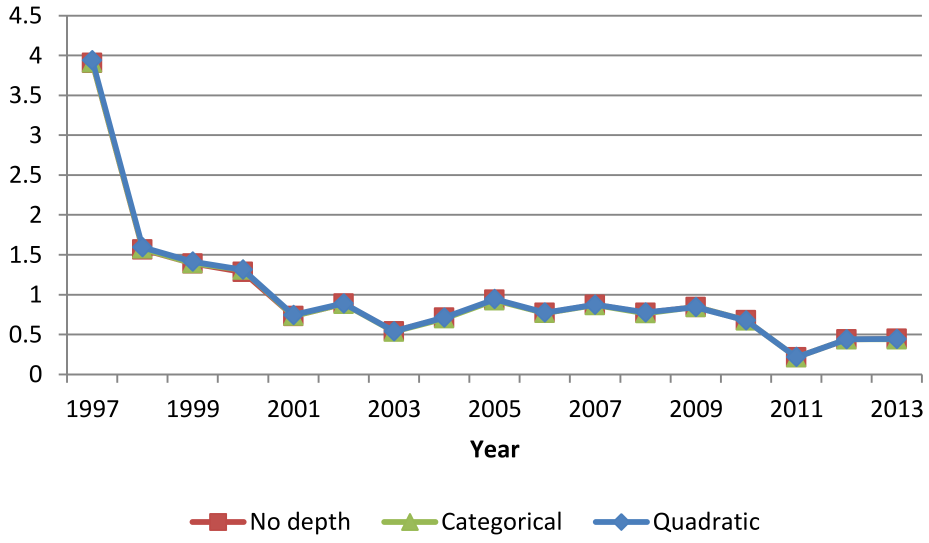

Figure 5. Comparison of the GLMM-standardised CPUE trends for the Spanish longline toothfish fisheries for the Prince Edward Islands EEZ between including a relationship (quadratic or categorical) between average depth and CPUE and not including any depth factor (all are normalised to their means over the 2008 to 2013 period). These series are practically indistinguishable from each other, with marginal differences in the years 1998 to 2000.

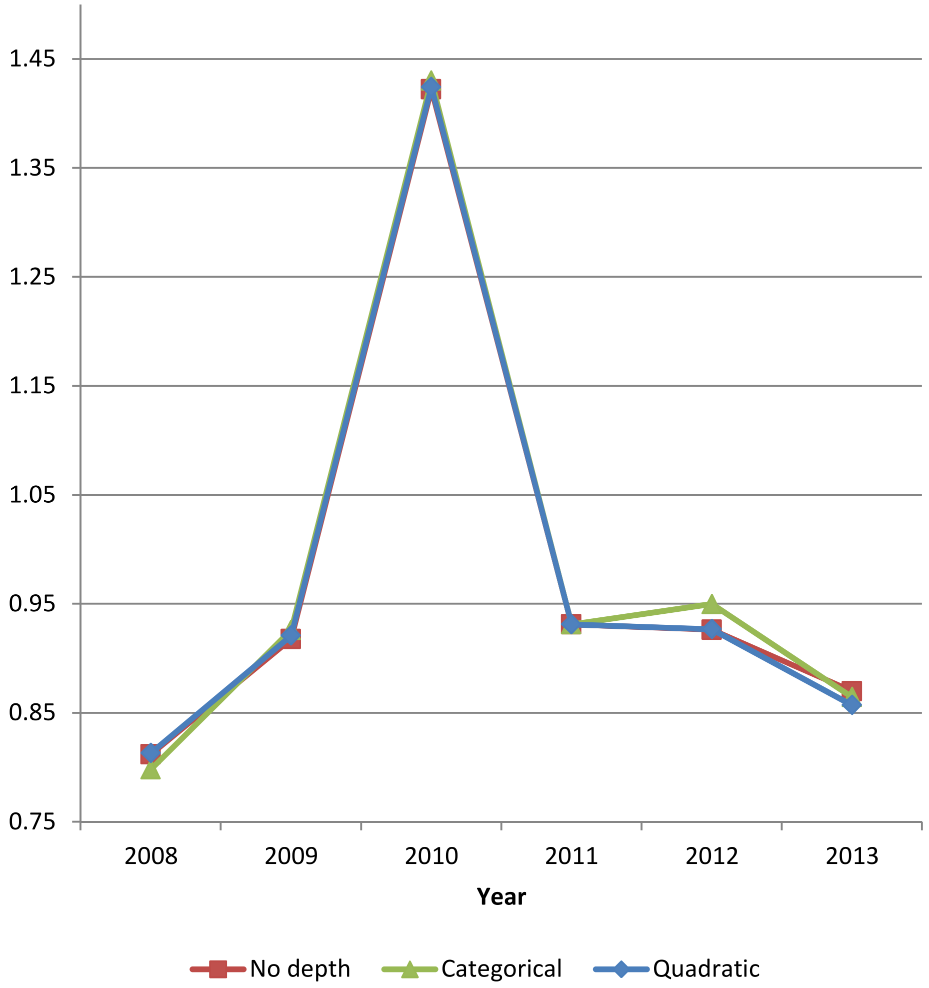

Figure 6. Comparison of the GLMM-standardised CPUE trends for the trotline toothfish fisheries for the Prince Edward Islands EEZ between including a relationship (quadratic or categorical) between average depth and CPUE and not including any depth factor (all are normalised to their means over the 2008 to 2013 period).