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Generalized Additive Model Analyses to Standardize Swordfish (*Xiphias gladius*) Catch Rates in the Hawaii-based Longline Fishery, 1995-2006

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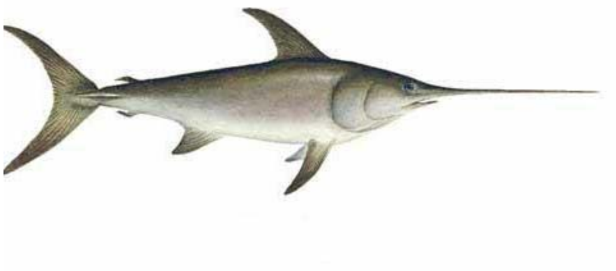

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This working paper presents analyses to standardize swordfish (*Xiphias gladius*) catch rates in the Hawaii-based longline fishery during 1995-2006. Swordfish catch rates were based on observer data collected by the Hawaii Longline Observer Program of NOAA Fisheries. Generalized additive models (GAMs) were applied to develop standardized swordfish catch rates on observed sets which are compared to nominal catch rates.

Swordfish catch data were collected from 26,507 longline sets during the entire study period. Observers covered roughly half of the swordfish sets in 1994 (48%). From 1995–1999, the allocation of observer coverage was reduced to approximate fleet-wide effort and about 1/10 of swordfish sets were observed (10-13% by year). Since April 2004, shallow-set swordfish sets have had mandatory (100%) observer coverage. The sample size for the GAM analyses was 25,169 sets (95% of observed sets) because sets with missing predictor values were excluded.

GAMs were fit to observed swordfish catch rates using procedures outlined in Walsh et al. (2002; 2005; 2006). Catch per set was the response variable. The GAMs included seven predictive variables; these were: (1) begin-set time, (2) date of fishing, (3) latitude, (4) number of hooks per float, (5) number of hooks total, (6) sea surface temperature (SST°C), and (7) longitude. Some predictive variables were not independent. For example, SST°C and latitude were significantly negatively correlated ($r = -0.691$; df = 25167; $P < 0.001$). Similarly, hook numbers, hooks per float, and begin-set time were proxy variables for the species targeted by the longline set. In particular, swordfish sets typically begin in the late afternoon/evening, use relatively low numbers of hooks and hooks per float (i.e., < 15 hooks per float), and are shallower than bigeye tuna sets. In contrast, bigeye-tuna sets typically begin around dawn, use relatively high numbers of hooks and hooks per float (i.e., ≥ 15 hooks per float), and are deeper than swordfish sets.

GAMs were fit using three different definitions of date of fishing; these were monthly (mo/yr), quarterly (qtr/yr) and annual (yr) intervals. Otherwise, the three GAMs were identical. Standardized catch per set was computed separately for the three swordfish GAMs with monthly, quarterly, and annual time steps. Standardized catch per set was divided by the observed hook numbers and re-expressed as catch-per-unit-effort (CPUE with units of swordfish per 1000 hooks). Standardized catch rates were also computed separately for swordfish sets (i.e., < 15 hooks per float) and bigeye sets (i.e., ≥ 15 hooks per float). In this case, standardized catch rates were determined by setting all predictors (other than the date of fishing) to their respective mean values in the two subsets of longline fishing operations (swordfish set means: begin-set time=18:23 h, latitude=29.3 ˚N, longitude=159.0 ˚W, hooks/set=816, hooks/float=4.5, SST=20.7˚C; bigeye tuna set means: begin-set time=07:53 h, latitude=19.9 ˚N, longitude=158.8 ˚W, hooks/set=1987, hooks/float=27.3, SST=25.8˚C) and calculating the response.

For each GAM, a pseudo-R^2 value (ρ^2) was evaluated to measure the goodness of model fit from the null deviance (D_{NULL}) and residual deviance ($D_{RESIDUAL}$) as

$$\rho^2 = \left(D_{NULL} - D_{RESIDUAL}\right) \Big/ D_{NULL}$$

The observer data set (2,121 trips that deployed 26,507 longline sets) had a catch of 62,246 swordfish, equivalent to 2.3 per set or 2.7 per 1000 hooks. The effort was comprised of 17% swordfish and 83% bigeye sets. Despite this difference in the percentages of set types, the overall swordfish catch from the shallow sets was 87% of the total.

The swordfish GAM fit with a monthly time step explained 82% of the null deviance of observed swordfish catch rates (Table 1A). All predictors yielded highly significant deviance reductions (all *F*-tests, $P < 0.001$). The predicted values from the swordfish GAM were highly correlated with the mean catch rates reported by the observers (Figure 1A); the correlation between the observed catch rates and the monthly GAM-corrected values was highly significant ($r = 0.87$; df = 25,167; $P < 0.001$).

The swordfish GAM fit with a monthly time step explained 82% of the null deviance of observed swordfish catch rates (Table 1B). All predictors yielded highly significant deviance reductions (all *F*-tests, $P < 0.001$). The predicted values from the swordfish GAM were highly correlated with the mean catch rates reported by the observers (Figure 1B); the correlation between the observed catch rates and the quarterly GAM-corrected values was also highly significant ($r = 0.87$; df = 25,167; $P < 0.001$).

The swordfish GAM fit with a monthly time step explained 81% of the null deviance of observed swordfish catch rates (Table 1C). All predictors yielded highly significant deviance reductions (all *F*-tests, $P < 0.001$). The predicted values from the swordfish GAM were highly correlated with the mean catch rates reported by the observers (Figure 1C); the correlation between the observed catch rates and the annually GAM-corrected values was also highly significant ($r = 0.86$; df = 25,167; $P < 0.001$).

Standardized and nominal catch per set were computed separately for the shallow-set (Figure 2) and deep-set (Figure 3) sectors to depict the targeted and incidental catches respectively. For shallow sets, the swordfish GAMs fit monthly, quarterly, and annually (Figures 2A, 2B, 2C) all suggest that catch per set in the shallow-set sector increased during the 10-year study period. Similarly, for deep sets, the swordfish GAMs fit monthly, quarterly, and annually (Figures 3A, 3B, 3C) all suggest that catch per set in the deep-set sector also increased during the 10-year study period. The linear regressions of catches per set on date of fishing all had small but significant and positive slopes, which suggested that if there was any trend, it involved increases in catch rates. (Figures 2 and 3). The largest increases in catch per set occurred in 2004 coincident with a management action that resulted in closure of swordfish targeted fishing in Hawaii during this period. Because of the swordfish fishery closure, the apparent increase in catch per set during in 2004 may be an artifact due to low sample size.

Standardized and nominal CPUE were also computed separately for the swordfish set (Figure 4) and bigeye tuna set (Figure 5) operations to depict the targeted and incidental catches respectively. Standardized monthly swordfish CPUE was significantly correlated for both the shallow- (Figure 4A) and deep-set (Figure 5A) sectors, although the strength of the association differed. The standardized and nominal mean monthly swordfish CPUE were highly correlated for the targeted, shallow-set sector (Figure 4A; $r = 0.82$; df = 98; $P < 0.001$), but less so for the incidental catches of swordfish in the deep-set sector (Figure 5A; $r = 0.33$; df =133; $P = 0.001$).

The standardized and nominal quarterly swordfish CPUE values were significantly correlated for both the swordfish (Figure 4B) and bigeye set (Figure 5B) operations, although the strength of the association differed. The nominal and standardized mean quarterly swordfish CPUE values were highly correlated for the targeted, swordfish sets (Figure 4B; $r = 0.85$; df = 38; $P < 0.001$), but less so for the incidental catches of swordfish in the bigeye sets (Figure 5B; $r = 0.41$; df =133; $P = 0.003$).

The standardized and nominal quarterly swordfish CPUE values were significantly correlated for the swordfish set (Figure 4C) but not the bigeye set (Figure 5C) operations. The nominal and standardized monthly swordfish CPUE mean values were highly correlated for the targeted, swordfish set operations (Figure 4C; $r = 0.99$; df = 10; $P < 0.001$), but not significantly correlated for the incidental catches of swordfish in the bigeye set operations (Figure5C; $r = 0.14$; df =10; $P = 0.67$).

Standardized and nominal swordfish CPUE decreased in the swordfish set operations (Figure 4) in 2004 coincident with a management action that resulted in closure of swordfish targeted fishing during this period. Standardized and nominal swordfish CPUE did not decrease in 2004 in the bigeye tuna set operations (Figure 5). This contrasts with the standardized and nominal swordfish catch per set in the swordfish and bigeye sets (Figures 5 and 6) which increased during the same period. Because of the swordfish closure, the apparent decrease in CPUE during 2004 in the swordfish sets may be an artifact of low sample size.

Preliminary examination of patterns of residuals from the GAM scatterplot smoothers suggested that three groupings of targeted fisheries may exist: shallow-sector swordfish, shallow-sector yellowfin tuna, and deep-sector bigeye tuna. Heterogeneity of average swordfish catch rates and their variances in these fishing operations may warrant further investigation.

This initial standardization analysis of swordfish catch rates in the Hawaii-based longline fishery suggested an apparent increase in catch rates since the mid-1990s. Although there was a large difference in catch rates between the shallow- and deep-set sectors of the Hawaii-based longline fishery, reflecting the fact that swordfish is targeted by the former and taken incidentally in the latter, the within-sector trends were stable. As such, the results provided no indication that the relative abundance of swordfish available to the Hawaii-based longline fishery has exhibited a declining trend during 1995-2006.

Table 1. Analysis of deviance table for GAM analyses to standardize swordfish catch rates using monthly (A), quarterly (B), and annual (C) time steps. Column entries are the pseudo-R^2 value, the nonparametric degrees of freedom (df), the *F*-test statistic and its P-value, and the percent deviance explained by each predictor.

A. Monthly time step ($\text{mo} \cdot \text{yr}^{-1}$)

Predictor	ρ^2	df	F_{enter}	*P*	Percent deviance explained
Begin-set time	77.9	3.9	16,796.0	< 0.001	77.9
Date of fishing	80.3	45.2	59.8	< 0.001	2.4
Latitude	81.0	8.5	73.1	< 0.001	0.6
Hooks per float	81.4	3.8	112.5	< 0.001	0.4
Hooks	81.9	3.8	121.3	< 0.001	0.5
SST(°C)	82.2	3.9	82.2	< 0.001	0.3
Longitude	82.3	8.7	20.0	< 0.001	0.2

B. Quarterly time step ($\text{qtr} \cdot \text{yr}^{-1}$)

Predictor	ρ^2	df	F_{enter}	*P*	Percent deviance explained
Begin-set time	77.9	3.9	16,796.0	< 0.001	77.9
Date of fishing	78.9	10.7	91.3	< 0.001	1.0
Latitude	79.9	8.5	107.7	< 0.001	1.0
Hooks per float	80.4	3.8	129.6	< 0.001	0.5
Hooks	80.9	3.8	115.3	< 0.001	0.5
SST(°C)	81.4	3.9	127.2	< 0.001	0.5
Longitude	81.5	8.7	18.8	< 0.001	0.1

C. Annual time step (yr^{-1})

Predictor	ρ^2	df	F_{enter}	*P*	Percent deviance explained
Begin-set time	77.9	3.9	16,796.0	< 0.001	77.9
Date of fishing	78.4	2.8	120.7	< 0.001	0.5
Latitude	79.5	8.5	124.7	< 0.001	1.1
Hooks per float	80.1	3.8	123.8	< 0.001	0.6
Hooks	80.6	3.8	111.3	< 0.001	0.5
SST(°C)	81.1	3.9	142.1	< 0.001	0.6
Longitude	81.3	8.7	20.0	< 0.001	0.2

References

Walsh, W.A., Kleiber, P. and McCracken, M. 2002. Comparison of logbook reports of incidental blue shark catch rates by Hawaii-based longline vessels to fishery observer data by application of a generalized additive model. Fisheries Research 58:79–94.

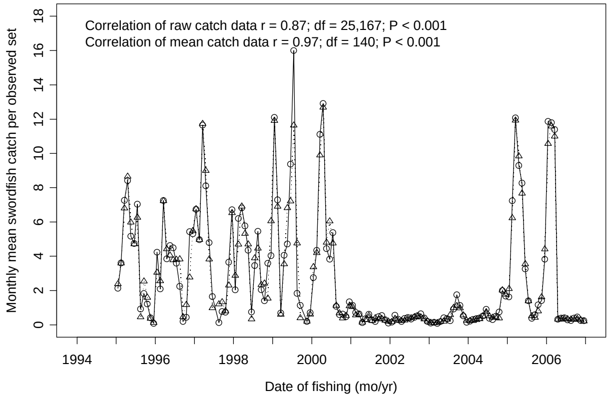
Walsh, W.A., Ito, R.Y., Kawamoto, K.E., and McCracken, M. 2005. Analysis of logbook accuracy for blue marlin (*Makaira nigricans*) in the Hawaii-based longline fishery with a generalized additive model and commercial sales data. Fisheries Research 75:175–192.

Walsh, W.A., Howell, E.A., Bigelow, K.A., and McCracken, M.L. 2006. Analyses of observed longline catches of blue marlin, *Makaira nigricans*, using generalized additive models with operational and environmental predictors. Bulletin of Marine Science 79:607–622.

Figure 1. Predicted swordfish catch per set from swordfish GAMs fit with monthly (A), quarterly (B), and annual (C) time steps in relation to the mean catch rates reported by the observers.

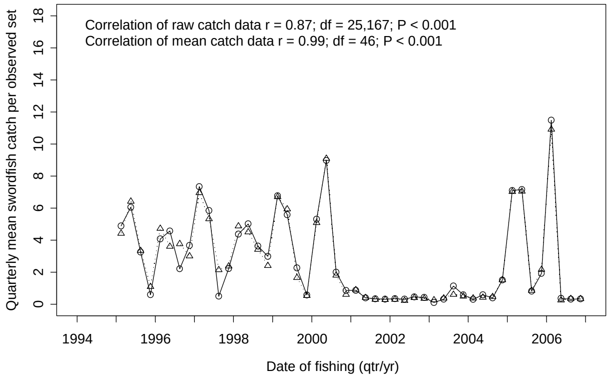
A.Date of fishing fit monthly (month/year)

Solid trace: Observer catch data
Dashed trace: Monthly GAM-corrected catch rates



B.Date of fishing fit quarterly (quarterly/year)

Solid trace: Observer catch data
Dashed trace: Quarterly GAM-corrected catch rates



C.Date of fishing fit yearly (year)

Solid trace: observer catch data
Dashed trace: Yearly GAM-corrected catch rates

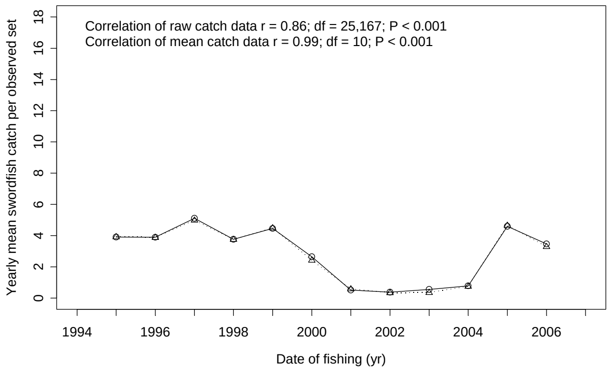
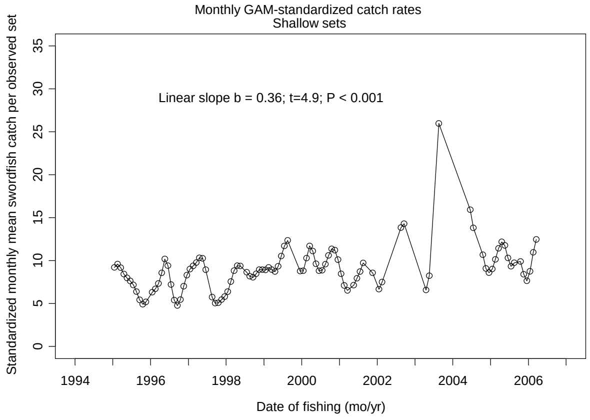
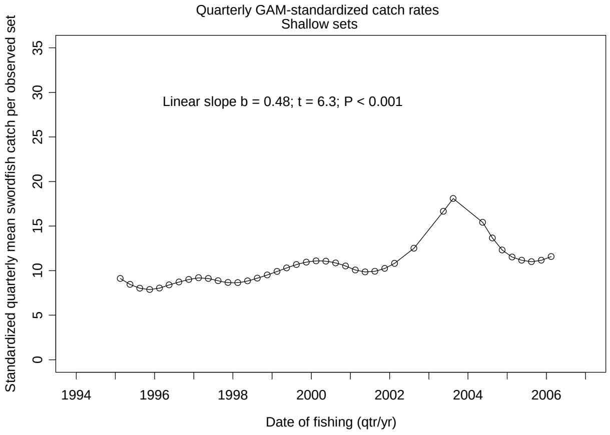


Figure 2. Standardized and nominal swordfish catch per set for the shallow-set sector from swordfish GAMs fit with monthly (A), quarterly (B), and annual (C) time steps.

A.Date of fishing fit monthly (month/year)



B.Date of fishing fit quarterly (quarterly/year)



C.Date of fishing fit yearly (year)

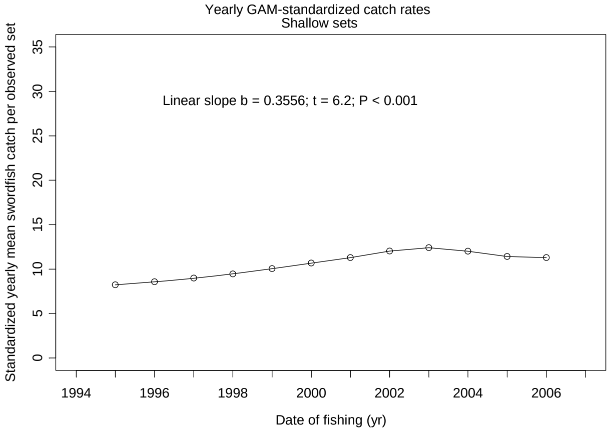
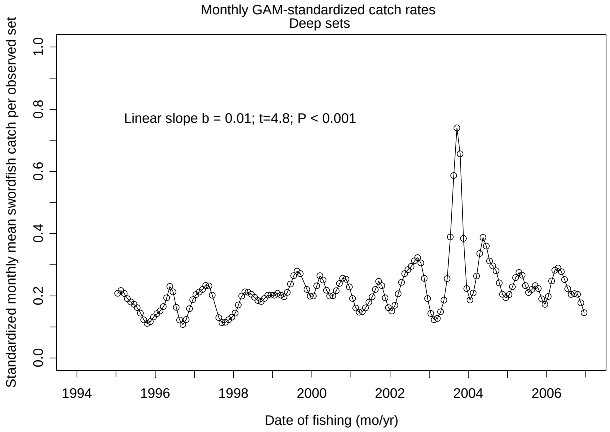
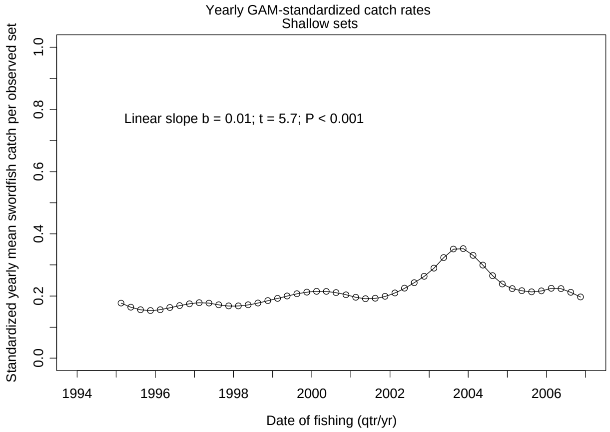


Figure 3. Standardized and nominal swordfish catch per set for the deep-set sector from swordfish GAMs fit with monthly (A), quarterly (B), and annual (C) time steps.

A.Date of fishing fit monthly (month/year)



B.Date of fishing fit quarterly (quarterly/year)



C.Date of fishing fit yearly (year)

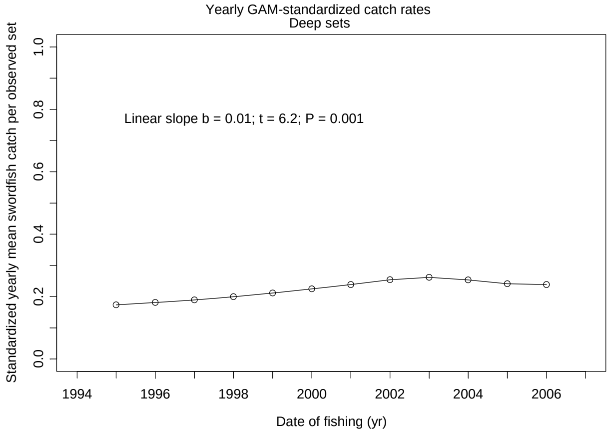
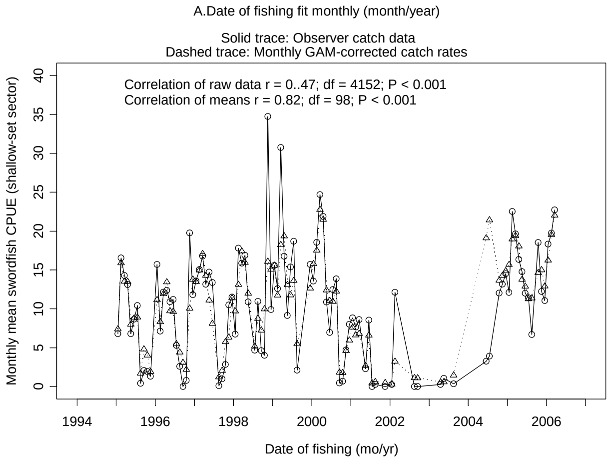
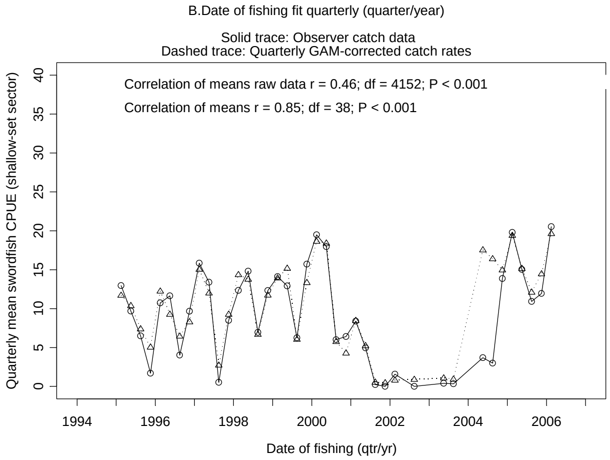


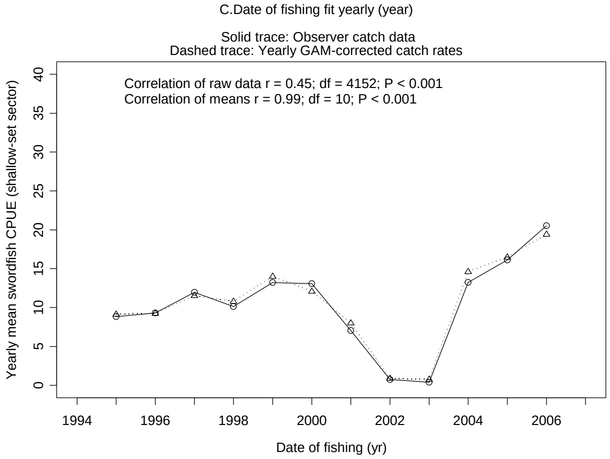
Figure 4. Standardized and nominal swordfish CPUE for the shallow-set sector from swordfish GAMs fit with monthly (A), quarterly (B), and annual (C) time steps.


A.Date of fishing fit monthly (month/year)

Solid trace: Observer catch data
Dashed trace: Monthly GAM-corrected catch rates


B.Date of fishing fit quarterly (quarter/year)

Solid trace: Observer catch data
Dashed trace: Quarterly GAM-corrected catch rates

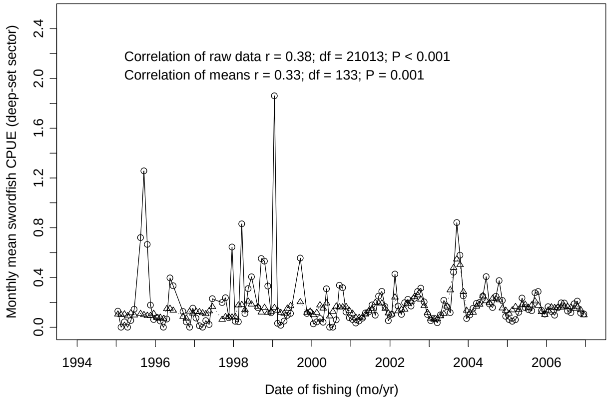

C.Date of fishing fit yearly (year)

Solid trace: Observer catch data
Dashed trace: Yearly GAM-corrected catch rates

Figure 5. Standardized and nominal monthly swordfish CPUE for the deep-set sector from swordfish GAMs fit with monthly (A), quarterly (B), and annual (C) time steps.

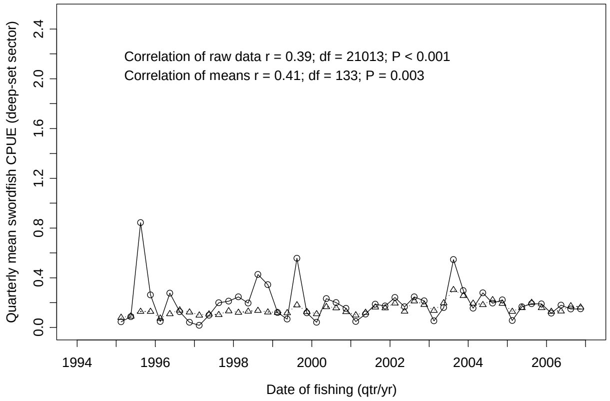
A.Date of fishing fit monthly (month/year)

Solid trace: Observer catch data
Dashed trace: Monthly GAM-corrected catch rates



B.Date of fishing fit quarterly (quarterly/year)

Solid trace: Observer catch data
Dashed trace: Quarterly GAM-corrected catch rates



C.Date of fishing fit yearly (year)

Solid trace: Observer catch data
Dashed trace: Yearly GAM-corrected catch rates