Observed Swordfish (*Xiphias gladius*) Catch Rates in the Hawaii-based Longline Fishery, 1994-2006[1]

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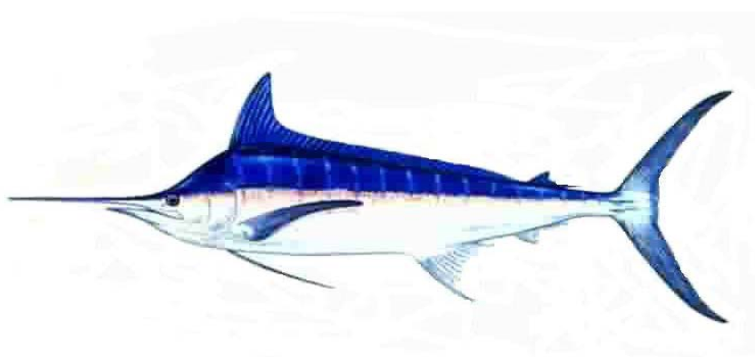

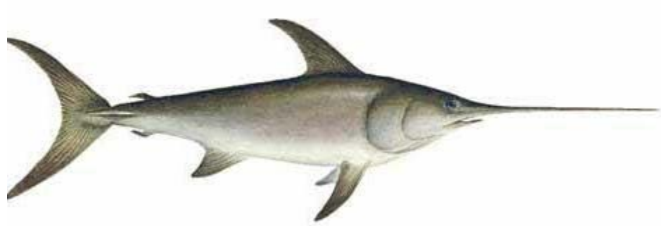

[1]Working document submitted to the ISC Billfish Working Group Workshop, 19-26 March 2007, Chinese Taipei. Document not to be cited without author's written permission.

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Introduction

Swordfish**,** *Xiphias gladius*, is a large, ecologically important, highly migratory marine teleost, with a cosmopolitan distribution in tropical, temperate, and some cold waters of all oceans (Nakamura 2001; Mundy 2005). It is highly valuable commercially, as the target species for directed fisheries in the Atlantic, Pacific, and Indian Oceans, and as incidental catch in tuna longline fisheries (FAO 1985). Along with bigeye tuna, *Thunnus obesus*, swordfish is one of the main target species in the Hawaii-based longline fishery (Howell and Kobayashi 2006).

This paper presents statistical analyses of swordfish catch rates in the Hawaii-based longline fishery from March 1994 through February 2006. The analyses used data gathered by the Hawaii Longline Observer Program of NOAA Fisheries. The results include a generalized additive model of swordfish catch rates on observed sets, with the associated statistical and graphical output, standardized time series developed from the model, and a comparison with nominal catch data on these sets.

This report, submitted to the Swordfish Working Group of the Interim Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean, complements that of Ito and Coan ("U.S. Swordfish Fisheries in the North Pacific Ocean"), which summarizes recent and historical trends in the nominal catch data from Hawaii and California. This document was prepared at the behest of the Stock Assessment Division of NOAA Fisheries' Pacific Islands Fisheries Science Center.

[2] PIFSC Working Paper WP-07-002
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Methods

Data Sources

Swordfish catch data were gathered by personnel of the Hawaii Longline Observer Program from March 1994 through February 2006. Observers were aboard longline vessels during 2,023 trips that deployed 25,868 sets during the entire study period, but the annual coverage rates varied widely among types of fishing (i.e., swordfish-targeted, tuna-targeted) because these were expected to be characterized by high rates of sea turtle interactions. Because the initial purpose of the program was to monitor interactions with endangered sea turtles (DiNardo 1993), there was a high coverage rate for swordfish-targeted sets in 1994 (48% of the observed sets targeted swordfish). From 1995–1999, however, the allocation of observer coverage was revised to approximate fleet-wide effort and targeting more closely, which resulted in reduced observer coverage (10-13%) of swordfish-targeted sets. A shallow-set (i.e., swordfish-targeted) fishery was subsequently re-opened in April 2004, contingent upon mandatory 100% observer coverage. This requirement remains in force. There is a separate requirement for at least 20% observer coverage of deep-set (i.e., tuna-targeted) activity.

The observers record species-specific catch tallies and several environmental (e.g., sea surface temperature, weather) and operational (e.g., position, number of hooks deployed, set and haul times) descriptors from each longline set (Pacific Islands Regional Office 2003). Because the observers receive specialized training when hired and undergo thorough debriefings after trips, their records were generally considered accurate. The sample size for the detailed analyses was 22419 sets (87% of the observed sets), after having removed sets with missing predictor values.

Analytical Procedures

A generalized additive model (GAM) of swordfish catch rates was fitted to the observer data according to procedures outlined in Walsh et al. (2002; 2005; 2006). Catch per set was the response variable; the predictors were the date of fishing (month/year), begin-set time, latitude, longitude, sea surface temperature (SST°C), number of hooks, and number of hooks per float. These selections did not represent a complete list of possible predictors, but were chosen because most logbook reports include their values. Other possible predictors (e.g., hook type, number of light sticks) were not chosen because these are not always provided in the logs, which would preclude application of the model coefficients to unobserved sets. It is recognized that certain predictors were not independent of one another; SST°C and latitude, for example, were negatively correlated (r = -0.666; df = 22417; P = 0). In addition, hook numbers, hooks per float, and begin-set time were essentially proxy variables related to types of fishing activity. Swordfish-targeted sets typically begin in the late afternoon or evening, with relatively low numbers of hooks and hooks per float. Tuna-targeted sets, in contrast, typically begin near dawn, and deploy relatively high numbers of hooks and hooks per float. All statistical procedures were conducted in S-Plus Version 6.1.2.

Standardized Catch Rates

Standardized catch rates were computed separately for shallow- (i.e., < 15 hooks per float) and deep (i.e., ≥ 15 hooks per float) longline sets, which generally correspond to swordfish- and tuna-targeted fishing. These rates were computed by setting all predictors other than the date of fishing to their respective mean values in the two subsets and then obtaining the back-transformed response from the GAM. These catch rates were then adjusted by the hook numbers and re-expressed as catch-per-unit-effort (CPUE; i.e., swordfish per 1000 hooks).

Results

Effort and Catch

The complete observer data set (2057 trips that deployed 25868 longline sets) had a catch of 67303 swordfish, equivalent to 2.6 per set or 3.0 per 1000 hooks (Table 1). The effort was comprised of 19.6% shallow- and 80.4% deep sets. Despite this difference in the percentages of set types, the overall catch from the shallow sets was 7.4-fold greater than that from deep sets.

GAM Analyses

The GAM (Table 2) explained 81.1% of the null deviance of observed swordfish catch rates. All predictors yielded highly significant deviance reductions (all F-tests, $P = 0$). Figure 1 presents the fit of the GAM in relation to the mean catch rates reported by the observers; the correlation between the observed catch rates and the GAM-corrected values was very highly significant ($r = 0.866$; df = 22402; $P = 0$).

Figure 2 depicts the relationships between observed swordfish catch rates and the predictors. Begin-set time (Figure 2a) alone accounted for 75.7% of the null deviance. The smoother trace for this predictor, with its somewhat bimodal appearance representing the type of fishing, was reminiscent of those for numbers of hooks per float (Figure 2b), and to a lesser extent, those for SST°C (Figure 2c) and latitude (Figure 2d), although the latter plot revealed high influences of 10 sets south of 5°N that collectively yielded 27 swordfish. The effect of hook numbers was generally positive (Figure 2e); this plot was generated after truncating the data to 3000 hooks per set or less because there were again a small number of highly influential sets. These results reflected the general pattern that swordfish-targeted effort in this fishery typically entails setting the gear in late afternoon or evening, with relatively low numbers of hooks (*ca*. 800) and hooks per float (*ca*. 5), and with effort concentrated north of 25°N in relatively cool waters (*ca*. 21°C). Tuna-targeted effort, in contrast, is characterized by morning sets, high numbers of hooks (*ca*. 2000) and hooks per float (*ca*. 30), concentrated at lower latitudes (*ca*. 20°N) and in warmer waters (*ca*. 26°C). It should be noted that this longline fishery is now managed according to depth of set, defined in turn according to the numbers of hooks per float (shallow-set: < 15 hooks per float; deep-set: ≥ 15 hooks per float). These terms will be employed throughout the remainder of this report. The date of fishing, computed at monthly intervals, exhibited an oscillatory relationship with catch rates (Figure 2f), which probably corresponded, to some extent, to the seasonality of the shallow-set sector. Longitude (Figure 2g) exerted a relatively minor effect on observed swordfish catch rates[3].

Standardized Catch Rates and CPUE

The standardized catch rates (Figure 3) were computed separately for the shallow- and deep-set sectors, to depict the targeted and incidental catches, respectively. The predictor values for the two sectors are presented in Table 3. The catches per set (Figures 3a,b) did not decrease during the 12-year study period. The linear regressions of catches per set on time had small but positive slopes, which suggested that if there was any trend, it involved increases in catch rates.

Discussion

This analysis of swordfish catch data gathered by fishery observers from March 1994 through February 2006 revealed no apparent pattern of decline during this relatively short time series. 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, but the within-sector trends appear stable. As such, the observed sets provided no indication that this species is being exploited unsustainably in the Hawaii-based longline fishery.

Acknowledgments

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[3] This plot was prepared after deleting three sets from west of the International Date Line for ease of interpretation.

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Table 1. Summary of nominal effort and swordfish catches by the Hawaii-based longline fishery, March 1994–February 2006.

All observed data				
Trips[4]	Sets	Swordfish	Catch/set	CPUE
2057	25868	67303	2.6	3.0
All observed data from shallow-set fishing				
360	5083	59252	11.7	14.6
All observed data from deep-set fishing				
1703	20785	8051	0.4	0.2
Observed data used in GAM fitting and analyses				
1854	22419	49822	2.2	2.5

[4] Three trips deployed both shallow and deep sets so the sum of the numbers of trips in these categories exceeds the total.

Table 2. Analysis of deviance of observed swordfish catches, March 1994–February 2006. Entries are the reductions in the Akaike Information Criterion and residual deviance, the F-test and its significance, and the stepwise percent deviance reductions.

Predictor	Δ AIC	Δ Residual Deviance	d.f. (npar)	F_{enter}	P	Deviance explained
Begin-set time	118459.4	118469	3.8	13232.44	0	75.7
Date of fishing	4356.9	4449.6	45.4	58.480	0	2.8
Latitude	1380.95	1400.3	8.7	89.074	0	0.9
Hooks per float	981.13	991.11	4.0	124.255	0	0.6
Hooks	806.36	816.02	3.8	108.109	0	0.5
SST(°C)	386.64	396.42	3.9	53.376	0	0.3
Longitude	374.21	393.88	8.8	26.686	0	0.3

Null deviance = 155971.7; df = 22403

Residual deviance = 29434.15; df = 22317.65

Pseudo-R^2 = 100 *((155971.7 - 29434.15) / 155971.7)
= 81.1%

Table 3. Summary of predictor values used to compute standardized catch rates and CPUE.

Sector	Begin-set time	Latitude	Longitude	Hooks	Hooks per float	SST
Shallow-set	1800 h	28.8°N	159.0°W	823	4.5	21.3°C
Deep-set	0735 h	20.0°N	158.8°W	1966	27.2	25.9°C

Figure 1.

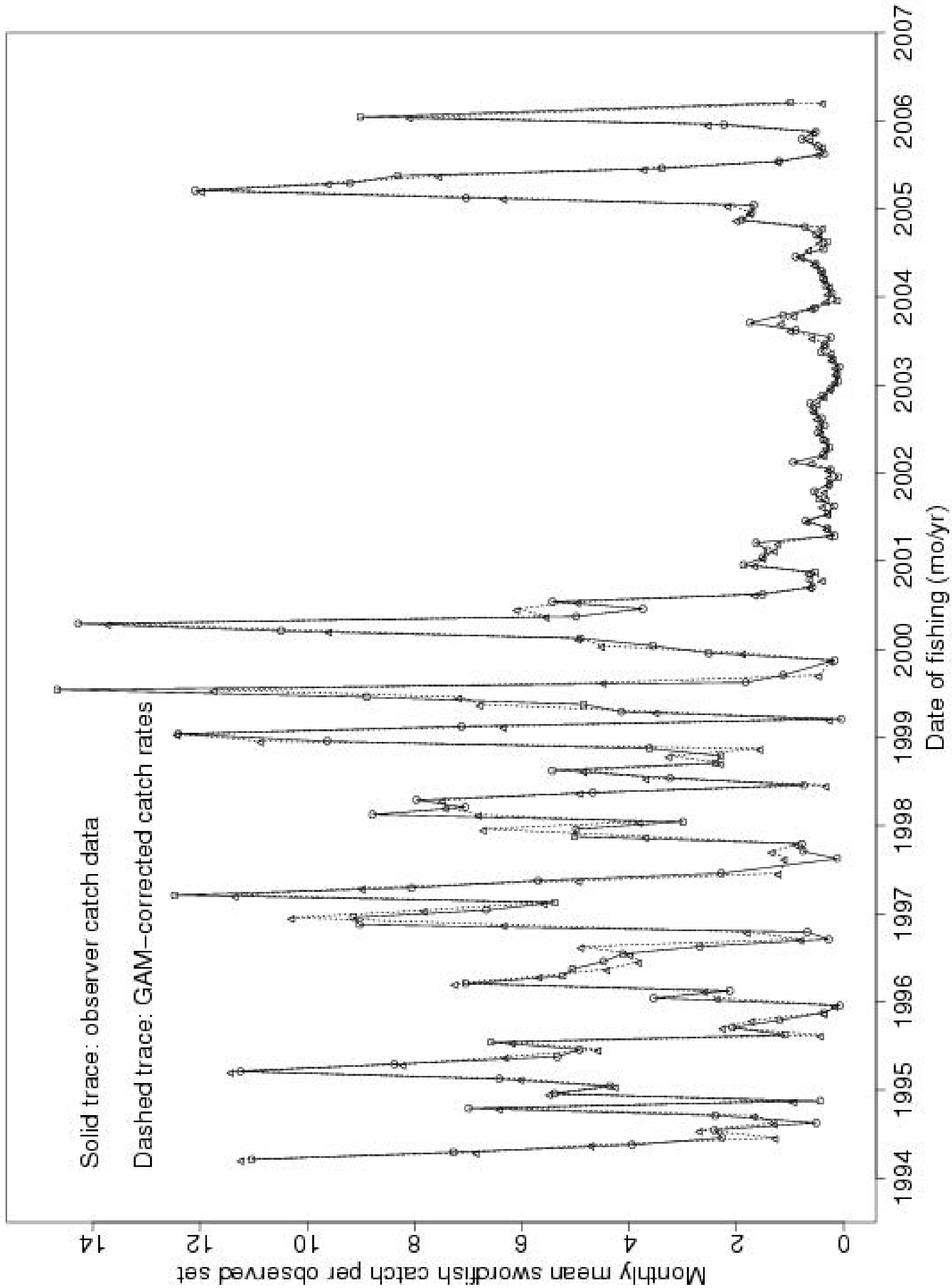
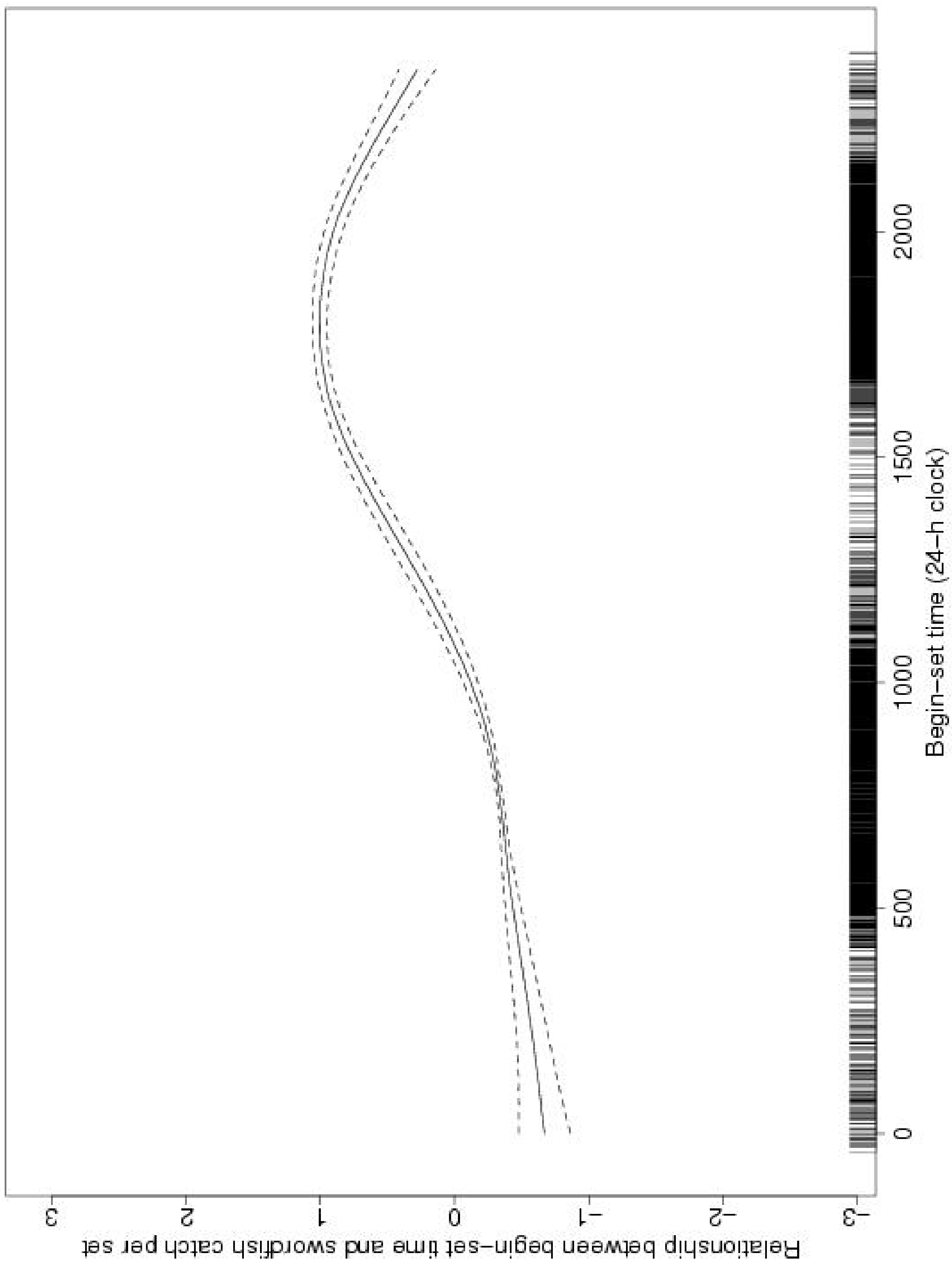
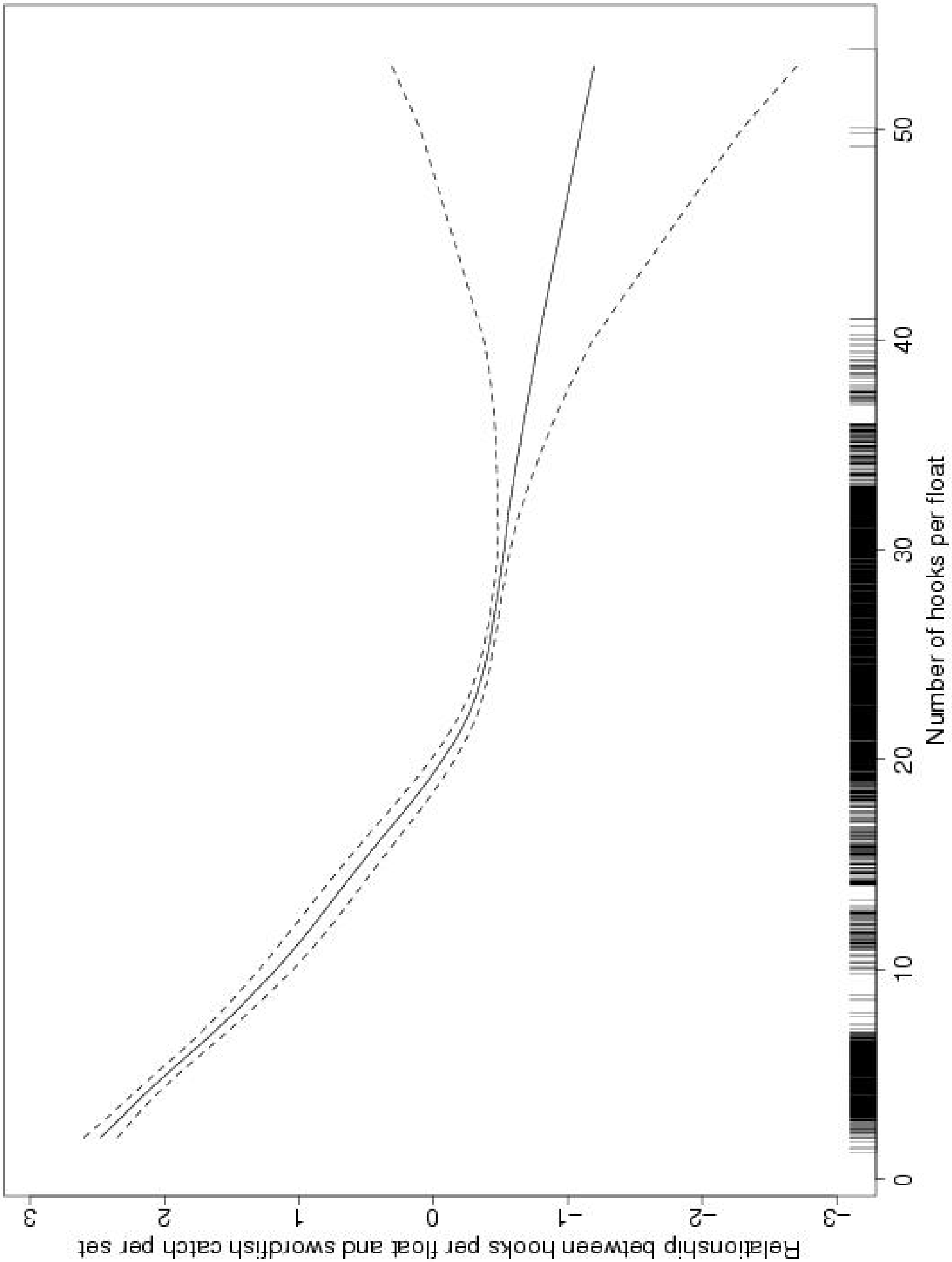

Solid trace: observer catch data
Dashed trace: GAM−corrected catch rates
Monthly mean swordfish catch per observed set
0
2
4
6
8
10
12
14
Date of fishing (mo/yr)
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007

Figure 2a.



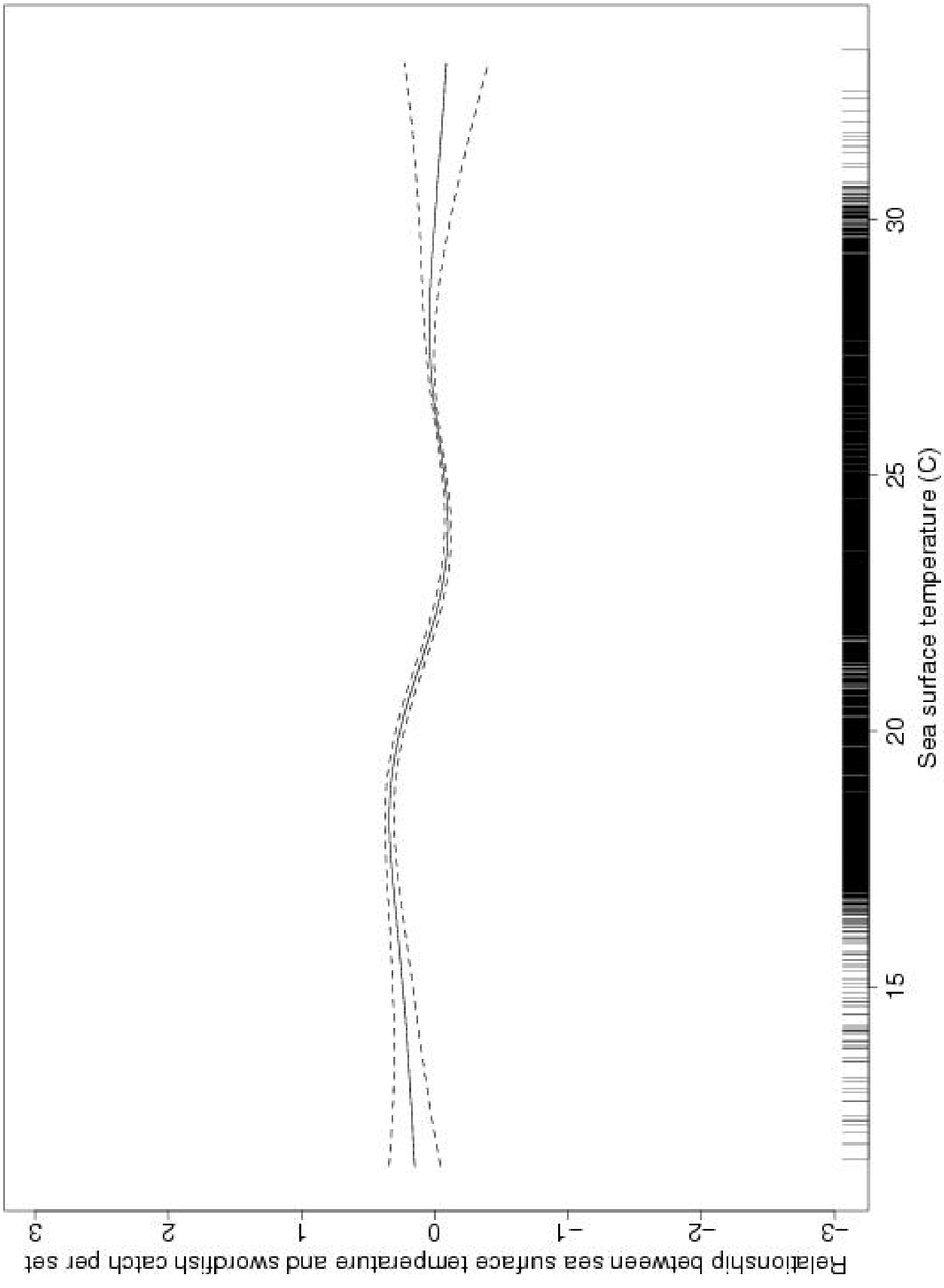
Begin−set time (24−h clock)
0
500
1000
1500
2000
Relationship between begin−set time and swordfish catch per set
−3
−2
−1
0
1
2
3

Figure 2b.



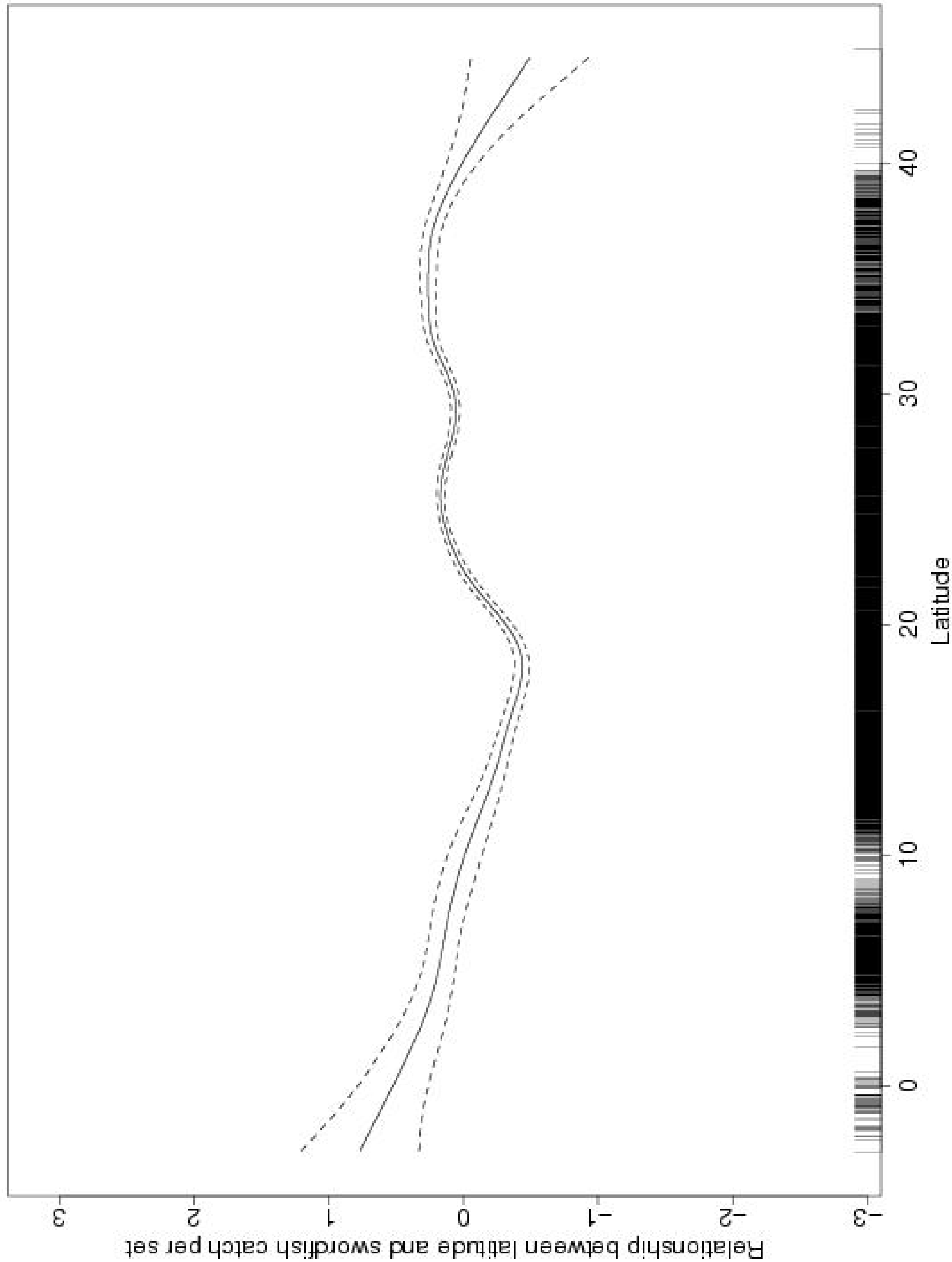
Number of hooks per float
Relationship between hooks per float and swordfish catch per set
0
10
20
30
40
50
−3
−2
−1
0
1
2
3

Figure 2c.



Sea surface temperature (C)
Relationship between sea surface temperature and swordfish catch per set
15
20
25
30
−3
−2
−1
0
1
2
3

Figure 2d.



Relationship between latitude and swordfish catch per set
−3
−2
−1
0
1
2
3
0
10
20
30
40
Latitude

Figure 2e.

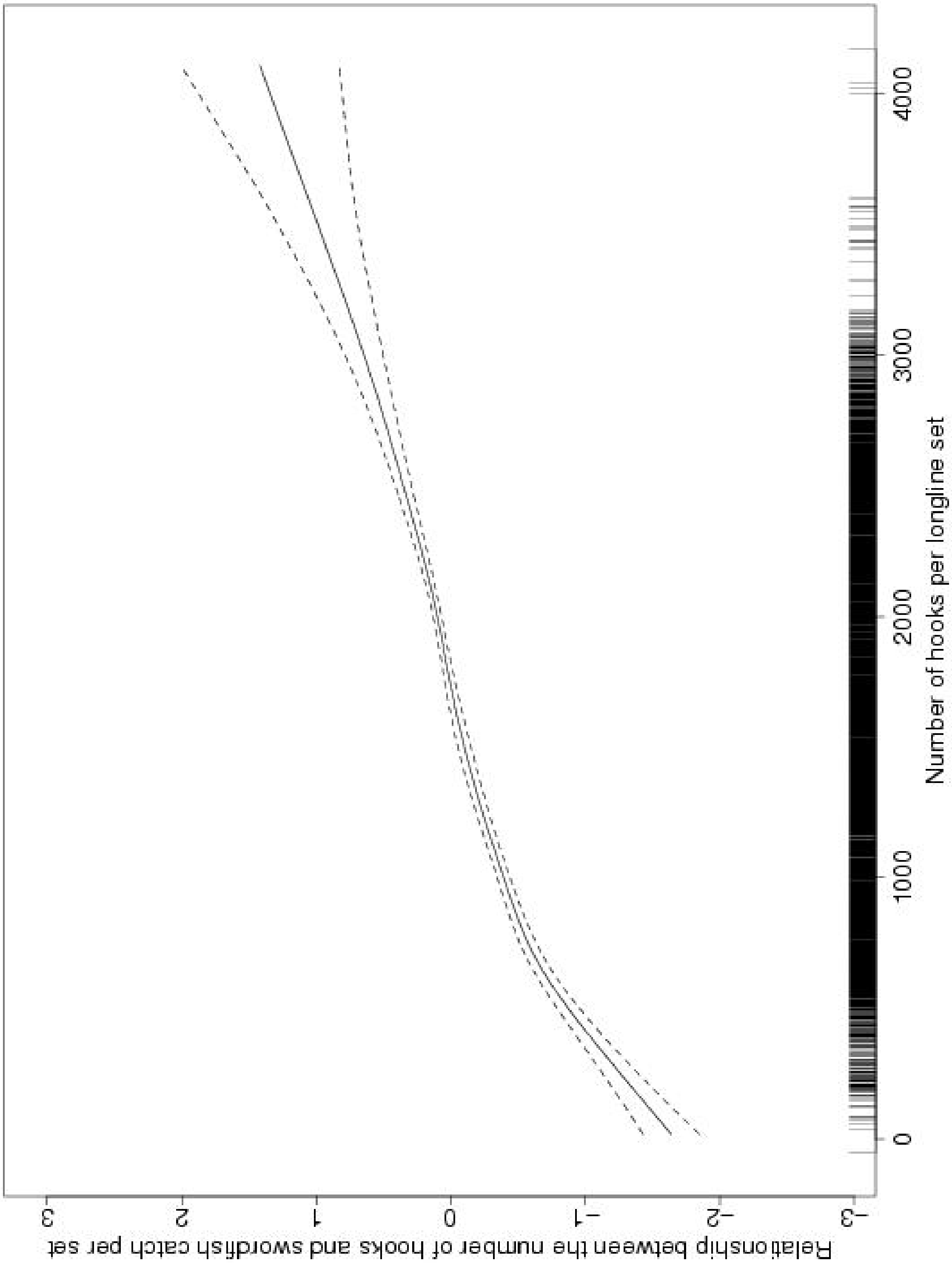

Relationship between the number of hooks and swordfish catch per set
−3
−2
−1
0
1
2
3
Number of hooks per longline set
0
1000
2000
3000
4000

Figure 2f.

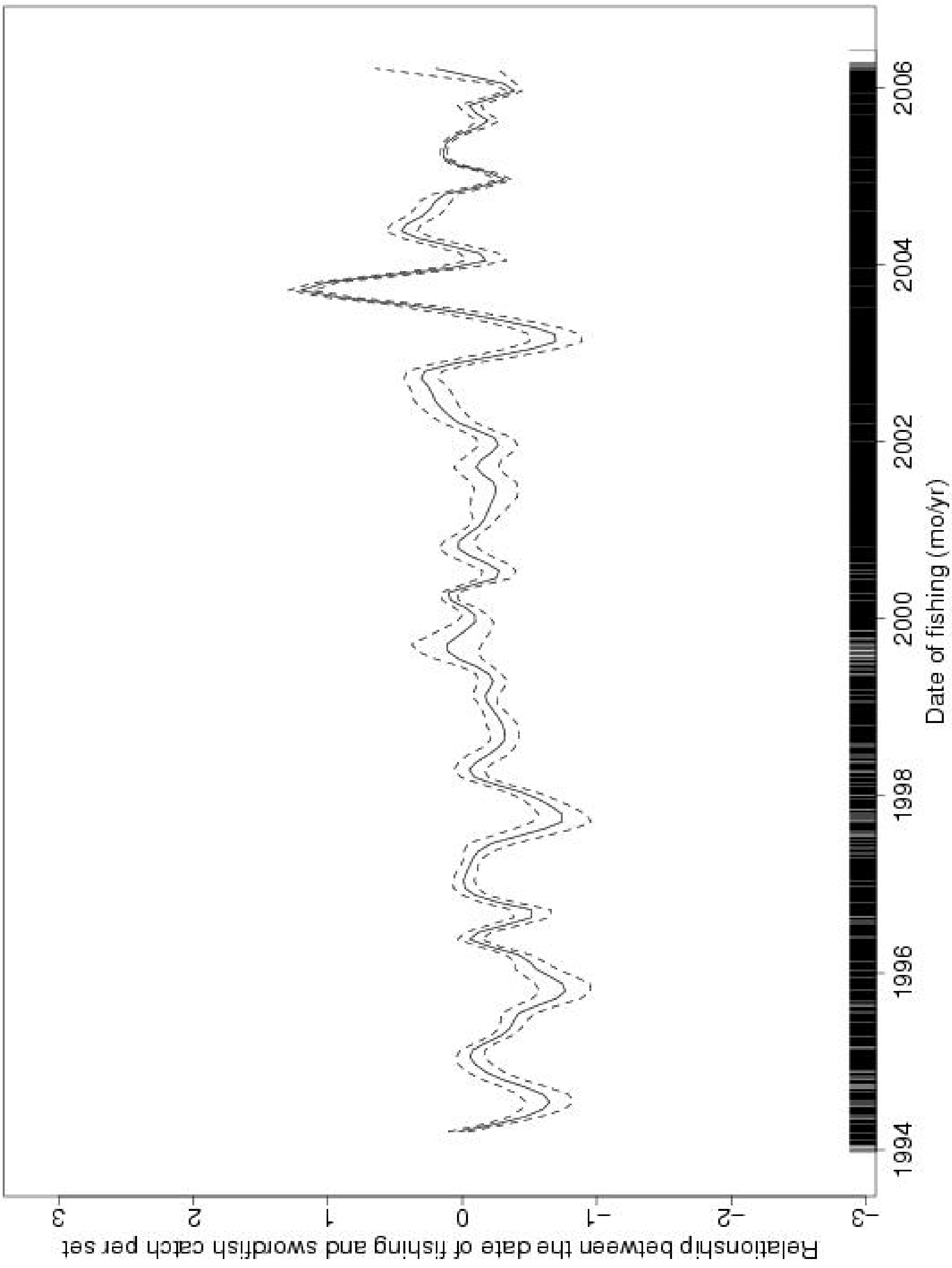
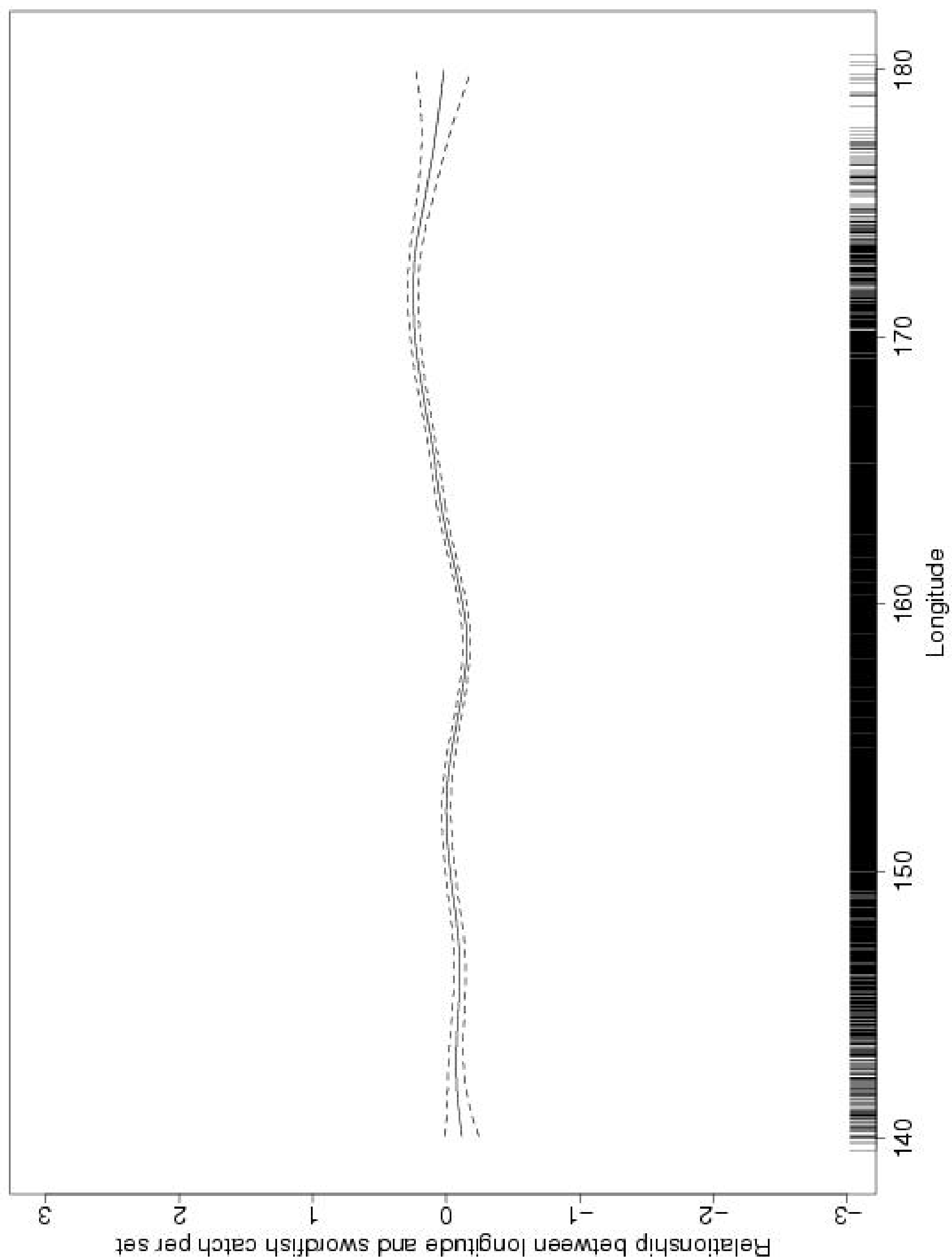

Relationship between the date of fishing and swordfish catch per set
Date of fishing (mo/yr)
1994
1996
1998
2000
2002
2004
2006
−3
−2
−1
0
1
2
3

Figure 2g.



Relationship between longitude and swordfish catch per set
Longitude
140
150
160
170
180
−3
−2
−1
0
1
2
3

Figure 3a.

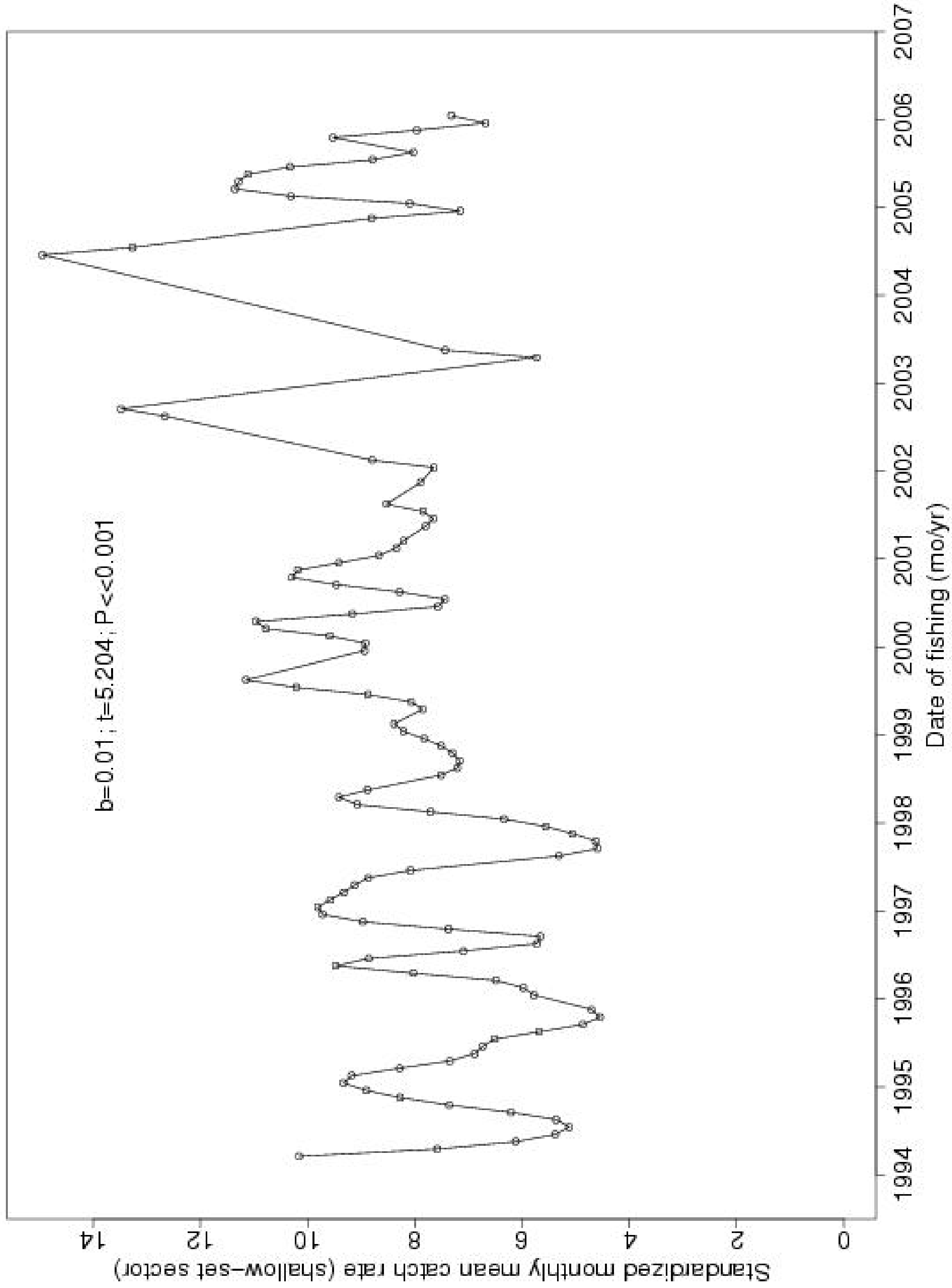
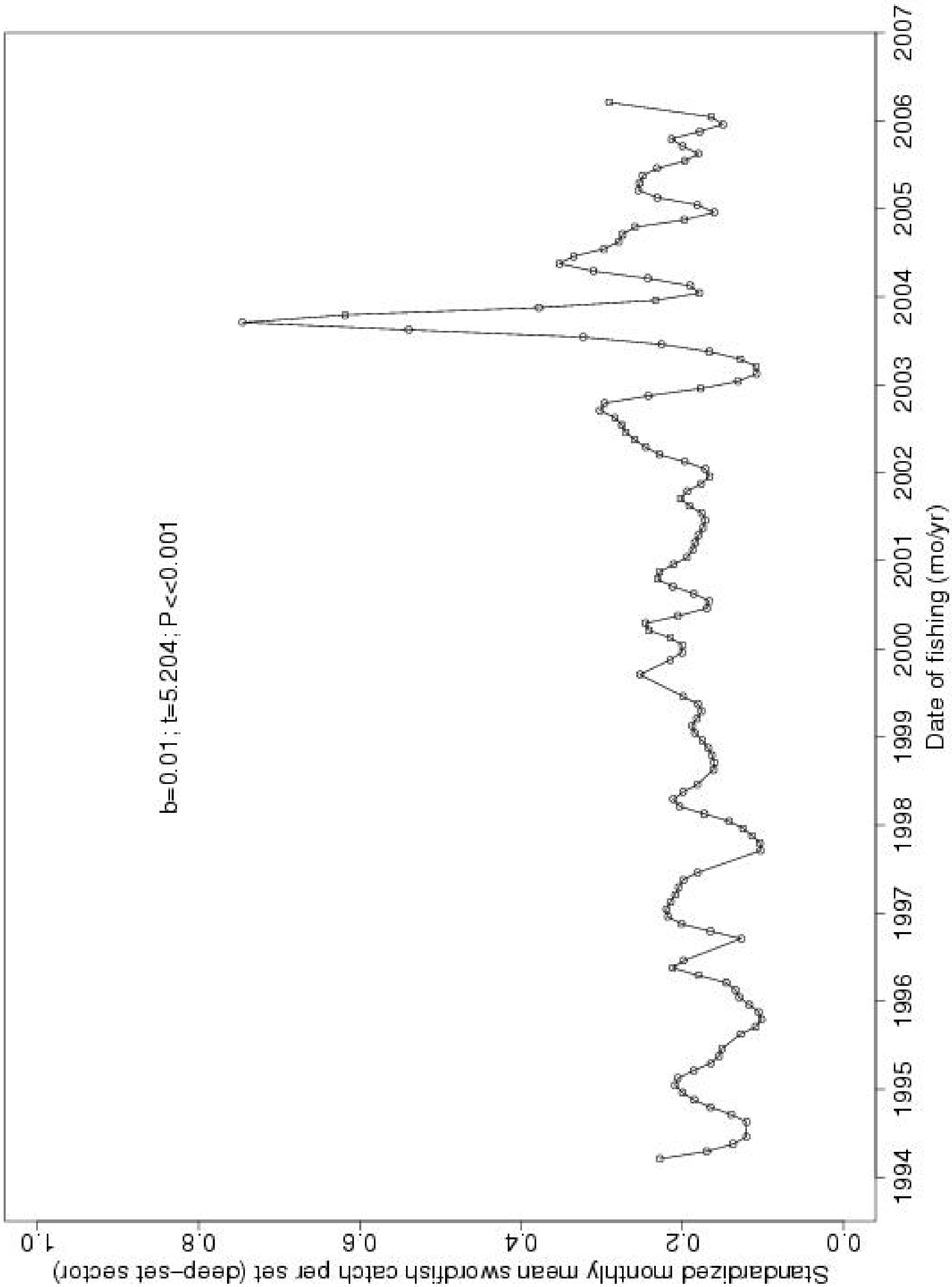

b=0.01; t=5.204; P<<0.001
Date of fishing (mo/yr)
Standardized monthly mean catch rate (shallow−set sector)
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
0
2
4
6
8
10
12
14

Figure 3b.


b=0.01 ; t=5.204 ; P<<0.001
Date of fishing (mo/yr)
Standardized monthly mean swordfish catch per set (deep–set sector)
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
0.0
0.2
0.4
0.6
0.8
1.0