International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

ISC/08/BILLWG-1/04

A comparison of observed catenary angles and estimated angles with a statistical habitat-based standardization model with a multiple species approach

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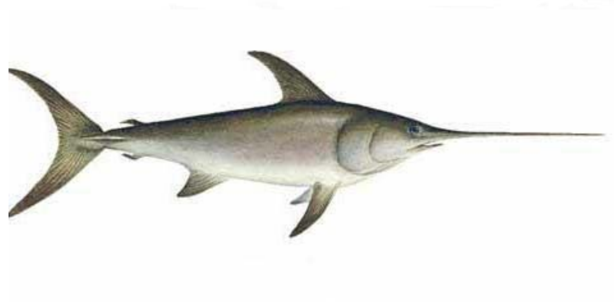

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Abstract

A statistical habitat-based standardization (statHBS) model was applied to eight species to estimate the catenary angle of longline gear depth. Previous statHBS applications have included a deterministic catenary curve, but recent information indicates that Japanese longliners have modified gear components historically over time, by area and season. Introducing multiple species data, which have different longline vulnerabilities provides a wider and more various range of vertical (depth) information into the model. The model was applied to yellowfin, skipjack, bigeye and albacore tuna, striped and blue marlin, shortbill spearfish and blue shark and compared the estimated gear configuration (catenary angle) to a subset of the Japanese training vessel and Hawaii-based tuna fishery that monitored hook depth. The best total likelihood value for Japanese training vessels to the north of 20ºN corresponded to longline gear with a catenary angle of 66º compared to an observed value of 69.1º. The estimated catenary angle for Japanese training vessels to the south of 20ºS was problematic (80º) as this is the largest angle considered in the analysis and larger than the observed angle (66.9º). An angle of 52º was estimated for the Hawaii-based fishery, similar to an observed value of 50.4º. The use of a multiple species approach to estimate actual longline gear depth was encouraging and recommendations for future research are provided.

Introduction

Statistical habitat-based standardization (statHBS; Maunder et. al. 2006) has been used to model CPUE standardization of North Pacific striped marlin caught by Japanese offshore and distant-water longliners (Kanaiwa et al. 2005, Bigelow 2006). The statHBS model contains two submodels: (1) hook depth distribution of the longline gear and (2) depth or habitat-at-capture. The current version of the statHBS model implements a deterministic gear distribution and statistically estimates depth or habitat-at-capture and annual year effects by maximum likelihood. A statHBS analysis of the Japanese distant-water longline fishery concluded that oceanography (e.g. ambient temperature, temperature gradient) had a greater influence on the vertical distribution in catch rates of bigeye tuna and blue shark than depth (Bigelow and Maunder 2007); however, the hook depth distribution remains deterministic in the statHBS framework because the gear sub-model cannot currently be parameterized (non-differentiable in ADMB).

Hook depth distribution is generally unknown in longline fisheries and Goodyear et al. (2002) noted that the weakest component in HBS models may be a quantitative understanding of hook depth distributions and gear behaviors. The comments of Goodyear et al. (2002) are also applicable to other effort and CPUE standardization models such as GLMs/GAMs. Alternative hook depth distributions can be considered in sensitivity analyses, but have typically only been applied in a single species context (Bigelow and Maunder, 2007).

Kanaiwa and Yokawa (2006) extended the statHBS methodology by developing a multispecies (blue marlin, yellowfin tuna and striped marlin) approach to estimate hook depth given that pelagic species have differential habitat envelopes and vulnerability to longline gear. Results from this preliminary study were realistic, shallower gear depth was estimated in temperate N. Pacific areas with deeper gear in the tropics. The purpose of this study is to further expand the multispecies approach to eight species: yellowfin (YFT), skipjack (SKJ), bigeye (BET) and albacore (ALB) tuna, striped (MLS) and blue marlin (BUM), shortbill spearfish (SPF) and blue shark (BSK) and compare the estimated gear configuration (catenary angle) to a subset of the Japanese training vessel and Hawaii-based tuna fishery that monitored hook depth.

Methods

Dataset

This study provides a comparison of observed catenary angles and estimated angles with a statistical habitat-based standardization model with a multiple species approach. The comparison with observed longline gear and several statHBS assumptions relies on a working paper for this workshop (ISC/08/BILLWG−1/03) which describes the study area (Figure 1) and two fisheries (Japanese training vessel and Hawaii-based tuna fishery) analyzed. Briefly, this study considered a total of 4,154 longline sets in the Japanese training vessel fishery from 2000 to 2006 and 18,594 sets in the Hawaii-based tuna fishery from 1995 to 2006 (Table 1). The area of the Japanese fishery was spatially stratified at 20ºN into northern and southern components.

statistical habitat-based (statHBS) standardization methods

The methodology for the calculation of statHBS indices followed Maunder et al. (2007) and previous applications presented to the ISC (Kanaiwa et al., 2005, Bigelow 2006, Kanaiwa and Yokawa 2006). Catch rates are standardized by estimating effective longline effort from the vertical distribution of hooks, species-specific habitat preferences and the vertical, horizontal, and temporal distribution of environmental conditions. The parameters of the model are estimated by fitting to the observed catch. This is accomplished by minimizing the negative log-likelihood. A lognormal likelihood function is used as:

$$-\ln L\left(\boldsymbol{\theta} \mid \tilde{\mathbf{C}}\right)=\sum_{i}\ln[\sigma]+\left[\frac{\left(\ln\left[\tilde{C}_i+\delta\right]-\ln\left[C_i+\delta\right]\right)^2}{2\sigma^2}\right]$$

where $\tilde{C}_i$ is the observed catch and δ is a small constant (1.0, see justification in Maunder et al. 2006) to avoid computational problems when the observed or predicted catch is zero. The standard deviation, σ, of the likelihood function is estimated as a parameter in the model.

For individual observations (*i*) from an effort (*E*) series *j*, an estimate of catch (*C*) in year *y* is obtained as $\hat{C}_{i,j,y} = E_{i,j,y} q_j B_y$, where *q* is overall catchability and *B* is abundance. Year effects ($\theta_y = qB_y$) are estimated because both *q* and *B* are unknown. The negative log-likelihood is minimized by simultaneously estimating various parameters with the function minimizer in AD Model Builder.

Hook depth for each longline set was based on catenary geometry and five associated attributes: hooks between floats (HBF), floatline and branchline length, distance between hooks and catenary angle (sag ratio). The hooks between floats is specific to each longline set and three attributes (floatline and branchline length and distance between hooks) were assumed as mean values (invariant to estimating hook depth) estimated for each fishery (Tables 2−3, Kanaiwa et al. 2008). The vertical distribution of hooks was generated by changing the catenary angle from 24º to 80º by 2º intervals. The depth of catenary hooks was estimated as:

$$D_j = h_a + h_b + 0.5 * L \left\{ \left(1 + \cot^2 \phi\right)^{1/2} - \left[\left(1 - 2\frac{j}{N}\right)^2 + \cot^2 \phi \right]^{1/2} \right\} \quad (3)$$

where D_j is the depth of catenary hook (*j*), h_a is the length of branch line, h_b is the length of float line, *j* is the number of the catenary hook midway between floats and *N* is HBF+1. Figure 2 illustrates the 29 profiles based on mean HBF for the Japanese training vessel (13 HBF) and Hawaii-based tuna fishery (27 HBF). A total of 696 statHBS models were fit to the fisheries data (3 fisheries, 29 gear configurations and 8 species).

Environmental covariates of ambient temperature and thermocline gradient were obtained from the Global Ocean Data Assimilation System (GODAS, (http://cfs.ncep.noaa.gov/cfs/godas/) and processed according to Bigelow and Maunder (2007).

Results

Likelihood (negative log-likelihood) values for each species, gear configuration and fishery are illustrated in Figures 3−5. The best fit in each profile is indicated by the smallest value. The number of parameters is the same within each fishery (37 for the Japanese training vessel, 42 for the Hawaii-based) thus comparisons can be conducted without calculating AIC or BIC statistics. A total likelihood value was calculated by summing individual species likelihoods for each gear configuration (Figures 3−5).

In general, the estimated catenary angles by statHBS were similar to the subset of the fishery that observed catenary angles from longline monitoring (Table 2); however the likelihood profiles by catenary angle differed between areas and fisheries.

Japanese training vessel fishery – northern area

The best total likelihood value for the northern area corresponded to longline gear with a catenary angle of 66º compared to an observed value of 69.1º. Likelihood profiles were flat for yellowfin and skipjack tuna, blue marlin and shortbill spearfish indicating that these species contributed little to the total likelihood trend (Figure 3). These four species were the least caught of the eight species (Table 1). The total likelihood was largely influenced by species distributed deeper in the water column, such as bigeye, albacore, blue shark and striped marlin.

Japanese training vessel fishery – southern area

The best total likelihood value for the southern area corresponded to longline gear with a catenary angle of 80º compared to an observed value of 66.9º. The estimated catenary angle of 80º is problematic as this is the largest angle considered in the analysis. Similar to the northern area, the total likelihood trend is mainly influenced by the deeper species, especially albacore, blue shark and striped marlin (Figure 4).

Hawaii-based tuna fishery

The best total likelihood value for the Hawaii fishery corresponded to longline gear with a catenary angle of 52º compared to an observed value of 50.4º. Contrary to the Japanese fishery, the total likelihood trend was mainly influenced by species that occupy intermediate depths, such as yellowfin, albacore, striped and blue shark (Figure 5). Likelihood values for bigeye tuna indicate a relatively non-informative effect on the total likelihood due to gear configuration.

Additional model diagnostics for longline gear with a catenary angle of 52º were produced for the Hawaii-based fishery (Figures 6−7). The distribution of residuals appears normally distributed for bigeye and blue shark (Figure 6). The remaining species have a longer positive tail and a negative residual mode that is probably related to the model inadequately estimating zero catches, especially for blue marlin. Model residuals in a spatial context are illustrated in Figure 7. There are few spatial trends in residuals for the near-surface species (e.g. yellowfin, skipjack, blue marlin and shortbill spearfish). For the deeper species, the statHBS predicted catch well near the Hawaiian Islands, but residuals were low (bigeye tuna) or high (blue shark and striped marlin) in the eastern and western areas of the fishery, respectively. Albacore had substantial positive residuals in the western area of the fishery.

There was good coherence for five of the eight species between fitted habitat-at-capture and observed habitat-at-capture from a subset of longline sets with TDR monitoring (Figure 8). Warmer habitat-at-capture was predicted for yellowfin, albacore, skipjack, blue shark, blue marlin and spearfish. These fitted trends agree well with TDR monitoring with the exception of yellowfin, albacore and blue shark. Yellowfin and blue shark exhibited no apparent trend in CPUE with depth for the Hawaii-based fishery, though yellowfin TDR results may be biased due to capture on longline deployment or retrieval. Fitted habitat-at-capture for albacore appeared warmer (23º−29ºC) than TDR results. Fitted habitat-at-capture was bimodal for bigeye tuna and a prominent mode from 15º to 21ºC for striped marlin.

Discussion

The use of a multiple species approach to estimate actual longline gear depth is encouraging. In a single species approach, the habitat of a species may not cover the entire vertical range of the longline gear and the model may have an inability to estimate gear depth. However, longline gear can be better estimated in a multiple species approach by taking advantage of longline vulnerabilities than differ amongst species.

The estimated gear depth from the statHBS model was consistent with the observed depth for each fishery, though the Japanese fishery operating in the southern area requires further investigation. Japanese training vessels were estimated to deploy gear with a larger catenary angle than the Hawaii-based fishery which was confirmed in a longline monitoring study (Kanaiwa et al. 2008).

The reason why the estimated catenary angles are larger than observed angles may relate to the implicit use of the catenary formulation (Yoshihara 1951, 1954) and the deepest hook depth. Bigelow et al. (2006) showed that the observed hook's depth is shallower than catenary prediction due to longline shallowing from environmental effects. While theory predicts that the hooks will conform to a catenary shape, in reality the observed distribution of hooks may not conform to a catenary shape. For example, the longline shape may be more flat (i.e. deeper hooks fish at similar depths) than predicted by catenary geometry with an observed catenary angle (Figure 9). Thus, if we estimate the catenary curve based on the observed deepest hook, the predicted catenary angle would be shallower than the true catenary angle. In this study, we used Yoshihara's equation because of the historical use of the catenary assumption but future work should consider alternative formulations to catenary geometry.

Recommendations for future research on multiple species statHBS approach

1) Likelihood weighting.
The likelihoods have been summed to estimate a total likelihood, but this may be too simplistic and likelihood weighting may be preferable (Kanaiwa and Yokawa, 2006). Likelihoods could be weighted by the variability in the habitat-at-capture distribution where more uncertainty in the habitat-at-capture would imply less certainty regarding the depth at which a species was caught.

2) Alternative likelihood functions.
Previous multiple species applications were developed on 5º-month data with a lognormal likelihood. This study used individual longline set data and other GLM error models and link functions may be appropriate (Maunder et al. 2006). Specifically, delta-lognormal methods commonly used in fisheries to deal with zero observations could also be applied with two separate statHBS models with one model used for the proportion of zero observations and a second for positive observations. If the number of individuals caught is small, then likelihoods for count data, such as the Poisson or negative binomial, may be appropriate.

3) Considering floatline and branchline attributes.
This study concentrated on longline depth with regard to catenary angles, but did not incorporate the variability in floatline or branchline lengths. While the largest effect in longline depth would be due to the catenary angle, additional gear sub-models could be tested similar to Kanaiwa and Yokawa (2006) and formulated with the observed variability of floatline and branchline length (Kanaiwa et al. 2008).

4) Spatio-temporal scale of habitat information.
The environmental (GODAS) data had a resolution of 0.3º in latitude and 1º in longitude. Some of Japanese training vessels have observational oceanographic data for temperature at depths and surface salinity. A statHBS analysis with *in situ* data may provide an evaluation of model performance with regard to the resolution of oceanographic data.

5) Use alternative mathematical formulations for hook depth.
Several studies have demonstrated that the true hook distribution is different from a predicted catenary curve (e.g. Matsumoto et al. 2001; Bigelow et al. 2006; Rice et al. 2006). The resulting hook depths are shallower than the predicted catenary geometry and effect estimates of depth and habitat-at-capture. The catenary assumption may be unrealistic and alternative mathematical formulations should be compared. These alternative formulations can be incorporated into the statHBS framework and statistically evaluated.

6) Model comparisons considering spatial aggregation and statistical methods.
In developing habitat-based models or GLMs it is important to stratify areas with relatively homogeneous conditions because a species may have different habitat requirements between tropical, sub-tropical and temperate areas (Yokawa et al. 2005). Standardized CPUE indices within the ISC process are generated with fishing data at various spatial scales (set by set, aggregated over 1º or 5º latitude and longitude). It would beneficial to apply the standardization methods over these spatial scales and methods (GLM, statHBS) in order to compare indices for inclusion into stock assessments (Kanaiwa et al. 2007).

References

Bigelow, K.A. 2006. Comparison of Delta GLM and statistical habitat-based (statHBS) models to estimate standardized CPUE for striped marlin. ISC/06/MAR&SWO-WG/14, 12p.

Bigelow, K. A., M. K. Musyl, F. Poisson and Kleiber, P. 2006 Pelagic longline gear depth and shoaling. Fish.Res.77: 173-183.

Bigelow, K.A. and Maunder, M.N. 2007. Does habitat or depth influence catch rates of pelagic species?, Can. J. Fish. Aqu. Sci. 64:1581−1594.

Goodyear, C.P., Die, D., Kerstetter, D.W., Olson, D.B., Prince, E. and Scott, G. 2002. Habitat standardization of CPUE indices: research needs. Inter. Comm. Cons. Atlan. Tunas, Coll. Vol. Sci. Pap. 55: 613−623.

Rice, P.R., Goodyear, C.P., Prince, E.D., Snodgrass, D. and Serafy, J.E. 2007. Use of Catenary Geometry to Estimate Hook Depth during Near-Surface Pelagic Longline Fishing: Theory versus Practice**.** N. Amer. J. Fish. Man. , 27:1148–1161.

Kanaiwa, M., Bigelow, K. and Yokawa, K. 2008. A comparison of gear configuration and capture by hook, depth and habitat for Japanese training vessel and Hawaii-based tuna longline fisheries. ISC/08/BILLWG−1/03, 21p.

Kanaiwa, M., Takeuchi, Y., Saito, H., Shono, H. and Yokawa, K. 2005. Preliminary results of striped marlin CPUE standardization using a statistical habitat model. ISC/05/MAR&SWO-WG/17, 14p.

Kanaiwa, M., Takeuchi, Y., Ichinokawa, M. and Yokawa, K. 2007. Suggestion for evaluating statistical methods to estimate abundance indices. ISC/07/MARWG&SWOWG−1/12, 3p.

Kanaiwa, M. and Yokawa, K. 2006. Using statHBS with multiple species on same time to estimate catenary curve. ISC/06/MAR&SWO-WG/08, 10p.

Maunder, M.N., Hinton, M.G., Bigelow, K.A. and Langley, A.D. 2006a. Developing indices of abundance using habitat data in a statistical framework. Bull. Mar. Sci. **79**: 545−559.

Matsumoto, T., Uoyumi, Y., Uosaki, K. and Okazaki, M. 2001 Preliminary review of billfish hooking depth measured by small bathythermograph systems attached to longline gear. Collective Volume of Scientific Papers, ICCAT 53: 337−344.

Yokawa, K., Kanaiwa, M., Takeuchi, Y. and Saito, H. 2005. Vertical distribution pattern of CPUE for striped marlin in the North Pacific estimated by the with data of the time, depth, and temperature recorders collected through a longline research cruise of Shoyo-maru in 2004 in the north east Pacific, preliminary results. ISC/05/MAR&SWO-WG/14, 15p.

Yoshihara, T. 1951. Distribution of fishes caught by the long line. II. Vertical distribution. Bull. Japn. Soc. Scien. Fish. 16, 370–374.

Yoshihara, T. 1954. Distribution of catch of tuna longline. IV. On the relation between K and φ_0 with a table and diagram. Bull. Japn. Soc. Scien. Fish. 19, 1012–1014.

Table 1. Number of longline sets and individuals caught by species by Japanese training vessels and the Hawaii-based tuna longline fisheries. A subset of longline sets were monitored with time-depth recorders (TDRs) and have known depth and environmental conditions.

Species	Japan - North		Japan - South		Hawaii	
	Observed	TDR monitored	Observed	TDR monitored	Observed	TDR monitored
Longline sets	1,825	310	2,329	268	18,594	207
Bigeye tuna	42,406	7,542	51,080	6,502	151,705	2,102
Blue shark	8,369	1,292	17,862	2,334	98,539	1,292
Skipjack	381	49	2,643	363	39,191	346
Albacore	3,199	38	11,445	1,190	36,714	853
Yellowfin	1,560	260	10,128	854	34,149	424
Striped marlin	3,978	887	4,366	519	25,399	373
Spearfish	827	139	3,177	439	19,544	227
Blue marlin	358	47	3,554	277	5,324	138

Table 2. Comparison of observed catenary angles and estimated angles with a statistical habitat-based standardization model with a multiple species approach.

	Japan - North	Japan - South	Hawaii
Estimated (statHBS) catenary angle	66º	80º	52º
Observed (TDR) catenary angle	69.1º	66.9º	50.4º

Figure 1. Geographical area of longline analyses for Japanese training vessels and observed Hawaii-based tuna fishery. Japanese data were analyzed as northern (north of 20ºN) and southern (south of 20ºN) areas.

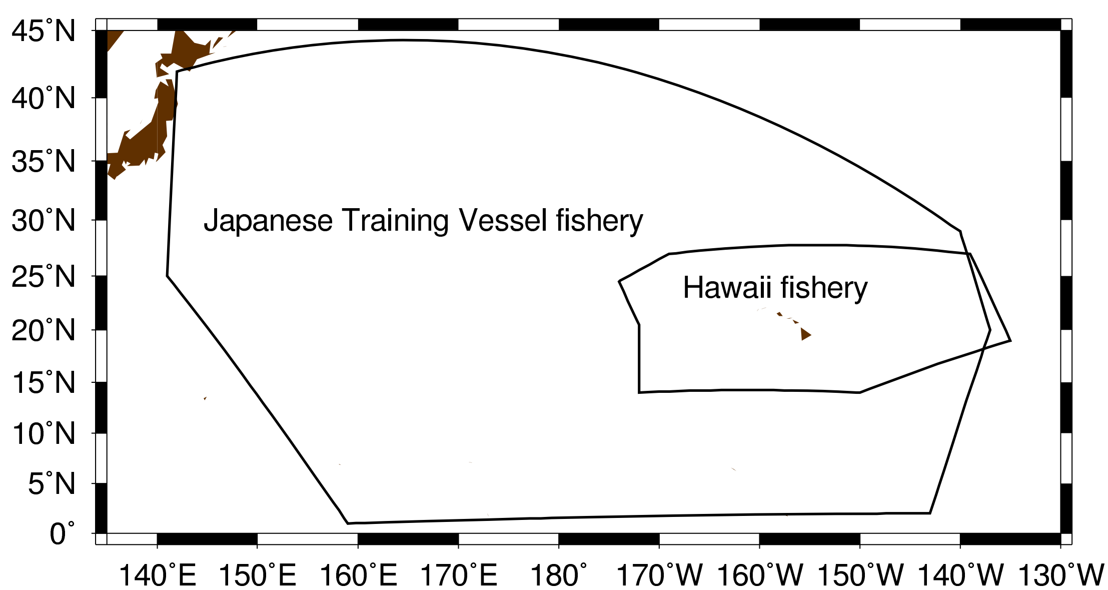

Figure 2. Longline gear configuration considered in a multiple species application of a statistical habitat-based standardization (statHBS) model. Shallowest and deepest gear considered is based on catenary angles of 24º and 80º, respectively.

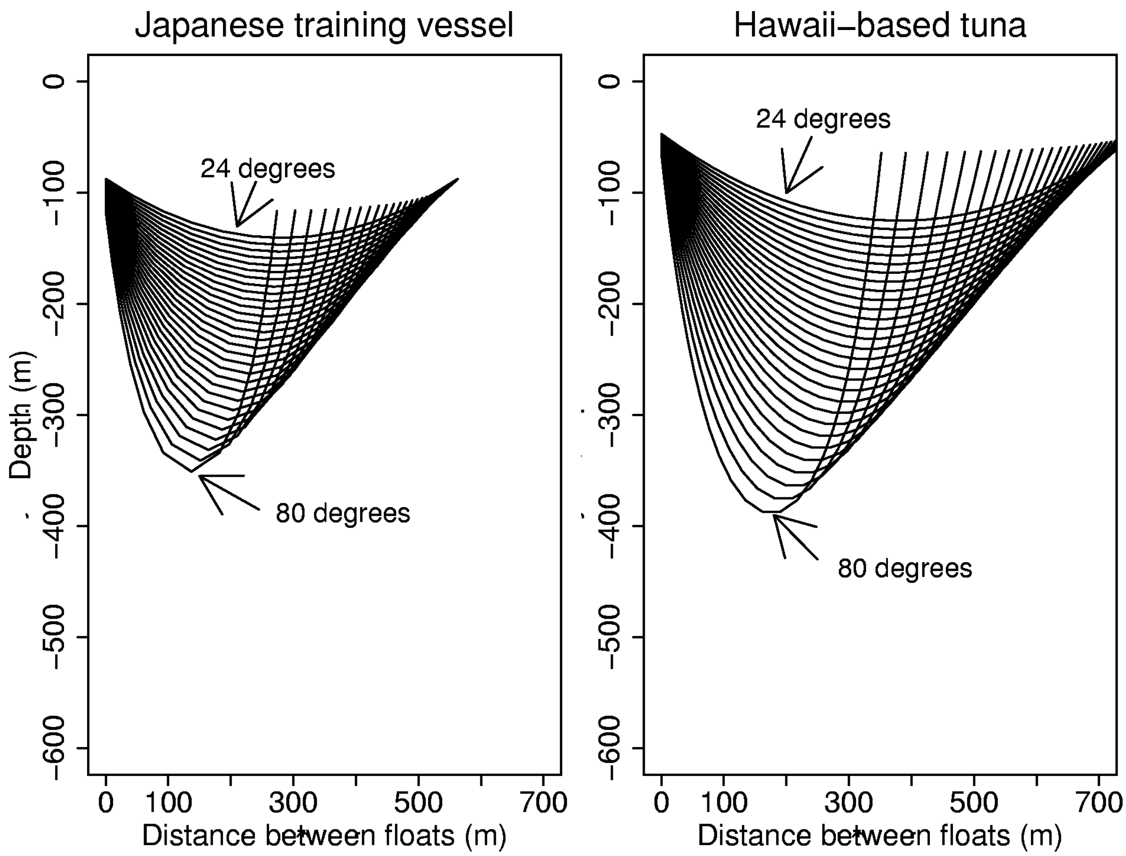

Figure 3. Comparison by species of likelihood values for catenary angles 24º to 80º for a multiple species application of a statistical habitat-based standardization (statHBS) model for the Japanese training vessel fishery to the north of 20ºN.

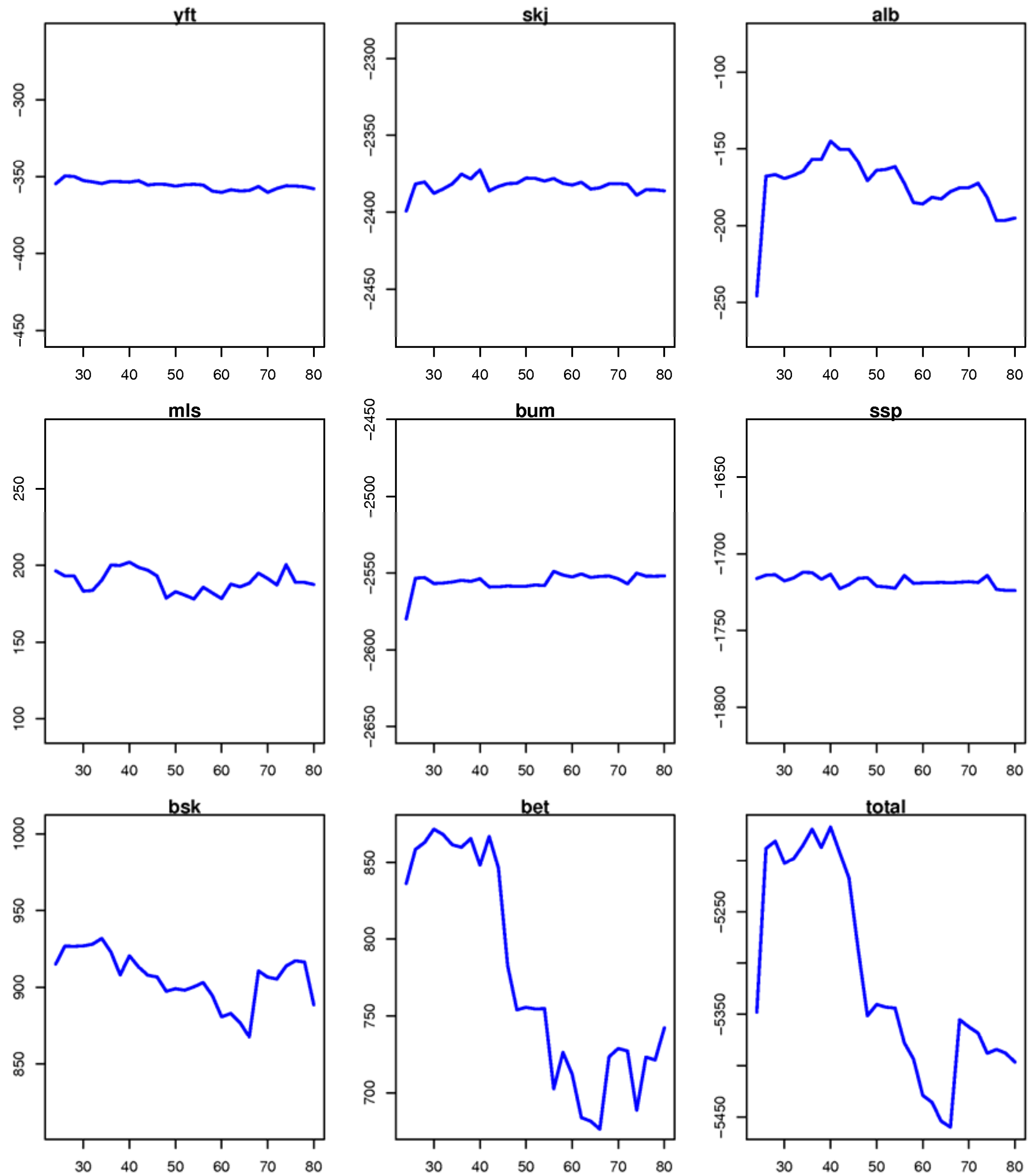

Figure 4. Comparison by species of likelihood values for catenary angles 24º to 80º for a multiple species application of a statistical habitat-based standardization (statHBS) model for the Japanese training vessel fishery to the south of 20ºN.

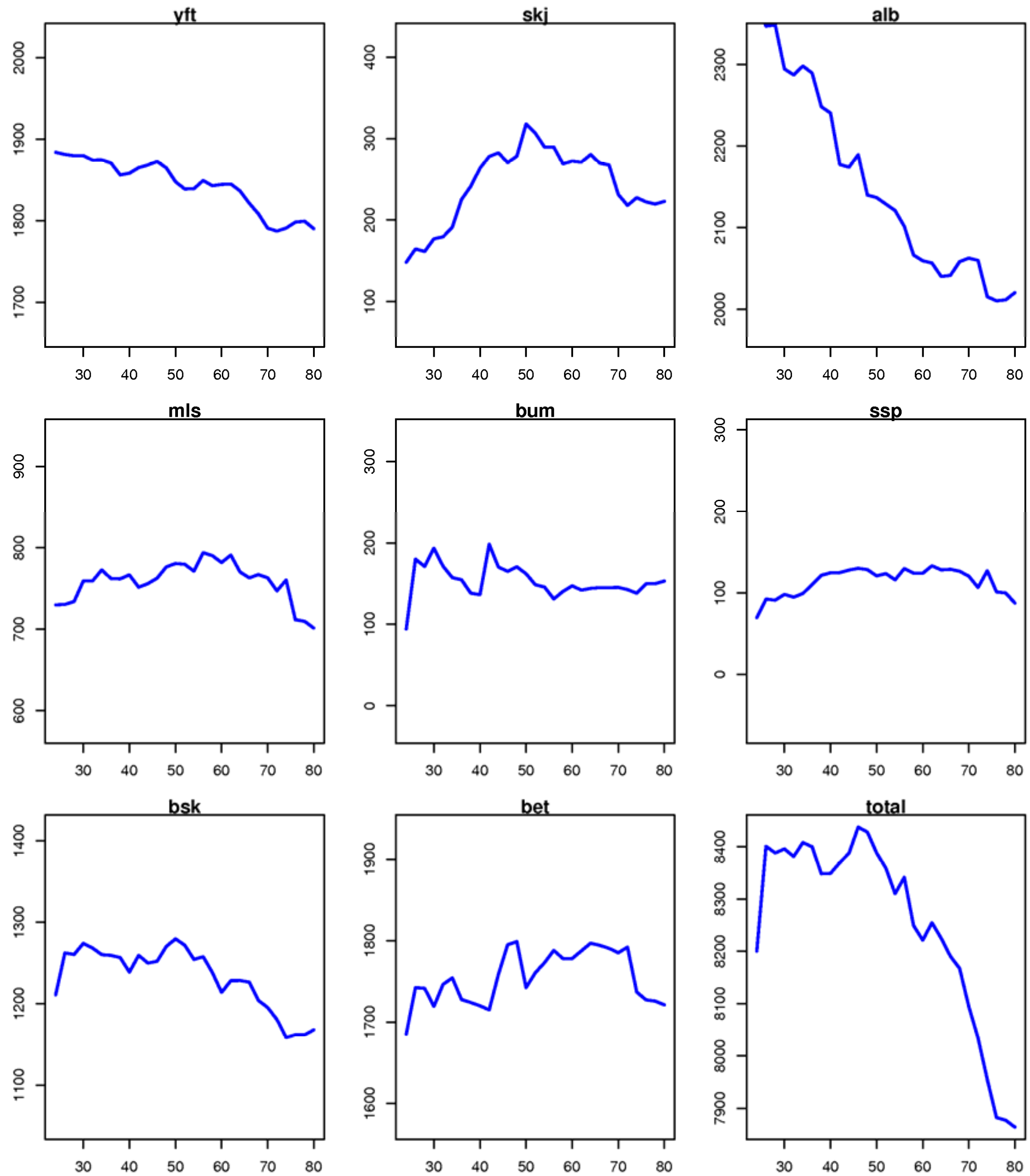

Figure 5. Comparison by species of likelihood values for catenary angles 24º to 80º for a multiple species application of a statistical habitat-based standardization (statHBS) model for the Hawaii-based tuna fishery.

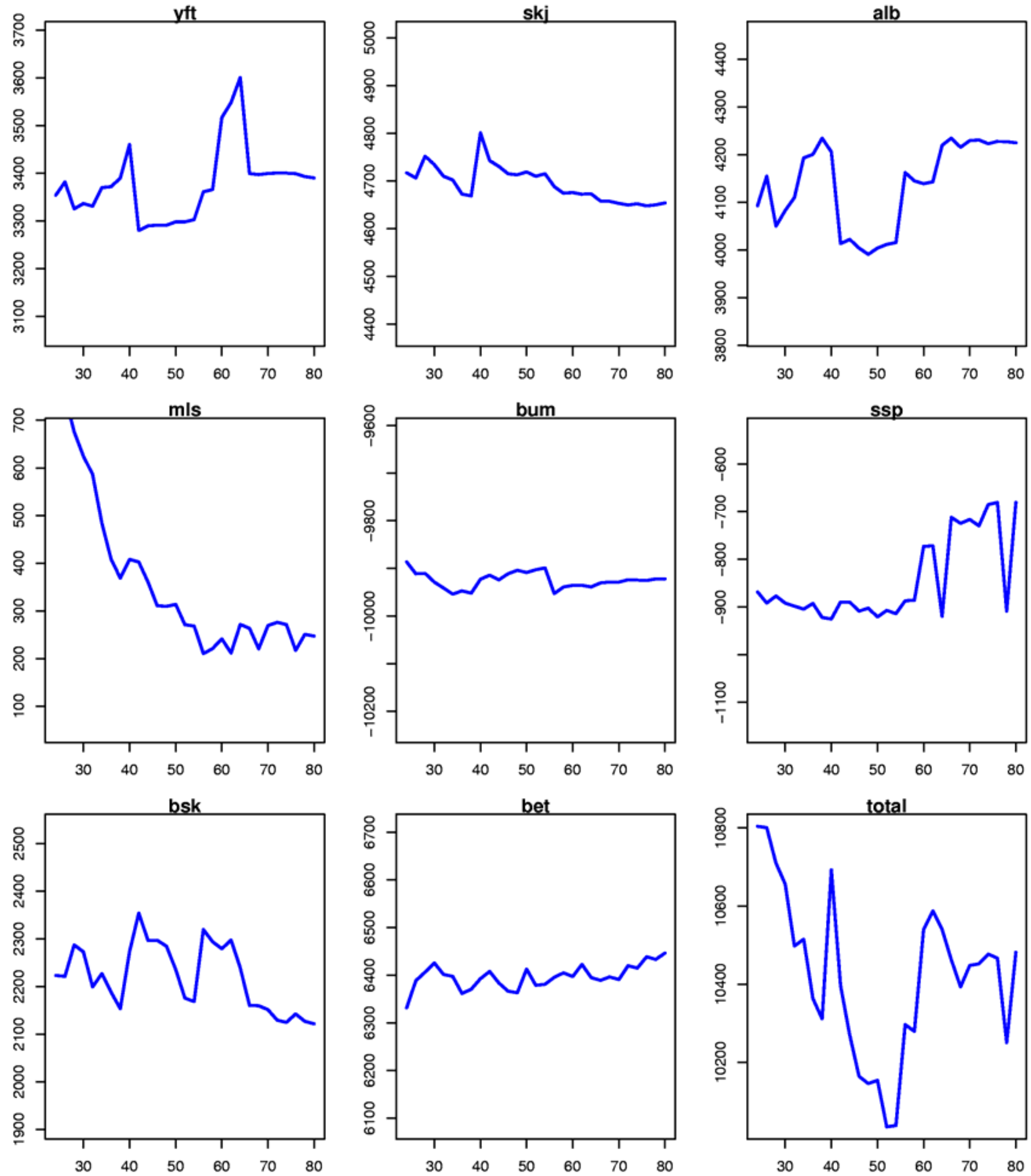

Figure 6. Model diagnostics by species of residuals (log(observed catch+1)-log(estimated catch+1)) and qqnorm for a multiple species application of statistical habitat-based standardization (statHBS) model for the Hawaii-based tuna fishery. Diagnostics are illustrated for the best fit with a longline configuration with a 52º catenary angle.

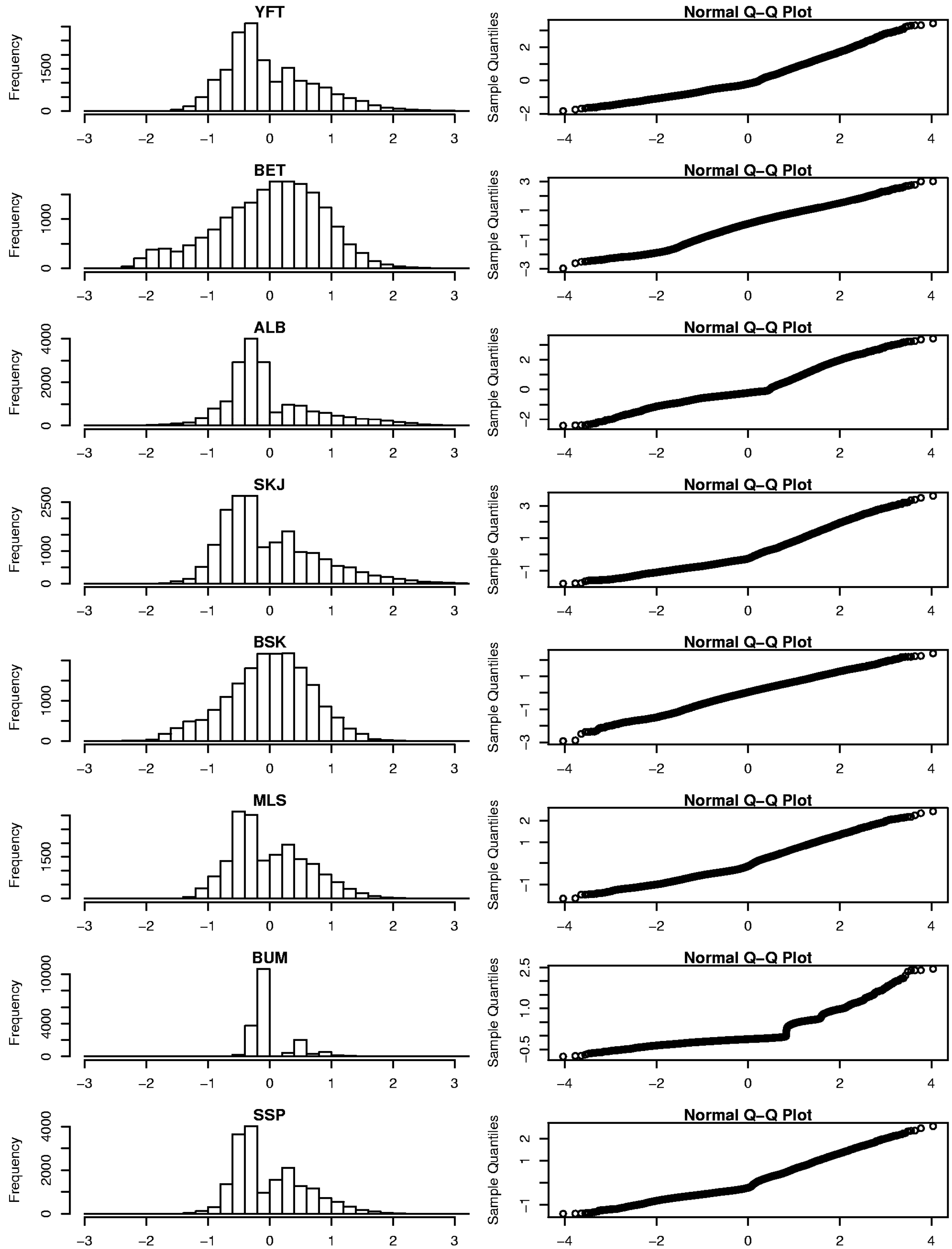

Figure 7. Model diagnostics by species of the spatial distribution of residuals (observed catch-estimated catch) for a multiple species application of statistical habitat-based standardization (statHBS) model for the Hawaii-based tuna fishery. Residuals are estimated as the median for each 1° square for the best fitting model (longline configuration with a 52° catenary angle).

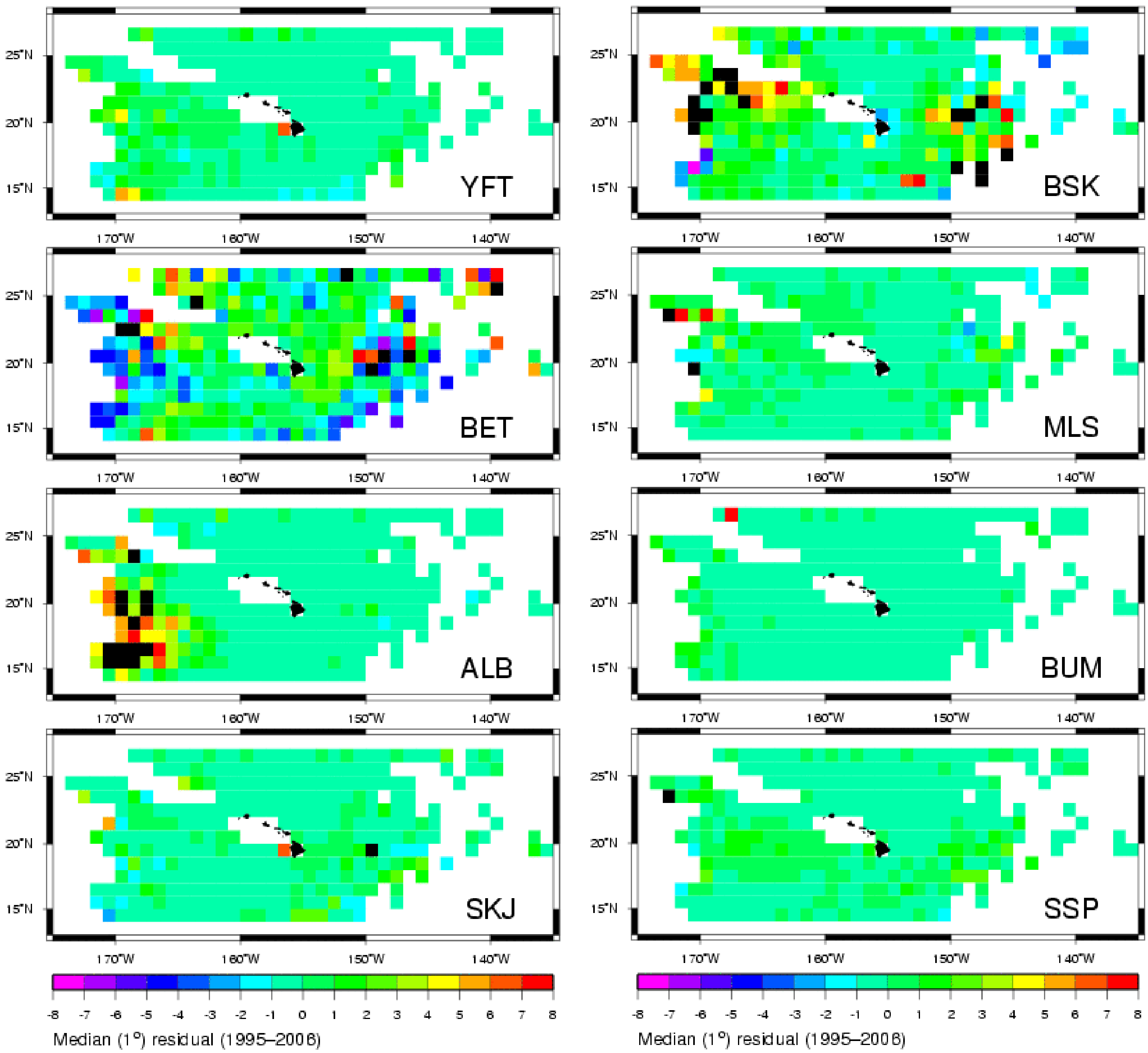

Figure 8. Comparison by species of fitted ambient temperature-at-capture from a multiple species application of statistical habitat-based standardization (statHBS) model and temperature-at-capture from longlines monitored with time-depth-recorders (TDR) in the Hawaii-based tuna fishery.

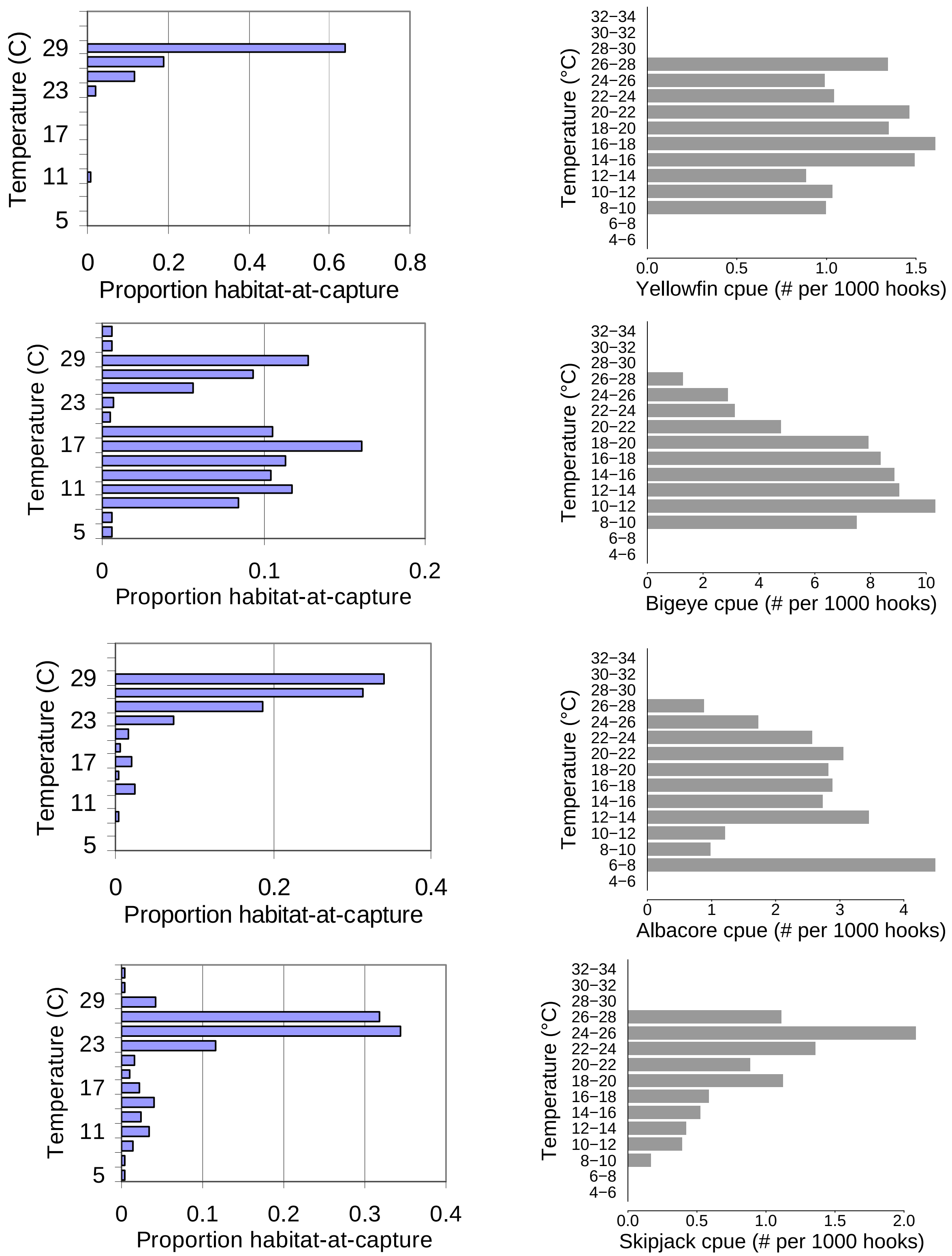

Figure 8 Continued.

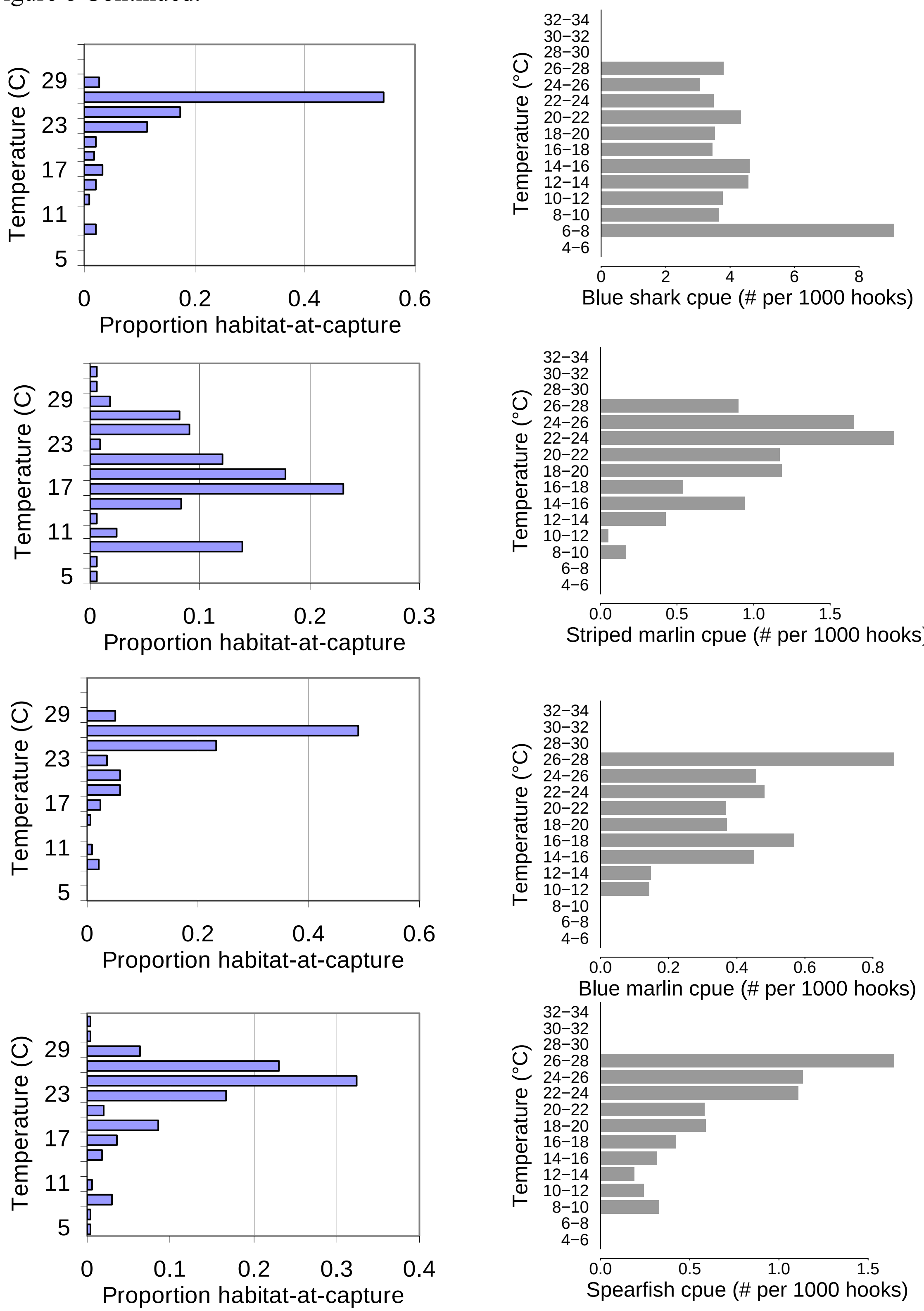

Figure 9. Hypothetical differences in estimating longline shape.