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STOMACH CONTENTS ANALYSIS OF WHITE MARLIN (*TETRAPTURUS ALBIDUS*) CAUGHT OFF SOUTHERN AND SOUTHEASTERN BRAZIL: A BAYESIAN ANALYSIS

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SUMMARY

This study proposes to ascertain the importance of each alimentary category in the Tetrapturus albidus *diet composition, as well as to propose the use of the Bayesian approach for analysis of these data. The stomachs were collected during fishing cruises carried out by the Santos-SP longliner from July 2007 to June 2008. For Bayesian model formulation, each alimentary item was clustered in four food categories as: teleost, cephalopod, crustaceans, and others. To estimate the proportion of each food category, the multinomial model with Dirichlet conjugate prior distribution was used. After the stomach contents analysis, 133 food items were identified, which belonged to 9 taxa. The most important food category is constituted by cephalopod molluscs, followed by teleost fishes. The food category comprised of crustaceans presents a low contribution and in this case it could be considered to be an accidental food item. The Bayesian approach means a distinct view in relation to traditional methods, as it permits one to incorporate information obtained from the literature. It should be useful to analyse great top predators, which are usually caught in small numbers.*

RÉSUMÉ

Cette étude propose de déterminer l'importance des catégories alimentaires dans la composition du régime du Tetrapturus albidus *et propose également d'utiliser l'approche bayésienne pour analyser ces données. Les estomacs ont été recueillis pendant les sorties de pêche réalisées par le palangrier Santos-SP entre le mois de juillet 2007 et le mois de juin 2008. Pour la formulation du modèle bayésien, chaque aliment a été classé dans les quatre catégories alimentaires suivantes : téléostéen, céphalopode, crustacés et autres. Le modèle multinomial employant une distribution a priori combinée de Dirichlet a été utilisé pour estimer la proportion de chaque catégorie alimentaire. Au terme de l'analyse des contenus des estomacs, 133 aliments ont été identifiés qui appartenaient à 9 taxons. La catégorie alimentaire la plus importante est composée des mollusques céphalopodes, suivis des poissons téléostéens. La catégorie alimentaire composée des crustacés présente une contribution faible et il conviendrait dans ce cas-là de la considérer comme étant un aliment accidentel. L'approche bayésienne constitue une vision différente par rapport aux méthodes traditionnelles, car elle permet d'intégrer les informations obtenues dans les publications. Il serait utile d'analyser les principaux grands prédateurs, dont un nombre limité est généralement capturé.*

RESUMEN

Este estudio pretende determinar la importancia de cada categoría alimentaria en la composición de la dieta de Tetrapturus albidus*, así como proponer el uso de un enfoque bayesiano para el análisis de estos datos. Los estómagos se recogieron durante los cruceros de pesca realizados por el palangrero Santos-SP desde julio de 2007 a junio de 2008. Para la formulación del modelo bayesiano, cada producto alimentario se agrupó en cuatro categorías de alimentos como: teleósteos, cefalópodos, crustáceos y otros. Para estimar la proporción de cada cada categoría alimentaria, se utilizó un modelo multinomial con una distribución previa conjugada Dirchlet. Tras el análisis de los contenidos estomacales, se identificaron 133 productos alimentarios que pertenecían a 9 taxones. La categoría alimentaria más importantes estaba constituida por cefalópodos y moluscos, seguidos por los teleósteos. La categoría alimentaria formada por crustáceos presentaba una contribución baja y en este caso podría*

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considerarse un producto de alimentación accidental. El enfoque bayesiano implica una visión diferente que la de los métodos tradicionales, ya que permite incorporar información obtenida de la bibliografía. Sería útil analizar a los principales grandes predadores, que generalmente se capturan en pequeño número.

KEYWORDS

Stomach contents, white marlin, longliner, Bayesian approach

1. Introduction

The white marlin (*Tetrapturus albidus*, Poey 1860) caught by pelagic longliner in the southern and southeastern off Brazil constitutes about 2% (in weight) of the pelagic fishes present by such captures in this region (Amorim and Arfelli, 2003). According to these authors the CPUE of the white marlin ranged from 23 to 57 kg per thousand hooks between 1995 to 1999.

Pelagic oceanic species of white marlins are often found in wide open blue waters over 100 m whose surface temperatures attain more than 22°C, and are known to occur in ocean fronts, and near steep drop offs, submarine canyons and shoals for feeding concentrations (Nakamura 1985). However, the habitat preferences of billfish are poorly known compared to those used by tuna. This should be one of the main reasons to keep and rear such species in captivity (Arocha and Ortiz, 2006).

According to Garcia de los Salmones *et al.* (1989) the white marlin are behave as predators and they opportunistically prey on schooling stocks of flying fishes, small tunas, dolphinfish, and squids. In the northeastern United States, most prey items include the round herring (*Etrumerus teres*) and the squid (*Loligo pealei*), as well as *Dactylopterus volitans* (De Sylva and Davis 1963). Other prey items include, moon fishes, puffer fishes, pomfret fishes, snake mackerels, and deep water red prawns.

In the North and tropical Atlantic, about 57% of the diet was composed by fish prey and most of the remaining by cephalopods (42%). Among prey fish, species of the families Bramidae followed by the Gempylidae comprised over 75% in importance (Satoh *et al*. 2004).

Studies of the feeding of the Istiophoridae in Brazil have provided faunistic lists of prey. Zavala-Camin (1981) described the identification of partially digested fish specimens in the diet of Istiophorid species in the south and southeast regions of the West Atlantic coast. In this study the author verified the white marlin diet composed mainly by fish (66% of occurrence) followed by cephalopods (38% of occurrence). The predominance was represented by species from the families Scombridae, Carangidae and Monachantidae.

This study proposes to describe (1) diet compositions of white marlin, (2) ascertaining the importance of each alimentary category for the diet composition, and (3) to propose the use of the Bayesian approach for analysis of fish stomach contents.

2. Material and methods

2.1 Study site

This study was carried out in association with the longliner commercial fleet settled in Santos-SP. This fleet operates in the south-eastern and southern coast of Brazil, including the area comprised within 17-35° S and 27-52° W, at the side of the continental platform **(Figure 1)**. According to the autonomy of each boat, the trips extend from 15 to 20 days, limiting the fishing distance.

2.2 Feeding analysis

Fish were collected during fishing cruises accomplished by the longliner fleet of Santos-SP, from July of 2007 to June of 2008. The collection of the stomachs was made during the evisceration, after the shipment of fish. The stomach was labeled, closed with nylon line and deposited in a 50 l box containing a formalin solution at 10%.

In the laboratory the stomach contents were washed and drizzled in mesh of 1 mm and conditioned in flasks with alcohol 70%. The whole material kept has been identified until the smallest possible taxa, following criteria adopted for Nesis (1987), Figueiredo and Menezes (2000), Figueiredo *et al.* (2002) and Vaske-Junior (2006). For Bayesian model formulation, each alimentary item was clustered in four food categories previously defined as: (1) Teleost fishes; (2) Cephalopod molluscs; (3) Crustaceans; and (4) Others.

2.3 Bayesian inference

Multinomial model

To estimate the proportion of each food category of white marlin, the count vector is defined as $Y_i = (Y_{i1}, Y_{i2}, Y_{i3}, Y_{i4})$, where Y_{ij} represents the number of the item in category j in the stomach i (i = 1, ...7 and j = 1, ..., 4) and considered as the multinomial model with parameters $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$, given by:

$$(1) \qquad f(Y|\theta) = \frac{n!}{y_1!\, y_2!\, y_3!\, y_4!}\prod_{j=1}^{4}\theta_j^{yi}, \quad j = 1,2,3$$

where

$$(2) \qquad \sum_{j=1}^{4}\theta_j = 1 \qquad and \qquad \sum_{j=1}^{4} y_j = n, 0 \leq y_j \leq n$$

Likelihood function

The multinomial likelihood function is given by:

$$(3) \qquad L(Y|\theta) = \prod_{i=1}^{7}\prod_{j=1}^{4}\frac{n!}{y_{ij}!}\theta_j^{yij}; \quad i = 1\ldots,7; \quad j = 1,\ldots,4$$

or is considered to be the log-likelihood function,

$$(4) \qquad \ln L(Y|\theta) = \left\{ln(n!) - \sum_{i=1}^{7}\sum_{j=1}^{4} ln(y_{ij}!)\right\}\sum_{i=1}^{7}\sum_{j=1}^{4} y_{ij}\ ln(\theta_j)$$

The prior distribution

For the Bayesian approach of multinomial model one considers the parameters $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$ as random quantities and quantify the uncertainty of the parameter's values in the form of a prior distribution that represents some prior knowledge about θ (Box and Tiao, 1973; O'Hagan, 1994 and Paulino *et al.*, 2003). One can adopt the *Dirichlet* ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) joint prior distribution for θ, written as follows

$$(5) \qquad \pi_0(\theta_1, \theta_2, \theta_3, \theta_4) \propto \prod_{j=1}^{4}\theta_j^{\alpha j-1}, \theta_j \geq 0 \quad and \quad \sum_{j=1}^{4}\theta_j = 1$$

The hyperparameters ($\alpha_1, \alpha_2, \alpha_3, \alpha_4$) are given by:

$$(6) \qquad \alpha_j = \alpha E(\theta_j), \qquad j = 1,\ldots,4 \quad with \quad \alpha = \sum_{j=1}^{4}\alpha_j$$

With α fixed and expert information one defines the priori means (Zavala-Camin,1981; Vaske-Junior, 2000 and Satoh *et al.*, 2004).

The joint posterior distribution

We combine the multinomial likelihood function (3) is combined with the *Dirichlet* prior distribution (5) to obtain the joint posterior distribution for $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$ that is:

$$(7) \qquad \pi(\theta|Y) \propto \prod_{j=1}^{4} \frac{n!}{y_j!} \theta_j^{(\alpha j + yj) - 1}, \theta_j \geq 0, \qquad \sum_{j=1}^{4} \theta_j = 1 \quad and \quad n = \sum_{j=1}^{4} y_i$$

The marginal posterior distributions

The marginal posterior distribution for θ_j is the Beta distribution with parameters $A_j = \alpha_j + y_j$ and $B_j = a + n - (\alpha_j + y_j)$, with $\alpha = \sum_j \alpha_j$:

$$(8) \qquad \pi(\theta_j) = \frac{1}{B(A_j, B_j)} \theta_j^{A_j - 1} (1 - \theta_j)^{B_j - 1}, \qquad 0 \leq \theta_j \leq 1 \quad and \quad j = 1, \ldots, 4$$

The posterior mean and variance for θ_j are given by:

$$(9) \qquad E(\theta_j) = \frac{\alpha_j + y_j}{\alpha + n} \qquad and \qquad V(\theta_j) = \frac{(\alpha_j + y_j)(\alpha + n - \alpha_j - y_j)}{(\alpha + n)^2 (\alpha + n + 1)}$$

In order to obtain the 95% credibility intervals (95% Cred I) estimates, one gets the 2.5 – *percentile* and the 97.5 – *percentile* of $\pi(\theta_j)$, j = 1, ..., 4.

2.4 Classical inference

To compare the results one considers the classical inference approach (Bickel and Doksum, 2001). The maximum likelihood estimators (MLE) for the multinomial model parameters $\theta = (\theta_1, \theta_2, \theta_3, \theta_4)$ are given by:

$$(10) \qquad \hat{\theta}_j = \frac{y_j}{n}$$

The variance of the estimators is calculated using de asymptotic normality property of the MLE:

$$(11) \qquad \hat{\theta}_j \sim N[\theta_j, I^{-1}(\hat{\theta}_j)]$$

where $I(\theta)$ is the Fisher information matrix given by,

$$(12) \qquad I(\theta) = -E\left(\frac{\partial^2 \ln L(Y/\theta)}{\partial \theta^2}\right)$$

The Fisher information matrix considering the log-likelihood function in (4) is:

$$(13) \qquad I(\theta) = \begin{pmatrix} y_1/\theta_1^2 & 0 & 0 & 0 \\ 0 & y_2/\theta_2^2 & 0 & 0 \\ 0 & 0 & y_3/\theta_3^2 & 0 \\ 0 & 0 & 0 & y_4/\theta_4^2 \end{pmatrix}$$

The $I^{-1}(\theta_j)$ is the element I_{jj}^{-1} in the matrix $I(\theta)$ and the variance of the estimator is given by $V(\hat{\theta}_j) = \hat{\theta}_j^2 / y_j$. Then, the γ% confidence intervals for the proportions θj can be calculated with:

$$(14) \qquad \hat{\theta}_j \pm z_\gamma \frac{\hat{\theta}_j}{\sqrt{y_j}}, \qquad j = 1, \ldots, 4$$

where z_γ is the Normal percentile (γ).

Confidence intervals are asymptotic (10) and often the sample sizes are not that large. This is one of the reasons why we are proposing a Bayesian approach, considering an informative prior probability density function.

3. Results and discussions

The white marlins caught were 10 individuals whose size varied from 150 to 231 centimetres. After the stomach contents analysis 133 food items were identified, which belonged to 9 taxa. They were mainly composed by molluscs and fish (see details in **Table 1**). Strange objects like wood and plastic pieces were also detected, in 42% of the analysed stomachs.

In **Table 2** classic and Bayesian results are presented to permit estimations for the proportions of each alimentary category of the white marlin: EMV and their confidence intervals ($\gamma = 95\%$); and the posterior mode (PM) and its credibility intervals ($\gamma = 95\%$). Following the calculation, the most important food category of *T. albidus* is constituted by cephalopod molluscs (PM= 0.5166), followed by teleost fishes. (PM = 0.4506). Such information disagrees to the results obtained by Zavala-Camin (1981), Salmones *et al.* (1989), Vaske-Junior (2000) and Satoh *et al.* (2004), who registered fish (Bramidae, Clupeidae, Scombridae and Gempyliidae as their main food sources and then followed by cephalopods. Such a change of the importance of food composition may be related to the lower availability among other factors, as well which may oblige white marlins to depend on other resources.

In any case, the fact given by the great importance of such cephalopods may reinforce, besides the relationship predator prey, an hypothesis that this Istiophoridae species displays an epipelagic behavior, as such molluscs use to perform vertical migrations, remaining close to the sea surface during night and at deeper places during the clear hours of the day (Vaske-Junior *et al.*, 2004).

The food category composed by crustaceans presents a low contribution for the white marlin feeding habit (PM = 0.0166) (Table 2), and in this case it could be considered to be an accidental food item, which corroborates results obtained by Sylva and Davis (1963), who did not even register crustaceans to be present within the stomach contents of 73 specimens of *T. albidus* caught at the Atlantic ocean. Following such authors one may consider that the inexistence of gill rakers in Istiophorids may also be show that such fish do not use to retain easily small organisms even when accidentally swallowed, So, such organisms do not constitute their potentially prey due to their relatively low size (<1 cm), though their relative abundance

Besides the information obtained with relation to the feeding of white marlins, this study tries to introduce the statistic technique known as Bayesian approach whose purpose is to give a distinct statistic treatment to data obtained from studies of fish feeding. This approach means a distinct view in relation to traditional methods (see Cortés, 1997), as it permits one to incorporate information obtained from the literature. It should be useful to analyse great top predators, which are usually caught in small numbers.

It should also be emphasised that the Bayesian inference presented an amplification to the intervals of credibility (Cred I) when compared to the classic inference (CI) (see **Table 2**), giving the opportunity to more conclusive information.

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As demonstrated by the methodology, the Bayesian formulation is totally based on numerical percentages for each food category. Other studies under development (Gorni and Loibel, *in prep.*) are going to bring the utilization at a conjunct form, either by its numerical metric, or by the percentage of the weight of each registered food item, a more complete analysis for the biological point of view.

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Table 1. Prey items in the white marlin stomachs.

Prey taxa
Chordata: Teleost fish
Scombridae: *Scomber colias*
Pomatomidae
Monacanthidae: *Stephanolepis* sp.
Unidentified fish
Urochordata: Salpa
Mollusca: Cephalopoda
Order Teuthida
Mollusca: Gastropoda
Arthropoda: Crustacea
Other

Table 2. Summaries of classic and Bayesian inferences.

Proportion	*MLE*	*CI (95%)*	*Posterior Mode*	*Cred I (95%)*
θ_1 (Teleost fish)	0.1579	(0.0000 ; 0.4366)	0.4506	(0.3806 ; 0.4919)
θ_2 (Cephalopoda)	0.7444	(0.6773 ; 0.8115)	0.5166	(0.4626 ; 0.5688)
θ_3 (Crustacea)	0.0150	(0.0000 ; 0.0440)	0.0166	(0.0062 ; 0.0354)
θ_4 (Other)	0.0827	(0.0803 ; 0.0851)	0.0362	(0.0195 ; 0.0637)

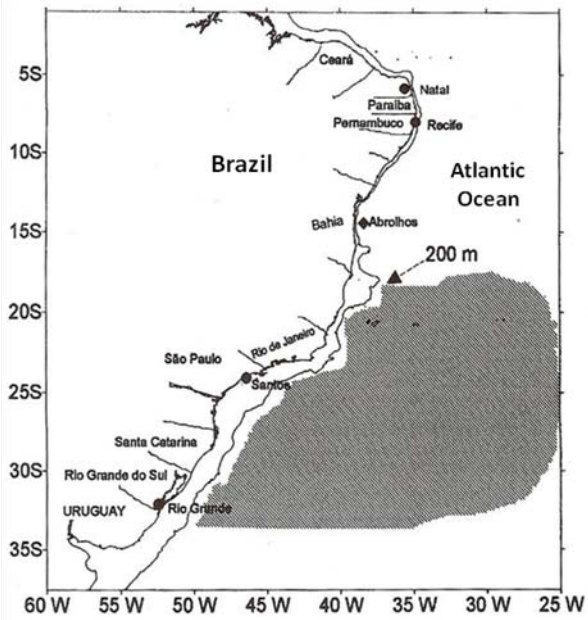

Figure 1. Fishing area of the longliner fleet of Santos - SP (adapted of Amorim *et al.*, 1998).