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Billfish CPUE standardization in the Hawaii longline fishery: Model selection and multimodel inference

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ABSTRACT

This paper presents catch per unit effort (CPUE) standardizations and model selection procedures for four billfish species (Family Istiophoridae) caught primarily as bycatch in the Hawaii-based pelagic longline fishery during 1995–2011: Blue marlin *Makaira nigricans*; Striped marlin *Kajikia audax*; Shortbill spearfish *Tetrapturus angustirostris*; and Sailfish *Istiophorus platypterus*. The first three species were analyzed on a fishery-wide basis. For sailfish, the fishery data came exclusively from tuna-targeted longline sets in the deep-set sector of the Hawaii-based fishery. We used fishery observer data from the NOAA Fisheries Pacific Islands Regional Observer Program to fit the CPUE standardization models. In this context, our objective was to investigate the quality of model fit for five types of generalized linear models (GLMs: Poisson; negative binomial; zero-inflated Poisson; zero-inflated negative binomial; delta-Gamma). Each of these models represented a different hypothesis about the capture process for a bycatch species for which the catch data primarily consisted of zero catch observations. The five GLMs were fitted by forward entry variable selection, and the best fitting GLM for each species was selected on the basis of Akaike Information Criterion values and calculated Akaike weights. The best-fitting model selected for each species was a zero-inflated negative binomial GLM (ZINB). The ZINB model was comprised of a negative binomial counts model for expected zero catch sets and a positive catch per set distribution along with a binomial inflation model to account for excess zeros. For each species, the important explanatory variables for standardizing CPUE were fishing year, fishing (i.e., calendar) quarter, and fishing region. The best-fitting models indicated that standardized CPUE for striped and blue marlins decreased significantly during the study period. Because the ZINB model was selected as the best fitting model for all species, we suggest that longline CPUE for incidentally caught billfishes is best represented as a process characterized by zero inflation and overdispersion in the positive catches and expected zero catches. We therefore recommend that ZINB models be considered as an *a priori* model for CPUE standardizations of billfishes and other bycatch species in longline fisheries.

1. Introduction

Population status of billfishes (Class Actinopterygii; Division Teleostei; Order Perciformes; Suborder Xiphioidei; Family Istiophoridae), as with many other non-target species, is often inferred from time series of standardized catch rates because costs associated with fishery-independent surveys are prohibitive (Lynch et al., 2012). Even in this context of reliance upon fishery-dependent data, where non-random sampling, fishermen's behavior, and gear selectivity may adversely affect sample representativeness (Jennings et al., 2001), billfishes present at least three additional, potentially serious challenges. First, their migratory behaviors may not coincide with those of target species. Second, large numbers of zero catches are common (Lynch et al., 2012). Third, the external morphological similarities that have long caused taxonomic confusion among marlin species (Royce, 1957) continue to engender species misidentifications, as documented for marlins in the Hawaii-based pelagic longline fishery (Walsh et al., 2005, 2007) and spearfishes along the mid-Atlantic coast of the United States (Shivji et al., 2006).

Catch per unit effort (CPUE) standardization analyses for bycatch species caught in low numbers, such as billfishes, were reviewed by Maunder and Punt (2004). Their recommendations for standardizing such catches included use of mixture models that analyze the proportions of zeros and the positive catch rates separately (i.e., Delta distribution models) or use of zero-inflated models.

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Brodziak and Walsh (2013) presented a model selection and multimodel inference procedure (Burnham and Anderson, 2002; Zuur et al., 2009) for standardizing catch per unit of effort (CPUE) of bycatch species. The procedure was applied to standardize CPUE of oceanic whitetip shark *Carcharhinus longimanus* in the Hawaii-based pelagic longline fishery during 1995–2010. Brodziak and Walsh (2013) investigated the use of zero-inflated models and selected a zero-inflated negative binomial model (ZINB) for CPUE standardization. This zero-inflated model is comprised of a counts model that allows for overdispersion in both the zeros and positive catches and a binomial model that allows for "extra" zeros (Zuur et al., 2009, 2012; Brodziak and Walsh, 2013), with the latter defined as a higher frequency of zeros than expected under the Poisson, negative binomial, or other count distributions (Zuur et al., 2009). This paper presents a new application of the model selection and multimodel inference procedure to four billfishes caught in the Hawaii-based pelagic longline fishery during 1995–2011.

These incidentally-caught billfishes (Walsh et al., 2007) and the oceanic whitetip shark taken as bycatch (Brodziak and Walsh, 2013) had similarly high proportions of zero catches, but differed in productivity and resilience. Further, the ecology, life histories, behavior, and distributions of the billfishes (Royce, 1957; Strasburg, 1970; Nakamura, 2001; Kitchell et al., 2006) are far better known than those of the oceanic whitetip shark, a species that has never been thoroughly studied despite its formerly high level of abundance (Strasburg, 1958; Bonfil et al., 2008). Thus, it was possible to test a larger suite of explanatory variables in the CPUE standardization models than had been possible for the oceanic whitetip shark. Catch and operational data from Hawaii longline fishery observers for blue marlin *Makaira nigricans*, striped marlin *Kajikia audax*, and shortbill spearfish *Tetrapturus angustirostris* on a fishery-wide basis and sailfish *Istiophorus platypterus* from the deep-set (i.e., tuna-targeted) sector were used in the analyses.

Our analytical objective was to standardize CPUE using five types of GLMs (see below) for each billfish species and then apply model selection and multimodel inference procedures to identify the best-fitting GLM. We were particularly interested in determining whether the ZINB model previously selected for oceanic whitetip shark would also be selected for any of these incidentally caught billfishes.

The primary impetus for this research was generated by studies of the population status of the two marlin species in the fishing grounds exploited by the Hawaiian pelagic longline fishery. A recent stock assessment for striped marlin in the western and central North Pacific Ocean for 1975–2010 concluded that this species is overfished and subject to overfishing (Lee et al., 2012a). A second stock assessment for blue marlin concluded that this species is neither overfished nor subject to overfishing, but the stock is nearly fully exploited and stock biomass underwent a period of decline that began in the mid-1970s and continued for about three decades until stabilizing about 10 years ago (Lee et al., 2012b). Finally, knowledge about the relative abundance of shortbill spearfish is limited, other than a recent analysis presented by Gilman et al. (2012), and there is no information about sailfish population status in this fishery. This paper presents new information about billfish catch rates and abundance trends in the Hawaii-based pelagic longline fishery in 1995–2011 and also contributes to the understanding of catch rate standardization with incidentally caught billfishes.

2. Methods

2.1. Fishery description

The Hawaii-based longline fishery is managed in two fishing sectors, defined as deep-set (≥15 hooks per float) and shallow-set longline operations (<15 hooks per float). The target species for the deep-set sector is usually bigeye tuna *Thunnus obesus* while the shallow-set sector predominantly targets swordfish *Xiphias gladius*. Deep sets are generally deployed around dawn and hauled in near dusk; shallow sets are generally deployed after dusk, use about half as many hooks as deep sets, and are hauled in around dawn. For the last decade, shallow-set activity has been concentrated at relatively high latitudes (ca. 30°N) in the first and fourth quarters (Walsh et al., 2009). Deep-set activity extends southward to waters near the equator with considerable fishing activity throughout the year. Gilman et al. (2012) provide a detailed description of the deep-set fishery sector.

2.2. Data sources

Fishery observers from the Pacific Islands Regional Observer Program (PIROP) recorded species-specific catch tallies and operational descriptors (e.g., geographic position, number of hooks deployed, set and haul times) according to protocols in a field manual (Pacific Islands Regional Office, 2009). This catch and operational data set was used by Brodziak and Walsh (2013), but with 2011 fishery observer data added to make a 17-year time series (N = 51,515 observed longline sets). We used fishery observer data to avoid problems with species misidentifications that complicate use of logbook data.

Two environmental predictors and fishing vessel size were evaluated as possible continuous explanatory variables in the analyses; these were sea surface temperature and the Multivariate El Niño/Southern Oscillation Index. Sea surface temperature (SST°C) data were weekly mean values measured by an advanced, very high resolution radiometer borne by a NOAA satellite (Walsh et al., 2007). Numerical values of the Multivariate El Niño/Southern Oscillation Index (MEI) were obtained from the NOAA Earth System Research Laboratory Physical Sciences Division (http://www.esrl.noaa.gov/psd/enso/mei/). The sizes of fishing vessels (hull length, feet) were obtained from the NOAA Fisheries Office of Science and Technology (http://www.st.nmfs.noaa.gov/st1/CoastGuard/VesselByName.html).

2.3. CPUE standardizations

Five distributional assumptions for billfish CPUE standardization were investigated. These included distributions that could exhibit overdispersion and underdispersion, as well as zero-inflation. The five distributions were: delta-Gamma; Poisson; negative binomial; zero-inflated Poisson; zero-inflated negative binomial (ZINB). Full details of GLM fitting procedures and the theory underlying these models are presented in Brodziak and Walsh (2013). Details of model structure, including the probability function, expected value, variance, and the variance to mean ratio are compared in Table 1.

The models were fitted by step-wise variable selection, beginning with the factor variables, followed by the continuous variables, interactions between factors, and interactions between factors and continuous variables. Factor variables tested for inclusion were the 17 fishing years, four calendar quarters, two set types, eight fishing regions (Region 1: 0–10°N, east of 160°W; Region 2: 0–10°N, west of 160°W; Region 3:10–20°N, east of 160°W; Region 4: 10–20°N, west of 160°W; Region 5:20–30°N, east of 160°W; Region 6:20–30°N, west of 160°W; Region 7: above 30°N, east of 160°W; Region 8: above 30°N, west of 160°W) six bait types, three leader materials, and four hook types (See Chapter 6 of the Hawaii Longline Observer Manual for descriptions of bait types, hook types and leader materials). Continuous variables tested were the SST, the MEI, the begin-set time (HST), the illuminated fraction of the face of the moon, and the soak duration. Year–quarter, year–region, quarter–region, set type–hooks per float, set type–vessel length,