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Accounting for vessel effects when standardizing catch rates from cooperative surveys

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ABSTRACT

Interpretation of fishery-dependent and independent-survey data requires accounting for changes in the proportion of local individuals that are caught by fishing gear ("catchability"). Catchability may be influenced by measured characteristics of fishing gear, and even standardized fishing techniques may experience changing catchability over time due to changes in fishing vessel characteristics and personnel. The importance of vessel power has long been recognized in the analysis of fishery dependent catch per unit effort data, but less-studied in the analysis of fishery independent data collected by research vessel surveys. Here we demonstrate how differences in catchability among vessels ("vessel effects"), as well as random variation in vessel-specific catchability over time ("vessel-year effects") can be incorporated into generalized linear mixed models through their treatment as random effects. We apply these methods to data for 28 groundfish species caught in a standardized survey using contracted fishery vessels and personnel in the Northeast Pacific. Model selection shows that vessel, vessel-year, and both effects simultaneously are supported by available data for at least a few species. However, vessel-year effects generally have a larger effect on catch rates than vessel-effects and hence abundance indices estimated using both vessel- and vessel-year effects are generally similar to estimates when using just vessel-year effects. Additionally, models indicate little support for the hypothesis that characteristics such as length and displacement of the contracted vessels used in this survey have a substantial impact on catch rates. Finally, inclusion of vessel- or vessel-year effects generally results in wider estimates of credible intervals for resulting indices of abundance. This increased credible interval width is consistent with statistical theory, because vessel effects will result in non-independence of different sampling occasions, thus decreasing effective sample sizes. For this reason, we advocate that future analyses include vessel- and/or vessel-year effects when standardizing survey data from cooperative research programs.

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1. Introduction

Population dynamics and stock assessment models are central to the scientific approach to managing fisheries in the United States and elsewhere (Cardinale et al., 2013; Methot et al., 2014). Assessment models ideally incorporate information regarding the age and length-composition of the population, as well as trends in population abundance that are informed by survey data collection efforts using a randomized design. However, scientific sampling of fish populations is complicated due to large spatial ranges of fish populations, variable fish densities throughout their range and from year to year, and difficulties in accessing fish habitats (Walters and Martell, 2004).

To obtain data for estimating abundance trends and age/length-composition of marine populations, fisheries scientists and managers will sometimes conduct cooperative research in which fishery vessels are contracted to conduct randomized sampling of a region or population following a pre-determined design. Cooperative research may improve stakeholder confidence for resulting information and increase communication between researchers and fishers. Also, it may in some cases be significantly more cost-efficient that other sampling designs, e.g., by using existing fishing vessels and expertise. However, using fishing vessels for scientific

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surveys also implies that sampling is conducted using pre-existing vessels and personnel, which may influence sampling catch rates and resulting data (Helser et al., 2004).

The importance of quantifying differences in catchability among fishing vessels (whether contracted or exclusively for scientific research) and accounting for these differences when interpreting fishery data has been recognized for more than a century (Beverton and Holt, 1957; Garstang, 1900; Wilberg et al., 2010). In particular, temporal changes in fishing efficiency may mask or magnify any evidence of changes in population abundance (Thorson and Berkson, 2010). Because of large variability in fishing power within and between commercial fishing fleets, much of the previous research into vessel power and estimating vessel effects has focused on vessel power for fishery-dependent rather than fishery-independent data (e.g., Marchal et al., 2001). However, different fishing captains of a fishery-independent survey may also select different micro-habitats for the placement of fishing gear, and this can affect catch rates for species that have strong associations with particular habitats (e.g., rocky habitats for many rockfishes). Therefore, it remains important to consider how variation in vessel effects (whether constant or annually varying) may impact fishery-independent survey data. In particular, this variability may ultimately influence the net-present value of different management procedures, as well as the relative performance of different sampling designs for fishery resources (McAllister and Pikitch, 1997).

As one example, the Northwest Fisheries Science Center (NWFSC) has contracted vessels and personnel from the groundfish fishery off the U.S. West Coast (Oregon, Washington, and California) to conduct bottom trawl sampling of fish populations since 1998 (Bradburn et al., 2011). Information from this trawl sampling protocol is the primary source of information regarding length, age, maturity, and abundance trends for most groundfish stock assessments in this region. Catch rate data from this survey have typically been analyzed using delta-generalized linear mixed models (delta-GLMMs) to estimate abundance indices (Maunder and Punt, 2004), which are in turn used to inform assessment estimates of abundance trends (Francis, 2011). Delta-GLMM models approximate catch rates as a mixture of zero and non-zero values. Biologically, this means that the total estimate of abundance is partitioned into a model relating covariates to occurrence, and a second model relating covariates to densities in areas where a species is present (Pennington, 1983; Stefansson, 1996).

The mixed-effects framework is often preferred when estimating abundance indices from survey data because it can account for spatiotemporal variability in fish densities while also propagating uncertainty due to potentially small sample sizes in multiple spatial area (Thorson and Ward, 2013). The mixed-effects framework also allows vessels to be treated as a random effect, thus controlling for their influence on catch rates. Treating vessels as a random effect has previously provided estimates of vessel effects using five years of data (1998–2002) from a similar sampling design operated by the Alaska Fisheries Science Center (Helser et al., 2004). When estimating vessel power as a random effects, differences in average catch rates by different vessels in the same year and strata are interpreted as differences in fishing power. Alternatively, a sampling design may use paired sampling by multiple sampling vessels and/or gears to calibrate relative difference among sampling vessels. Paired sampling by multiple vessels at the same location and time remains the gold-standard for estimating relative vessel power (Cadigan and Dowden, 2010; Miller, 2013), although paired sampling is sometimes not logistically or financially feasible.

Despite including vessel effects in a delta-GLMM, there has been relatively little investigation of the influence of different fishing vessels on catch rates or estimated indices of abundance (with the exception of Helser et al., 2004). We therefore seek to determine: (1) whether each contract vessel has a specific fishing power; (2) whether this power is constant over time or varies among years; (3) whether vessel power can be explained by vessel characteristics such as length and horsepower; and (4) whether differences in vessel power ultimately affect estimates of relative abundance. To do so, we modify an existing delta-GLMM model (Thorson and Ward, 2013) that is freely and publically available as an R-package via R-forge (https://r-forge.r-project.org/R/?group_id=1316 or calling install.packages ("nwfscDeltaGLM", repos = "http://R-Forge.R-project.org") from within R version ≥3.2.0), and use it to explore different treatments of vessel effects for 28 fish species.

2. Methods

In previous applications of the delta-GLMM from Thorson and Ward (2013) for stock assessment purposes, differences in catch rates among spatial strata and calendar years have been estimated using fixed-effect parameters (factors), and strata-year interactions have sometimes been additionally estimated as either random- or fixed-effect parameters. Previous applications of this method have also included relative changes in fishing power for each vessel in each year ("vessel-year effects") as a random effect. Here we modify the delta-GLMM model to allow inclusion of a coefficient for each vessel that is constant over time ("vessel effects"), potentially including both vessel and vessel-year effects simultaneously, and allowing for measured covariates (i.e., vessel characteristics) to also affect catch rates. This leads to the following model for positive catch rates:

$$\mu_i = a_i \cdot \exp\left(\begin{array}{l} \sum_{j=1}^{n_{strata}} \gamma_j^{(s)} I(s_i = j) + \sum_{k=1}^{n_{year}} \gamma_k^{(y)} I(y_i = k) + \sum_{j=1}^{n_{strata}} \sum_{k=1}^{n_{year}} \gamma_{j,k}^{(sy)} I(s_i = j) I(y_i = k) \\ \sum_{l=1}^{n_{vessel}} \gamma_l^{(v)} I(v_i = l) + \sum_{k=1}^{n_{year}} \sum_{l=1}^{n_{vessel}} \gamma_{k,l}^{(vy)} I(y_i = k) I(v_i = l) + \sum_{m=1}^{n_{cov}} \gamma_m^{(h)} \boldsymbol{H}_{i,m} \end{array}\right) \quad (1)$$

where s_i, y_i, and v_i are strata, year, and vessel ID for tow i, a_i is the area swept (in hectares) for tow i, $\boldsymbol{H}$ is a matrix of covariates (representing vessel characteristics), $\gamma^{(s)}$, $\gamma^{(y)}$, $\gamma^{(sy)}$, $\gamma^{(v)}$, $\gamma^{(yv)}$ and $\gamma^{(h)}$ are parameters representing the effect of strata, year, strata-year interactions, vessel, vessel-year interactions, and covariates on the expected value of non-zero catch C_i, n_{strata}, n_{year}, n_{vessel}, and n_{cov} are the number of strata, years, vessels, and covariates, respectively, j, k, l, and m are indices representing strata, year, vessel, and covariate, respectively, and $I(x = b)$ is an indicator variable that equals one if $x = b$ and zero otherwise. Thorson and Ward (2013) previously concluded that different treatments of spatiotemporal effects had little effect on resulting indices of abundance. We therefore use as base case a model that includes the effect of spatial strata and year as fixed effects, without including their interaction (i.e., $\gamma^{(sy)} = 0$). However, we present a sensitivity analysis in which models are re-estimated when treating the interaction of strata and year as a random effect. Observed catches are then gamma-distributed:

$$Pr(C_i = c | C_i > 0) = \mathrm{Gamma}(c | \alpha, \beta_i)$$