Sensitivity of Gray Snapper, *Lutjanus griseus*, Stock Assessment Models to Age Inputs Estimated with Near Infrared Spectroscopy

Sensibilidad del pargo gris, *Lutjanus griseus*, modelos de evaluación de poblaciones a entradas de edad estimadas con espectroscopía de infrarrojo cercano

Sensibilité du vivaneau gris, *Lutjanus griseus*, modèles d'évaluation des stocks aux entrées d'âge estimées avec la spectroscopie proche infrarouge

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EXTENDED ABSTRACT

Age-structured stock assessment models for data rich species like Gulf of Mexico gray snapper, *Lutjanus griseus*, require significant time commitments to process and age samples. Next generation ageing methods, such as Fourier-transform near infrared spectroscopy provide a means to drastically reduce the time required for production ageing because only a relatively small portion of samples would require sectioning and enumerating annuli. The majority of samples would be processed via near infrared scans of whole otoliths, which require <1 minute per otolith, and ages are estimated with species-specific predictive models. We used the Stock Synthesis assessment modeling framework to evaluate the sensitivity of gray snapper assessment model parameters to age data inputs estimated from models derived with FT-NIRS-predicted ages. Assessment outputs were insensitive to FT-NIRS-predicted ages but sample sizes were very low. Greater sample sizes or resampling schemes are necessary to better evaluate the effects of imprecision on simulated assessment outputs.

INTRODUCTION

Artificial reefs have been deployed around the world, especially in the northern Gulf of Mexico in areas with limited Modern, age-structured stock assessment models require age data of sufficient quality (i.e., high precision and accuracy), quantity (i.e., sample size), and composition (i.e., representativeness). Standard protocols for developing age estimates from fish ageing structures (primarily otoliths) require relatively tedious sample processing procedures that can take several minutes per sample over multiple days. Thus, the number of samples available for input into stock assessments is dependent upon the processing power of ageing laboratories, while the quality of age estimates is dependent upon the ageing expertise of fishery scientists and species-specific otolith section clarity. Fourier transform near infrared spectroscopy (FT-NIRS) offers a potential solution to increase sample sizes for production ages through increased processing efficiency. Used in the food and drug industry for decades, FT-NIRS spectroscopy has only recently been applied to ageing fish (e.g., Robins et al. 2015; Helser et al. 2018; Passerotti et al. 2020), but with much promise. With FT-NIRS, all otoliths of interest are irradiated with near infrared light and their spectral absorbance data are collected and stored. A subset of scanned otoliths are then sectioned and aged according to traditional methods. The observed ages are then paired with their spectral absorbance data and a model is built to predict age for the remainder of otoliths from their spectral data, without the need for traditional sectioning and ageing. Considering that a spectral scan requires approximately one minute to complete, there is enormous potential for increasing production ageing efficiency with this approach. However, the effects of utilizing age estimates generated from FT-NIRS on stock assessment outputs have not been explored. Our objective was to evaluate the sensitivity of the Gulf of Mexico gray snapper, *Lutjanus griseus*, stock assessment to FT-NIRS-predicted ages by substituting them for their observed ages and comparing model outputs under different simulation scenarios in the Stock Synthesis framework.

METHODS

Sample selection, model building, and simulations

Gray snapper otoliths were selected from the archive at the National Marine Fisheries Service Panama City Laboratory from the years 2016-2020, with a target of 300 per yr^{-1}. Each otolith was placed distal side up on a quartz sampling window of a Bruker[1] Multi Purpose Analyzer II FT-NIR spectrometer to collect spectral scans of diffuse reflectance (Robins et al. 2015; Helser et al. 2018). Samples were irradiated with NIR light at 16 cm^{-1} resolution with absorbance measured in wavenumbers (cm^{-1}). Following scanning, otoliths were processed using standard protocols and sectioned on a Hillquist high-speed saw to produce a thin-section (~0.5 mm) for traditional ageing. Only whole, clean, unbroken, left otoliths were sampled to maintain consistency among FT-NIRS scans. Observed ages were input along with paired spectral data into chemometric software (OPUS, v8.5, Bruker Optics) to develop predictive models using partial least squares regression (Chen and Wang 2001). Individual samples were selected from the calibration set iteratively and cross-validated to develop the best possible predictive model (based on residual mean square error and the ratio of prediction deviance). The predictive model built from the calibration set was then applied to the validation set (i.e., the remaining 70% of scanned otoliths) to predict age only from their spectral scan.

The FT-NIRS-predicted age estimates from the validation set were substituted for their respective observed ages in the dataset used to assess gray snapper in SEDAR 75. The assessment model was then rerun with n = 10,000 iterations in the R package ss3sim (Anderson et al. 2014). The ss3sim function fits relevant distributions to the data in the operating (base) model from which to resample the data to the specified number of iterations and rerun the model estimating procedure (estimation model). The SS model output from all the iterations is then compared to the base model (percent error) and summarized. Model outputs including SSB, F, depletion, and recruitment deviations were compared between the base assessment model and simulation runs with substituted FT-NIRS ages.

RESULTS

In total, 1,419 gray snapper otoliths were available for FT-NIRS scanning with n = 420 samples comprising the calibration set and n=999 samples comprising the validation set. Samples ranged in age from 2 to 29 yrs. The relationship between the observed ages and FT-NIRS-predicted ages in the calibration set had an R^2 of 92.0, a root mean-square error of the cross validation (RMSECV) of 1.5 yrs, and a ratio of prediction deviance (RPD) of 3.5. The validation set had an R^2 of 89.7, an RMSEP of 1.6 yrs, an RPD of 3.1, an average percent error (APE) of 7.6, and an average coefficient of variation (ACV) of 10.7 (Figure 1). Relative error between assessment model outputs with FT-NIRS-predicted ages and ageing error were relatively low (<5%) (Figure 2). Simulation results indicated that utilizing FT-NIRS-predicted ages did not have a noticeable effect on estimates of fishing or biomass reference points

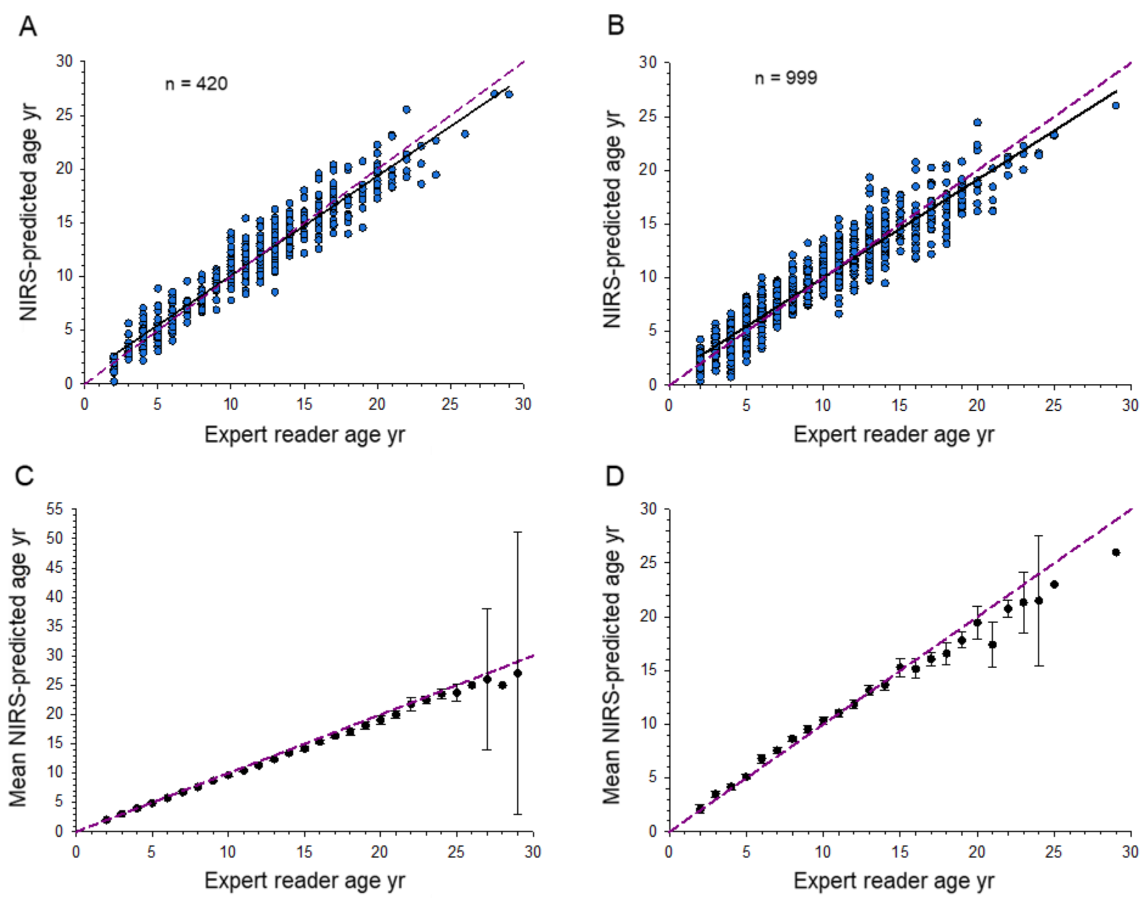

Figure 1. Expert reader age (yr) versus FT-NIRS-predicted age in the calibration set (A and C) or the validation set (B and D). FT-NIRS-predicted ages are rounded to the nearest integer age. Error bars indicate 95% CI of the mean. Sample sizes are shown at the top left of panels A and B.

given the FT-NIRS sample sizes.

DISCUSSION

FT-NIRS-predicted ages were generally similar to observed ages with little bias but greater imprecision. FT-NIRS-predicted ages were under-predicted for ages >15 yr, and APE was nearly 3 times higher than error between human readers for those ages. Imprecision of FT-NIRS estimates for young ages, which had extremely high between-reader agreement, has a disproportionate impact on APE and potentially assessment output due to cohort smoothing. However, bias in older ages has minimal impact on assessment outputs because older fish represent relatively few individuals in the landings or population, and most are contained in the plus group in age composition data for this species (≥21 yr). While, greater imprecision in FT-NIRS-predicted ages is a concern, the assessment model was insensitive to this source of error. However, it is unclear if model insensitivity was simply due to imprecision from FT-NIRS-predicted ages being diluted by higher precision of the remaining observed ages in the data for years 2016-2020. FT-NIRS-predicted ages comprised only 3-10% of age estimates in the data for each year, which reduces our power to evaluate model sensitivity. Generally, greater imprecision in age estimates will increase uncertainty in and possibly shift assessment outputs, but it is difficult to estimate at what sample size effects of reduced precision and accuracy might become apparent. Scanning additional otoliths or resampling schemes in simulation will allow us to fully evaluate effects of utilizing FT-NIRS-predicted ages versus observed ages to produce catch-at-age matrices for stock assessments when precision is reduced.

KEYWORDS: FT-NIR spectroscopy, stock assessment, gray snapper

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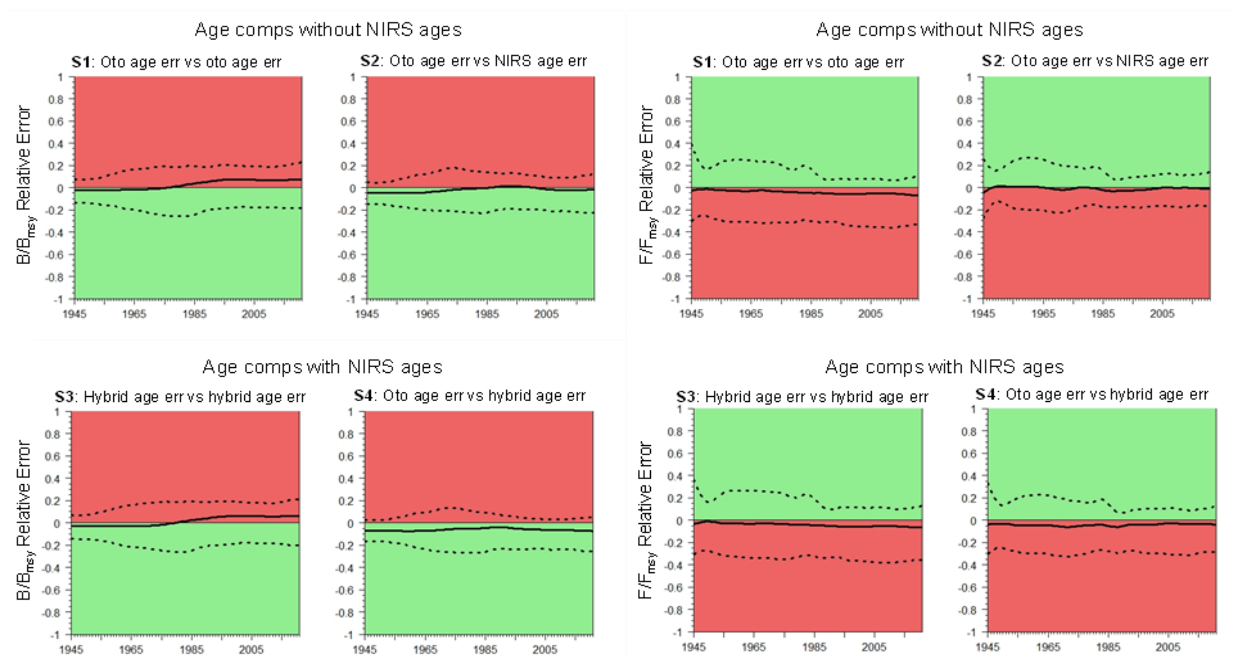

Figure 2. Relative error (Scenario-Base/Base) for reference points under various combinations of ageing error scenarios: 1) otolith vs otolith error (base model), 2) otolith vs FT-NIRS error, 3) hybrid error only (observed and FT-NIRS ages), or 4) otolith vs hybrid error (base vs FT-NIRS ages). The black line indicates median values while the dashed line indicates the