Gulf of Mexico Fishery Management Council
USM Greater Amberjack – Final Report
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Assessing the influence of *Sargassum* habitat on greater amberjack recruitment in the Gulf of Mexico

PIs: Frank Hernandez, Verena Wang (University of Southern Mississippi)

Project rationale and objectives

Pelagic *Sargassum* provides structure within the open ocean to support a diverse assemblage of fishes (Dooley 1972, Wells and Rooker 2004). Sargassum is designated as Essential Fish Habitat in the Gulf of Mexico and the South Atlantic (SAFMC 2002), and it is presumed to play an important nursery role given the high densities of associated juvenile stage fishes. We hypothesize that measures of *Sargassum* abundance can serve as valuable fishery-independent recruitment indices, but assessing the relationship between *Sargassum* and fisheries productivity has until recently been hindered by the ephemeral nature of *Sargassum* and the difficulty in accurately quantifying its abundance and distribution. As part of an ongoing NOAA-RESTORE funded project led by PI Hernandez, *Sargassum* habitat indices have recently been developed for the Gulf of Mexico at multiple spatial and temporal scales. These include ship-based *Sargassum* indices, developed from volumetric *Sargassum* measurements recorded during SEAMAP ichthyoplankton surveys beginning in 2002, and remotely sensed *Sargassum* indices, derived from field-validated satellite reflectance observations and water column chlorophyll a, available from 2003-2019 (in prep).

Here, we apply the recently developed *Sargassum* indices to evaluate recruitment in Gulf of Mexico greater amberjack (*Seriola dumerili*), a federally managed species which has been designated as overfished and undergoing overfishing (SEDAR 2016). This objective is in line with Priority Code A (stocks designated as overfished and undergoing overfishing or in critical need of an assessment) for priorities associated with individual species or specific research topics in the Gulf of Mexico Fishery Management Council fishery monitoring and research priorities for 2020-2024. If *Sargassum* is an effective predictor of greater amberjack recruitment, *Sargassum* habitat indices can used to tune stock assessment models and reduce variability in recruitment estimates. Incorporation of habitat-based parameters would better inform models and contribute to improved understanding of the role of *Sargassum* in supporting the early life stages of target fisheries species.

The primary objective of this project was to evaluate the relationship between *Sargassum* habitat indices and greater amberjack recruitment and abundance indices developed from both fishery-dependent and fishery-independent data sources. To contribute to this aim, our secondary objective was to develop larval indices of relative abundance for *Seriola* spp. using SEAMAP ichthyoplankton survey data. Larval indices are often incorporated into stock assessments as a fishery-independent estimate of abundance of early life history stages, including for Gulf of Mexico red snapper (SEDAR 52), king mackerel (SEDAR 38), and vermilion snapper (SEDAR 67). Thus far, indices of relative abundance have not been developed for greater amberjack because *Seriola* spp. larvae from SEAMAP surveys are not identified to the species level. Here, we evaluate the potential utility of genus-level *Seriola* larval abundance indices and *Sargassum* habitat indices to contribute to improved understanding of variation in greater amberjack recruitment in the Gulf of Mexico.

Methods

Abundance data sources

Estimates of age-0 recruits (1947-2014) were obtained from the SEDAR 33 Stock Assessment Update Report Gulf of Mexico Greater Amberjack (SEDAR 2016). Fishery-dependent data sources were also extracted from the SEDAR 33 Update, and included standardized catch per unit effort (CPUE) indices for Gulf of Mexico greater amberjack from the commercial longline, commercial handline, and recreational headboat fisheries. Fishery-independent data sources from the SEDAR 33 Update included standardized CPUE indices from the Panama City Video Survey and the SEAMAP Video Survey. Time series length and completeness varied for each annual abundance index, but ranged from 1985-2014. At the time this project was conducted, SEDAR 70 for Gulf of Mexico Greater Amberjack (SEDAR 2020) was in progress and included abundance estimates through 2018. However, the final report was not completed until October 2020 and not reviewed until January 2021. Thus, data from the most recent SEDAR 70 effort are not included in this analysis. SEDAR abundance data sources here are annualized (one value for each year), in contrast to the spatially and temporally discrete larval fish and habitat indices described below.

Seriola larval abundance indices

Larval indices of relative abundance were developed for *Seriola* spp. sampled in SEAMAP plankton surveys conducted from 1982-2016. *Seriola* spp. larvae were rarely identified to species (<1%), so indices were developed at the genus level and include greater amberjack (*Seriola dumerili)* and the other jacks complex (lesser amberjack – *S. fasciata*, almaco jack – *S. rivoliana*, banded rudderfish – *S. zonata*). SEAMAP ichthyoplankton sampling was conducted with both neuston and bongo nets, but bongo *Seriola* catches were very low (present in 2.2% of samples) so only neuston (present in 14.7% of samples) data are included here. Indices were developed separately for four SEAMAP ichthyoplankton survey seasons (spring plankton, summer groundfish, fall plankton, and fall groundfish), each of which sample different regions of the Gulf of Mexico during different times of year (Figure 1). Plankton and groundfish surveys both sample ichthyoplankton using the same gear (2 x 1 m neuston net with 0.948 mm mesh towed half-submerged at the surface), with groundfish surveys sampling ichthyoplankton opportunistically as a secondary objective. Neuston data were standardized to number of larvae per 10-minute tow.

Seriola abundance was modeled using a delta-lognormal approach (Lo et al. 1992), a two-part method that combines (1) estimates of the proportion of positive abundance (presence/absence) using a binomial model and (2) estimates of abundance for positive catches using a lognormal model, resulting in an annual index of relative abundance. We followed the methods used by Ingram et al. (2010) and Hanisko et al. (2017) for Atlantic bluefin tuna and king mackerel, respectively. Model selection was conducted on the binomial and lognormal models separately, and tested all possible combinations of covariates: year (always included), month, time of day (day – 6:00-18:00; night – 18:00-6:00), and region (East GOM: >89.25 degrees W Longitude; West GOM: < 89.25 degrees W Longitude). The best fit submodel (AIC) was included in the final delta lognormal estimation for each survey season. Final delta lognormal models were developed using the package 'fishMod' in R.

Sargassum indices

Ship-based relative indices of *Sargassum* abundance were developed from volumetric *Sargassum* measurements recorded during SEAMAP ichthyoplankton surveys using the delta lognormal method described above. Remotely sensed *Sargassum* indices were derived from field-validated satellite reflectance observations and water column chlorophyll a (Wang and Hu 2016). Both ship-based and remotely-sensed *Sargassum* indices were developed for the northern Gulf of Mexico at multiple spatial scales corresponding to the survey areas sampled during the SEAMAP survey seasons (in prep). Here, remotely-sensed indices represent monthly *Sargassum* area coverage (km^2) for each survey season polygon (roughly represented by the distribution of stations in Figure 1), and were included in the analyses as two annual abundance metrics to represent both spatial and temporal variability: (1) seasonal - summed *Sargassum* area coverage over the nominal survey months, (2) annual - summed *Sargassum* area coverage over the survey year.

Analyses

To evaluate the relationship between the *Sargassum* abundance indices and age-0 greater amberjack recruits, fishery-dependent and fishery-independent abundance indices, and larval abundance indices, Pearson's product moment correlation was calculated for each pair of variables. Generalized additive models (GAMs) were applied to further assess greater amberjack abundance relative to *Sargassum* abundance using thin plate regression splines. Larval abundance indices relative to recruitment were also evaluated using both methods. All analyses were conducted separately for each survey season and area. Prior to analyses, a one year offset was applied to greater amberjack age-0 recruit and fishery-dependent and fishery-independent abundance indices to account for the influence of *Sargassum* habitat during early life stages. No offset was applied to the larval abundance indices because *Sargassum* influence was presumed to be concurrent to development.

Results

Seriola larval abundance indices

Larval abundance indices were estimated for *Seriola* spp. sampled in the northern Gulf of Mexico from 1982-2016 (Figure 1). For the spring plankton survey, the best fit model included year, month, and region for both the binomial and lognormal models. For the fall plankton survey, the best fit binomial model included year, and the lognormal model included year and time of day. Scaled annual larval abundance index values for spring plankton (Table 1) and fall plankton (Table 2) are provided here and were utilized in further analyses. Larval abundance indices developed from summer groundfish and fall groundfish surveys were also developed and included in the analyses, but were rarely correlated with *Sargassum* or greater amberjack recruitment, and thus are not presented in full here.

Larval-recruit relationship

Results for GAM analysis of the linkage between *Seriola* spp. larval abundances and greater amberjack age-0 recruits were significant for the fall plankton survey season (P = 0.047), although trends suggest a near-zero effect of larval abundance on recruitment for most of the range of larval index values and correlations were not significant (R = -0.24, P = 0.21, Figure 2). When evaluating the spring plankton survey season, both GAM (P = 0.09) and correlation analyses (R = -0.08, P = 0.67) were not significant, although visual inspection of the data indicated a potential trend in larval abundance and recruitment from 1990-2001. This truncated time period was investigated, revealing a positive effect of larval abundance on recruitment, although strength of association, while increased, remained not significant (GAM: P = 0.09; Correlation: R = 0.52, P = 0.09, Figure 3). Larval-recruit relationships were not significant for larval *Seriola* spp. indices developed for fall and summer groundfish survey seasons, and trends were less clear.

Sargassum-amberjack relationship

Sargassum abundance varied among seasons and regions, particularly for seasonal remotely-sensed indices (Figure 4). Indices of *Sargassum* abundance were positively associated with age-0 greater amberjack recruitment for summer and fall survey seasons. Ship-based *Sargassum* indices from the summer groundfish survey season were correlated with age-0 recruits (R = 0.71, P = 0.03), with a strong positive effect of summer *Sargassum* abundance on recruitment (GAM: P = 0.003, Figure 5). The positive effect of remotely-sensed seasonal *Sargassum* indices from the fall plankton survey area on recruitment was marginally significant (GAM: P = 0.06), and the relationship between *Sargassum* habitat and recruitment was visually evident although not statistically significant (R = 0.53, P = 0.08, Figure 6). Recruitment trends were variable for seasonal *Sargassum* indices from the fall groundfish survey area, although the effect was significant (GAM: P = 0.03; Correlation: R = 0.20, P = 0.54, Figure 7).

Seasonal remotely-sensed *Sargassum* abundance indices from the fall groundfish survey area had a significant effect on greater amberjack CPUE estimated from the SEAMAP video survey (GAM: 0.02), although the pattern of association was variable and correlation was not significant (R = 0.29, P = 0.36, Figure 8). Annual remotely-sensed *Sargassum* indices (summed *Sargassum* area coverage over 12 months) were never significant predictors of greater amberjack recruitment or CPUE. All other estimates of CPUE (commercial longline, commercial handline, recreational headboat, Panama City video survey) showed no significant relationship with *Sargassum* habitat indices. Relationships between larval *Seriola* spp. and *Sargassum* abundance indices were also investigated, but trends were equivocal and only marginally significant, and thus are not presented here.

Project assessment and conclusions

Project timelines were shifted due to the ongoing COVID-19 pandemic, and data acquisition was not completed until the fourth quarter of the project. Regardless, project objectives were met and analyses were completed within the revised project timeframe. In reviewing the availability of fishery-independent data for greater amberjack, we recognized that patterns of abundance in early life history stages of greater amberjack represented a knowledge gap. We expanded the scope of our project to develop larval abundance indices for *Seriola* spp. and incorporated them into our habitat and recruitment analyses.

The early life history stages of *Seriola* spp. demonstrated the potential to inform future greater amberjack stock assessments, despite the poor taxonomic resolution of this group in SEAMAP ichthyoplankton surveys in the Gulf of Mexico. At the genus level, *Seriola* relative abundance indices for the spring survey season and area followed greater amberjack recruitment trends, particularly from 1990-2001. Larval abundance indices in the fall were less predictive of recruitment. The variability in correlation between larvae and recruits during the spring time series suggests that further investigation into the early life stages of greater amberjack is warranted. It is possible that species composition shifted during the time series, with a larger proportion of greater amberjack present in the larval catch during the period of interest contributing to stronger larval-recruit associations. But early life history stages are highly influenced by environmental variation, so it is also possible that a mismatch between larval abundance and recruitment is due to variability in conditions for larval development and dispersal. Taxonomic characters for identification of larval greater amberjack have been developed (Comyns et al. 2009), and in conjunction with DNA barcoding could provide increased taxonomic resolution for specimens from future SEAMAP ichthyoplankton surveys. We did not detect an association between *Seriola* spp. larval abundances and *Sargassum* habitat indices, which is in agreement with previous studies which found similar species composition and abundance of larval fishes both adjacent to and away from *Sargassum* habitat features (Comyns et al. 2002).

Greater amberjack recruitment was positively associated with *Sargassum* habitat abundance indices for summer (June, July) and fall (plankton – August, September, October; groundfish – September, October) survey seasons. Spring *Sargassum* indices were not significantly correlated with recruitment, despite having the largest area coverage of *Sargassum* (Figure 4). This suggests that timing of habitat availability may be important for providing nursery function for juvenile greater amberjack. Additionally, summer groundfish, fall plankton, and fall groundfish survey areas were more closely associated with the continental shelf than the spring plankton survey area, which encompasses open ocean regions in the north central Gulf of Mexico (Figure 1). These results suggest that availability of *Sargassum* habitat in the continental shelf region during summer and fall may be important for greater amberjack early life growth and survival. Relationships were variable and strength of correlations was often weak or not statistically significant, highlighting the complex nature of using habitat to predict abundance. The time frame for which *Sargassum* habitat indices are available (2002-2016) is relatively short compared to the scope of the greater amberjack recruitment estimates (1947-2014), and habitat-recruit associations will be better understood with extended *Sargassum* habitat time series.

References

Comyns, B. H., N. M. Crochet, J. S. Franks, J. R. Hendon, and R. S. Waller. 2002. Preliminary assessment of the association of larval fishes with pelagic Sargassum habitat and convergence zones in the north central Gulf of Mexico. GCFI:53

Comyns, B. H., E. Hoffmayer, J. S. Franks, G. L. Grammer. 2009. Early Life History and Recruitment of Dolphinfish (Coryphaena hippurus) and Greater Amberjack (Seriola dumerili) to Pelagic Sargassum Habitat in the Northcentral Gulf of Mexico. Final report submitted to National Marine Fisheries Service, St. Petersurg, FL.

Dooley, J. K. 1972. Fishes associated with the pelagic Sargassum complex, with a discussion of the Sargassum community. Contrib. Mar. Sci. **16**:1-32.

Hanisko, D. S., A. Pollack, G. Zapfe, and G. W. Ingram Jr. 2017. King mackerel (Scomberomorus cavalla) larval indices of relative abundance from SEAMAP fall plankton surveys in the Gulf of Mexico, 1986 to 2014. SCRS/2017/095. 32pp.

Ingram Jr., G. W., W. J. Richards, J. T. Lamkin, and B. Muhling. 2010. Annual indices of Atlantic bluefin tuna (Thunnus thynnus) larvae in the Gulf of Mexico developed using delta-lognormal and multivariate models*. Aquat. Living Resour. **23**:35-47.

Lo, N. C.-h., L. D. Jacobson, and J. L. Squire. 1992. Indices of Relative Abundance from Fish Spotter Data based on Delta-Lognornial Models. Canadian Journal of Fisheries and Aquatic Sciences **49**:2515-2526.

SAFMC (South Atlantic Fishery Management Council) (2002) Fishery management plan for pelagic *Sargassum* habitat of the South Atlantic region. South Atlantic Fishery Management Council, Charleston, SC. 228 pp.

SEDAR (Southeast Data, Assessment, and Review) (2014) SEDAR 38 – Gulf of Mexico King Mackerel Stock Assessment Report. SEDAR, North Charleston SC. 465 pp.

SEDAR (Southeast Data, Assessment, and Review) (2016) SEDAR 33 Update – Gulf of Mexico Greater Amberjack Stock Assessment Report. SEDAR, North Charleston SC. 148 pp.

SEDAR (Southeast Data, Assessment, and Review) (2018) SEDAR 52 – Gulf of Mexico Greater Amberjack Stock Assessment Report. SEDAR, North Charleston SC. 434 pp.

SEDAR (Southeast Data, Assessment, and Review) (2020) SEDAR 67 – Gulf of Mexico Vermilion Snapper Stock Assessment Report. SEDAR, North Charleston SC. 199 pp.

Wang, M., and C. Hu. 2016. Mapping and quantifying Sargassum distribution and coverage in the Central West Atlantic using MODIS observations. Remote Sensing of Environment **183**:350-367.

Wells, R., and J. R. Rooker. 2004. Spatial and temporal patterns of habitat use by fishes associated with Sargassum mats in the northwestern Gulf of Mexico. Bulletin of Marine Science **74**:81-99.

Tables

Table 1. Relative abundance index of *Seriola* spp. larvae for the spring plankton survey season. Index represents the annual delta lognormal abundance (number of *Seriola* spp. larvae per 10 min. tow), and scaled index values represent the index value divided by the mean index value across all years. CV = coefficient of variation, LCL = lower confidence limit, and UCL = upper confidence limit for the scaled index.

Year	Index	CV	Scaled Index	LCL	UCL
1982	0.218	0.329	0.369	0.194	0.702
1983	0.373	0.259	0.632	0.380	1.053
1984	0.084	0.306	0.142	0.078	0.258
1986	0.699	0.292	1.183	0.668	2.096
1987	0.581	0.000	0.984	0.984	0.984
1988	0.671	0.000	1.135	1.135	1.135
1989	0.891	0.280	1.508	0.871	2.611
1990	0.589	0.394	0.996	0.466	2.130
1991	0.476	0.271	0.806	0.473	1.373
1992	0.817	0.241	1.383	0.859	2.226
1993	0.332	0.380	0.562	0.270	1.171
1994	0.316	0.309	0.535	0.292	0.979
1995	0.533	0.427	0.902	0.398	2.047
1996	0.501	0.284	0.849	0.487	1.481
1997	0.947	0.288	1.603	0.912	2.818
1998	0.666	0.319	1.127	0.604	2.102
1999	0.885	0.260	1.498	0.898	2.497
2000	0.456	0.267	0.772	0.457	1.305
2001	0.122	0.353	0.206	0.104	0.408
2002	0.135	0.312	0.228	0.124	0.420
2003	0.741	0.287	1.254	0.714	2.203
2004	0.533	0.298	0.902	0.503	1.616
2005	0.891	0.283	1.508	0.865	2.630
2006	0.953	0.246	1.614	0.993	2.623
2007	0.304	0.281	0.514	0.296	0.893
2008	0.811	0.262	1.372	0.820	2.295
2009	0.442	0.334	0.748	0.391	1.434
2010	0.088	0.398	0.149	0.069	0.321
2011	0.964	0.274	1.632	0.952	2.797
2012	0.843	0.266	1.427	0.846	2.408
2013	1.128	0.285	1.910	1.092	3.341
2014	0.914	0.299	1.546	0.862	2.774

Table 2. Relative abundance index of *Seriola* spp. larvae for the fall plankton survey season. Index represents the annual delta lognormal abundance (number of *Seriola* spp. larvae per 10 min. tow), and scaled index values represent the index value divided by the mean index value across all years. CV = coefficient of variation, LCL = lower confidence limit, and UCL = upper confidence limit for the scaled index.

Year	Index	CV	Scaled Index	LCL	UCL
1984	0.016	0.310	0.077	0.042	0.141
1986	0.380	0.271	1.864	1.094	3.176
1987	0.240	0.286	1.176	0.672	2.060
1988	0.177	0.285	0.868	0.496	1.518
1989	0.297	0.277	1.457	0.845	2.512
1990	0.165	0.283	0.807	0.463	1.405
1991	0.104	0.293	0.509	0.287	0.904
1992	0.185	0.281	0.907	0.522	1.574
1993	0.182	0.276	0.891	0.518	1.532
1994	0.199	0.280	0.974	0.562	1.689
1995	0.154	0.281	0.752	0.434	1.305
1996	0.231	0.279	1.131	0.654	1.958
1997	0.143	0.299	0.700	0.390	1.256
1998	0.072	0.283	0.350	0.201	0.610
1999	0.179	0.271	0.875	0.514	1.491
2000	0.218	0.268	1.069	0.631	1.811
2001	0.078	0.290	0.382	0.216	0.675
2002	0.253	0.263	1.241	0.740	2.081
2003	0.339	0.272	1.663	0.974	2.839
2004	0.121	0.286	0.594	0.339	1.040
2006	0.241	0.273	1.179	0.690	2.016
2007	0.299	0.273	1.466	0.857	2.508
2008	0.164	0.277	0.803	0.467	1.383
2009	0.279	0.272	1.367	0.801	2.335
2010	0.108	0.285	0.528	0.302	0.923
2011	0.140	0.289	0.686	0.390	1.209
2012	0.072	0.302	0.355	0.196	0.641
2013	0.222	0.269	1.089	0.642	1.846
2014	0.387	0.260	1.895	1.136	3.160
2015	0.457	0.268	2.239	1.322	3.791
2016	0.226	0.253	1.107	0.672	1.824

Figures

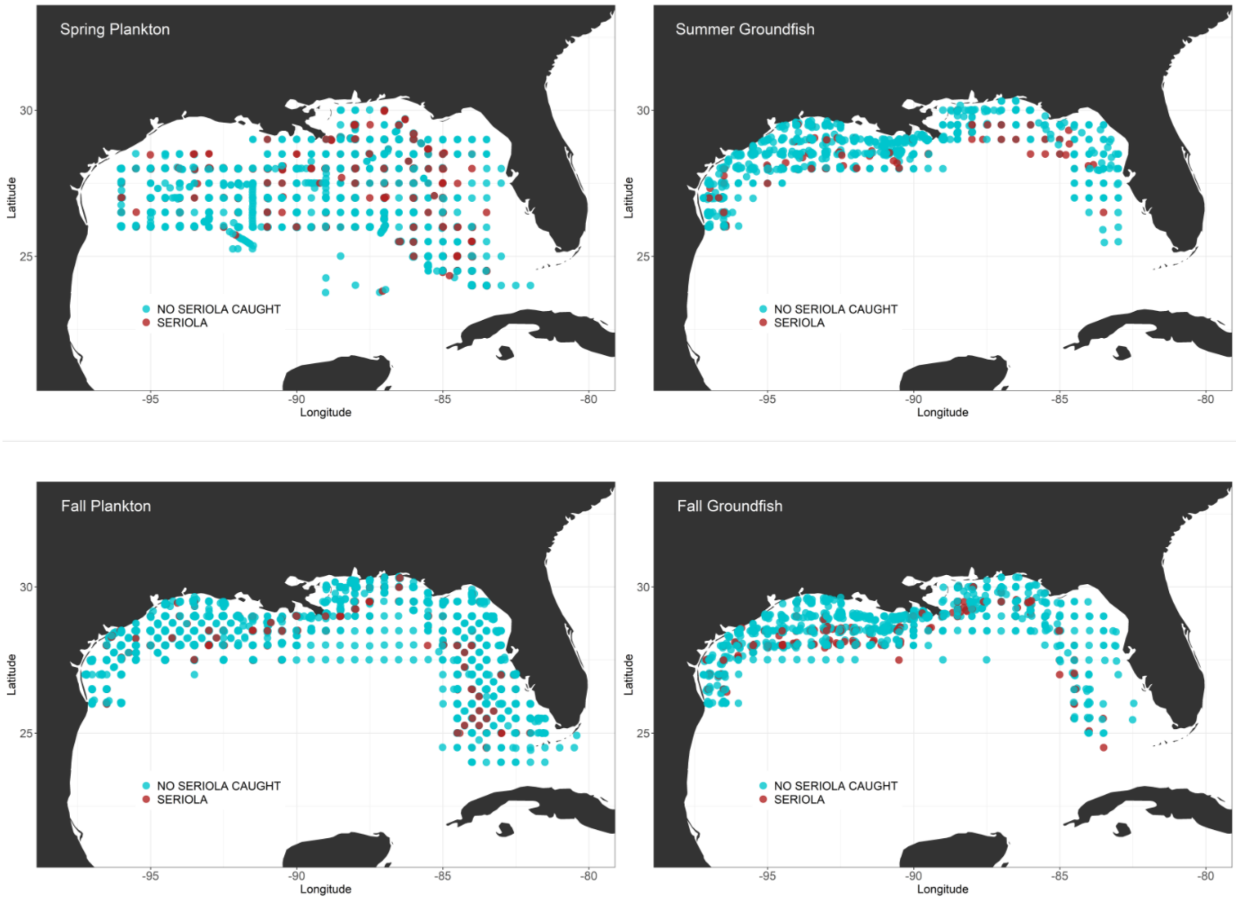

Figure 1. Maps of SEAMAP ichthyoplankton survey seasons (spring plankton, summer groundfish, fall plankton, fall groundfish) with sampling stations indicated over the entire survey time series (1982-2016). Positive or negative *Seriola* spp. catch is indicated by symbol color.

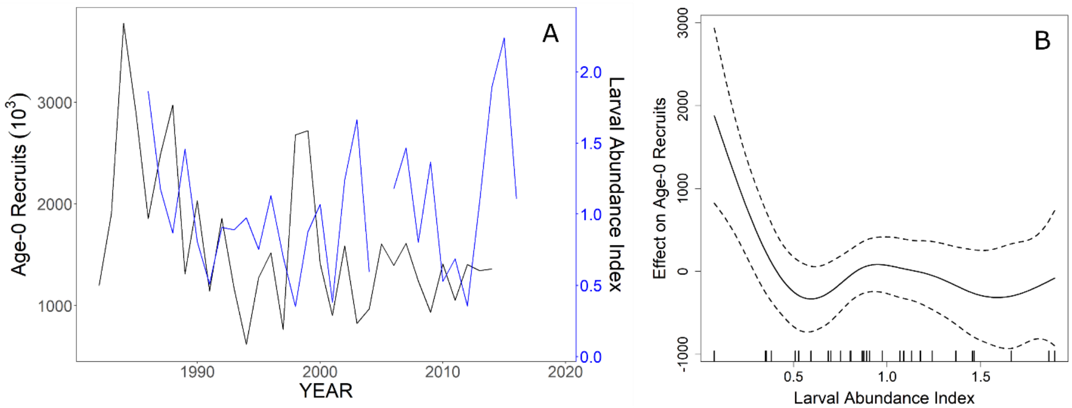

Figure 2. Fall plankton survey season (A) time series plots of age-0 greater amberjack recruits and *Seriola* spp. standardized relative larval abundance indices (number per 10 minute tow); (B) effect of standardized larval abundance indices on age-0 recruits based on GAM analyses.

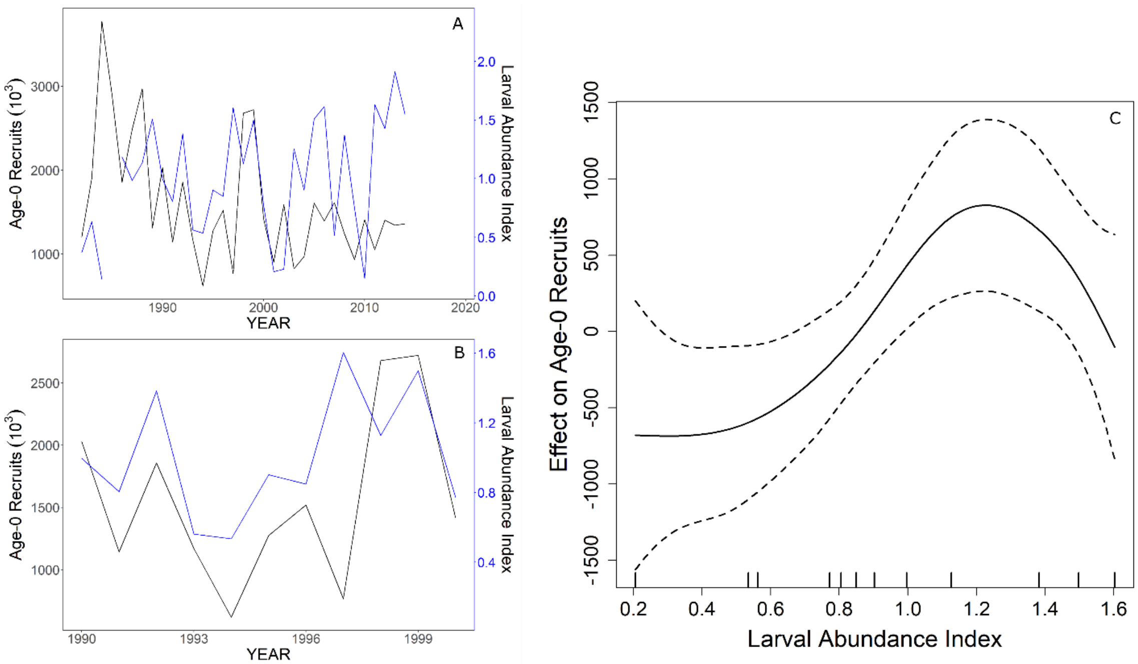

Figure 3. Spring plankton survey season (A) full time series plots of age-0 greater amberjack recruits and *Seriola* spp. standardized relative larval abundance indices (number per 10 minute tow); (B) truncated time series (1990-2001) highlighting period of strong match between age-0 recruits and larval abundance indices; (C) effect of standardized larval abundance indices on age-0 recruits based on GAM analyses conducted on truncated time series (1990-2001) data only.

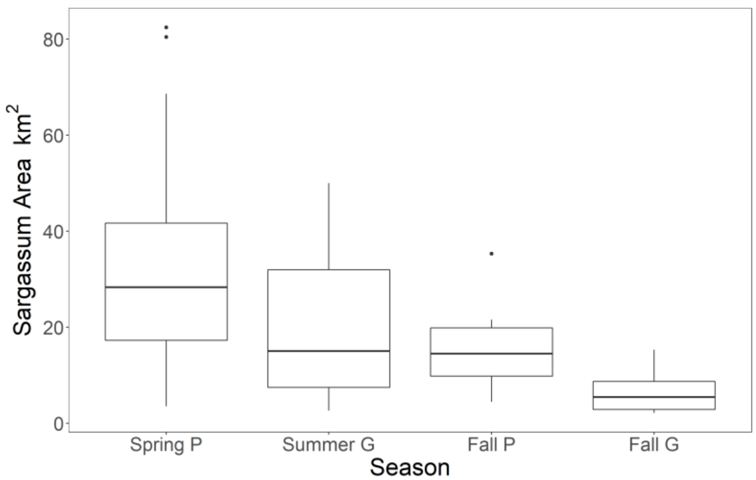

Figure 4. Variation in remotely-sensed seasonal *Sargassum* abundance indices by survey region. Spring P = spring plankton, Summer G = summer groundfish, Fall P = fall plankton, Fall G = fall groundfish. Boxplots display the median value (horizontal line), 25th and 75th percentiles (lower and upper hinges, respectively), and the extent of the whiskers from each hinge represents 1.5 x IQR (inter-quartile range; distance between 25th and 75th percentiles), with outliers beyond the whiskers shown as filled symbols. Three outlier values (spring plankton, summer groundfish) were truncated here for ease of visualization, but retained in all analyses.

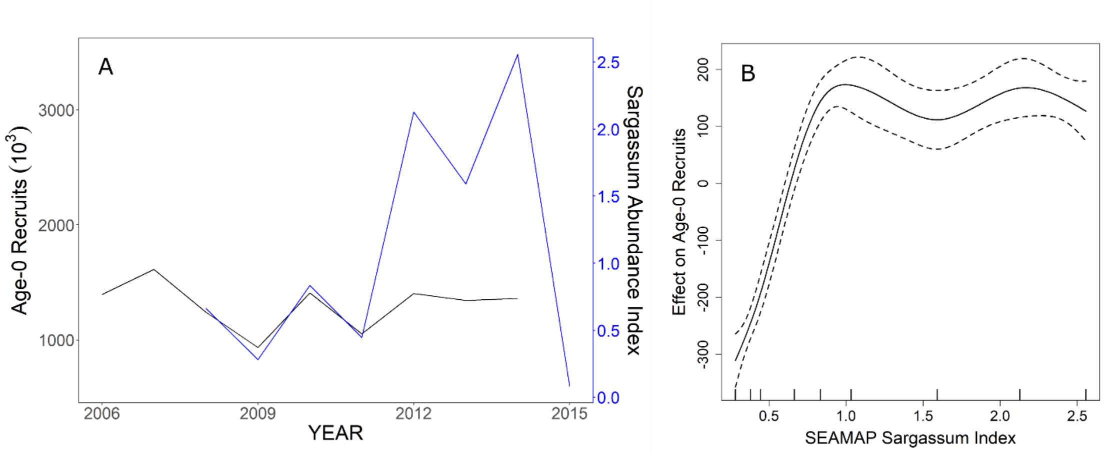

Figure 5. Summer groundfish survey season (A) time series plots of age-0 greater amberjack recruits and ship-based standardized relative *Sargassum* abundance indices (liters per 10 minute tow); (B) effect of ship-based standardized *Sargassum* abundance on age-0 recruits based on GAM analyses.

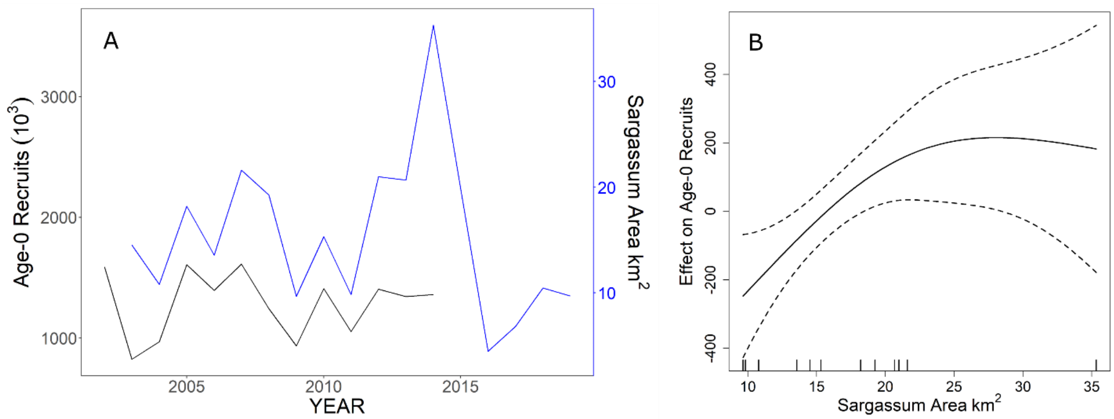

Figure 6. Fall plankton survey season (A) time series plots of age-0 greater amberjack recruits and remotely-sensed seasonal *Sargassum* abundance indices; (B) effect of remotely-sensed seasonal *Sargassum* abundance on age-0 recruits based on GAM analyses.

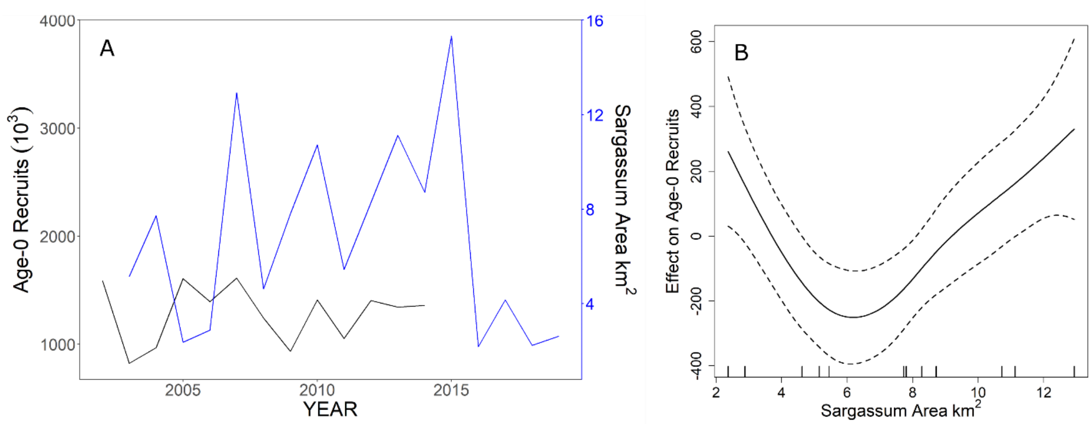

Figure 7. Fall groundfish survey season (A) time series plots of age-0 greater amberjack recruits and remotely-sensed seasonal *Sargassum* abundance indices; (B) effect of remotely-sensed seasonal *Sargassum* abundance on age-0 recruits based on GAM analyses.

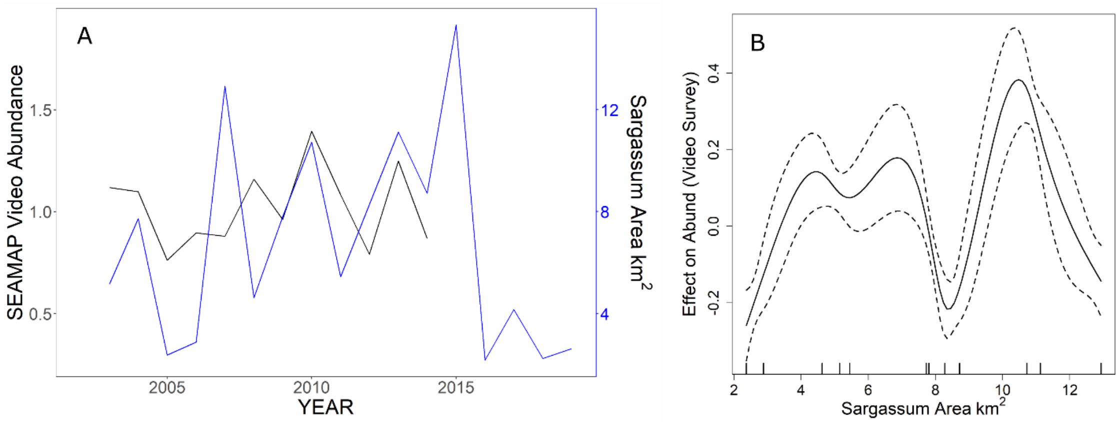

Figure 8. Fall groundfish survey season (A) time series plots of greater amberjack standardized CPUE estimated from the SEAMAP video survey and remotely-sensed seasonal *Sargassum* abundance indices; (B) effect of remotely-sensed seasonal *Sargassum* abundance on age-0 recruits based on GAM analyses.