Species groupings for management of the South Atlantic Fishery Management Council Snapper-Grouper Fishery Management Unit

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Abstract

The Magnuson-Stevens Reauthorization Act of 2006 requires regional fishery management councils to implement annual catch limits (ACL) and accountability measures for all stocks under Federal management by 2011, to ensure overfishing does not occur. Many species are data-limited and have no formal stock assessment. One possible approach to managing these unassessed species is to assign them to assemblages that would be managed as units. The utility of this approach was evaluated using fishery-dependent and fishery-independent data from the United States southern Atlantic Ocean. Multivariate statistical analyses revealed several consistent assemblages among the 35 species requiring an ACL under the South Atlantic Fishery Management Council's June 2010 preferred alternative. Identified stock complexes and sub-complexes may be useful for fisheries management, as a management measure implemented for any member of a complex might be expected to result in a similar trajectory of fishing mortality rate (F) for other members of the complex. Productivity-Susceptibility Analysis and life history were also considered, as differences in productivity, vulnerability, life history, and other population dynamic parameters for species within complexes might imply different population responses to a similar change in F. Identified linkages between species also provide guidance for ecosystem-based management considerations such as the impacts of regulations upon multi-species fisheries.

Introduction

The Magnuson-Stevens Reauthorization Act (MSRA 2006) requires regional fishery management councils to implement annual catch limits (ACLs) and accountability measures (AMs) to ensure overfishing does not occur. ACLs and AMs are required for all stocks under federal management, except stocks with annual life cycles and those managed by international agreement in which the United States participates. These ACL/AM provisions must be implemented in 2010 or earlier for stocks subject to overfishing, and in 2011 or earlier for all other federally-managed stocks. The South Atlantic Fisheries Management Council (SAFMC) currently manages 73 finfish species under its Snapper-Grouper Fishery Management Plan (FMP). Formally establishing ACLs for many of these species will be accomplished via the SAFMC's Comprehensive ACL Amendment. In June 2010, the SAFMC selected a preferred alternative which would reduce the number of Snapper-Grouper species requiring an ACL to 35. Management measures are traditionally implemented based upon species-specific stock assessment results. However, only 11 species managed by the SAFMC Snapper-Grouper FMP will have been assessed through a formal Southeast Data Assessment and Review (SEDAR) process by 2011 (e.g., gag, red porgy, red snapper, vermilion snapper, tilefish, snowy grouper, greater amberjack, black grouper, red grouper, goliath grouper, and yellowtail snapper).

One possible approach for developing ACLs for unassessed species would be to assign them to assemblages that would be managed as units. The NMFS ACL Final Rule states that "…the vulnerability of stocks to the fishery should be evaluated when determining if a particular stock complex should be established or reorganized, or if a particular stock should be included in a complex" (50 CFR 600.310(b)(8) in 74 FR 3205). National Standard 3 for fishery conservation and management (MSRA §301) states that "to the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination." A stock complex, as defined by the recently amended National Standard 1 guidance, is "a group of stocks that are sufficiently similar in geographic distribution, life history, and vulnerabilities to the fishery such that the impact of management actions on the stocks is similar" (74 FR 3178). Stocks may be grouped into complexes if: 1) they cannot be targeted independently of one another in a multispecies fishery; 2) there is not sufficient data to measure their status relative to established status determination criteria; or 3) when it is feasible for fishermen to distinguish individual stocks among their catch (50 CFR 600.310(b)(8) in 74 FR 3178). A management unit is defined as "a fishery or that portion of a fishery identified in a FMP as relevant to the FMP's management objectives" (50 CFR 600.320(d)). Management units may be organized based on biological, geographic, economic, technical, social, or ecological considerations (50 CFR 600.320(d)(1)).

The objectives of this paper are threefold: (1) To determine whether species assemblages can be identified in the U.S. southern Atlantic Ocean among the 35 (June 2010 SAFMC Preferred Alternative) managed Snapper-Grouper FMP species, (2) To determine if these assemblages are consistent between commercial and recreational fisheries, and (3) To develop species complexes that are "…sufficiently similar in geographic distribution, life history, and vulnerabilities to the fishery such that the impact of management actions on the stocks is similar" per National Standard 1. The results of these analyses should provide guidance for the SAFMC in setting ACLs for reef fish species in the Comprehensive ACL Amendment.

Methods

Following Lee and Sampson (2000), multiple statistical techniques were used to identify species assemblages: (1) species life history and depth of occurrence, (2) percent records by dataset, (3) dimension reduction and hierarchical cluster analyses based on life history; abundance; and presence-absence, (4) weighted mean cluster association indices, and (5) maps of species distributions. These results were synthesized across analyses to develop potential species complexes for ACL management sufficiently similar in geographic distribution, life history, and vulnerabilities to the fishery such that the impact of management actions on the stocks would be similar.

Life History and Landings Data

Life history parameters were assembled from peer-reviewed literature (see Appendices), Southeast Data Assessment and Review (SEDAR) reports, unpublished data from the NMFS Panama City Laboratory, Stock Assessment and Fishery Evaluation (SAFE) reports, and from FishBase (Froese & Pauly 2009). Data from the U.S. south Atlantic was used whenever possible. Depth of occurrence records were assimilated from the peer-reviewed literature (South Atlantic Fishery Independent Monitoring Program Workshop 2009) and FishBase (Froese & Pauly 2009), with minimum and maximum depths of occurrence recorded.

Commercial logbook, commercial observer, headboat logbook, recreational survey, and fishery-independent Marine Resources Monitoring, Assessment and Prediction (MARMAP) data were used to evaluate similarities in spatial and temporal patterns of fisheries exploitation in the U.S. south Atlantic for species in the SAFMC Snapper-Grouper FMP requiring an ACL under the Council's June 2010 Preferred Alternative. Commercial logbook records (SEFSC logbook data, accessed 6 May 2010) summarize landings on a trip level, with information for each species encountered including landings (in lbs), primary gear used, and primary area and depth of capture. Depth of capture is an important consideration when evaluating similarities in fisheries vulnerability and is only available in logbook records from 2005 onward, reported as a mean depth of capture, by species captured. It should be noted that a single depth of fishing is reported for each species per trip, although they may be encountered at numerous depths during multiple sets, and even within a single drifting longline set.

For the purposes of these analyses, logbook landings were summarized by species, year, month, geartype, statistical area, and depth. Year and month were defined by the date the fish were landed. Vertical line (e.g., handline and electric rig) and longline geartypes were evaluated separately. Area fished was based on 1° longitude by 1° latitude commercial logbook statistical areas. Depth of capture was aggregated into atmospheric pressure bins (e.g., 33 ft = 2 atm, 66 ft = 3 atm, etc.). Records with no reported depth or area of capture were removed from consideration; these represented approximately 6% of the total available records for both the longline and vertical line clusters. Overall, 2,047 longline and 136,005 vertical line commercial logbook records from 2005-2009 were evaluated.

For the commercial logbook data, separate analyses were conducted for commercial longline (CLL) and commercial vertical line (CVL) geartypes. Landings were aggregated by month to maximize the variety of species landed while still capturing temporal trends in abundance. Fishermen will typically make multiple sets on a trip, sometimes in geographically distant areas, targeting different species. Aggregating landings by area and depth reduced the probability of grouping species caught during the same time period that would likely not co-occur during any given set due to disparate geographic distributions. The CLL dataset suffers from potential bias because possession is limited to recreational bag limit for species other than snowy grouper, warsaw grouper, yellowedge grouper, misty grouper, golden tilefish, blueline tilefish, and sand tilefish (50 CFR 622.41(6)). As such, presence-absence clusters for the CLL dataset are probably more reliable than weight-of-catch clusters.

In July 2006, NMFS implemented a mandatory reef fish observer program (RFOP) to characterize the reef fish fishery operating in the U.S. Gulf of Mexico. The mandatory RFOP provides general fishery landing and bycatch characterization, estimates managed finfish discard levels; dispositions; and size distributions, and provides observations of protected species takes. In the U.S. southern Atlantic Ocean, the RFOP has been voluntary, primarily associated with special projects. As such, it suffers from spatial and sampling biases; however, it does provide accurate species identification at the set-level for species encountered using bottom longline, electric (bandit) reel, and handlines. Overall, 18,268 records representing encounters (e.g., landings plus discards) in numbers by species for 2,084 observed sets in the U.S. southern Atlantic Ocean from 2006-2009 were evaluated.

The recreational headboat sector of the reef fish fishery was evaluated using headboat survey (HBS) logbook data (Southeast Region Headboat Survey data, accessed 19 April 2010) reported by headboat operators. Headboats are large, for-hire vessels that typically accommodate 20 or more anglers on half- or full-day trips. HBS records are arranged similar to commercial logbook records, and contain trip-level information on number of anglers, trip duration, date, area fished, landings (number of fish), and releases (number of fish) of each species. Headboat landings and encounters (landings plus releases) were summarized by species, year, month, trip duration, and area fished. Trip duration was considered the best proxy for depth fished, as trips of longer duration are more likely to go farther offshore. Area fished was aggregated at the most common reporting level (1° latitude by 1° longitude). As with the commercial fishery data, area fished is self-reported and this introduces error into the analysis. Additionally, vessels fishing in multiple areas during a trip would be constrained by the current data form to select one area fished for the trip, which limits the spatial precision of the analysis. Records with no geographic area reported (~9%) were removed from consideration. Overall, 170,475 headboat records from 2004-2009 were evaluated.

The private, rental, and for-hire charter sectors were evaluated using data from the Marine Recreational Fisheries Statistics Survey (MRFSS) dockside intercept records. MRFSS intercepts collect data on port agent observed landings ('A' catch), angler reported landings ('B1' catch) and discards ('B2' catch). Data are reported in numbers by species, two-month wave (e.g., Wave 1 = Jan/Feb, … Wave 6 = Nov/Dec), area fished (inland, state, and federal waters), mode of fishing (charter, private/rental, shore), and state (east Florida, Georgia, South Carolina, and North Carolina). MRFSS intercepts from the U.S. southern Atlantic Ocean from 2000-2009 were aggregated by state, year, wave, mode, and area fished; computing a catch-per-angler-per-trip (CPAT) by species for the whole catch (e.g., 'A'+'B1'+'B2' catch). Overall, 93,911 dockside intercept records from 2000-2009 were evaluated.

For thirty years, the Marine Resources Research Institute at the South Carolina Department of Natural Resources, through the Marine Resources Monitoring, Assessment and Prediction (MARMAP) program, has conducted fisheries-independent research on groundfish, reef fish, ichthyoplankton, and coastal pelagic fishes within the region between Cape Lookout, North Carolina, and Ft Pierce, Florida. The overall mission of the program has been to determine distribution, relative abundance, and critical habitat of economically and ecologically important fishes of the South Atlantic Bight, and to relate these features to environmental factors and exploitation activities. MARMAP survey work has provided a monitoring program that has allowed the standardized sampling of fish populations over time and development of an historical base for future comparisons of long-term trends. The gears (e.g., Chevron trap, vertical line, and longline) and methodologies used have been consistent over the years to allow for long term analysis and comparisons. Historically, sampling effort for reef fish has been most heavily concentrated off South Carolina using various trap gears. MARMAP samples accurately identify fish to species and also collect valuable information on undersized fish. MARMAP data was aggregated by gear, at the set level. Overall, 25,304 records of managed reef fish landings from 1978-2009 were evaluated, comprised of 70% Chevron trap, 16% blackfish trap, 11% Antillean trap, 2% vertical line, and 1% longline samples.

Each data set was formatted as a matrix, with columns representing species (i) and rows representing aggregation bins (j). For commercial fisheries, aggregation bins were *year-month-area-depth* combinations, resulting in 636 longline bins and 9036 vertical line bins. For the RFOP, aggregation bins were *set-level*, resulting in 2084 bins. For headboat fisheries, aggregation bins were *year-month-area-trip duration* combinations, resulting in 2217 bins. For MRFSS, aggregation bins were *year-wave-state-mode-area* combinations, resulting in 1384 bins. For MARMAP, aggregation bins were *set-level*, resulting in 10,780 bins. Each element of the matrix (c_{ij}) quantified the amount (in units of pounds of fish for commercial and number of fish for all other sources) of a species (i) landed in a specific bin (j).

Initially, species were excluded from analyses if they appeared in <1% of bins, following Shertzer and Williams (2008). Rare species may distort inferred patterns (Koch 1987, Mueter and Norcross 2000). As a primary goal of these analyses was to assign less abundant species to species complexes, and a previous analysis for the Gulf of Mexico (SERO-LAPP-2010-03) suggested the inclusion of rare species did not impact inferred patterns in any of the cluster analyses, all species were included in the final analyses.

For hierarchical cluster analyses of landings data, prior to computing dissimilarities, data were transformed with a root-root transformation to moderate the influence of abundant species upon the resultant clusters:

$$— \quad (1)$$

This transformation is recommended for density and biomass data (Field et al. 1982) and was applied in a similar clustering approach described by Shertzer and Williams (2008).

Because the fishing effort that generates the landings data does not represent a consistent sampling program, reported landings data might not be quantitatively comparable between collections. Additionally, many species are heavily targeted, whereas the catch of others is incidental. Boesch (1977) suggested a binary index (e.g., 'presence-absence') may be a more appropriate measure of similarity with fisheries-dependent data. A binary index also reduces distortions caused by super-abundant (headboat and commercial) and heavier (commercial) species. For analyses of presence-absence data, landings data matrices were converted to binary, where a '1' was assigned to positive data elements (c_{ij}) and data elements with no landings were left as '0's.

Dimension Reduction and Hierarchical Cluster Analyses

Dimension reduction was conducted using PROC VARCLUS in SAS V9.2 (SAS Institute Inc., Cary, NC). PROC VARCLUS is a dimension reduction tool that clusters variables that are as correlated as possible among themselves and as uncorrelated as possible with variables in other clusters. The algorithm used by PROC VARCLUS is binary and divisive - all variables start in one cluster. A cluster is chosen for splitting and split into two clusters by performing an orthoblique rotation on the first two principal components. Each variable is assigned to the rotated component with which it has the higher squared correlation. The procedure is nonhierarchical; variables are iteratively reassigned to clusters to maximize the variance accounted for by the cluster components. Clusters are split until 95% of the variance is explained.

Hierarchical cluster analyses were conducted using PASW V17.0.3 (SPSS Inc., Chicago, Illinois). Hierarchical cluster analysis identifies relatively homogeneous groups of cases (or variables) based on selected characteristics. It is an agglomerative method which optimizes a route between individual entities to the entire set of entities through progressive fusion (Boesch 1977).

Life history parameters in Tables 1 and 2, plus a categorical variable denoting Genus, were clustered using Ward's minimum-variance linkage method (Sneath & Sokal 1973) with a Euclidean distance measure and a Z-score transformation by variable. Ward's minimum-variance linkage method minimizes within-group dispersion. This method agglomerates clusters when the increase in variance is less than it would be if either of the two clusters were joined with any other cluster (Sneath & Sokal 1973). Minimum-variance fusion is similar to average-linkage fusion, except that it minimizes a squared distance weighted by cluster size. Minimum-variance linkage is a space-dilating strategy because penalty by squared-distance results in tighter clusters than average-linkage. An additional cluster was performed following this methodology but dropping the 'Genus' dummy variable from the analysis.

The Euclidean distance (*ED*) measure is the square root of the sum of the squared differences between two entities (*j* and *k*) based on *P* variables:

(3)

The Z-score transformation normalized the data by parameter, facilitating comparisons between species.

The method employed to hierarchically cluster the fisheries datasets (e.g., CLL, CVL, RFOP, HBS, MRFSS, and MARMAP) was slightly different. After root-root transformation of landings in numbers or pounds, a matrix of dissimilarities between two species (*a*, *b*) was computed using a Chi-square (χ^2) measure of distance:

(4)

The Chi-square measure is based on the chi-square test of equality for two sets of frequencies, and is the default measure in PASW for count (e.g., abundance or landings) data. The magnitude of this dissimilarity measure depends on the total frequencies of the two cases or variables whose dissimilarity is computed. Expected values (*E*) are from the model of independence of species *a* and *b*. The resultant dissimilarity matrix was clustered using Ward's minimum-variance linkage method.

Presence-absence of species in the commercial longline, commercial vertical line, and headboat fisheries were clustered using average linkage between groups with a Sørenson measure of dissimilarity:

(5)

where D_{ih} is the distance between species *i* and *h*, and *j* is the number of rows (bins). In an average linkage method, the linkage function specifies the distance between two clusters as the average distance between objects from the first cluster and objects from the second cluster. Averaging is performed over all pairs (x, y) of objects, where x is an object from the first cluster and y is an object from the second cluster.

The average linkage function is expressed as follows:

(2)

where *d(x, y)* is the distance between objects *x* *X* and *y* *Y*; *X* and *Y* are two sets of objects (clusters), and N_X and N_Y are the numbers of objects in clusters *X* and *Y*, respectively. Average-link clustering is less sensitive to outliers than complete-link clustering, and less likely to form long chains than single-link clustering. This method is also known as the 'unweighted pair-group method using arithmetic averages' (UPGMA), and is widely used in ecology (see Boesch 1977, McGarigal et al. 2000). This method is a space-conserving strategy that introduces little distortion to the relationships expressed in the similarity matrix (Boesch 1977).

The Sørenson (e.g. 'Dice', 'Bray-Curtis', 'Czekanowski') measure is an index in which joint absences are excluded from consideration, and matches are weighted double. The Sørenson measure has been found more robust in ecological studies (Beals 1973, Field et al. 1982, Faith et al. 1987). It is commonly used in studies of fish assemblages (e.g., Mueter & Norcross 2000, Gomes et al. 2001, Williams and Ralston 2002, Shertzer & Williams 2008, Shertzer et al. 2009).

Overall, 2 life history and 24 fishery-data clusters were generated. For each of the six input datasets (e.g., CLL, CVL, RFOP, HBS, MRFSS, and MARMAP), a dimension reduction and a Ward's cluster were generated on root-root transformed landings, and a dimension reduction and a UPGMA cluster were generated on presence-absence. Dendrograms were generated for each cluster, based upon the agglomeration schedule. The dendrogram is read from left to right, with vertical lines indicating joined clusters. The position of the line on the scale indicates the distance at which clusters are joined. In SPSS, observed distances are rescaled to fall into the range of 1 to 25; the ratio of the rescaled distances within the dendrogram is the same as the ratio of the original distances. In SAS, Proc TREE was used to plot the dimension reductions with the proportion of variability explained as the height variable. Species joined closer to the left of the dendrogram would be considered more associated.

Weighted Mean Cluster Association Index

A weighted mean cluster association index was developed to synthesize results across the two life history and 24 fishery-data clusters (see Appendices). The goal of the method was to provide a quantitative measure of cluster association across multiple dendrograms. Figure 1 illustrates a hypothetical cluster and cluster association table. The cluster association matrix for each dendrogram was completed on a species by species basis. For a given species on row *r*, the association level (α) with species in column *c* was computed as:

$$—\ , \qquad (6)$$

where η is the number of species lower than the species on row *r* on the branches of the dendrogram. For example, species D and E are both below species F on the branch; thus and in the association matrix.

Unique cluster association matrices were assembled for each of the 24 fishery-data dendrograms, and a weighted mean cluster association index matrix was computed. For a given species on row *r*, the weighted mean association level ( ) with species in column *c* was computed as:

$$\frac{\quad}{\quad}\,, \tag{7}$$

where D is the dataset under examination, m is the clustering method, and w_D is the weighting term for the dataset. Weighting terms were computed by dataset, and were based upon the proportional representation of species within bins, and were scaled to 1 as a proportion of the maximum representation of that species across the 7 datasets, with life history given the maximal default value of 1 (Table 6). For example, if a species appeared in 80% of bins in the CLL and 40% of bins in the other datasets, its weighting term would be 1.0 for CLL (e.g., ω_{CLL}=1.0) and 0.5 for the other datasets. This weighted mean approach was employed for two reasons: (1) clusters are generally considered more reliable for species that frequently appear in the bins (Koch 1987, Mueter and Norcross 2000), and (2) management measures upon a species complex would typically be expected to have a higher proportional impact upon the sector that encounters the species most frequently.

Maps of Stock Distributions

The RFOP and MARMAP surveys provide spatially-explicit information regarding encounters with managed species in the U.S. southern Atlantic Ocean. These datasets were imported into ArcGIS (ESRI Inc., Redlands, CA) and displayed for presence-absence on bathymetric maps. Trends in species distributions were used to explain inconsistencies between cluster analyses and to evaluate the MSRA '[similar] geographic distribution' requirement for stock complexes.

Results

Life History and Landings Data

Table 1 provides life history parameters for managed SAFMC reef fish species. It should be noted that life history may be influenced by time (Shertzer et al. 2009), geography, habitat (Hoss & Engel 1996), exploitation (Hughes 1994), and climate (Holbrook et al. 1997); therefore these point estimates for species may not accurately express the life history dynamics of the unexploited population or of all stock subpopulations. Additionally, life history data may be less reliable for data-poor species, lending uncertainty to the resultant clusters.

Table 2 provides ranges for depth of occurrence for managed species. For visualization purposes, species were placed into 'shallow' (yellow), 'shallow/mid' (pale orange), 'mid' (pale red), 'mid/deep' (orange), and 'deep-water' groups, based upon median depth of occurrence. Red grouper and gag grouper have a broader depth range of occurrence than other 'shallow-water' groupers (Table 2). Banded rudderfish and almaco jack have a more constricted depth range than greater amberjack (Table 2). Red snapper, silk snapper, blackfin snapper, vermilion snapper, lane snapper, and gray triggerfish all occur in mid-to-deep water (Table 2). Blueline tilefish and speckled hind have a shallower range than the other ‘deep-water’ groupers and tilefish (Table 2). The data in Tables 1 and 2 are clustered in Figure 2.

Dimension Reduction and Hierarchical Cluster Analyses

Not surprisingly, a hierarchical cluster analysis of the life history and depth of occurrence parameters in Tables 1 and 2 showed clustering by genus, depth of occurrence, and maximum size (Figure 2). All of these variables are highly inter-correlated. Additionally, maximum size was captured by L_{inf} and W_{inf}, and was also probably correlated to a_{λ}, l_m, a_m, and depth of occurrence.

A cursory examination of Tables 1 and 2 and Figure 2 supports many general trends observed in fisheries. Species of the same genus often exhibit similar growth patterns. Larger organisms tend to live longer and grow more slowly (e.g., ‘K-selected’ species), as do organisms that live in deeper water. Many species live up to 25-30 years, and some live to be older than 50.

In general, dimension reduction and hierarchical cluster analysis outputs should be considered more reliable for species that are more prevalent in the input data matrices (Table 3). For example, deep-water grouper, and tilefish were well-represented in the CLL matrix. Species diversity refers to the variety of living species within a geographic area. It may be measured by species richness; the number of species within a particular sample, and species evenness; the evenness in the number of each species encountered in the sample. The CVL, HBS, and MRFSS datasets had relatively high species richness and evenness (Table 4). The CLL most commonly encountered deep-water grouper and tilefish (Table 3). The CVL most commonly encountered shallow-water grouper, greater amberjack, and mid-water snapper and triggerfish (Table 3). The RFOP most commonly encountered red porgy, vermilion snapper, and scamp (Table 3). The HBS and MRFSS most commonly encountered gray triggerfish, gag, black sea bass, vermilion snapper, and white grunt (Table 3). MARMAP survey most commonly encountered black sea bass, red porgy, and tomtate (Table 3). The high species richness observed in the CVL, HBS, and MRFSS are probably attributable to the high levels of effort in their associated fisheries.

The MARMAP survey was the only fishery-independent dataset examined. Unfortunately, the limited spatial distribution of the sampling and the selectivity of the predominant gears led to proportionally low encounter rates with most managed Snapper-Grouper species (Tables 4-5). Only black sea bass, red porgy, tomtate, vermilion snapper, gray triggerfish, white grunt, knobbed porgy, and scamp were encountered in >5% of sets. However, MARMAP’s set-level data also led to substantially more aggregated bins than any other dataset.

Commercial longline landings in excess of the bag limit for anything other than deep-water species (e.g., snowy grouper, warsaw grouper, yellowedge grouper, misty grouper, golden tilefish, blueline tilefish, and sand tilefish) are prohibited; therefore landings of other species are extremely rare. Due to this prohibition, the binary-transformed CLL data matrix cluster is presented in Figures 3-4; as presence-absence would be more meaningful than landings totals given this management restriction. Tight clusters appeared between three deep-water species (e.g., blueline tilefish, yellowedge grouper, and snowy grouper), three shallow-water snapper species (e.g., lane snapper, yellowtail snapper, and gray snapper), and two shallow-water grouper species (e.g., red grouper and black grouper).

As commercial data are logged in weight units rather than numbers, the CVL dataset clusters are presented in terms of presence-absence to reduce the skewing of the data towards heavier species. The CVL landings data matrices produced clusters (Figures 5-6) of two shallow-water grouper (e.g., red grouper and scamp), two mid-water species (e.g., vermilion snapper and gray triggerfish), two porgies and hinds (e.g., rock hind and jolthead porgy), two shallow-water snapper (e.g., gray snapper and yellowtail snapper), and two deep-water species (e.g., snowy grouper and blueline tilefish).

The voluntary U.S. southern Atlantic RFOP represents a biased, but high-resolution sub-sample of the CLL and CVL datasets (Figure 7). Clusters were apparent between white grunt and red grouper, between vermilion snapper and tomtate, and between red hind; yellowfin grouper; and rock hind. Additional clusters were apparent between red porgy and gray triggerfish, between scamp and speckled hind, and between snowy grouper; blueline tilefish; and sand tilefish.

Cluster analysis of landed catch (in numbers) reported to the SEFSC HBS (Figures 8-9) provided similar results to the CLL and CVL. Shallow-water snapper (e.g., lane snapper and gray snapper) again clustered together, along with black grouper and yellowtail snapper. Red grouper, white grunt, and jolthead porgy formed a cluster. Red hind and rock hind clustered together, as did almaco jack and greater amberjack. Vermilion snapper and gray triggerfish formed a distinct cluster, as did scamp and red porgy. Two deep-water species (e.g., blueline tilefish and snowy grouper) also formed a cluster.

Cluster analysis of species presence-absence in MRFSS-reported landings (Figures 10-11) identified several apparent groups. Apparent clusters were identified between five deep-water species (e.g., snowy grouper, blueline tilefish, golden tilefish, silk snapper, and yellowedge grouper), three jacks and one porgy (e.g., almaco jack, greater amberjack, banded rudderfish, and whitebone porgy), and three shallow-water snapper (e.g., yellowtail snapper, lane snapper, and gray snapper).

Cluster analysis of species presence-absence in the MARMAP survey identified a few apparent groups (Figure 12). Two jacks formed a cluster (e.g., greater amberjack and almaco jack), as did three deep-water species (e.g., blueline tilefish, snowy grouper, and yellowedge grouper). Finally, vermilion snapper and gray triggerfish again appeared in the same cluster.

Weighted Mean Cluster Association Index

The weighted mean cluster association index matrix (Table 6) provided a quantitative approach to synthesizing information contained in the 24 unique cluster analyses performed (see

Appendix). This matrix was used to determine the top five most associated species with each managed species in the Gulf (Table 7). Stocks were then arranged with regards to association and vulnerability to provide ACL stock complex guidance.

Maps of Stock Distributions

Maps of the distribution of observed MARMAP and RFOP interactions with managed South Atlantic Snapper-Grouper species provided some insights into the outcomes of the cluster analyses described above. Figure 13A depicts the distribution of 'deep-water' stocks. Blueline tilefish and snowy grouper appear to have somewhat overlapping distributions, which periodically overlap with yellowedge grouper. Golden tilefish appears in somewhat deeper water in a relatively spatially restricted area. Silk snapper and warsaw grouper appear rare, but seem to overlap with snowy grouper where they occur. There is some hint of a latitudinal gradient in tilefish stocks, with golden tilefish off the GA/SC border, blueline tilefish off northern SC, and sand tilefish off NC.

Figure 13B depicts the distribution of many grunt, hind, and porgy stocks. Tomtate and white grunt, especially, appear ubiquitously distributed across depths out to the shelf break. Red hind and rock hind appear rare, but seem to have overlapping distributions. Knobbed porgy appears more commonly encountered along the shelf break.

Figure 14A depicts the distribution of jack stocks (e.g., greater amberjack, almaco jack, and banded rudderfish), which were encountered somewhat ubiquitously, but were most common near the shelf break. The distributions of the jacks were overlapping, although greater amberjack appears to have a broader depth distribution than almaco jack or banded rudderfish.

Figure 14B depicts the distribution of 'mid-water' stocks (e.g., gray triggerfish, red snapper, red porgy, and vermilion snapper). Of these, red porgy are more common northward; whereas red snapper are more common off northeast Florida and Georgia. Vermilion snapper appear to have distinct areas of high concentration, and these zones appear to overlap heavily with the other species. The distribution of gray triggerfish appears to extend somewhat further north than the other stocks.

Figure 15A depicts the distribution of 'shallow-water' grouper, sea bass, and hind stocks. Black sea bass is distinctly separated from the rest, with a distribution much further inshore. Red grouper is common off of Florida and North Carolina, but rare off Georgia and South Carolina. Yellowfin grouper is common along the shelf edge off North Carolina. Gag, scamp and speckled hind are common from Georgia northward, and their distributions overlap (Matheson and Huntsman 1984; Collins et al. 1987; Harris et al. 2002), although gag also occurs inshore, perhaps due to the well-documented ontogenetic migration of this species (Collins et al. 1987; Van Sant et al. 1994; McGovern et al. 1998; McGovern et al. 2005).

Figure 15B depicts the distribution of 'shallow-water' snapper stocks. These primarily southeastern Florida stocks are clearly not well-captured by the sampling of the RFOP and MARMAP.

Discussion

The MSRA requires fishery management plans to "…establish a mechanism for specifying annual catch limits…at a level such that overfishing does not occur in the fishery" (MSRA §303(a)(15)). Traditionally, a formal stock assessment, such as those conducted by the SEDAR process, will specify an overfishing limit (OFL) corresponding with yield at the maximum fishing mortality threshold (MFMT) or the fishing mortality rate that will allow the stock to rebuild by a target year ($F_{rebuild}$). Next, the Council's Scientific and Statistical Committee (SSC) sets an acceptable biological catch level (ABC) that cannot be set higher than OFL, as it accounts for scientific uncertainty in the estimate of OFL. Finally, an ACL is set by the Council. The ACL is the level of annual catch of the stock or stock complex that serves as the basis for invoking AMs. The ACL cannot be set higher than ABC, as it accounts for management uncertainty in ABC.

Under their preferred alternative from June 2010, by 2011, the SAFMC will need to establish ACLs for 35 Snapper-Grouper stocks, many of which are unassessed. Setting stock-specific ACLs for many of these stocks may be unrealistic due to inadequate data to determine stock status relative to established status determination criteria (SDC). Many of these stocks suffer from issues with species identification and/or extreme fluctuations in relative landings through time due to rarity or lack of targeted fishing effort. Thus, specifying a single-species ACL based on average catch for these stocks might result in periodic overages that would require AM implementation, creating additional burdens on science and enforcement. Grouping unassessed stocks into complexes may help avoid implementing AMs for species whose landings fluctuate due to rarity or species identification issues.

The primary goal of a stock complex in the context of the SAFMC Comprehensive ACL Amendment is to determine how to best aggregate stocks in order to establish an ACL. Unfortunately, many stocks are rarely caught, leading to difficulties with clustering approaches. Additionally, assessed stocks may not be good indicators for other, more vulnerable stocks in a complex. Using an assessed stock as an indicator may not facilitate detection of changes in the status of less abundant or less studied species, and may not prevent overfishing of more vulnerable stocks in the complex (Brown & Parrack 1985, Fahrig 1993, Shertzer & Williams 2008).

Indicator species have been used in management of both terrestrial and marine systems (Simberloff 1998, Zacharias & Roff 2001). The National Standard Guidelines of U.S. Federal fishery management state that where maximum sustainable yield (MSY) cannot be specified for each stock of a mixed-stock fishery, then, "MSY may be specified on the basis of one or more species as an indicator for the mixed stock as a whole or for the fishery as a whole" (50 CFR 600.310(c)(1)(iii). An implicit assumption of the use of an indicator species for management is that population trends of the indicator species reflect those of others in the assemblage. As such, assemblages should account for interspecies similarities in the context of biological characteristics, fisheries exploitation patterns, and stock dynamics. Biological assemblages may be defined by similarities in life history, trophic behavior, and geographic distribution. For fisheries management purposes, species that are caught together should be grouped, so that regulations similarly influence all assemblage members. If trends with an indicator species truly represent those of the assemblage as a whole, the catch-per-unit-effort (CPUE) for the indicator species should exhibit synchrony with the CPUE patterns of the other members of the assemblage.

For an assessed stock to be an appropriate indicator stock for a stock complex, assessed stocks and unassessed stocks in the complex should show similar trends in population abundance in response to environmental forcing, fishing pressure, and fisheries management regulations. Unfortunately, it is extremely difficult to separate out these signals without a full benchmark assessment. In a resource-limited environment, niche theory (May & MacArthur 1972, Landres et al. 1988, Leibold 1995) predicts that coexisting species would differ in their life history (e.g., reproductive dynamics, foraging behavior, habitat requirements) and population dynamics (e.g., responses to competition, predation, disease, and environmental variation). If these differences are substantial enough, population trends for one stock may not readily extrapolate to others in the complex (e.g, Niemi et al. 1997, Shaul et al. 2007, Shertzer & Williams 2008). The use of indicator species is not recommended unless supported by strong evidence from the system in question (Landres et al. 1988, Niemi et al. 1997). Even closely related species may have dissimilarities in their population structures and dispersal patterns that lead to different responses to exploitation (Bird et al. 2007).

Fishery-independent data is preferable for inferring patterns of biodiversity (e.g., Jay 1996, Collie et al. 2008), but is extremely limited for the majority of the stocks managed by the SAFMC, and where it is available, it suffers from a variety of spatial and gear biases that make it a poor representative for many species in the Snapper-Grouper FMU. Using fishery-dependent data as a proxy for trends in population abundance would introduce several layers of bias (e.g. gear, spatial, temporal, depth) into any evaluation of indices of abundance. These biases might generate spurious correlations that would be difficult to separate out from actual population trends.

A comprehensive understanding of concurrent stock vulnerabilities to various fisheries is critical to achieve the goal of ACL/AM management. The myriad of statistical approaches explored in this study tell a relatively consistent story regarding what stocks might be impacted by similar management measures. By considering some fishery and ecosystem variables such as life history, vulnerability, sector, gear, area, and depth fished, these analyses provide insights that may facilitate multispecies or ecosystem-based management.

Of the cluster analysis input variables, depth appeared the most important, with apparent shallow-water, mid-water, and deep-water assemblages frequently appearing in most analyses. A similar approach by Bortone et al. (1979) also found community association was influenced predominantly by depth, and to a lesser extent by substrate, latitude, and season. The species composition of apparent assemblages varied slightly by dataset. Headboats are less likely to catch deep-water stocks because deep-water stocks are farther offshore and not often targeted by limited duration headboat trips. Commercial bottom longliners are less likely to catch non-deep-water stocks because possession is limited to recreational bag limit for species other than snowy grouper, warsaw grouper, yellowedge grouper, misty grouper, golden tilefish, blueline tilefish, and sand tilefish (50 CFR 622.41(6)).

A latitudinal gradient in stock distribution was an underlying factor in the cluster analyses as well, with biogeographic boundaries near Cape Canaveral, Florida and Cape Hatteras, North Carolina (Wells and Gray 1959, Shertzer and Williams 2008, Shertzer et al. 2009). The influence of this gradient was profound when examining the 73 members of the Snapper-Grouper FMU prior to the Council's selection of the June 2010 preferred alternative, with only 35 commonly encountered species still requiring an ACL. Of these, 31 were likely to be reported in the CVL dataset (e.g., excluding black seabass, goliath grouper, Nassau grouper, and wreckfish). All of these 31 species were encountered south of Hatteras and south of Canaveral; however, only 22 were encountered north of Hatteras. No landings were reported for banded rudderfish, bar jack, gray snapper, lane snapper, sand tilefish, tomtate, warsaw grouper, and whitebone porgy north of Hatteras. Higher resolution in the cluster analyses might have been obtained by separating out this biogeographic region, but it is unclear how this biogeographic stratification would then be applied for ACL/AM management.

Genus and life history were also important factors in the clustering; for example, snappers and groupers were often separated. This is possibly due to differences in vulnerability to gears and fishing methods as well as differences in geographic and depth distributions. Caution should be taken when interpreting these results, as years of overexploitation may have altered community structure and species composition (Hughes 1994).

Stock complexes for ACL/AM management "may be comprised of: (1) one or more indicator stocks, each of which has SDC and ACLs, and several other stocks; (2) several stocks without an indicator stock, with SDC and an ACL for the complex as a whole; or (3) one of more indicator stocks, each of which has SDC and management objectives, with an ACL for the complex as a whole…" (50 CFR 600.310(b)(8) in 74 FR 3205). These approaches are not mutually exclusive. For example, a broad complex might be formed with an overall ACL, which, if exceeded, would trigger AMs. Within this broader complex, one or several sub-complexes might be designated. Each sub-complex could have an ACL either based on all species in the complex or on one or more indicator species. If this sub-complex ACL were exceeded, AMs might be implemented that impact all or some of the members of the sub-complex. Finally, some sub-complexes might contain only one species, and would require a species-specific ACL.

Setting an ACL for a stock complex containing a highly productive, targeted species might expose more vulnerable species to overfishing. One approach might be a multi-faceted approach to ACL management: (1) set species-specific ACLs for productive stocks; (2) set sub-complex ACLs for sub-complexes of related, less productive stocks; and (3) set complex ACLs that aggregate the single-species and sub-complex ACLs. This would provide multiple handles of control in the AMs that would help prevent overfishing of all species in the complex. If the single-species ACLs (e.g., ‘1’) were slightly exceeded, AMs would be implemented for that stock without necessarily impacting the stocks in the sub-complex (e.g., ‘2’), allowing the fishery to obtain optimum yield (OY) for the productive stock. This might be favorable, since most productive stocks in the U.S. southern Atlantic Ocean are assessed. If the sub-complex ACLs (e.g., ‘2’) were exceeded, AMs would be implemented for the sub-complex without necessarily impacting the most productive stock (e.g., ‘1’). Finally, if the ACL for the targeted stock were grossly exceeded, the complex ACL (e.g., ‘3’) might also be exceeded, resulting in implementation of AMs for the whole complex. This multi-faceted approach promotes attaining OY for the productive stocks while providing two mechanisms to prevent overfishing of the less productive—often more vulnerable—stocks. Grouping less productive, vulnerable, and/or data-poor stocks into sub-complexes helps mitigate uncertainty in individual landings histories, mitigates issues with species identification, and provides buffers against the unnecessary implementation of AMs. The use of an ACL for an overall complex containing one or more productive stocks plus other less productive stocks from the sub-complex helps protect the sub-complex stocks from overfishing because even if their sub-complex ACL is not exceeded according to the existent data collection program, undetected overfishing of these stocks may be taking place during overharvesting of a productive stock with which they are often incidentally or deliberately harvested.

Although many of the cluster analyses were based upon vulnerabilities to selective fishing gear, the major controlling factors included season, area, and depth; thus, some aspects of life history were *de facto* included in the analyses. These analyses mostly supported a ‘deep-water grouper’ assemblage of yellowedge grouper, snowy grouper, and warsaw grouper (Table 7). Due to their distance from shore and the specialized gears required to capture the ‘deep-water’ component of these stocks, there was a low relative percentage of encounters of these species in all datasets save CLL (Table 3). There was substantial clustering and geographic overlap between these stocks and managed tilefish species (Table 7, Figure 13A). It should be noted that yellowedge grouper is extremely long-lived and highly productive relative to the other members of this complex (Table 3), although its life history is similar (Figure 2). Warsaw grouper is the most vulnerable member of this complex, and was most highly associated with snowy grouper (Table 7).

The high levels of association between tilefish and ‘deep-water’ groupers that suggested management regulations upon stocks in either assemblage might impact stocks in the other (Table 7). The weighted mean cluster association index matrix suggested moderate levels of association between all the tilefish species (Table 7). Golden tilefish occurs at similar depths as yellowedge grouper and is occasionally caught on the same set, but is less structure-affiliated than the grouper, preferring soft bottom habitats on the upper continental slope (Harris et al. 2001, Sedberry et al. 2006). Blueline tilefish frequently clustered with snowy grouper, along with other ‘deep-water’ stocks (Table 7). Blueline tilefish are distributed further inshore along the shelf than the other ‘deep-water’ tilefish (Figure 13A). Blueline tilefish prefers irregular, rocky bottom from the outer shelf edge to the upper slope (Struhsaker 1969, Ross 1978, Ross and Huntsman 1982, Parker and Mays 1998). Silk snapper and wreckfish also associated with deep-water grouper and tilefish. Life history and vulnerability differences between these associated species may necessitate the management of several complexes or subcomplexes. Overall, identified deep-water grouper and tilefish complexes were consistent with results presented by Shertzer and Williams (2008).

The three managed jack species (e.g., greater amberjack, banded rudderfish, and almaco jack), were most frequently encountered by the HBS and CVL sectors (Table 3). In the HBS, almaco jack and greater amberjack clustered tightly with each other (Figures 8-9). In the CVL, no strong associations between jacks were observed (Figures 5-6). Data from trained observers in the RFOP suggested some association between banded rudderfish and almaco jack (Figure 7). A cluster of the MRFSS data suggested associations between all the jack species (Figure 10-11). Table 6 suggests moderate levels of cluster association between the jack species. SEDAR 15 (2009) concluded that almaco jack were correctly identified in most instances, but smaller greater amberjack and banded rudderfish were often misidentified. Issues with misidentification might lead to issues computing single-species ACLs for these species unless the rate of misidentification is quantifiable or has been (and remains) constant through time. The use of a 'Jacks' complex would mitigate issues with species identification by regulating misidentified species together. These findings are reasonably consistent with Shertzer and Williams (2008); using hierarchical cluster analysis, they identified a complex including banded rudderfish and almaco jack in the HBS, and greater amberjack and almaco jack in the commercial sector.

Although there was some overlap with some of the more broadly distributed 'shallow-water' grouper species such as gag and scamp, several species occurring at moderate depths (e.g., 'mid-water') were highly associated: gray triggerfish, red porgy, vermilion and red snapper (Table 7). These species were most consistently encountered in the HBS data (Table 3). Nearly all clusters indicated a strong association between gray triggerfish and vermilion snapper. Although gray triggerfish clustered with 'mid-water' snapper species, it may be desirable to manage it separately due to differences in life history (Table 1). Red snapper in the SAFMC jurisdiction are severely overfished (SEDAR 24 Pre-Review SAR 2010, SEDAR-15-SAR1 2008), which may explain the lack of compelling clustering with vermilion snapper despite similar distributions (Figure 14A). As all of these species except gray triggerfish have been assessed, it may be desirable to manage them individually. Shertzer and Williams (2008) identified clusters in both sectors using both *k*-medioids and hierarchical clustering methods that included black sea bass, gag, gray triggerfish, red porgy, red snapper, scamp, vermilion snapper, and white grunt.

Our analyses partially supported two 'shallow-water grouper' complexes; one comprised of red grouper, gag, and scamp, and a second comprised of yellowfin grouper and speckled hind (Table 7). All of these species were most commonly encountered by the HBS. Scamp clustered most strongly with red porgy in the HBS and MRFSS (Figure 8, 10-11). Given that red grouper and gag both have recent assessments, it may be desirable to manage them individually. Given the relatively poor association between these 'shallow-water grouper' complexes, it may be desirable to manage all these species individually, if possible. Shertzer and Williams (2008) found high similarity between gag and red snapper in the headboat, and between red grouper and white grunt in the commercial sector.

The weighted mean cluster association index method showed a fair level of association between several grunt, hind, and porgy species (Table 7). The majority of these species were most common in either the HBS or MRFSS data matrices. Within HBS, red hind and rock hind clustered tightly, as did jolthead porgy and white grunt, and tomtate and white porgy (Figure 8). These species are most likely incidentally caught by recreational fishermen in pursuit of larger species, particularly red grouper. These results were relatively inconsistent with the results of Shertzer and Williams (2008), probably due to both differences in the data sets used and the relative weakness of the associations between these non-targeted stocks.

The clustering for 'shallow-water' snappers (e.g., gray, lane, and yellowtail snapper) was very tight (Table 7). In the U.S. southern Atlantic Ocean, these stocks are primarily distributed in Southeast Florida (Farmer, unpublished data). All were most common in the HBS and MRFSS data matrices, but clustered tight for nearly all datasets. The gray snapper has a substantial fishery in Florida state waters, especially in the Florida Keys. Gray snapper may be misidentified with lane, which would artificially inflate the association between these species. Yellowtail snapper are more likely than gray and lane snapper to take bait at the surface; they may be a good candidate for a species-specific ACL. Shertzer and Williams (2008) also identified clusters in both sectors that included gray snapper, lane snapper, and yellowtail snapper.

ACL management using stock complexes may be the best management option when formal stock assessments are unavailable, and the data requirements (e.g., stable catch for several years, reliable estimate of natural mortality) of other methods such as Depletion-Adjusted Average Catch (MacCall 2007) are not met. Using stock complexes for ACL/AM management reduces management burden for quota monitoring, and may help mitigate the impacts of uncertainty in landings data or species identification by pooling data-poor species. Additionally, the unnecessary implementation of AMs may be avoided by setting ACLs for complexes rather than rarely-encountered single species.

Although ecosystem-based or single-species ACLs may be desirable for many species, stock complexes may provide a temporary solution for setting ACLs for species lacking stock assessments. In establishing stock complexes, managers should consider the geographic and depth distribution of species, life history characteristics, exploitation patterns, and vulnerabilities. Managers could then adapt their management strategies as new information and understanding of species linkages and complexes arises. This will allow for proactive management that accounts for ecosystem-based management considerations such as temporal fluctuations in stock abundance due to environmental forcing or multispecies interactions, as well as comprehensive assessments of the impacts of regulations on associated species. For this approach to succeed, data collection will need to be targeted at gaining a high-resolution map of the biogeographic distribution of fish stocks and the spatial distribution of fishing effort, as well as improved estimation of life history parameters and trophic linkages between species. This approach is especially relevant given that community structure may change through time

(Shertzer et al. 2009) due to heavy exploitation (Hughes 1994, McClenachan 2009), invasive species (Albins & Hixon 2008), habitat degradation (Hoss & Engel 1996, Anderson et al. 2008), and climate change (Holbrook et al. 1997, Attrill & Power 2002, Genner et al. 2004, Perry et al. 2005, Collie et al. 2008). Similarly, the structure of stock complexes may change through time if the fishery begins operating more heavily in different areas, using different gears, or targeting different species.

Acknowledgements

The authors are grateful for comments from A. Strelcheck, J. Walter III, J. Quinlan, C. Porch, S. Calay, R. Malinowski, J. McGovern, S. Branstetter, J. Kimmel, C. Simmons, L. Barbieri, and S. Atran. We are also grateful to K. Shertzer and E. Williams, who provided input and suggestions on clustering methods. These analyses would not have been possible without the greatly appreciated efforts of the commercial fishermen and headboat operators who submitted logbook data. We also thank the Southeast Fisheries Science Center's K. Brennan, K. McCarthy, S. Turner, V. Matter, J. Bennett, W. Ingram, and L. Scott-Denton for providing data used in this work.

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Table 1. Life history parameters for managed reef fish species in U.S. south Atlantic (see Appendix for references).

Common Name	***Scientific Name***	**a_λ (yr)**	**K**	**L_{inf} (cm)**	**a_0 (yr)**	**W_{inf} (kg)**	**L_m (mm)**	**a_m (mo)**
Bar jack	*Carangoides ruber*	20.5	0.14	70.0	-0.97	8	379	55
Jolthead porgy	*Calamus bajonado*	19.2	0.15	78.5	-0.77	10.1	420	52
Knobbed porgy	*Calamus nodosus*	21.0	0.17	51.2	-0.86	1.7	286	48
Red porgy	*Pagrus pagrus*	13.0	0.21	51.0	-1.32	7.7	289	18
Sand tilefish	*Malacanthus plumieri*	22.0	0.13	72.4	-1.04	2.1	391	59
Tomtate	*Haemulon aurolineatum*	9.0	0.21	32.5	-0.79	0.70	190	41
White grunt (Carolinas)	*Haemulon plumierii*	27.0	0.43	32.8	-0.20	4.4	167	12
White grunt (Florida)	*Haemulon plumierii*	15.0	0.19	32.7	-4.21	2.5	220	36
Whitebone porgy	*Calamus leucosteus*	12.0	0.23	36.8	-0.69	0.5	210	37
Gag	*Mycteroperca microlepis*	26.0	0.20	118.4	-1.34	36.5	643	38
Red Grouper	*Epinephelus morio*	26.0	0.21	84.8	-0.66	23.0	488	34
Black Grouper	*Mycteroperca bonaci*	33.0	0.14	133.4	-0.90	36.5	856	69
Black Sea Bass (Female)	*Centropristis striata*	10.0	0.16	54.5	-1.16	3.6	135	33
Black Sea Bass (Male)	*Centropristis striata*	10.0	0.16	54.5	-1.16	3.6	273	38
Snowy Grouper	*Epinephelus niveatus*	29.0	0.12	111.7	-1.41	30.0	541	60
Speckled Hind	*Epinephelus drummondhayi*	25.0	0.13	96.7	-1.01	30.0	497	56
Warsaw Grouper	*Epinephelus nigritus*	41.0	0.05	239.4	-3.62	82.1	810	49
Red Snapper	*Lutjanus campechanus*	54.0	0.25	90.2	-0.03	26.0	370	22
Vermilion Snapper	*Rhomboplites aurorubens*	19.0	0.12	50.6	-3.50	3.2	150	12
Golden Tilefish (female)	*Lopholatilus chamaeleonticeps*	32.0	0.10	77.7	-5.72	30.0	429	72
Golden Tilefish (male)	*Lopholatilus chamaeleonticeps*	32.0	0.14	96.7	-0.44	30.0	450	60
Wreckfish	*Polyprion americanus*	30.0	0.03	163.8	-16.56	15.0	838	96
Rock Hind	*Epinephelus adscensionis*	12.0	0.16	49.9	-0.93	4.1	280	73
Red Hind	*Epinephelus guttatus*	11.0	0.20	47.1	-0.75	25.0	266	41
Scamp	*Mycteroperca phenax*	30.0	0.09	108.0	-1.36	12.6	353	15
Yellowfin Grouper	*Mycteroperca venenosa*	15.0	0.09	89.5	-0.75	18.5	540	44
Yellowedge Grouper	*Epinephelus flavolimbatus*	85.0	0.06	100.5	-4.75	18.6	547	96
Nassau Grouper	*Epinephelus striatus*	29.0	0.13	76.0	-1.12	27.0	400	60
Goliath Grouper	*Epinephelus itajara*	37.0	0.13	200.6	-0.49	455.0	1200	72
Yellowtail Snapper	*Ocyurus chrysurus*	13.0	0.17	60.8	-1.88	4.1	209	20
Gray Snapper	*Lutjanus griseus*	24.0	0.17	71.7	-0.03	8.0	230	24
Silk Snapper	*Lutjnaus vivanus*	29.0	0.10	81.2	-1.32	8.3	434	63
Lane Snapper	*Lutjanus syngaris*	10.0	0.10	61.8	-1.73	3.0	205	12
Gray Triggerfish	*Balistes capriscus*	8.8	0.18	65.6	-1.58	6.2	328	12
Greater Amberjack	*Seriola dumerilli*	17.0	0.28	124.2	-1.56	80.6	822	16
Banded Rudderfish	*Seriola zonata*	10.3	0.28	77.5	-0.46	5.2	415	27
Almaco Jack	*Seriola rivoliana*	22.2	0.13	163.3	-0.83	60.0	811	53
Blueline Tilefish (female)	*Caulolatilus microps*	43.0	0.11	63.4	-4.54	5.6	338	54
Blueline Tilefish (male)	*Caulolatilus microps*	43.0	0.10	75.8	-5.40	7.0	513	72

Note: a_λ denotes maximum age in years, K denotes Brody growth coefficient, L_{inf} denotes asymptotic length coefficient for von Bertalanffy growth equation, $a_\circ$ denotes theoretical age at length zero scaling parameter for von Bertlanffy growth equation, W_{inf} denotes theoretical maximum weight in kilograms, L_m denotes length (in mm) at maturity, a_m denotes age (in months) at maturity.

Table 2. Depth of occurrence for managed reef fish species in U.S. south Atlantic Ocean (Source: Fishbase). Colors denote categorizations of ‘shallow’ (yellow), ‘shalllow/mid’ (pale orange), ‘mid’ (pale red), ‘mid/deep’ (orange), and ‘deep-water’ (deep red).

Common Name	30	60	90	120	150	180	210	240	270	300	330	360	390	420+
Bar jack	■	■												
Black Grouper	■	■												
White grunt	■	■												
Tomtate	■	■												
Black Sea Bass	■	■												
Nassau Grouper	■	■	■											
Knobbed porgy	■	■	■											
Goliath Grouper	■	■	■	■										
Red Hind	■	■	■	■										
Whitebone porgy	■	■	■	■										
Rock Hind	■	■	■	■										
Scamp		■	■	■										
Yellowfin Grouper	■	■	■	■	■									
Banded Rudderfish		■	■	■	■									
Sand tilefish	■	■	■	■	■									
Almaco Jack	■	■	■	■	■	■								
Yellowtail Snapper	■	■	■	■	■	■								
Gray Snapper	■	■	■	■	■	■								
Speckled Hind	■	■	■	■	■	■								
Gag		■	■	■	■									
Red Snapper	■	■	■	■	■	■	■							
Jolthead porgy	■	■	■	■	■	■	■							
Red porgy	■	■	■	■	■	■	■	■	■					
Blueline Tilefish		■	■	■	■	■	■	■						
Silk Snapper			■	■	■	■	■	■						
Red Grouper	■	■	■	■	■	■	■	■	■	■	■			
Yellowedge Grouper		■	■	■	■	■	■	■	■	■				
Vermilion Snapper		■	■	■	■	■	■	■	■	■				
Gray Triggerfish	■	■	■	■	■	■	■	■	■	■	■	■		
Greater Amberjack	■	■	■	■	■	■	■	■	■	■	■	■		
Lane Snapper	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Snowy Grouper	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Warsaw Grouper		■	■	■	■	■	■	■	■	■	■	■	■	■
Golden Tilefish		■	■	■	■	■	■	■	■	■	■	■	■	■
Wreckfish		■	■	■	■	■	■	■	■	■	■	■	■	■

Table 3. Percent of commercial bottom longline (CLL), vertical line (CVL), reef fish observer (RFOP), headboat (HBS), MRFSS, MARMAP, and life history (LH) data matrix bins with records of SAFMC Snapper-Grouper FMU species.

COMMON NAME	CVL	CLL	RFOP	HBS	MRFSS	MARMAP	LH	MEAN	MEDIAN
almaco jack	25%	0%	13%	34%	14%	1%	100%	**52%**	**55%**
banded rudderfish	10%	0%	3%	29%	11%	0%	100%	**49%**	**63%**
bar jack	1%	0%	0%	5%	6%	0%	100%	**45%**	**41%**
black grouper	20%	2%	1%	19%	12%	0%	100%	**35%**	**31%**
black sea bass	0%	0%	0%	72%	85%	58%	100%	**32%**	**24%**
blueline tilefish	18%	29%	0%	3%	4%	1%	100%	**28%**	**25%**
gag	30%	4%	16%	73%	38%	1%	100%	**25%**	**30%**
goliath grouper	0%	0%	0%	2%	7%	0%	100%	**25%**	**23%**
gray snapper	20%	1%	0%	48%	33%	0%	100%	**24%**	**14%**
gray triggerfish	32%	1%	27%	80%	41%	21%	100%	**23%**	**5%**
greater amberjack	35%	3%	8%	48%	28%	1%	100%	**18%**	**18%**
jolthead porgy	16%	0%	0%	33%	12%	0%	100%	**11%**	**5%**
knobbed porgy	7%	0%	7%	26%	9%	10%	100%	**8%**	**8%**
lane snapper	7%	0%	0%	42%	24%	0%	100%	**7%**	**5%**
nassau grouper	0%	0%	0%	0%	2%	0%	100%	**7%**	**3%**
red grouper	36%	4%	24%	53%	24%	3%	100%	**6%**	**0%**
red hind	12%	0%	4%	13%	6%	0%	100%	**6%**	**4%**
red porgy	22%	0%	43%	39%	19%	42%	100%	**5%**	**5%**
red snapper	28%	1%	8%	51%	25%	2%	100%	**5%**	**2%**
rock hind	14%	0%	6%	24%	6%	0%	100%	**5%**	**4%**
sand tilefish	2%	0%	2%	9%	12%	0%	100%	**4%**	**2%**
scamp	30%	0%	34%	47%	17%	9%	100%	**4%**	**2%**
silk snapper	5%	0%	0%	6%	2%	0%	100%	**4%**	**2%**
snowy grouper	26%	35%	2%	8%	5%	3%	100%	**2%**	**1%**
speckled hind	3%	0%	9%	11%	3%	2%	100%	**2%**	**1%**
tilefish	6%	65%	0%	0%	3%	0%	100%	**2%**	**2%**
tomtate	0%	0%	6%	47%	24%	41%	100%	**2%**	**1%**
vermilion snapper	35%	0%	33%	67%	33%	25%	100%	**1%**	**1%**
warsaw grouper	0%	0%	1%	8%	3%	0%	100%	**1%**	**0%**
white grunt	17%	0%	12%	57%	41%	11%	100%	**1%**	**0%**
whitebone porgy	4%	0%	1%	40%	12%	2%	100%	**1%**	**1%**
wreckfish	0%	0%	0%	0%	0%	0%	100%	**1%**	**0%**
yellowedge grouper	4%	16%	1%	1%	1%	0%	100%	**0%**	**0%**
yellowfin grouper	2%	0%	1%	3%	0%	0%	100%	**0%**	**0%**
yellowtail snapper	20%	0%	1%	40%	25%	0%	100%	**0%**	**0%**

Table 4. Species diversity metrics for presence of managed species in the Gulf in binned commercial longline (CLL), vertical line (CVL), reef fish observer (RFOP), headboat (HBS), MRFSS, and NMFS Bottom Longline (BLL) datasets.

COMMON NAME	CVL	CLL	RFOP	HBS	MRFSS	MARMAP	LH
>0%	**32**	**18**	**28**	**33**	**34**	**26**	**35**
>1%	28	10	21	31	32	15	35
>5%	22	4	14	28	26	8	35

Table 5. Weighting terms for mean cluster strength matrix.

COMMON NAME	CVL	CLL	RFOP	HBS	MRFSS	MARMAP	LH
almaco jack	0.25	0.00	0.13	0.34	0.14	0.01	1.00
banded rudderfish	0.10	0.00	0.03	0.29	0.11	0.00	1.00
bar jack	0.01	0.00	0.00	0.05	0.06	0.00	1.00
black grouper	0.20	0.02	0.01	0.19	0.12	0.00	1.00
black sea bass	0.00	0.00	0.00	0.72	0.85	0.58	1.00
blueline tilefish	0.18	0.29	0.00	0.03	0.04	0.01	1.00
gag	0.30	0.04	0.16	0.73	0.38	0.01	1.00
goliath grouper	0.00	0.00	0.00	0.02	0.07	0.00	1.00
gray snapper	0.20	0.01	0.00	0.48	0.33	0.00	1.00
gray triggerfish	0.32	0.01	0.27	0.80	0.41	0.21	1.00
greater amberjack	0.35	0.03	0.08	0.48	0.28	0.01	1.00
jolthead porgy	0.16	0.00	0.00	0.33	0.12	0.00	1.00
knobbed porgy	0.07	0.00	0.07	0.26	0.09	0.10	1.00
lane snapper	0.07	0.00	0.00	0.42	0.24	0.00	1.00
nassau grouper	0.00	0.00	0.00	0.00	0.02	0.00	1.00
red grouper	0.36	0.04	0.24	0.53	0.24	0.03	1.00
red hind	0.12	0.00	0.04	0.13	0.06	0.00	1.00
red porgy	0.22	0.00	0.43	0.39	0.19	0.42	1.00
red snapper	0.28	0.01	0.08	0.51	0.25	0.02	1.00
rock hind	0.14	0.00	0.06	0.24	0.06	0.00	1.00
sand tilefish	0.02	0.00	0.02	0.09	0.12	0.00	1.00
scamp	0.30	0.00	0.34	0.47	0.17	0.09	1.00
silk snapper	0.05	0.00	0.00	0.06	0.02	0.00	1.00
snowy grouper	0.26	0.35	0.02	0.08	0.05	0.03	1.00
speckled hind	0.03	0.00	0.09	0.11	0.03	0.02	1.00
tilefish	0.06	0.65	0.00	0.00	0.03	0.00	1.00
tomtate	0.00	0.00	0.06	0.47	0.24	0.41	1.00
vermilion snapper	0.35	0.00	0.33	0.67	0.33	0.25	1.00
warsaw grouper	0.00	0.00	0.01	0.08	0.03	0.00	1.00
white grunt	0.17	0.00	0.12	0.57	0.41	0.11	1.00
whitebone porgy	0.04	0.00	0.01	0.40	0.12	0.02	1.00
wreckfish	0.00	0.00	0.00	0.00	0.00	0.00	1.00
yellowedge grouper	0.04	0.16	0.01	0.01	0.01	0.00	1.00
yellowfin grouper	0.02	0.00	0.01	0.03	0.00	0.00	1.00
yellowtail snapper	0.20	0.00	0.01	0.40	0.25	0.00	1.00

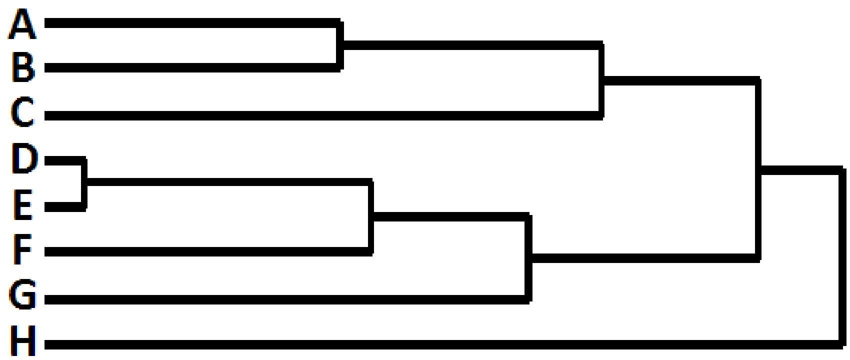
Table 6. Weighted mean cluster association matrix generated from the 24 CLL, CVL, RFOP, HBS, MRFSS, MARMAP, and 2 LH clusters (see Appendix). Darker red shading denotes higher levels of association between species on row with species in column.

	almaco jack	banded rudderfish	bar jack	black grouper	black sea bass	blueline tilefish	gag	goliath grouper	gray snapper	gray triggerfish	greater amberjack	jolthead porgy	knobbed porgy	lane snapper	nassau grouper	red grouper	red hind	red porgy	red snapper	rock hind	sand tilefish	scamp	silk snapper	snowy grouper	speckled hind	tilefish	tomtate	vermilion snapper	warsaw grouper	white grunt	whitebone porgy	wreckfish	yellowedge grouper	yellowfin grouper	yellowtail snapper
almaco jack		0.14	0.00	0.36	0.00	0.00	0.01	0.05	0.00	0.07	0.10	0.00	0.03	0.00	0.00	0.03	0.00	0.03	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.02	0.00	0.00	0.00	0.00
banded rudderfish	0.20		0.00	0.00	0.00	0.00	0.06	0.00	0.08	0.00	0.10	0.02	0.05	0.00	0.00	0.07	0.01	0.12	0.06	0.01	0.01	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.00	0.00	0.00	0.08
bar jack	0.00	0.00		0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.31	0.30	0.01	0.11	0.01	0.02	0.00	0.00	0.01	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
black grouper	0.48	0.00	0.00		0.04	0.00	0.00	0.03	0.09	0.00	0.00	0.01	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.16
black sea bass	0.02	0.02	0.00	0.09		0.00	0.04	0.02	0.02	0.04	0.02	0.00	0.12	0.02	0.00	0.01	0.05	0.05	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.20	0.08	0.00	0.06	0.10	0.00	0.00	0.00	0.02
blueline tilefish	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.24	0.00	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00
gag	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.08	0.22	0.00	0.00	0.05	0.00	0.00	0.02	0.01	0.00	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.00
goliath grouper	0.00	0.00	0.00	0.05	0.00	0.00	0.00		0.02	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.07	0.00	0.00	0.21	0.00	0.00	0.21	0.21	0.00	0.01
gray snapper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43
gray triggerfish	0.01	0.01	0.00	0.00	0.01	0.00	0.20	0.00	0.00		0.01	0.00	0.02	0.15	0.00	0.00	0.00	0.10	0.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03	0.38	0.00	0.05	0.01	0.00	0.00	0.00	0.00
greater amberjack	0.17	0.07	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.07		0.00	0.02	0.00	0.00	0.05	0.01	0.02	0.17	0.01	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.05	0.00	0.00	0.00	0.00
jolthead porgy	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.19	0.00	0.06	0.02	0.12	0.00	0.00	0.13	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.01
knobbed porgy	0.03	0.02	0.17	0.00	0.04	0.00	0.01	0.01	0.00	0.00	0.00	0.24		0.00	0.06	0.02	0.04	0.00	0.00	0.17	0.06	0.05	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
lane snapper	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.31	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.02	0.00	0.00	0.00	0.09
nassau grouper	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.12	0.00		0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.24	0.00
red grouper	0.00	0.00	0.00	0.02	0.00	0.00	0.29	0.00	0.09	0.00	0.00	0.04	0.02	0.09	0.00		0.06	0.02	0.00	0.02	0.03	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.07
red hind	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.08	0.01	0.00	0.00	0.05		0.01	0.01	0.12	0.01	0.01	0.00	0.00	0.00	0.00	0.29	0.01	0.00	0.01	0.29	0.00	0.00	0.04	0.01
red porgy	0.01	0.01	0.00	0.00	0.01	0.00	0.06	0.00	0.12	0.20	0.01	0.00	0.00	0.00	0.00	0.02	0.00		0.01	0.00	0.00	0.16	0.00	0.00	0.00	0.05	0.07	0.15	0.00	0.00	0.01	0.00	0.00	0.00	0.12
red snapper	0.02	0.05	0.00	0.00	0.02	0.00	0.30	0.00	0.00	0.05	0.21	0.00	0.00	0.00	0.00	0.05	0.00	0.07		0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.02	0.11	0.00	0.01	0.01	0.00	0.00	0.00	0.00
rock hind	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.26	0.00	0.04	0.01	0.17	0.00	0.00		0.04	0.00	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.00	0.05	0.00
sand tilefish	0.00	0.01	0.15	0.00	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.21	0.09	0.00	0.09	0.00	0.01	0.00	0.00	0.01		0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.04
scamp	0.02	0.02	0.00	0.00	0.01	0.13	0.10	0.00	0.00	0.02	0.15	0.00	0.04	0.00	0.00	0.15	0.00	0.17	0.00	0.00	0.00		0.00	0.04	0.10	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00	0.00
silk snapper	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.21	0.00	0.60	0.00	0.00	0.01	0.00	0.01	0.02	0.01	0.08	0.00
snowy grouper	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10		0.00	0.11	0.00	0.00	0.20	0.00	0.00	0.00	0.17	0.00	0.00
speckled hind	0.01	0.01	0.05	0.00	0.01	0.00	0.02	0.00	0.00	0.01	0.01	0.05	0.06	0.00	0.21	0.00	0.00	0.01	0.01	0.06	0.05	0.08	0.01	0.00		0.00	0.01	0.01	0.05	0.00	0.00	0.00	0.01	0.24	0.00
tilefish	0.00	0.00	0.00	0.00	0.00	0.09	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.20	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00
tomtate	0.00	0.00	0.00	0.00	0.07	0.00	0.02	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.15	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.28	0.00	0.02	0.40	0.00	0.00	0.00	0.00
vermilion snapper	0.01	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.45	0.01	0.00	0.00	0.10	0.00	0.00	0.00	0.13	0.03	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.17		0.00	0.00	0.01	0.00	0.00	0.00	0.00
warsaw grouper	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.14	0.14	0.05	0.14	0.01	0.00		0.00	0.01	0.00	0.41	0.01	0.00
white grunt	0.00	0.00	0.00	0.00	0.07	0.00	0.08	0.00	0.00	0.09	0.00	0.20	0.08	0.00	0.00	0.12	0.11	0.00	0.00	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.07	0.03	0.00		0.07	0.00	0.00	0.00	0.00
whitebone porgy	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.05	0.00	0.01	0.02	0.00	0.00	0.23	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.53	0.00	0.00	0.00		0.00	0.00	0.00	0.01
wreckfish	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.10	0.00	0.00	0.35	0.00	0.00		0.35	0.00	0.00
yellowedge grouper	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.24	0.00	0.10	0.00	0.00	0.44	0.00	0.00	0.00		0.01	0.00
yellowfin grouper	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.29	0.00	0.02	0.00	0.00	0.06	0.06	0.00	0.04	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01		0.00
yellowtail snapper	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.02	0.00	0.15	0.00	0.00	0.00	0.09	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

Table 7. Table of SAFMC Snapper-Grouper FMU species, indicating species with completed or pending assessments and top five most associated species, by species, per weighted mean cluster association index. Productivity-Susceptibility Analysis (PSA) scores of overall risk from MRAG Americas South Atlantic Final Report provided when available (MRAG 2009a,b). Color-coding denotes associations; dashed lines denote distinct life histories between associated species.

COMMON NAME	1	2	3	4	5	ASSESSED?	PSA
wreckfish	warsaw grouper	yellowedge grouper	silk snapper	tilefish	snowy grouper	Vaughan et al. 2001	3.64
warsaw grouper	yellowedge grouper	silk snapper	snowy grouper	tilefish	speckled hind		3.83
yellowedge grouper	warsaw grouper	snowy grouper	tilefish	blueline tilefish	silk snapper		3.52
snowy grouper	blueline tilefish	warsaw grouper	yellowedge grouper	tilefish	silk snapper	SEDAR 4 (2004)	3.45
blueline tilefish	snowy grouper	sand tilefish	scamp	yellowedge grouper	tilefish		3.4
sand tilefish	blueline tilefish	jolthead porgy	bar jack	knobbed porgy	nassau grouper		3.37
tilefish	silk snapper	gag	snowy grouper	yellowedge grouper	blueline tilefish	SEDAR 4 (2004)	3.4
silk snapper	tilefish	snowy grouper	yellowfin grouper	wreckfish	warsaw grouper		3.52
goliath grouper	yellowedge grouper	warsaw grouper	wreckfish	silk snapper	snowy grouper	SEDAR 23 (2010)	3.42*
nassau grouper	yellowfin grouper	speckled hind	bar jack	jolthead porgy	knobbed porgy		3.3
speckled hind	yellowfin grouper	nassau grouper	scamp	knobbed porgy	rock hind		3.42
yellowfin grouper	speckled hind	nassau grouper	bar jack	sand tilefish	knobbed porgy		3.39
gag	red grouper	red snapper	gray triggerfish	white grunt	red porgy	SEDAR 10 (2006)	3.52
red grouper	gag	scamp	white grunt	gray snapper	lane snapper	SEDAR 19 (2010)	3.28
scamp	red porgy	red grouper	greater amberjack	blueline tilefish	speckled hind		3.25
black grouper	almaco jack	yellowtail snapper	gray snapper	black sea bass	lane snapper	SEDAR 19 (2010)	3.36
banded rudderfish	almaco jack	red porgy	greater amberjack	gray snapper	yellowtail snapper		3.26
greater amberjack	scamp	red snapper	almaco jack	vermilion snapper	banded rudderfish	SEDAR 15 (2008)	3.07
almaco jack	black grouper	banded rudderfish	greater amberjack	vermilion snapper	gray triggerfish		3.35
red porgy	gray triggerfish	scamp	vermilion snapper	gray snapper	yellowtail snapper	SEDAR 1 Update (2006)	2.93
gray triggerfish	vermilion snapper	gag	lane snapper	red porgy	white grunt		2.46
vermilion snapper	gray triggerfish	tomtate	red porgy	lane snapper	gag	SEDAR 17 (2008)	3.14
red snapper	gag	greater amberjack	vermilion snapper	red porgy	scamp	SEDAR 24 (2010)	3.14
black sea bass	tomtate	knobbed porgy	whitebone porgy	black grouper	vermilion snapper	SEDAR 2 Update (2005)	3.02
red hind	whitebone porgy	tomtate	rock hind	jolthead porgy	red grouper	Potts & Manooch (1995)	3.18
rock hind	knobbed porgy	jolthead porgy	red hind	bar jack	yellowfin grouper	Potts & Manooch (1995)	3.23
knobbed porgy	jolthead porgy	bar jack	rock hind	white grunt	nassau grouper		3.14
whitebone porgy	tomtate	red hind	almaco jack	greater amberjack	banded rudderfish		3.51
jolthead porgy	knobbed porgy	bar jack	sand tilefish	white grunt	rock hind		3.18
tomtate	whitebone porgy	vermilion snapper	red hind	black sea bass	gray triggerfish		2.63
white grunt	jolthead porgy	red grouper	red hind	gray triggerfish	knobbed porgy		2.78
bar jack	jolthead porgy	knobbed porgy	sand tilefish	nassau grouper	red hind		3.33
gray snapper	lane snapper	yellowtail snapper	red porgy	warsaw grouper	silk snapper		3.24
lane snapper	gray snapper	gray triggerfish	vermilion snapper	yellowtail snapper	whitebone porgy		2.92
yellowtail snapper	gray snapper	black grouper	lane snapper	red porgy	sand tilefish	SEDAR 3 (2003)	2.84*

(*) = from MRAG Gulf of Mexico Final Report.



	A	B	C	D	E	F	G	H
A		1	0	0	0	0	0	0
B	1		0	0	0	0	0	0
C	0.5	0.5		0	0	0	0	0
D	0	0	0		1	0	0	0
E	0	0	0	1		0	0	0
F	0	0	0	0.5	0.5		0	0
G	0	0	0	0.33	0.33	0.33		0
H	0.14	0.14	0.14	0.14	0.14	0.14	0.14	

Figure 1. Example dendrogram and cluster association matrix.

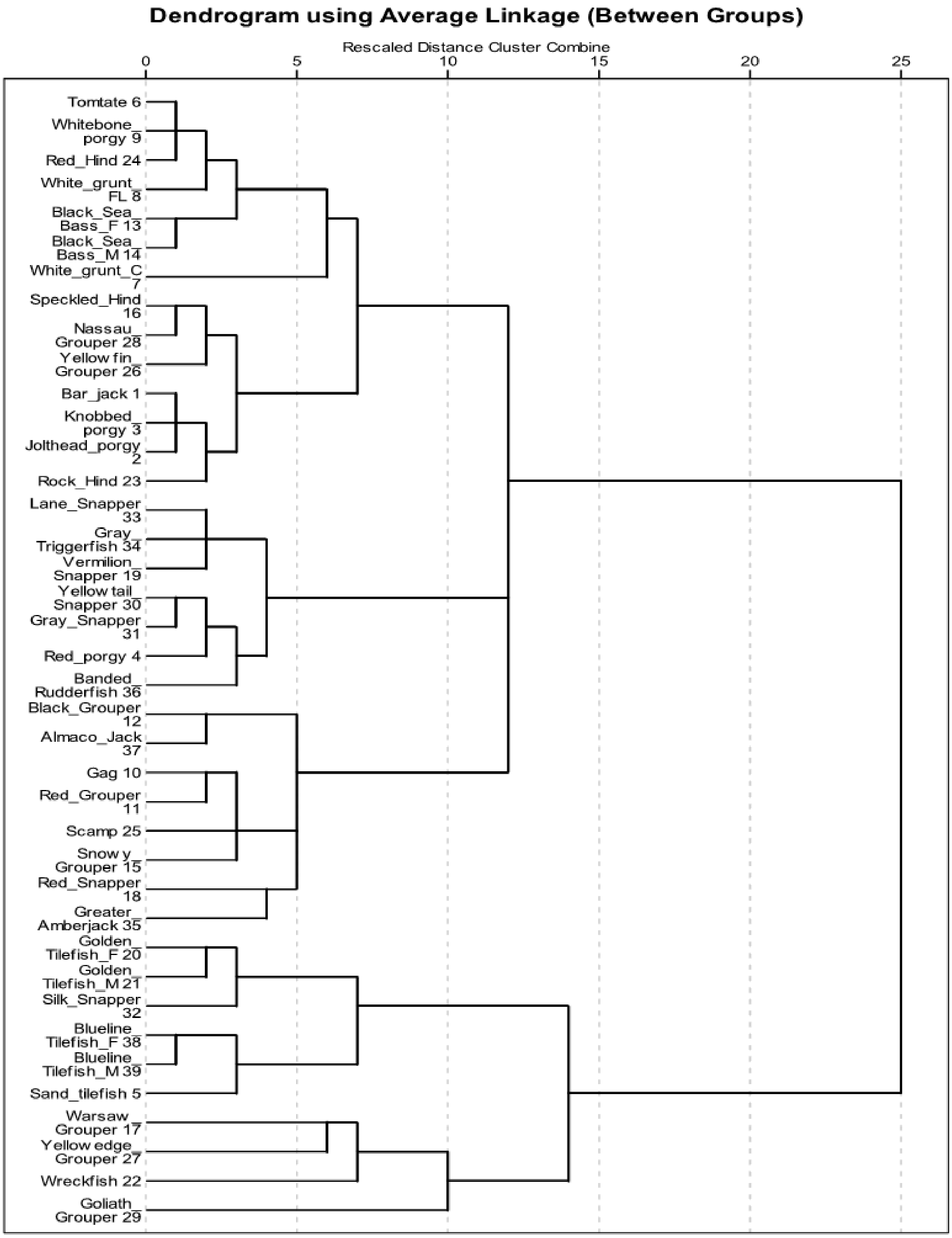


Figure 2. Hierarchical cluster analysis of life history parameters for SAFMC Snapper-Grouper species with dummy variable for genus (Linkage Method: Ward's, Dissimilarity Measure: Euclidean Distance, Transformation: Z-Score by Variable). Note 'F' denotes female, 'FL' denotes Florida population.

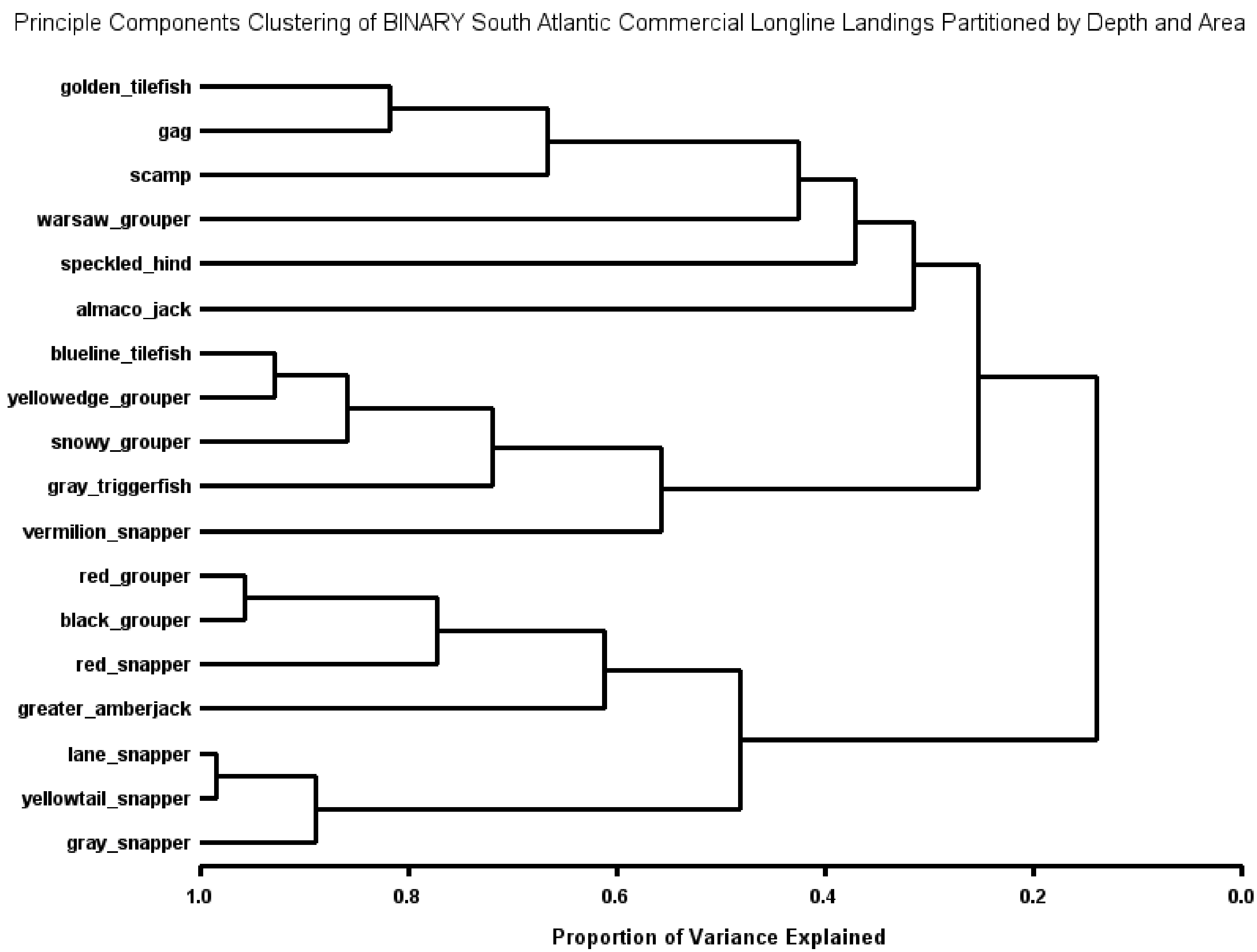


Figure 3. Dimension reduction cluster of presence-absence in SAFMC Snapper-Grouper commercial longline landings (2005-2009) aggregated by year, month, area, and depth (Linkage Method: VARCLUS, Height Measure: Proportion of Variance Explained, Transformation: Binary).

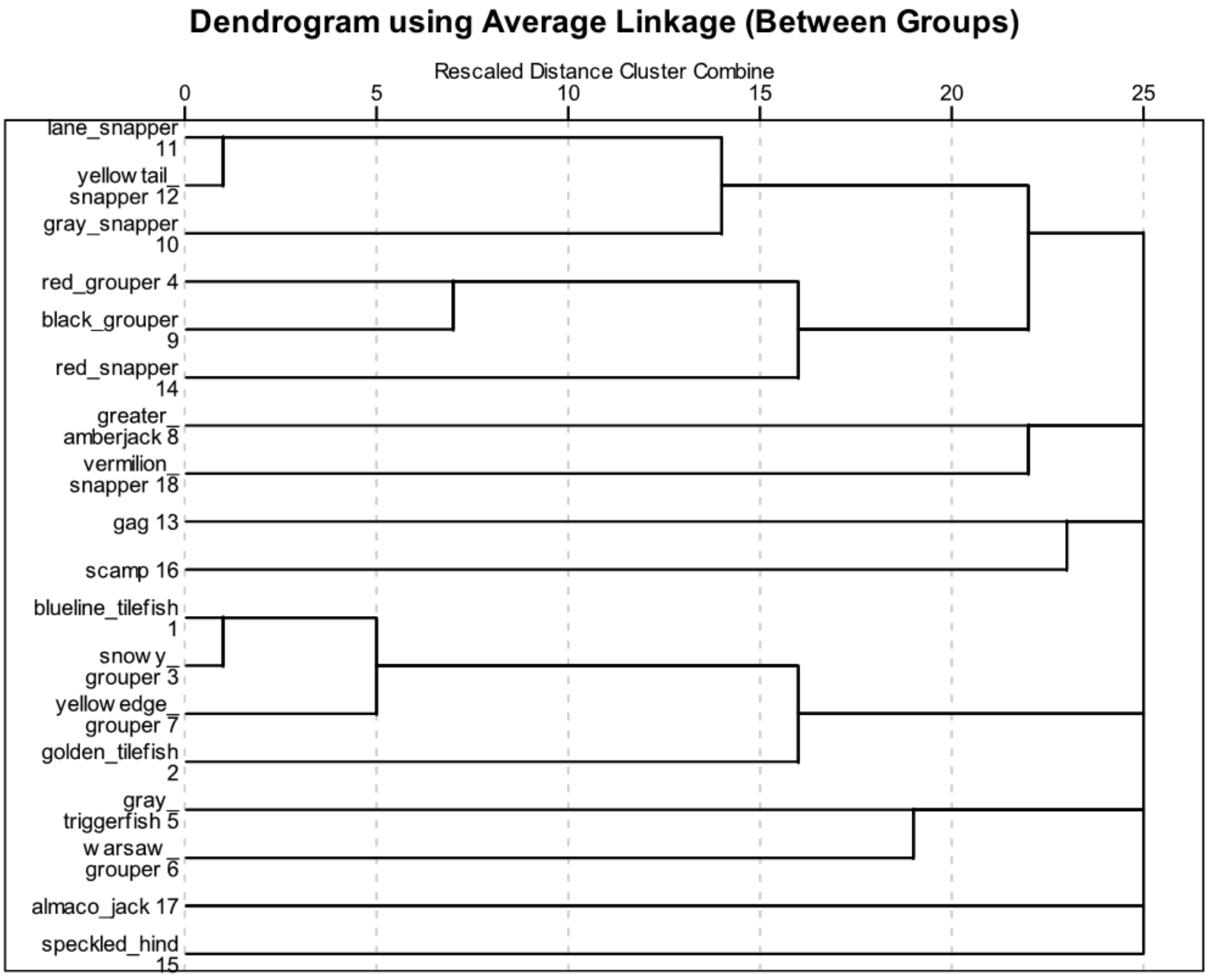


Figure 4. Hierarchical cluster analysis of species presence-absence in SAFMC Snapper-Grouper commercial longline landings (2005-2009) aggregated by year, month, area, and depth (Linkage Method: Between (Average), Dissimilarity Measure: Sørenson (Binary)).

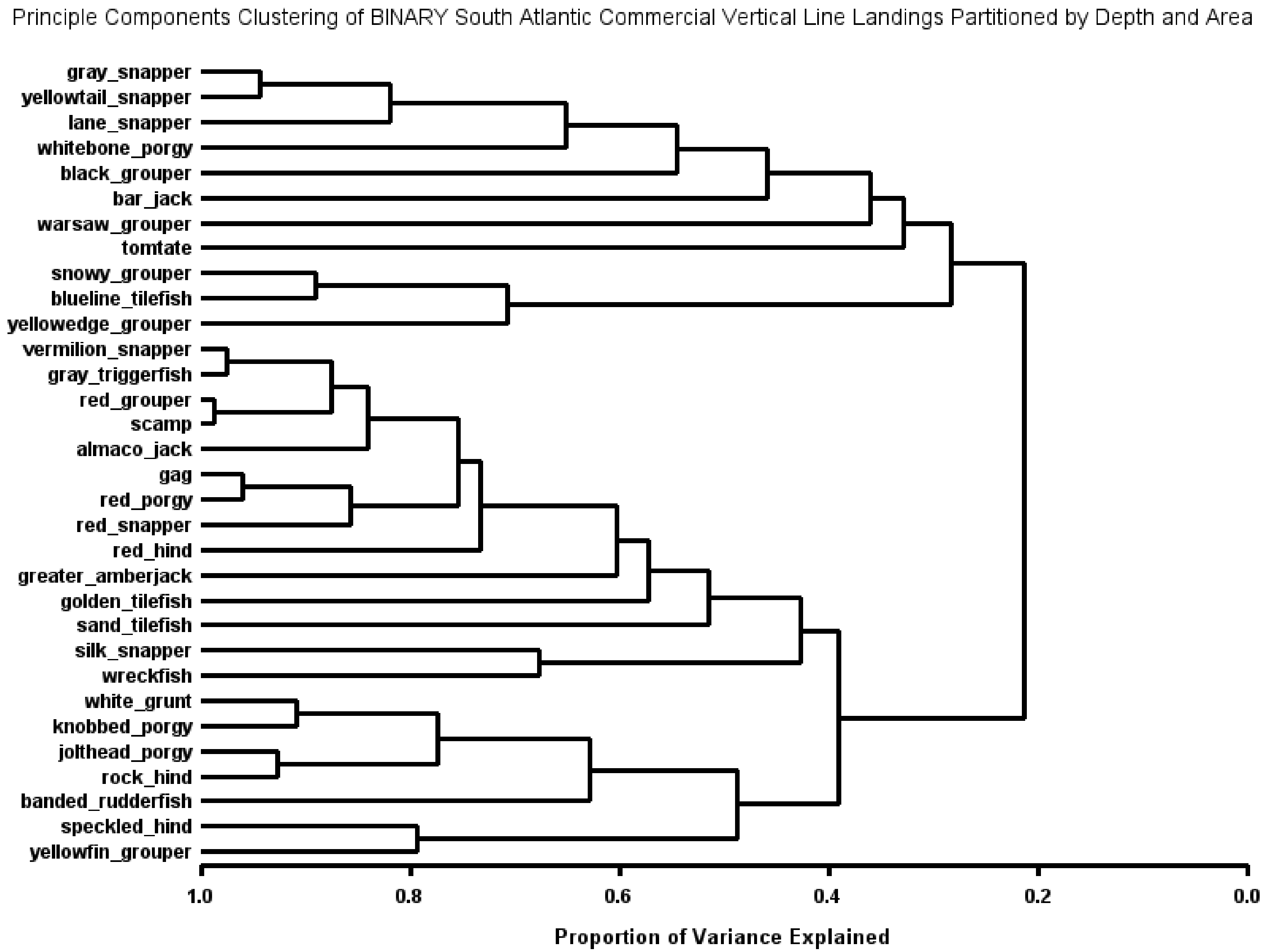


Figure 5. Dimension reduction cluster of SAFMC Snapper-Grouper commercial vertical line landings (2005-2009) aggregated by year, month, area, and depth (Linkage Method: VARCLUS, Height Measure: Proportion of Variance Explained, Transformation: Binary).

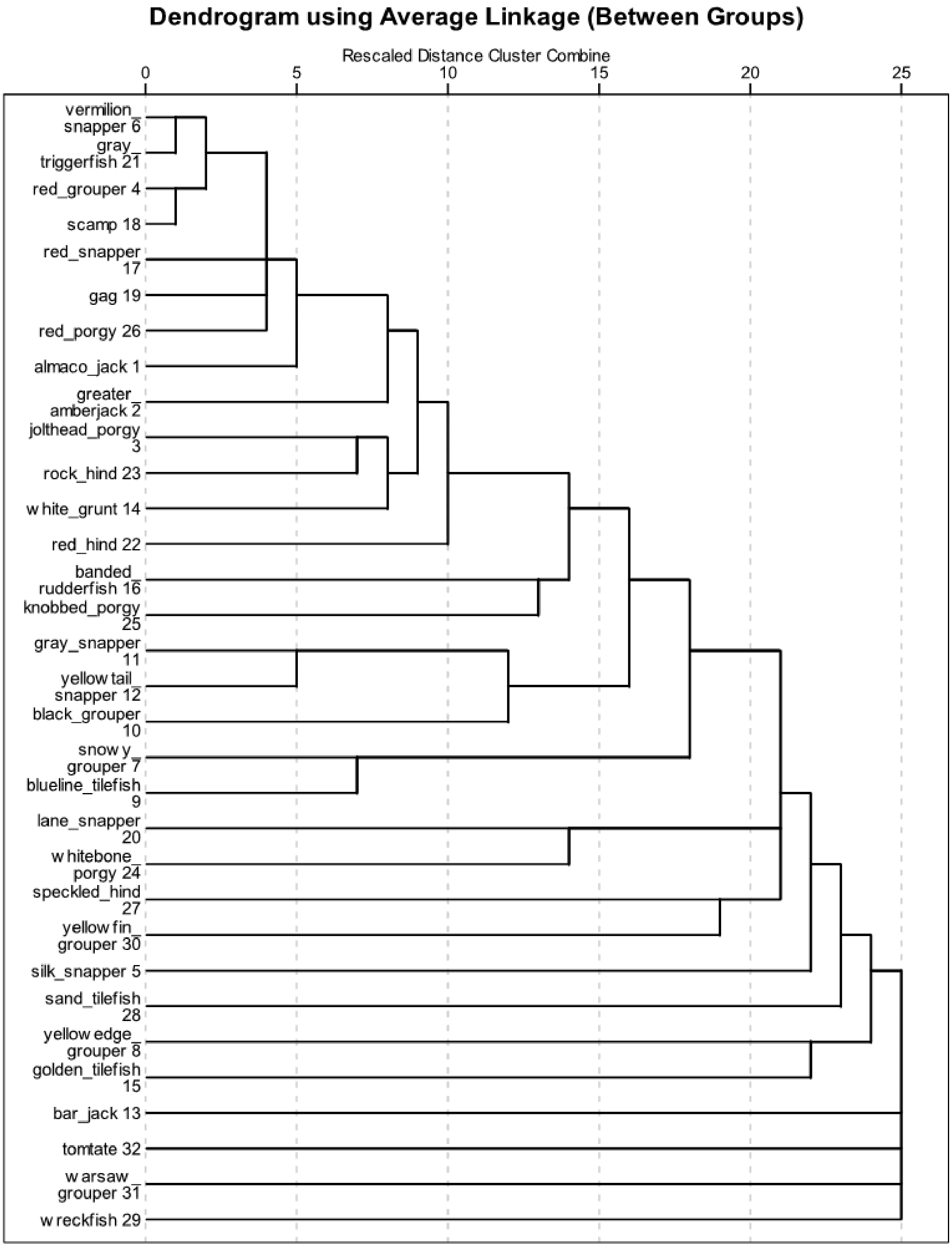


Figure 6. Hierarchical cluster analysis of species presence-absence in SAFMC Snapper-Grouper commercial vertical line landings aggregated by year, month, area, and depth (Linkage Method: Between (Average), Dissimilarity Measure: Sørenson (Binary)).

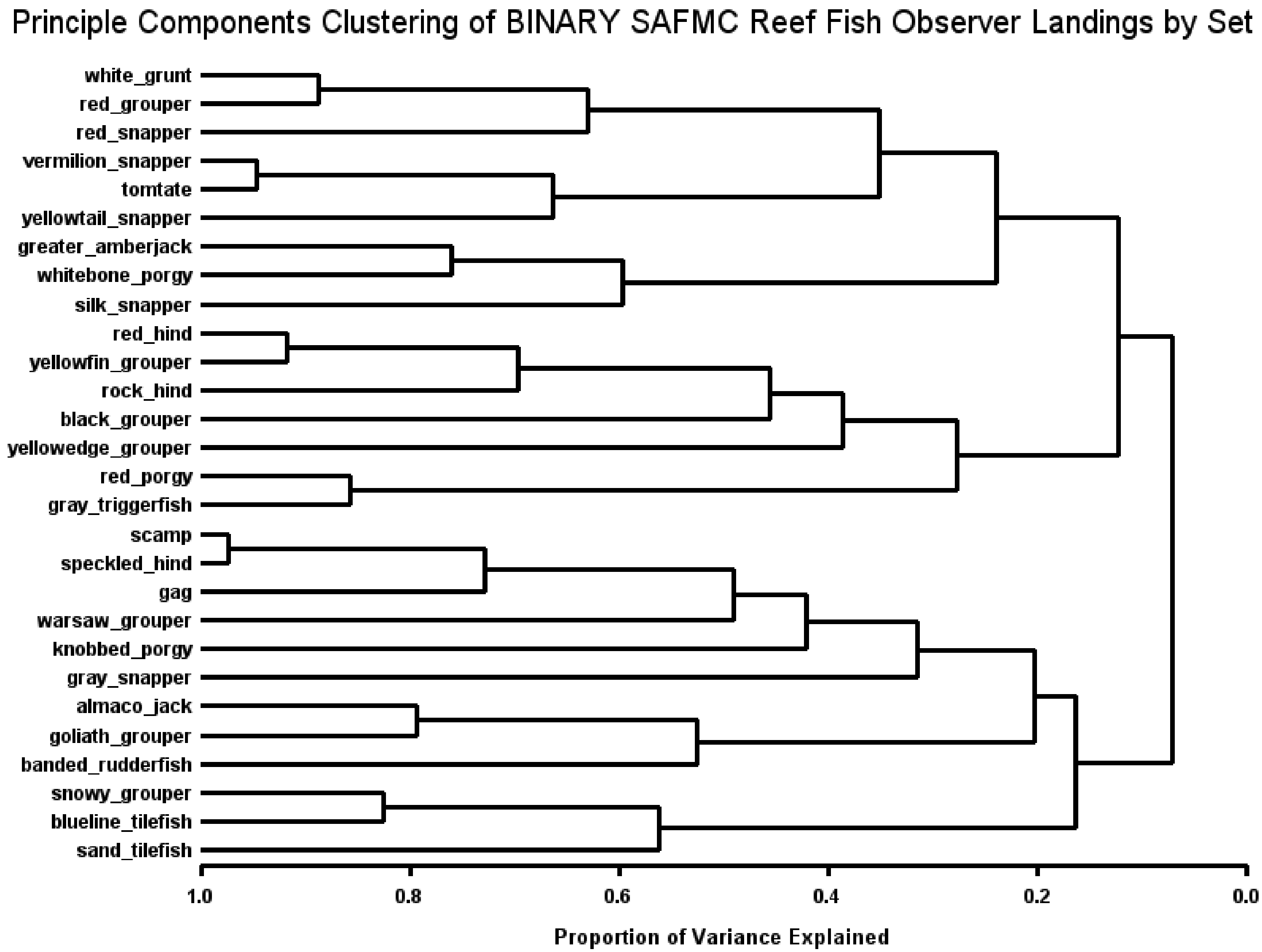


Figure 7. Dimension reduction cluster of species presence-absence in SAFMC Snapper-Grouper observer program landings aggregated at the individual set level (Linkage Method: VARCLUS, Measure: Proportion of Variance Explained, Transformation: Root-Root).

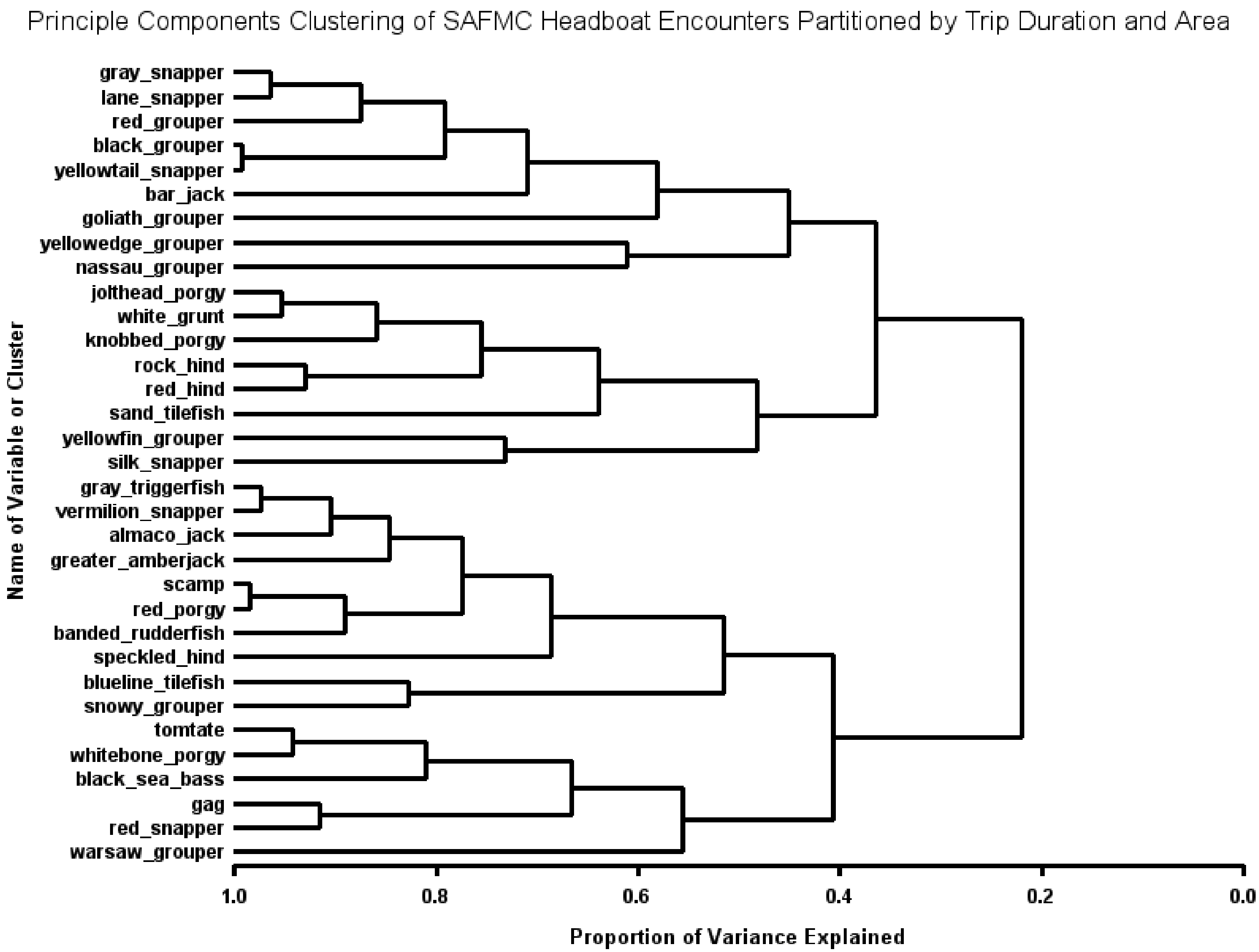


Figure 8. Dimension reduction cluster of landed catch (in numbers) of SAFMC Snapper-Grouper by recreational headboat aggregated by year, month, area, and trip duration (Linkage Method: VARCLUS, Height Measure: Proportion of Variance Explained, Transformation: Root-Root).

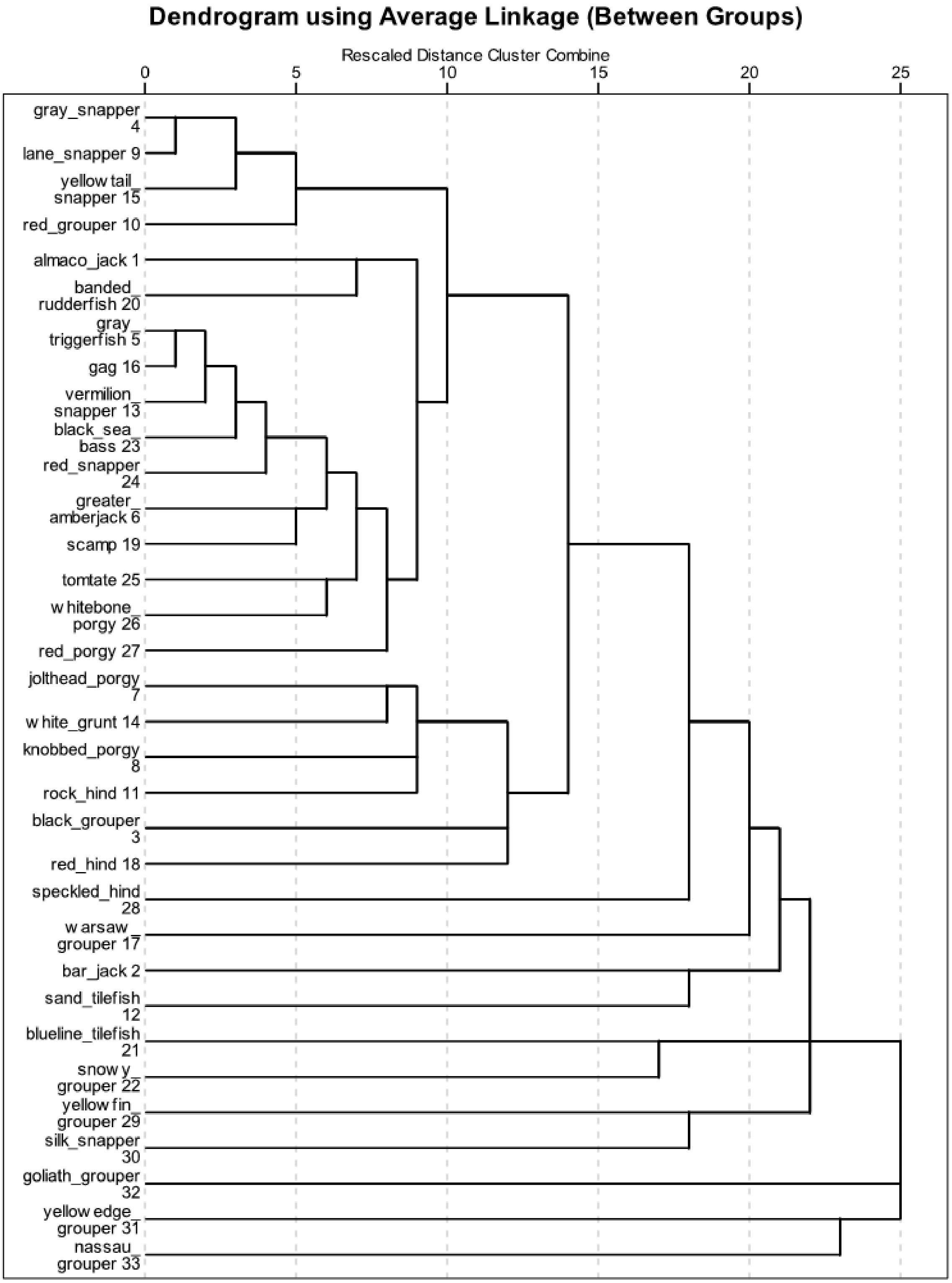


Figure 9. Hierarchical cluster analysis of presence-absence of SAFMC Snapper-Grouper by recreational headboat aggregated by year, month, area, and trip duration (Linkage Method: Between Groups Average, Dissimilarity Measure: Sørenson, Transformation: Binary).

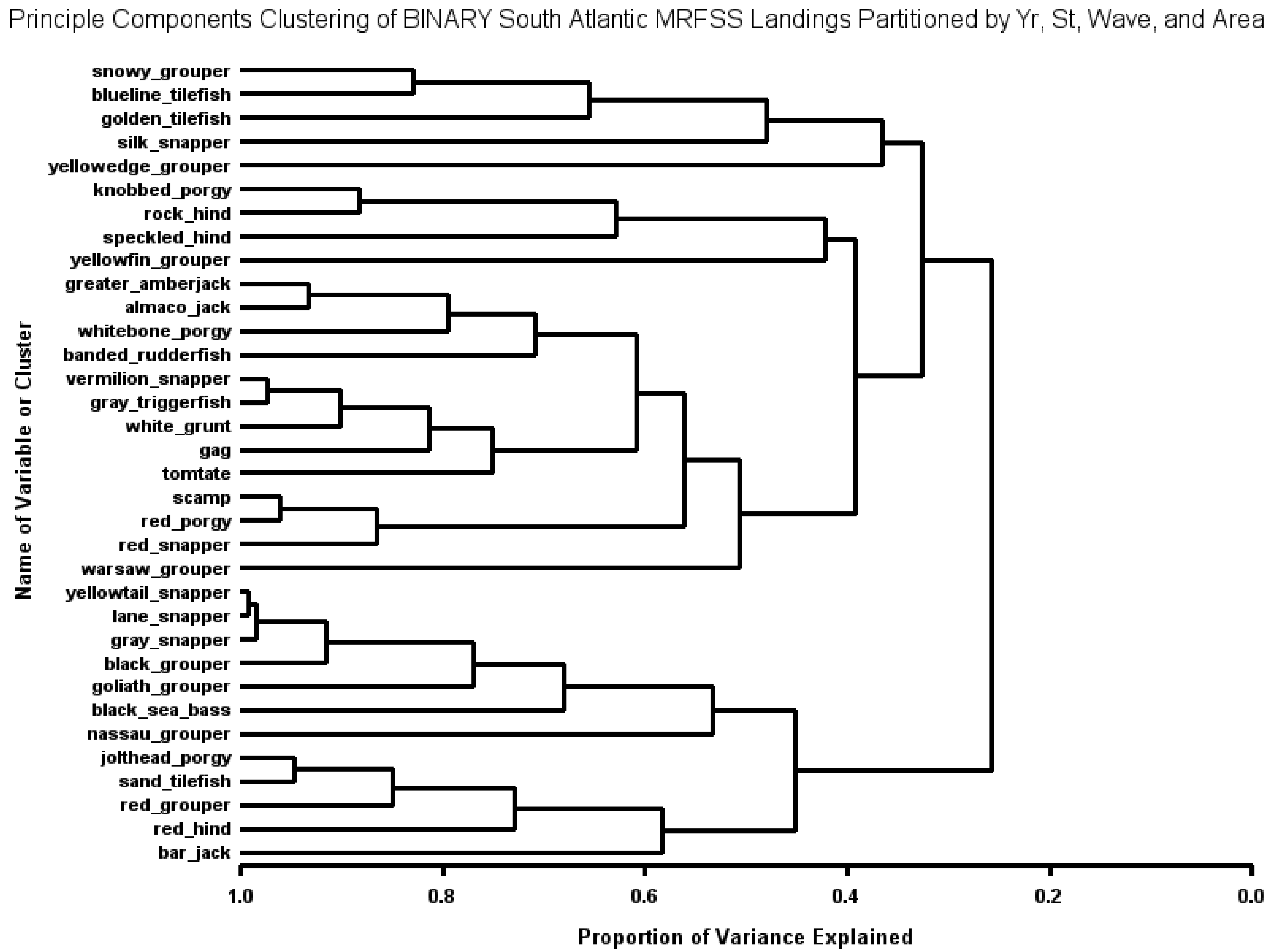


Figure 10. Dimension reduction cluster of species presence-absence in SAFMC Snapper-Grouper recreational MRFSS-reported landings aggregated by state, year, wave, mode of fishing, and area fished (Linkage Method: VARCLUS, Height Measure: Proportion of Variance Explained, Transformation: Binary).

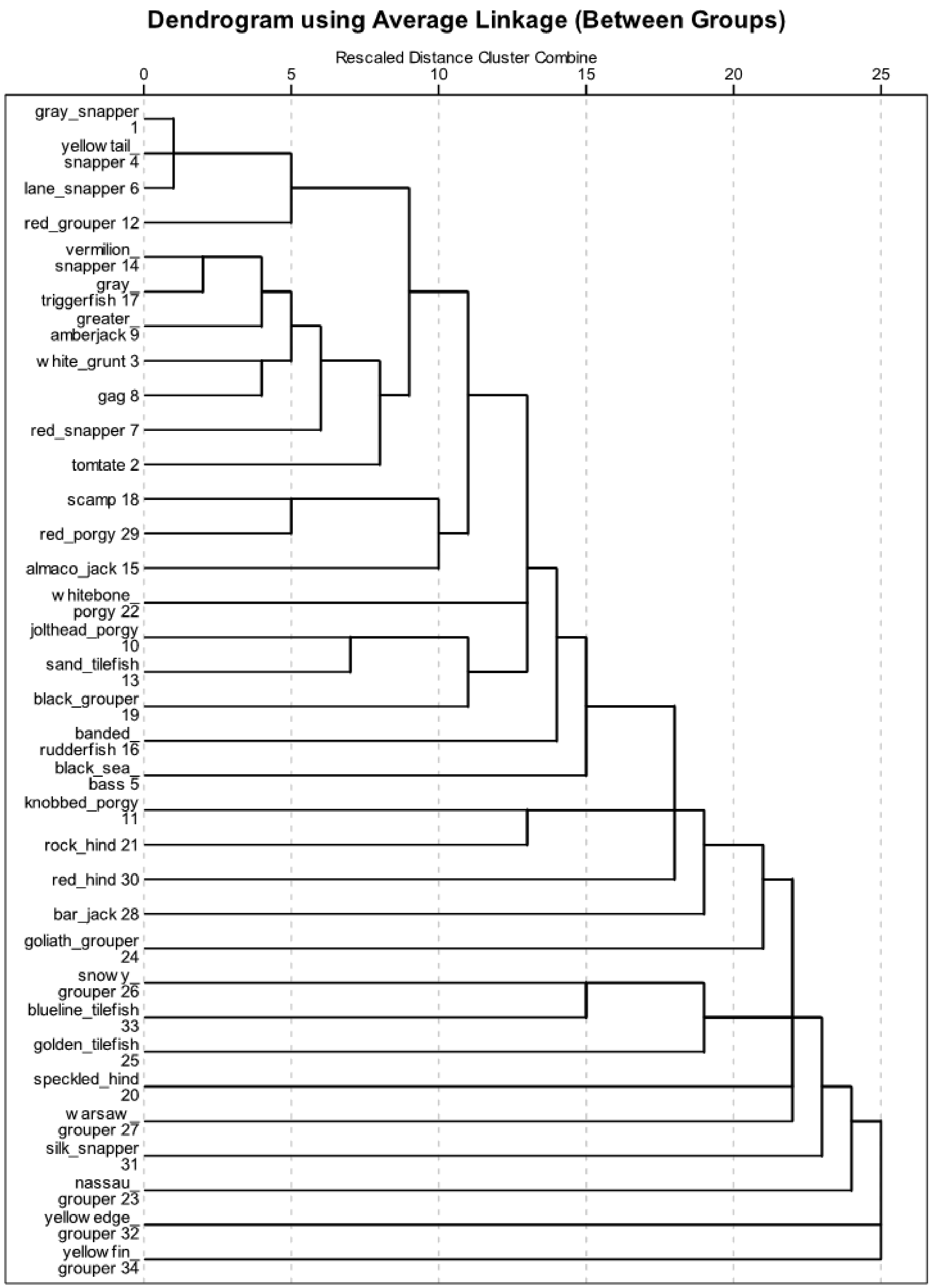


Figure 11. Hierarchical cluster analysis of species presence-absence in MRFSS-reported landings aggregated by state, year, wave, mode of fishing, and area fished (Linkage Method: Between Groups Average, Dissimilarity Measure: Sørenson, Transformation: Binary).

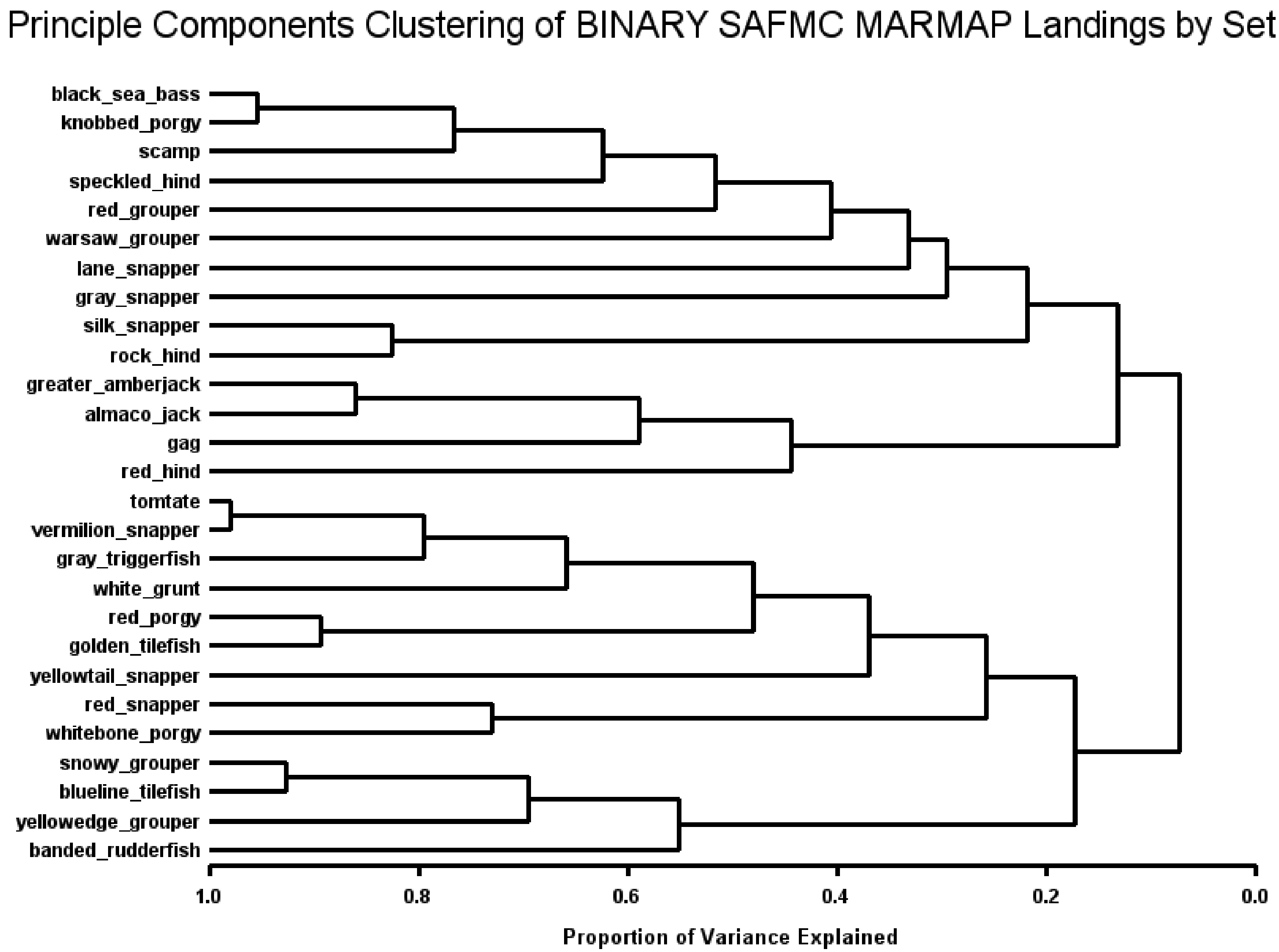
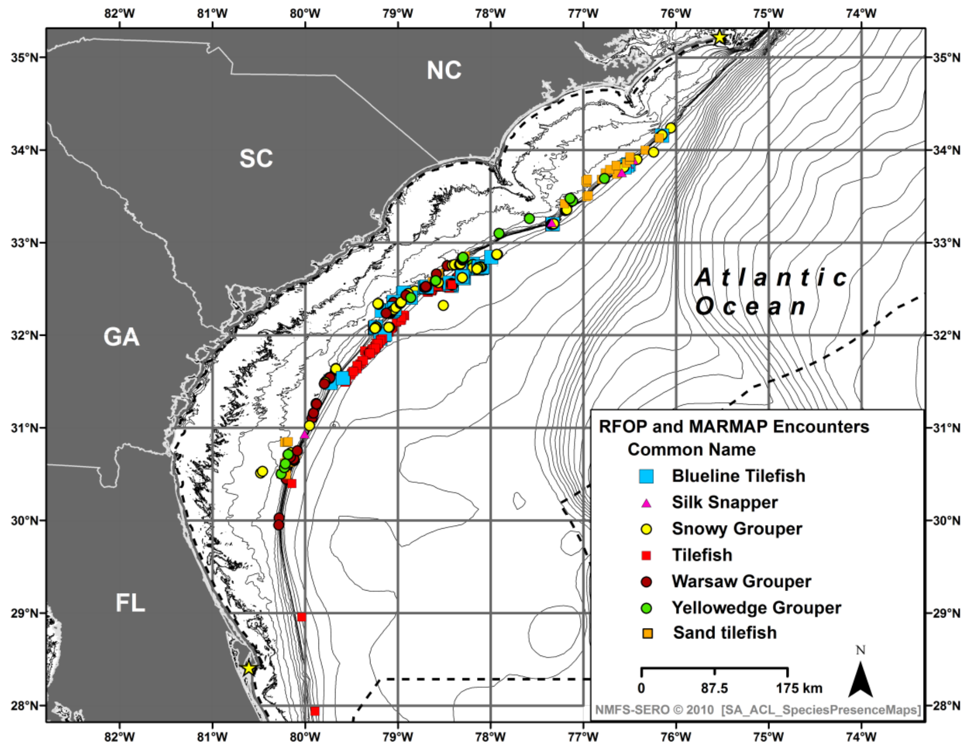
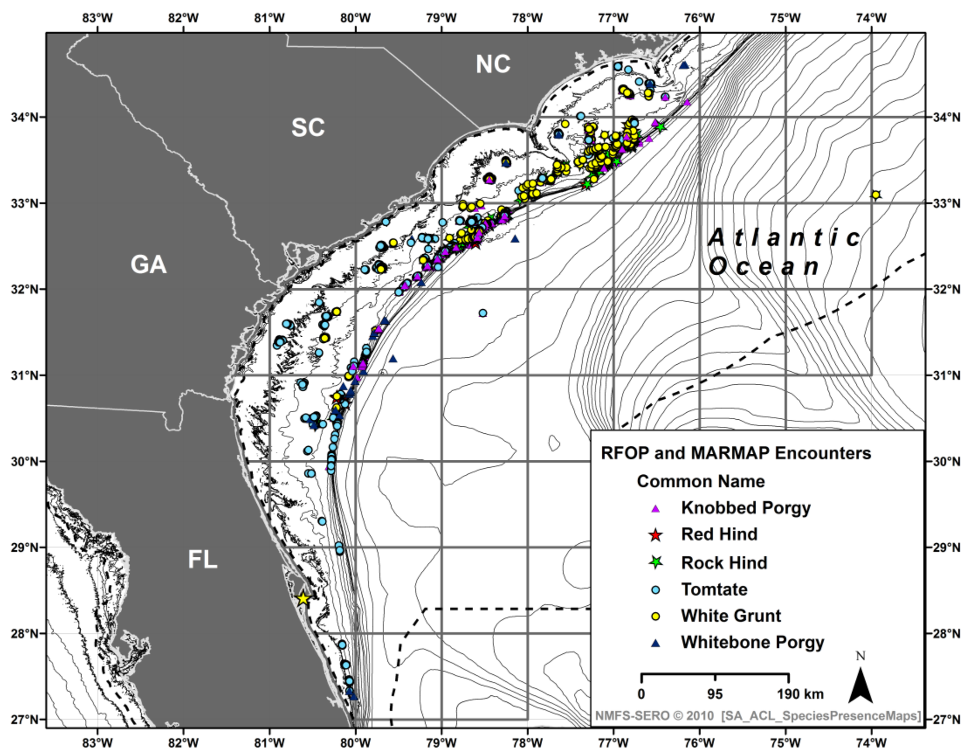


Figure 12. Hierarchical cluster analysis of species presence-absence in MARMAP scientific sample catch aggregated by gear and set (Linkage Method: VARCLUS, Height Measure: Proportion of variance explained, Transformation: Binary).

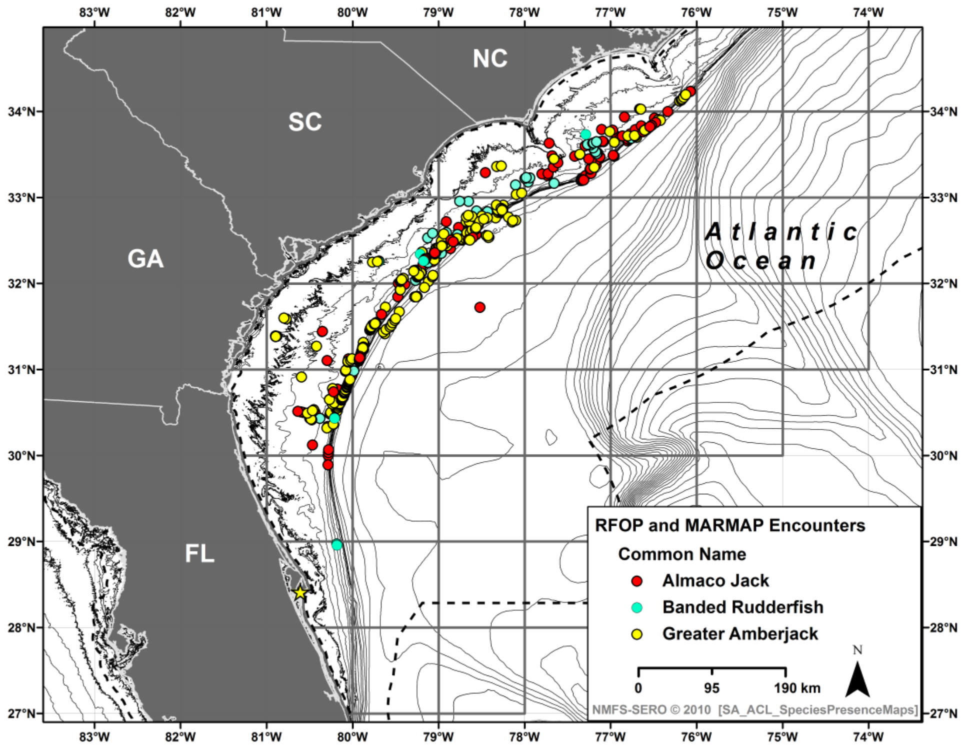


A)

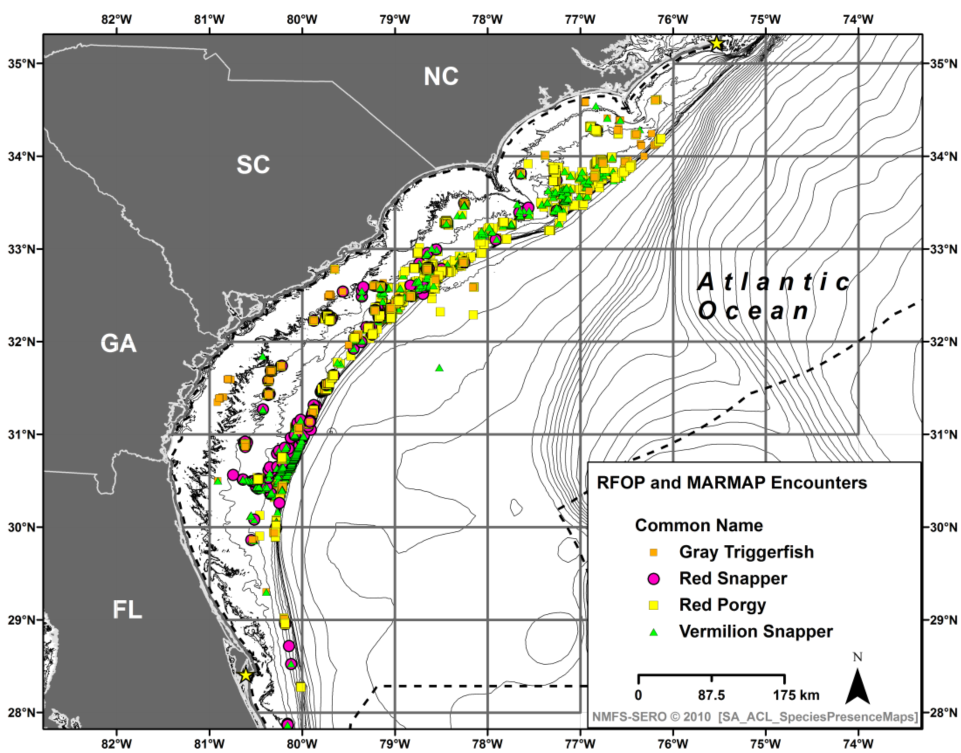


B)

Figure 13. Map of A) deep-water grouper and tilefish and B) porgy, hind, and grunt observations from aggregated MARMAP and Reef Fish Observer Program datasets relative to bathymetry and commercial fishery statistical reporting areas in U.S. southern Atlantic Ocean.

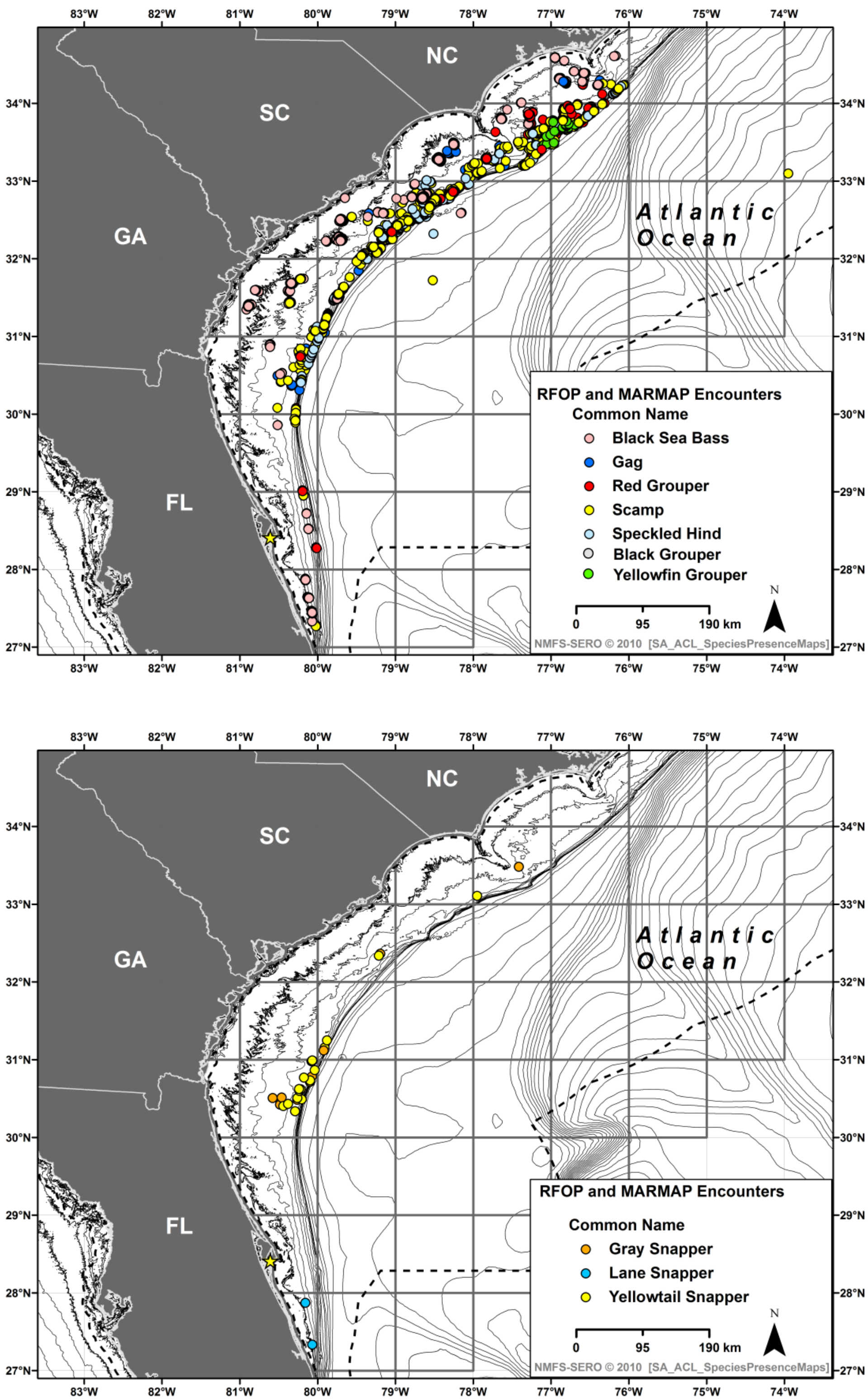


A)



B)

Figure 14. Map of A) jacks and B) mid-water species observations from aggregated MARMAP and Reef Fish Observer Program datasets relative to bathymetry and commercial fishery statistical reporting areas in U.S. southern Atlantic Ocean.



A)

B)

Figure 15. Map of A) shallow-water grouper and B) shallow-water snapper observations from aggregated MARMAP and Reef Fish Observer Program datasets relative to bathymetry and commercial fishery statistical reporting areas in U.S. southern Atlantic Ocean.