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Preliminary results of redefining fleet definitions of Hawaiian longline fisheries with spatiotemporal consideration of blue shark size data

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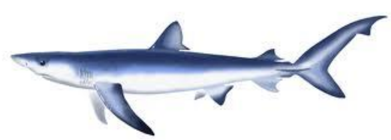

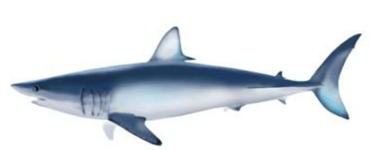

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Abstract

Our study looked at redefining the Hawaiian longline fleets that have been used for previous assessments of blue shark by investigating the size composition data from observer records in greater detail. Our goal is to provide more appropriate fleet definition that help reduce model misspecification by allowing the working group to produce indices and size compositions for the assessment that more appropriately consider the spatiotemporal characteristics of blue shark catch. In our analysis we divided the eastern North Pacific Ocean (10-45^{o}N and 120-170 ^{o}W) into 80 areas by 5x5° with available size composition data. A clustering approach was taken to discern areas with relatively consistent size compositions. The results suggested three distinct clusters. A core adult cluster (Southern area: 10-30^{o}N and 140-170 ^{o}W) which primarily consisted of individuals over 150cm PCL, a core juvenile cluster (North eastern area: 30-45^{o}N and 120-140 ^{o}W) with individuals less than 100 cm PCL, and an intermediate area linking the two which has a mixture of sub-adult individuals greater than 100cm but less than 150cm PCL (North western area: 30-45^{o}N and 140-170 ^{o}W). This is preliminary work and catch in the proposed clusters will need to be investigated before fully committing to the identified fleet structure in upcoming assessments, beyond this, we suggest to use this clustering approach on an expanded set of fisheries data in order to improve the fleet definitions currently used in the assessment of blue sharks with spatiotemporal consideration of size and sex data for future assessments.

Introduction

In past assessments for both blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*), longline catch for the Hawaiian Islands has been split between two fleets, the shallow and deep-set longline fisheries. These fleets have primarily been distinguished based on a combination of target species (either swordfish or tunas) and the number of hooks per float, a statistic that has been recorded in logbooks since 1995. Blue sharks caught by the deep-set component of the fishery were primarily adults while those caught by the shallow-set were a mixture of juveniles and adults. The size differences observed in blue sharks caught by these two fleets are likely due to ontogenetic shifts in spatial distribution.

While a fleet definition based on gear and target species is reasonable, we believe that it could be improved by examining the spatiotemporal characteristics of catch in greater detail. Building off the work of Sippel et al. (2015) with shortfin mako, and Teo (2016) and Ochi et al. (2016) with albacore, we attempted to refine the Hawaiian longline fleet definitions by examining spatiotemporal differences in size using a clustering approach. This may result in fleet definitions based on areas with more consistent size compositions, in addition to gear and target species. Improved fleet definitions can help to reduce model misspecification by allowing the working group to produce indices and size compositions that more appropriately consider the spatiotemporal characteristics of blue shark catch.

Data and Methods

The biological (body length, and sex) information for this paper was obtained from the observer sampling program for the Hawaiian longline fishery in the North Pacific (1994-2018). However, reliable size data for blue sharks in this fishery have only been available since 2005, consequently our investigation only includes observer data from 2005-2018.

All size data from Hawaii used in this analysis were in pre caudal length (PCL), lengths recorded in either fork length or total length were converted PCL to be consistent with length observations in the 2017 blue shark assessment (ISC 2017). Length conversation equations were taken from Fujinami et al. (2016b) Table 3.

In order to evaluate the spatiotemporal differences in size compositions of the Hawaiian longline fishery we divided the north Pacific into 80 5x5° areas. All areas with <5 measured blue sharks were discarded from the analysis. We used a clustering approach to discern areas with consistent size compositions. In order to reduce the dimensionality of the problem and autocorrelation between bins, the size composition data were aggregated to several maturity group compositions:

1) 4 groups, sex specific mature and immature individuals
2) 6 groups, sex specific immature, sub-adult, and adult individuals
3) 3 groups, immature, sub-adult, and adult individuals with sexes grouped

Composition 1 was established using the sex specific size at 50% maturity for blue sharks in the North Pacific (Fujinami et al. 2016b). Size at 50% maturity for males was 160.9 cm PCL, while female size at 50% maturity was 156.6 cm PCL. Composition 2 used the same sex specific size at 50% maturity to separate sub-adults and adults and then established a second sex specific point at which to distinguish immature individuals from sub-adults. This second separation point was based on the accepted growth model for blue sharks which indicates that both male and female blues grow rapidly, >25% of their total PCL for each of the first two years of life, up to 92.1 and 90.7 cm PCL for males and females respectively. Following this rapid growth period, average sizes between ages begins to decline (Fujinami et al. 2016a, Table 3). This second separation point is somewhat arbitrary, however, it allows the analysis to distinguish between rapidly growing young animals and larger, yet still immature ones, groups, which based on visual inspection of spatial catch data, appear to be distinct. Composition 3 is the same as composition 2 but with the sexes grouped together, length at 50% maturity was set at 158.7 cm while the split between immature and sub-adult was set at 91.4 cm, both the averages between males and females for each split.

For each 5x5° area, an overall maturity group composition was developed by averaging the group compositions from all years and seasons. Seasonal (season 1: Jan – Mar; season 2: Apr – Jun; season 3: Jul – Sep; season 4: Oct – Dec), and semester (semester 1: Jan-Jun; semester 2: Jul-Dec) age group compositions were also developed for each area.

We followed the same approach as Teo (2016) in his work on albacore, using the k-means clustering algorithm described in Hartigan and Wong (1979), with k (number of clusters) ranging from one to eight, and 100 random sets of initial centers each. For each k, the resulting clusters from the random initial set that lead to the smallest within cluster sum of squares was assumed to be the optimal clusters for that k. The change in the within cluster sum of squares with increasing k was used to evaluate the appropriate k for the data set. Finally, we used agglomerative hierarchical clustering with complete linkage and Euclidean distance to examine the clusters in the age group composition data. The appropriate clusters were evaluated by visually examining the resulting dendogram from the cluster analysis and mapping of the areas in each cluster. A pairs plot was used to examine the differences between the resulting clusters (Teo 2016).

Spatiotemporal clusters from the analyses were used to develop three preliminary size composition data sets for the Hawaii longline fishery: 1) size composition data in 5 cm bins by 5x5° area/season strata (all years combined); 2) size composition data in 5 cm bins by 5x5° area/semester strata (all years combined and seasons combined into semesters); 3) size composition data in 5 cm bins by 5x5° area strata (all seasons and years combined). Five centimeter length bins were established here due to apparent aliasing when data were kept in 1cm bins.

Results and Discussion

Trials across multiple maturity group compositions as well as spatiotemporal cluster groupings resulted in reasonably consistent results suggesting three clusters (Table 1, Figures 1, 3, & 4), although the areas included in each cluster varied somewhat between analyses. Regardless of the analysis there appeared to be a consistent core adult cluster south of 30° Latitude (areas 38, 47, 48, 49, 50, 60, 70) which was primarily composed of animals above 150cm PCL (67%, Figure 2). Additionally, there appeared to be a consistent core juvenile cluster as well which predominated in the areas north of 30°N and east of -140 °W (areas 20, 21, 31, 32, 33), with animals primarily less than 100 cm PCL (59%, Figure 2). Linking these two clusters of core adult and juvenile animals there appears to be an intermediate cluster which has a mixture of sub-adult individuals greater than 100cm but less than 150cm PCL (46%, Figure 2). This sub-adult cluster is predominantly north of 30°N and west of 140 °W (areas 3, 8, 16, 18, 19, 26, 27, 28, 29, 30). The pairs plot of clusters indicates similar differences in the size compositions of the three main clusters (Figure 5).

Our cluster results agree with tagging and scientific survey data collected by the Southwest Fisheries Science Center, with juvenile blue sharks predominately captured inshore, with rarer appearances of adult and sub-adult animals (Runcie et al. 2016), which when tagged appeared to head east and south out of coastal waters (unpublished SWFSC tagging data). Size frequency data out of Hawaii also agrees with the core adult area found south of 30° Latitude (ISC 2017).

While sex differences are likely, given the different growth rates identified between males and females and prior work that suggests sexual stratification (Sippel et al. 2014), this works focus on the longline fisheries of Hawaii does not included enough data to allow sexually explicit cluster analysis. Future work with data from other fisheries in the North Pacific Ocean will make a more robust analysis of sexually distinct spatiotemporal cluster analysis possible.

As Teo (2016) found with albacore, when the 5x5° areas were further disaggregated by years and seasons, the clustering pattern became more complex. In the case of blue sharks this also resulted in many areas no longer meeting the criteria for minimum number of individuals in order to be analyzed, thus making results hard to interoperate with large blanks between clustered areas. Combining years was necessary, as was some degree of seasonal aggregation. When seasons were aggregated into semesters (Jan-Jun, Jul-Dec) the issues related to data limitations were somewhat elevated but the resulting clusters were so similar to the aggregated season analysis that the aggregated season analysis was deemed preferable due to the reduced number of excluded areas.

Further analysis is needed to understand the proportion of catch in each of the defined clusters found here but given the results so far we recommend investigating the use of the three clusters defined in Figure 1, 3, and 4 in the upcoming assessment. Furthermore, we recommend using this clustering approach on an expanded set of fisheries data in order to improve the fleet definitions currently used in the assessment of blue sharks with spatiotemporal consideration of size and sex data.

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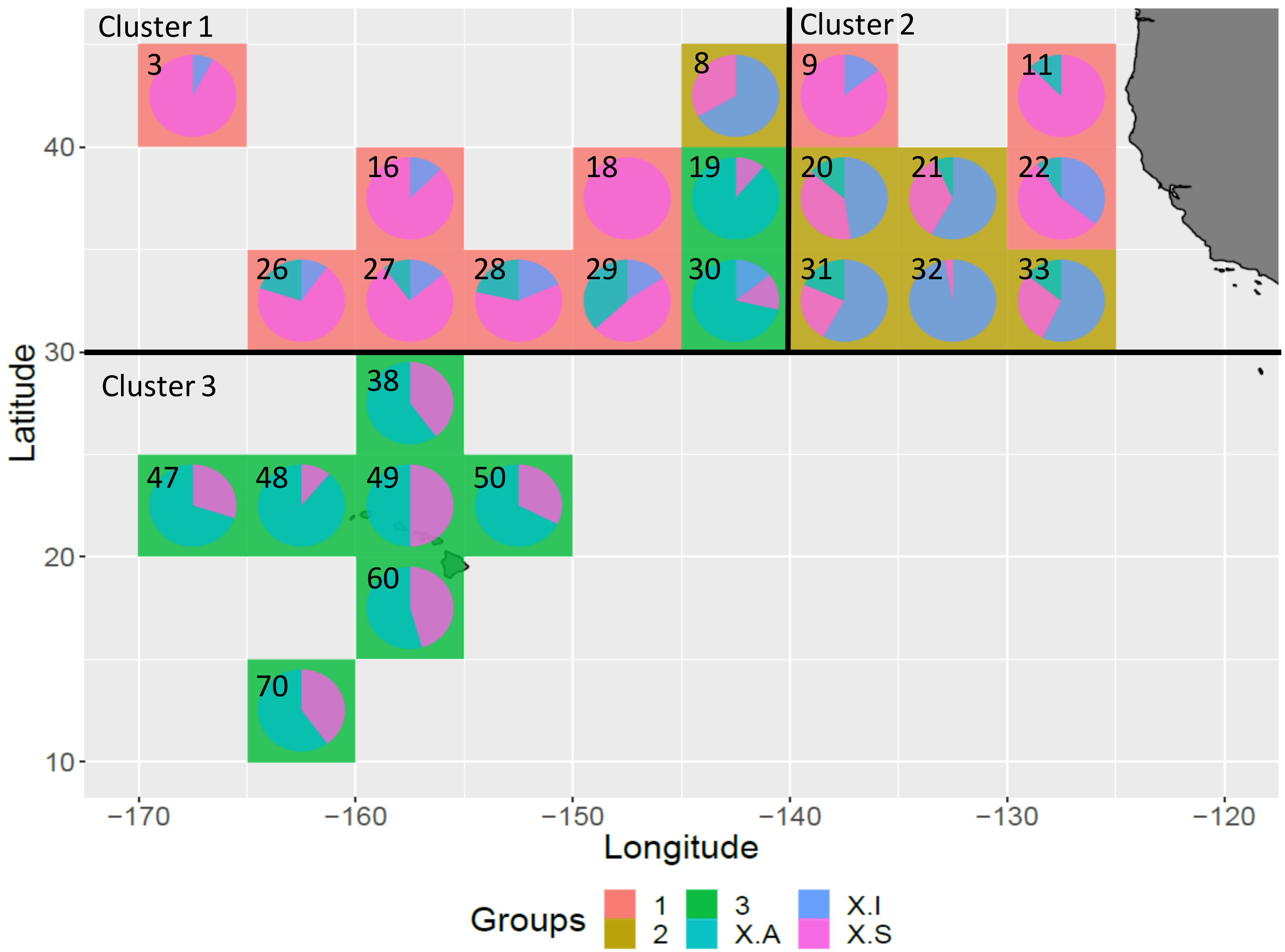

Figure 1: Map of eastern North Pacific Oceans with 5x5° grids. Groups 1, 2, and 3 identify the cluster that each 5x5° box belongs to, boxes without color (grey) did not meet the minimum criteria to be included in the cluster analysis (e.g. number of trips and number of individuals). Groups X.A (Adults), X.I (Immature), and X.S (Sub-adults) identify the pie chat colors. The pie charts indicate the percent of each age group within each box. Black lines indicate potential fleet boarders.

Figure 2: Size composition of each identified cluster (1-3; including samples not in any cluster "NA"). Males and females are identified here just for reference but gender was not included in cluster analysis

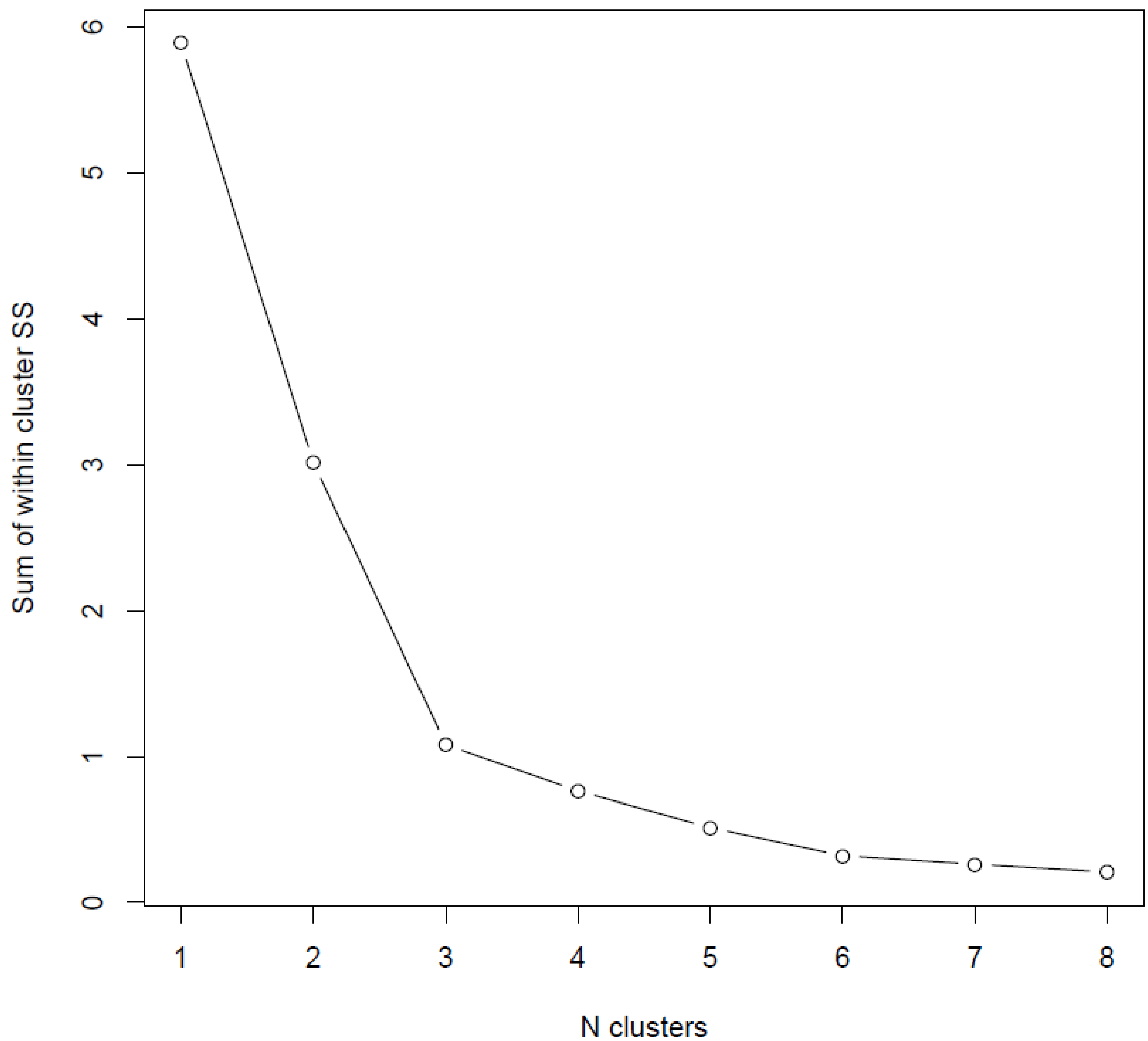

Figure 3: Change in the total within cluster sum of squares with increasing k (number of clusters; N clusters).

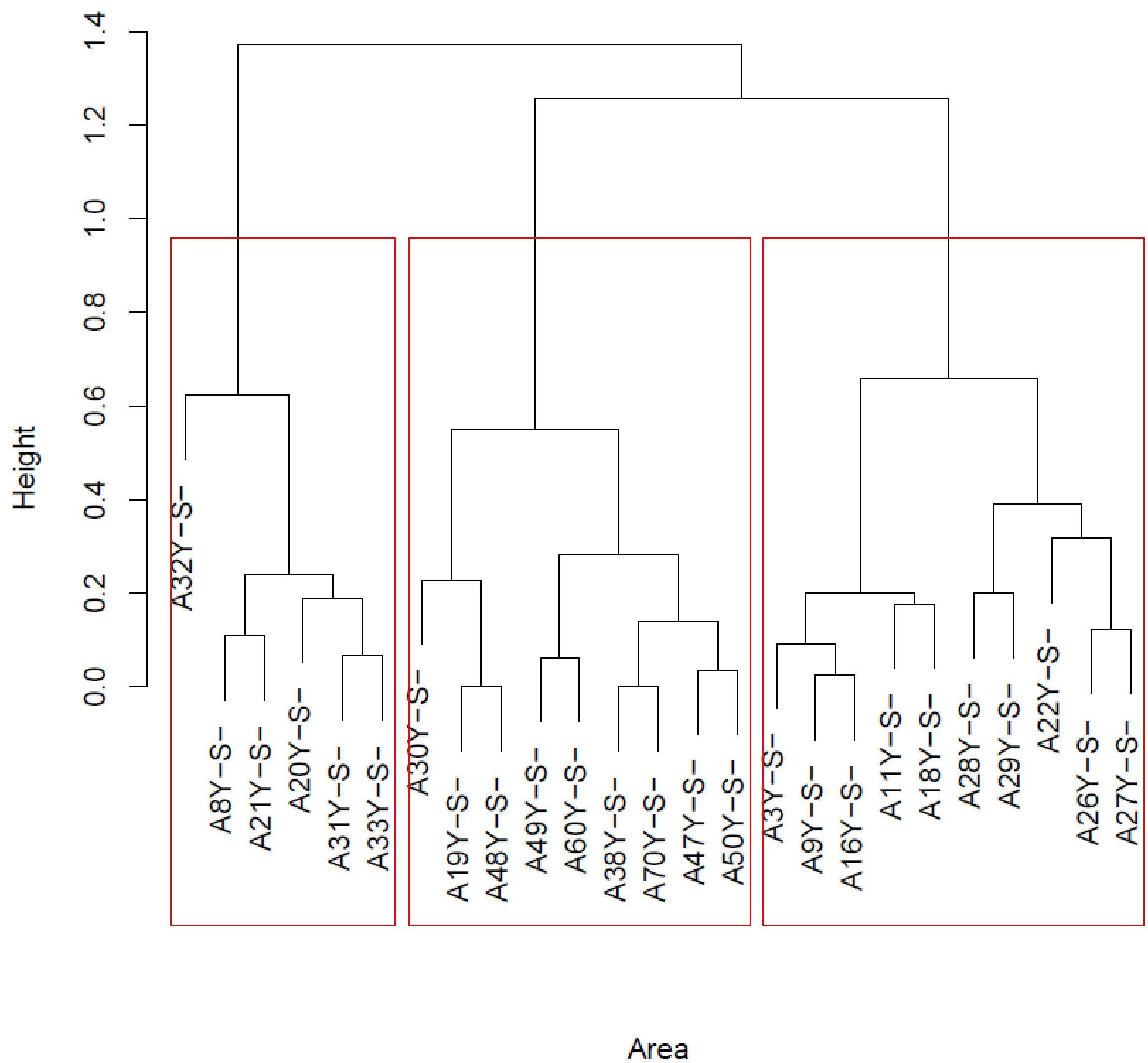

Figure 4: Dendogram of agglomerative hierarchical clustering performed on the size compositions of 5x5° areas outlined in Figure 1. Labels identify the areas 'A' in the dendogram, with 'Y-' and 'S-' indicating that size compositions from all years and seasons were averaged in this analysis. Red boxes indicate the cluster groups when three clusters were defined in the analysis.

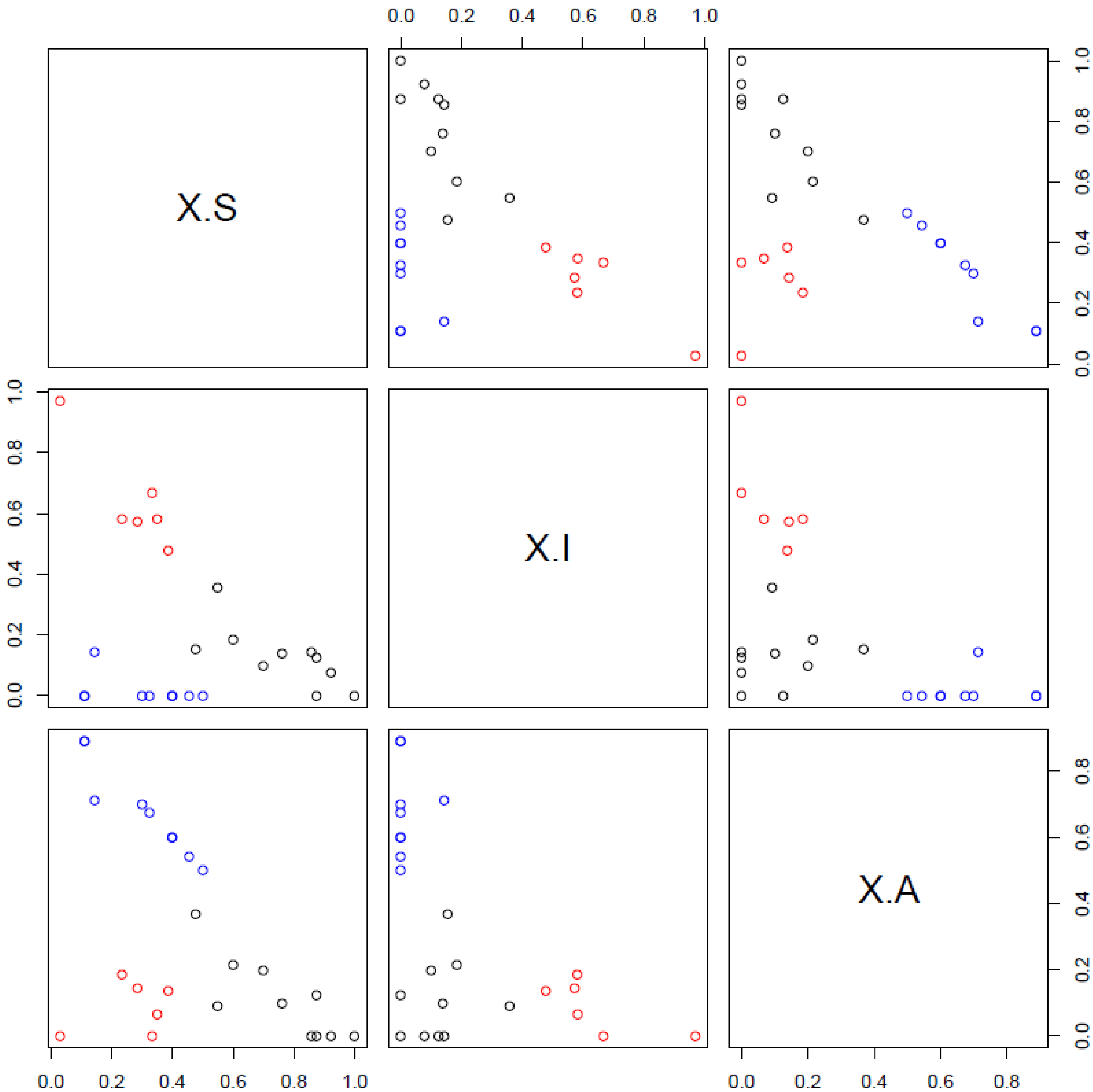

Figure 5: Pairs plot of the proportions of the three approximate age groups (immature, sub-adult, and adult) used in the agglomerative hierarchical cluster analyses in Figure 4. Red circles indicate areas 20, 21, 31, 32, and 33. Black circles indicate areas 3, 8, 16, 18, 19, 26, 27, 28, 29, and 30. Blue circles indicate areas 38, 47, 48, 49, 50, 60, and 70.

Table 1: Areas within each defined cluster, number of trips, number of individuals, average size and percent of each defined age class within all the areas of each cluster.

Cluster	Areas in cluster	n_trips	n_ind	PCL mean (cm)	PCL mode (cm)	Percent Immature	Percent Sub-adult	Percent Adult
1	3, 8, 16, 18, 19, 26, 27, 28, 29, 30	25	296	125.42568	110	16.6%	61.8%	21.6%
2	20, 21, 31, 32, 33	29	382	99.88743	66	56.3%	31.4%	12.3%
3	38, 47, 48, 49, 50, 60, 70	25	412	156.76699	150	4.9%	41.5%	53.6%