Class Wars: Chondrichthyes and Osteichthyes dominance in Chesapeake Bay, 2002-2012. 01 July 2013

Introduction

The objective of this analysis was to demonstrate a possible changing relationship between two Classes of fishes, Osteichthyes (the bony fishes) and Chondrichthyes (the cartilaginous fishes) in Chesapeake Bay based on 11 years of monitoring. If any changes between the two Classes appeared to be significant, either statistically or anecdotally, the data were explored further in an attempt to explain the variation.

The Class Osteichthyes is characterized by having a skeleton made of bone and is comprised of the majority of fish species worldwide, while the Chondrichthyes skeleton is made of cartilage and is represented by the sharks, skates, and rays (the elasmobranch fishes) and chimaeras[1]. Many shark species are generally categorized as apex predators, while skates and rays and some smaller sharks can be placed into the mesopredator functional group (Myers et al., 2007). By definition, mesopredators prey upon a significant array of lower trophic groups, but also serve as the prey base for apex predators. Global demand for shark and consequential shark fishing mortality, estimated at 97 million sharks in 2010 (Worm et al., 2013), is hypothesized to have contributed to the decline of these apex predators in recent years (Baum et al., 2003 and Fowler et al., 2005), which in turn is suggested to have had a cascading effect on lower trophic levels—an increase in mesopredators and subsequent decrease in the prey base (Myers et al., 2007). According to 10 years of trawl survey monitoring of Chesapeake Bay, fish species composition of catches has shown a marked change over the years (Buchheister et al., 2013).

[1] Chimaeras are not found in the study area, so the terms Elasmobranch and Chondrichthyes are functionally interchangeable for this analysis.

Particularly, the contribution of cartilaginous fishes biomass relative to bony fishes appears to have increased over time, with a notably large increase from 2005 to 2006 (Figure 1).

The trawl data also reflect that the Chesapeake Bay Chondrichthyes species biomass is dominated by mesopredators (98%) represented by clearnose skate (*Raja eglanteria*), bluntnose stingray (*Dasyatis say*), cownose ray (*Rhinoptera bonasus*), bullnose ray (*Myliobatis freminvillei*), spiny butterfly ray (*Gymnura altivera*), southern stingray (*Dasyatis americana*), smooth dogfish (*Mustelis canis*), smooth butterfly ray (*Gymnura micrura*), spiny dogfish (*Squalus acanthias*), Atlantic stingray (*Dasyatis sabina*), roughtail stingray (*Dasyatis centroura*), little skate (*Raja erinacea*), winter skate (*Raja ocellata*), and Atlantic sharpnose shark (*Rhizoprionodon terraenovae*). The species composition of Chondrichthyes from 2002 to 2005 and from 2006 to 2012 could be driven by a shift in *Dasyatis spp*. (southern stingray and bluntnose stingray) contributions between time periods (Figure 2).

Section II: Methodology

The study area was Chesapeake Bay, USA. The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) at the Virginia Institute of Marine Science (VIMS) is a long-term fishery-independent fish monitoring trawl survey. Five ChesMMAP cruises per year (March, May, July, September, and November) employing a stratified random sampling design within the Chesapeake Bay main stem were completed from 2002 to 2012. The ChesMMAP database structure includes a total of 80 stations selected for sampling per cruise and stratifications defined by three depth strata and five roughly equal latitudinal regions (Figure 3). Upon completing each cruise, the data is stored in a hierarchical and relational Microsoft Access database where each station name in the main table is a unique identifier and includes location coordinates and area trawled information. The station name relates the main table to a catch table (one-to-many) where many species records including catch totals are assigned to one station name.

For this study, in Microsoft Access, biomass (kg) catches of Osteichthyes and Chondrichthyes were queried and summarized for each year from 2002 to 2012 and then summarized again for the periods 2002-2005 and 2006-2012 using taxonomic Class assignments to each species and a query design. Catch biomass was normalized by either area sampled, in the case of catch biomass, or by number of stations sampled, in the case of percent contribution.

In ArcMAP, the density of catch biomass for each class was spatially interpolated using the Kernel Density (Spatial Analyst) tool which produced a smoothed surface estimate around each point feature including influence from distant points within a 10,000 meter search radius. The ratio of Chondrichthyes to Osteichthyes for each year was calculated using the kernel density rasters and the Raster Calculator (Spatial Analyst). To summarize earlier and later time periods for comparison, the Raster Calculator was used again to average the density ratio from 2002 to 2005 and from 2006 to 2012. The total normalized biomass of Chondrichthyes species for the two time periods was interpolated using the Inverse Distance Weighted (IDW, Spatial Analyst) tool to visualize the estimated change. To demonstrate the possible shift in *Dasyatis spp.* contributions from southern stingray to bluntnose stingray as well as the contribution of the bluntnose stingray to the shift in class dominance, the normalized biomass of each of these two species was interpolated for the two time periods using the IDW tool. Finally, to investigate any major changes in significant spatial clustering of Chondrichthyes between the time periods, a Hotspot Analysis (Getis-Ord Gi*) was performed on the total normalized biomass of Chondrichthyes species for each time period. The biomass was considered a hotspot if the observed value was at least 2.5 standard deviations larger than the expected value at a $p<0.01$ significance level.

Section III: Results

This study has shown an increase in the cartilaginous to bony fish ratio between two time periods of an 11-year monitoring program 2002 to 2005 and 2006 to 2012, suggesting that the Chondrichthyes have gained dominance in the spatial range in which they inhabit. (Figure 4). The interpolated surface of the biomass per area sampled for all Chondrichthyes revealed larger areas of high biomass from one time period to the next (Figure 5). Further exploration of the data indicated that the bluntnose stingray (*Dasyatis say*) increased in biomass (Figure 6) while the southern stingray (*Dasyatis americana*) decreased (Figure 7). This decrease was less substantial than the increase in bluntnose stingray. Finally, the hotspot analysis of the normalized Chondrichthyes biomass revealed twice as many hotspots after 2005 than before (34 to 69 significant hotspots identified) characterized by a few additional clusters in the northern reaches of the bay from one time period to the next (Figure 8).

Section VI: Discussion

Chondrichthyan species inhabit the higher salinity water of lower Chesapeake Bay where tidal influx is greatest and freshwater input is at a minimum. Within this range, a clear shift in dominance of the Chondrichthyes relative to Osteichthyes has occurred in the years since 2005. Within the Chondrichthyes range, the bluntnose stingray, a species whose Chondrichthyes biomass proportion increased from 1% before 2005 to 25% after 2005, appeared to be the most influential in driving this dominance. Generally, areas of low biomass of this species became areas of high biomass, and new areas of low biomass began to appear farther north into the upper reaches of the Bay where bluntnose ray were previously absent. Preliminary data suggested that the bluntnose stingray may have replaced or outcompeted the southern stingray, a species whose Chondrichthyes biomass proportion decreased from 19% to 4% after 2005, but obvious inter-species dominance was not evident in this study, as the actual southern stingray biomass decreased only slightly in comparison to the large bluntnose ray increase. Additionally, new pockets of the cartilaginous fishes dominance over the bony fishes appeared along Maryland's Eastern Shore in some upper Bay reaches near the mouths of the Nanticoke and Choptank Rivers. The biomass catch at the stations representing these isolated pockets was comprised exclusively of cownose ray (*Rhinoptera bonasus*), although the biomass contribution of this species to the Chondrichthyes biomass as a whole actually decreased between the two time periods. This may suggest that the cownose ray is better at competing with and exhibiting dominance over Osteichthyan species rather than other Chondrichthyans. Another change that emerged after 2005 was the appearance of more Chondrichthyes biomass hotspots, which represented spatially significant clusters of high biomass, including new areas in the upper reaches of the Bay. This is evidence that the Chondrichthyes species in Chesapeake Bay are not only gaining dominance over Osteichthyes within the Chondrichthyes habitat, but also increasing in biomass outside of their previous range.

The diets of large predatory sharks are comprised of mesopredator species (Myers et al, 2007, Ellis and Musick, 2007, and Lucifora et al., 2009), and mesopredator diet is partially comprised of bivalves such as scallops, clams, and oysters (Smith and Merriner, 1985, Murdy and Musick, 2013, VIMS 2013). While global demand for shark and shark fins has decreased the abundance of the apex predators, subsequent increased abundance of mesopredator Chondrichthyes species such as those in this study is suggested to exhibit a detriment to some commercially importance bivalve species such as the bay scallop (*Argopecten irradians*) (Myers et al., 2007) as well as concern that Chesapeake Bay oyster populations (*Crassostrea virginica*) may be vulnerable. Elsewhere along the Western Atlantic, the cownose ray is showing evidence of increased population due to this trophic cascade, imposing deleterious effects on bay scallop populations (Myers et al., 2007).

In conclusion, future efforts to continue monitoring the Chondrichthyes to Osteichthyes ratio in Chesapeake Bay would increase our knowledge and understanding of how fishing pressure on apex predators can affect commercially important bivalve species at lower trophic levels. Other monitoring programs, such as the VIMS Longline Survey, operational since 1972 and targeting both large predatory sharks and the mesopredators, may also be essential in revealing these trophic dynamic patterns, particularly for the sandbar shark (*Carcharhinus plumbeus*), the dominant shark species in the Chesapeake Bay vicinity (Ellis and Musick, 2007).

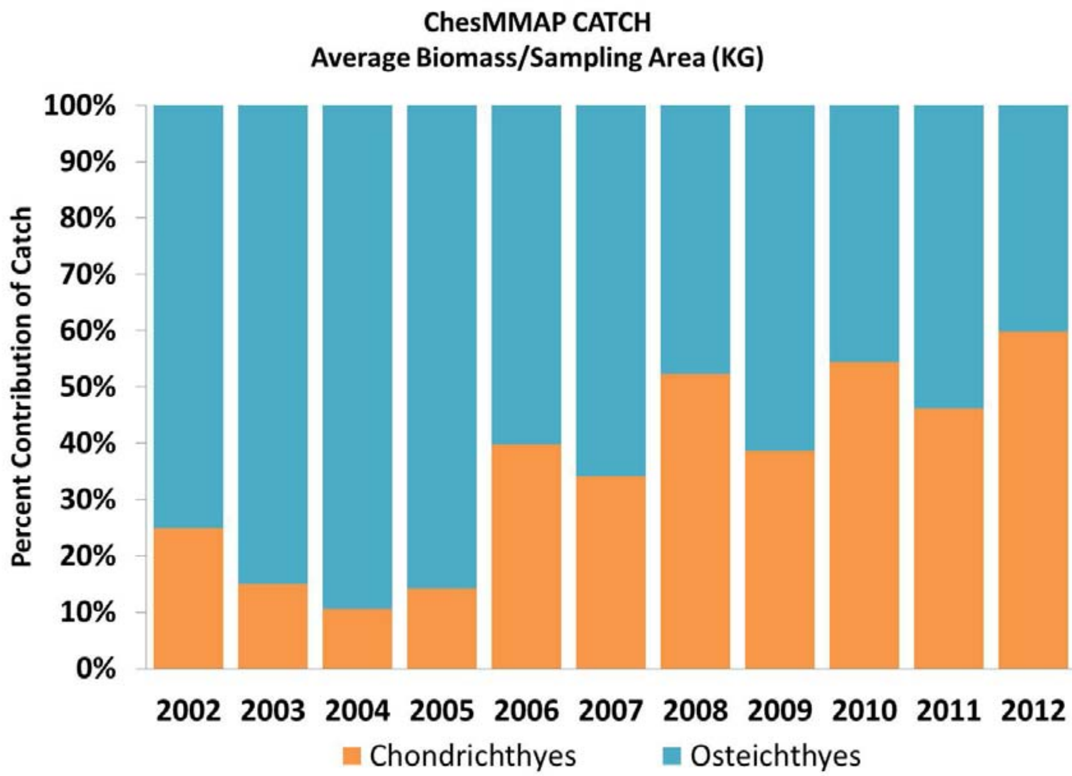

Figure 1. Percent contribution to annual average catch biomass of Osteichthyes (bony fishes) and Chondrichthyes (cartilaginous fishes), 2002-2012

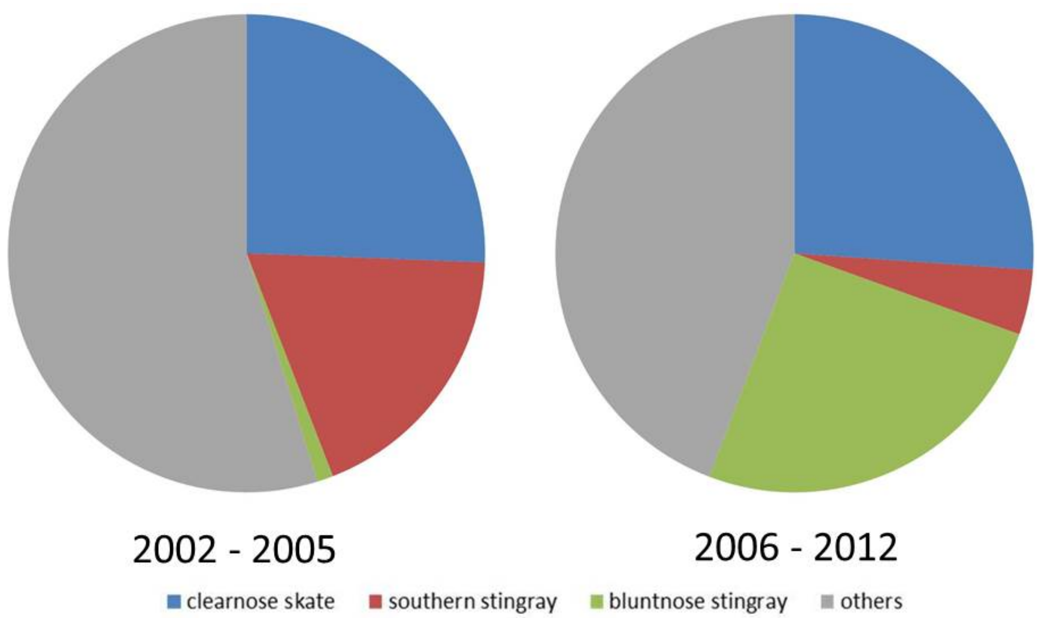

Figure 2. Change in average annual species composition of Chondrichthyes fishes 2002-2005 and 2006-2012. The species composition making up the "other" category (9 species) remained relatively unchanged.

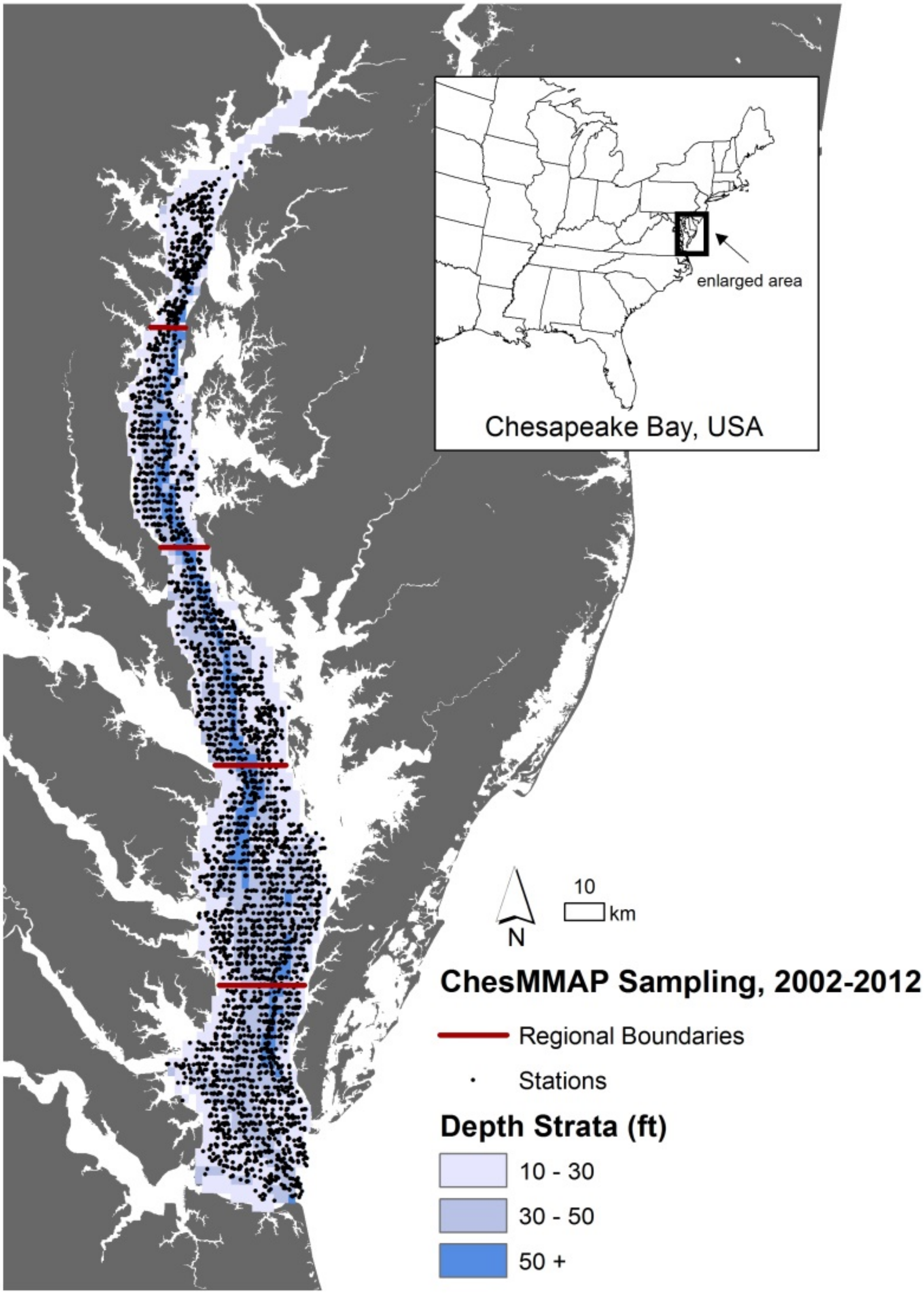

Figure 3. Locations sampled during ChesMMAP cruises from 2002 to 2012 with stratified random sampling design. Stratifications are 5 regional boundaries and 3 depth strata.

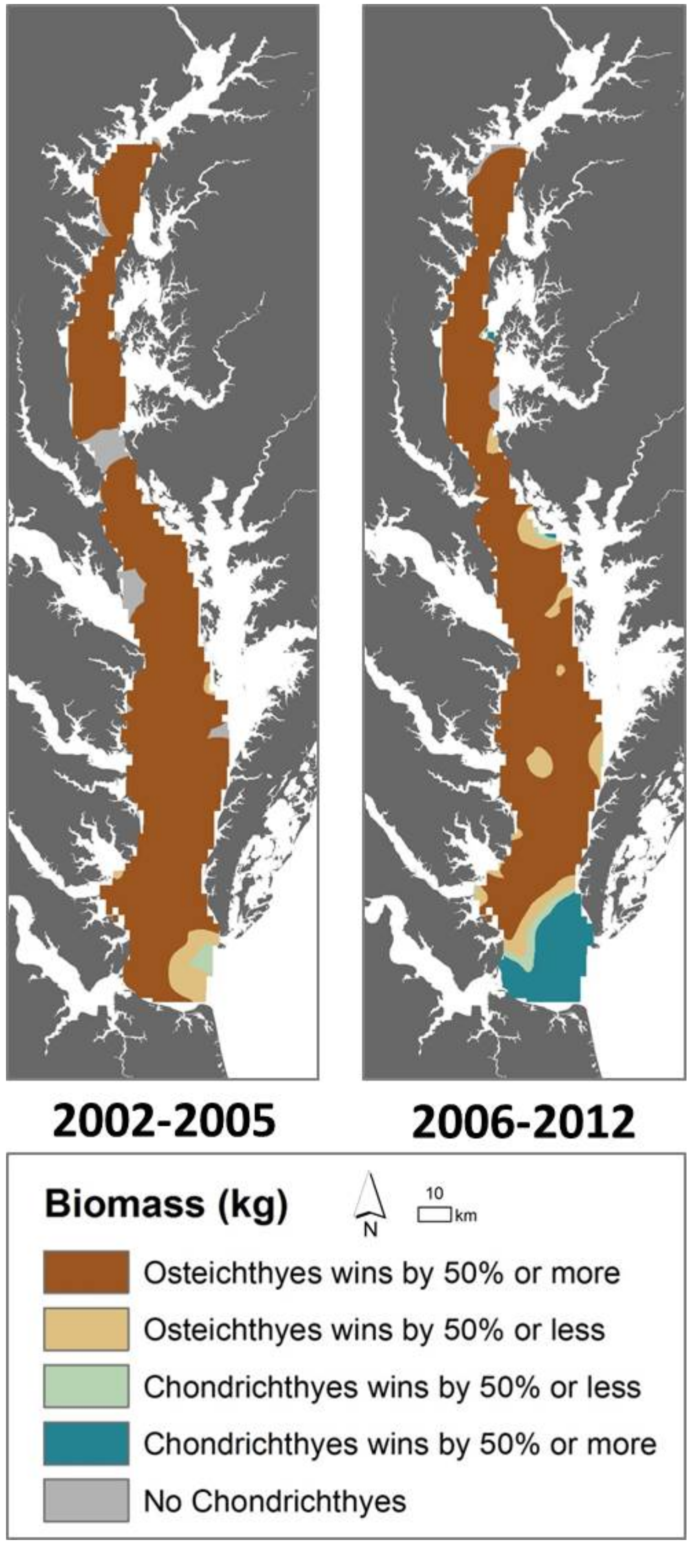

Figure 4. Biomass density ratio of Chondrichthyes to Osteichthyes

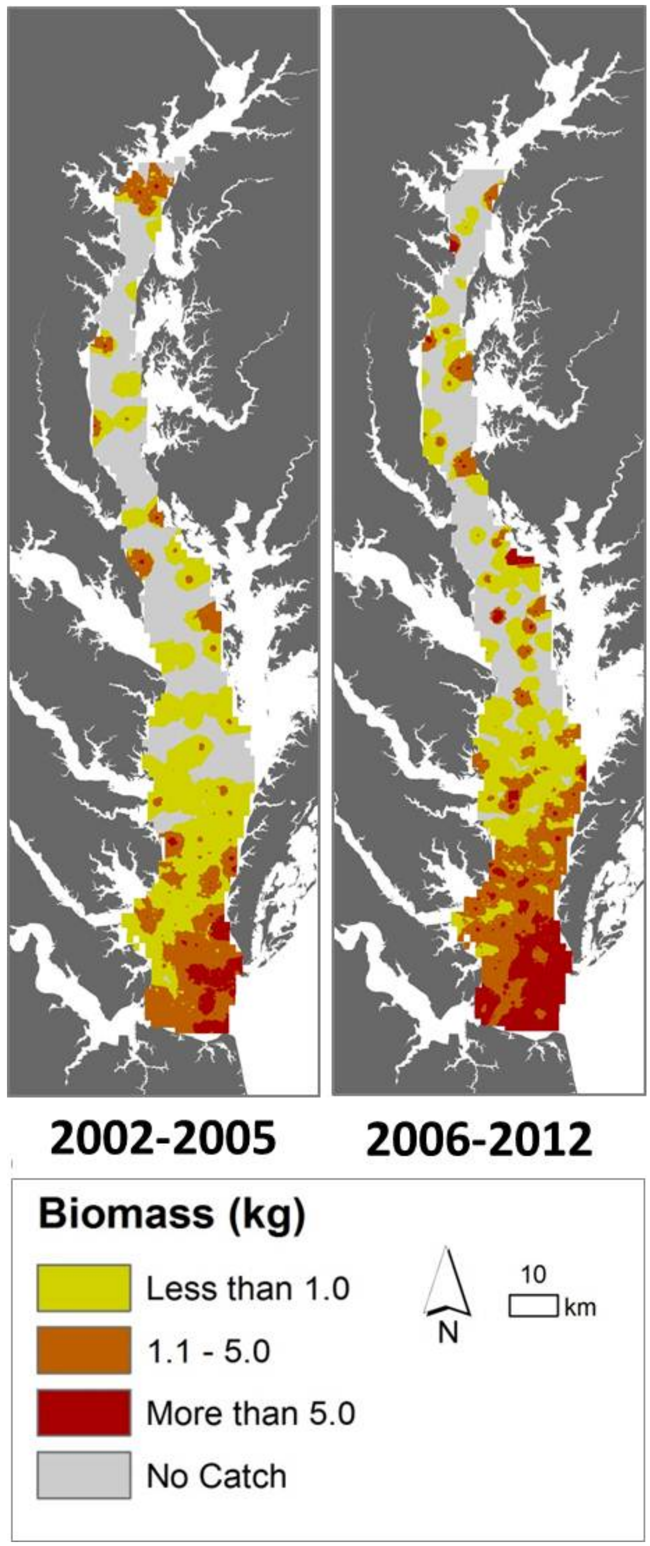

Figure 5 Biomass per unit area of all Chondrichthyes 2002-2005 and 2006-2012

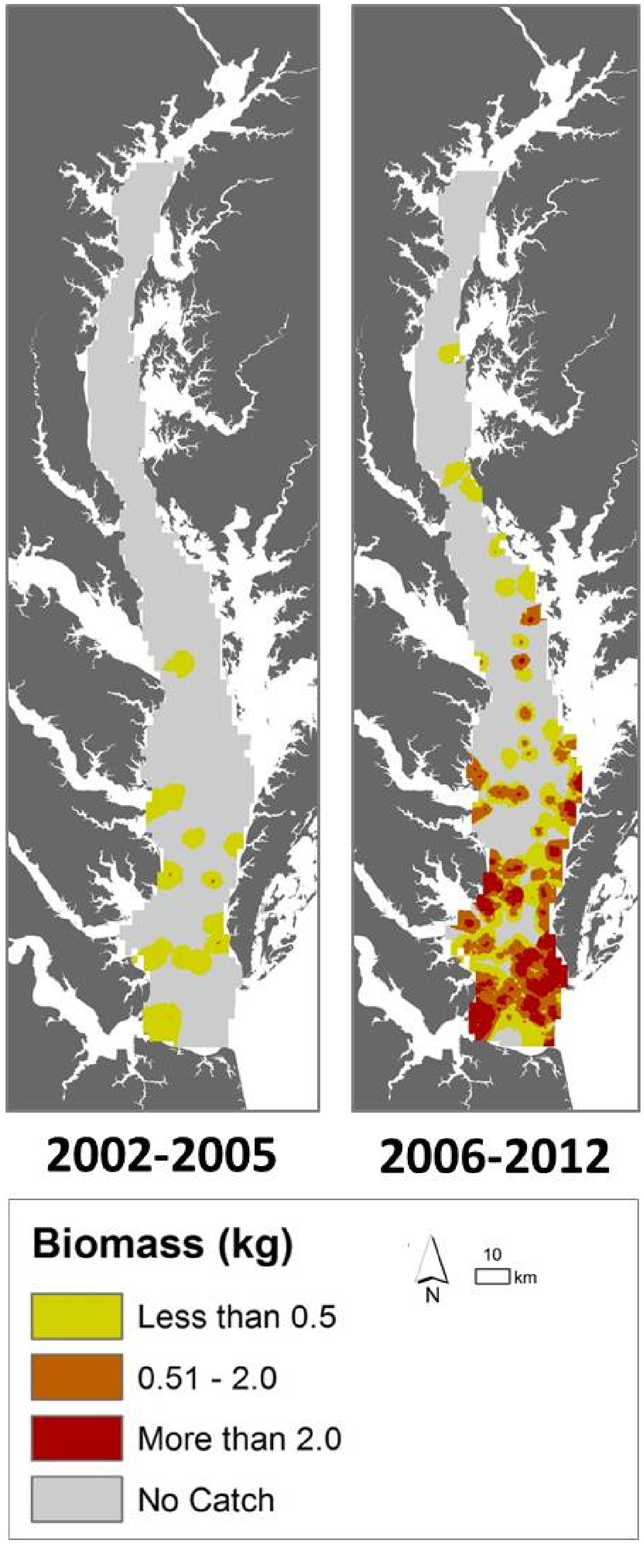

Figure 6. Biomass per unit area of bluntnose stingray 2002-2005 and 2006-2012

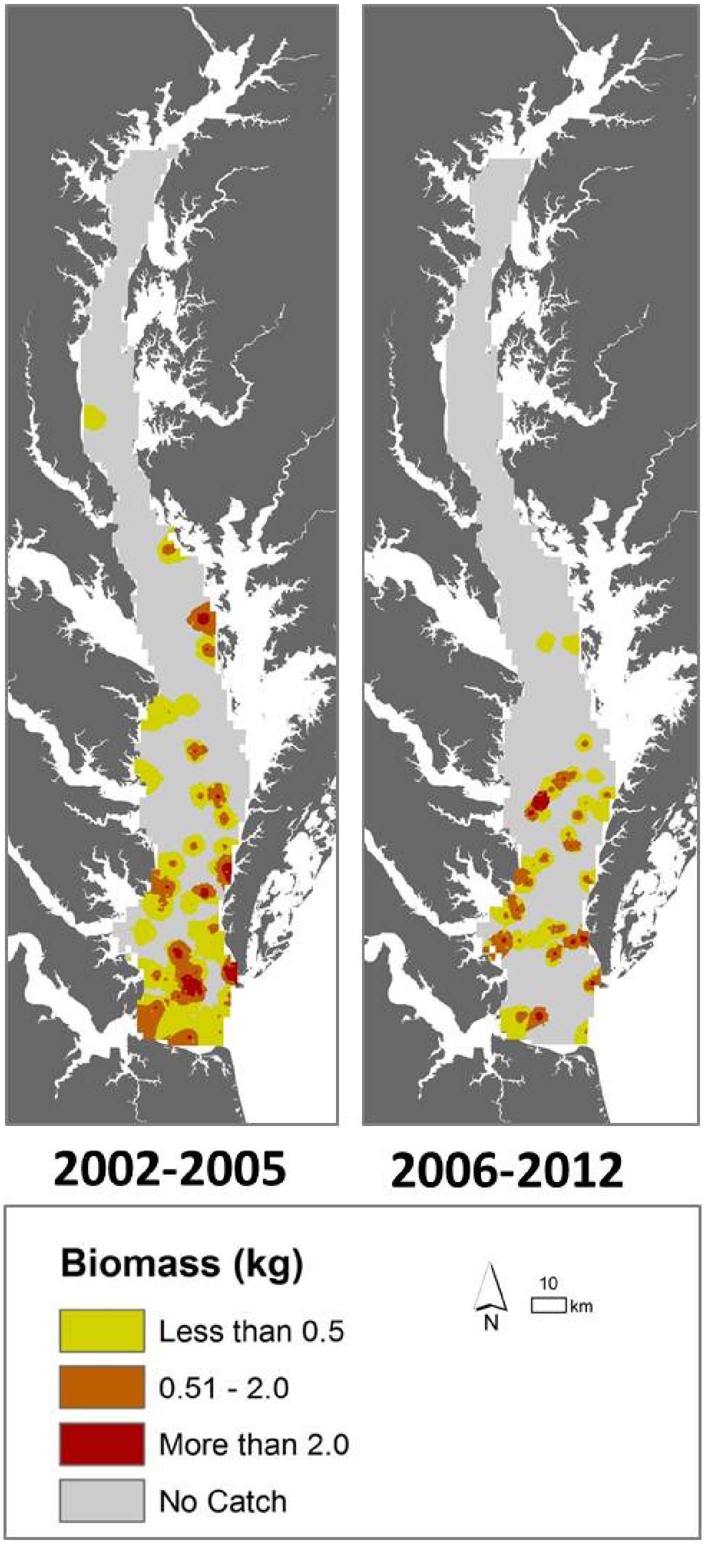

Figure 7 Biomass per unit area of southern stingray 2002-2005 and 2006-2012

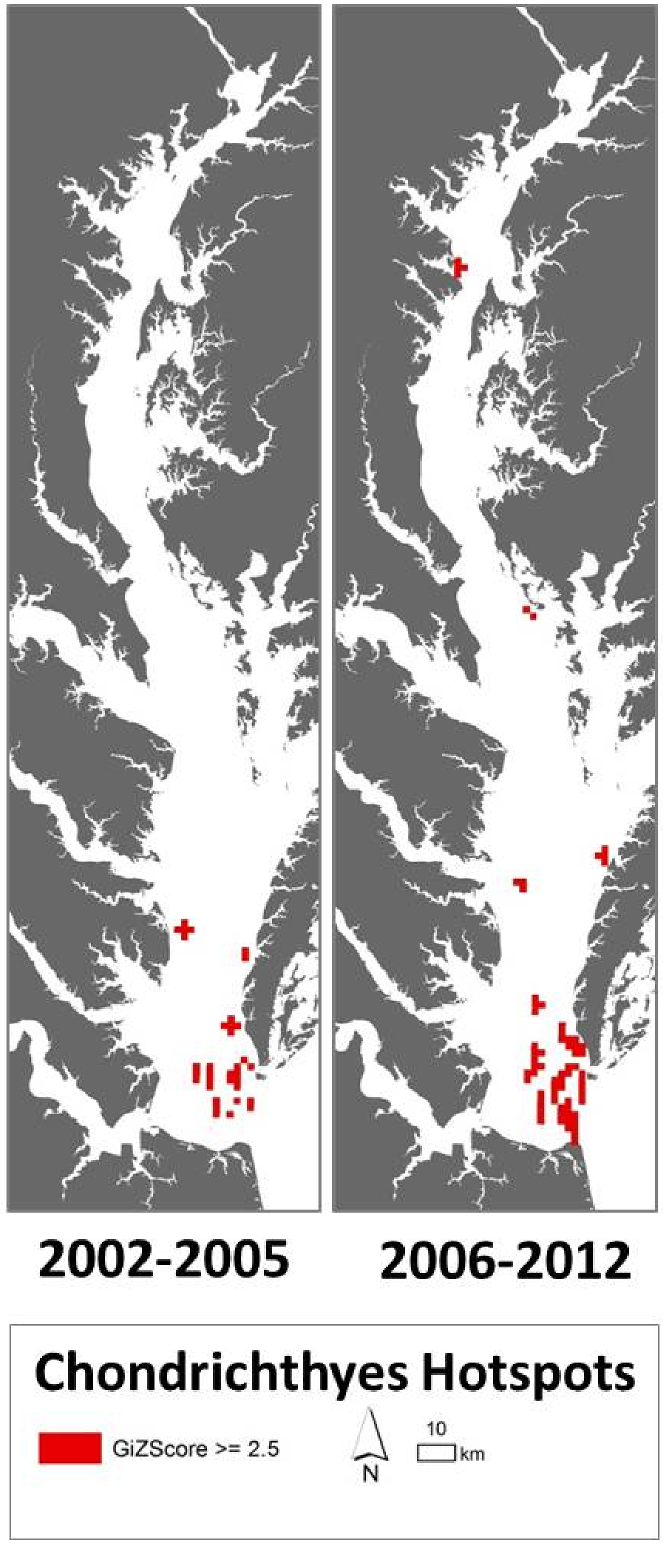

Figure 8 Hotspot analysis of Chondrichthyes biomass 2002-2005 and 2006-2012. Hotspots denote clusters where the observed biomass is at least 2.5 standard deviations higher than expected (p<0.01)

Section V: References

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