Hammerhead Sharks of the Northwest Atlantic and Gulf of Mexico (2014 – 2020)

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Bibliography

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Background & Scope

Great hammerhead (*Sphyrna mokarran*), smooth hammerhead (*Sphyrna zygaena*), and Carolina hammerhead (*Sphyrna gilberti*) sharks are highly migratory species (HMS). The great and smooth hammerhead sharks have a global distribution, including the Northwest Atlantic and Gulf of Mexico. Articles about the Carolina hammerhead shark, formally identified in 2013, place this species in the Northwest Atlantic region.

This bibliography focuses on literature since 2014 that provides information about great, smooth, and Carolina hammerhead sharks in the Northwest Atlantic and Gulf of Mexico – two older articles focusing on the genetics of the Carolina hammerhead shark are included to provide thorough information on this newly identified shark species. The literature review is intended as a reference to inform the SouthEast Data, Assessment, and Review's (SEDAR) stock assessment for HMS hammerhead sharks in the specified region. SEDAR is the cooperative process by which stock assessment projects are conducted in NOAA Fisheries' Southeast Region. The bibliography will be organized in four sections: Genetics, Biology and Life History, Ecology, and Population Abundance and Trends.

Section I – Genetics
Section one is intended to provide an overview of new information since 2014 on genetic diversity, trends, and population structures of great, smooth, and Carolina hammerhead sharks.

Section II – Biology and Life History
Section two is intended to provide an overview of new information since 2014 on the biology of the great, smooth, and Carolina hammerhead sharks. The research in this area includes a compilation of lifespan, metabolism, reproduction, and body size.

Section III – Ecology
Section three is intended to provide an overview of ecology for great, smooth, and Carolina hammerhead sharks. The research in this area includes migration, feeding, behavior, and social ecology.

Section IV – Population Abundance and Trends
Section four is intended to provide an overview of the latest population estimates since 2014 for great, smooth, and Carolina hammerhead sharks, as well as information about activities that are affecting populations.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; Digital Science's Dimensions; ProQuest's Science and Technology, including Aquatic Science Fisheries Abstracts; Elsevier's Science Direct; Lexis Advance; JSTOR; EBSCO's Academic Search Complete and Environment Complete; NOAA's Institutional Repository; Science.gov; the Biodiversity Heritage Library; BioOne Complete; and Google Scholar.

Section I: Genetics

Barker, A., Adams, D., Driggers, W., Frazier, B., & Portnoy, D. (2019). Hybridization between Sympatric Hammerhead Sharks in the Western North Atlantic Ocean. *Biology letters, 15*. https://doi.org/10.1098/rsbl.2019.0004

Hybridization between closely related species has been documented across a wide range of taxa but has not been well studied in elasmobranchs. Hammerhead sharks have drawn global conservation concern because they experience some of the highest mortality rates among sharks when interacting with fisheries. Here we report on the detection of hybrids between the globally distributed scalloped hammerhead (*Sphyrna lewini*) and recently described Carolina hammerhead *(S. gilberti)* which are only known from the western Atlantic Ocean. Using a genomics approach, 10 first-generation hybrids and 15–17 backcrosses were detected from 554 individuals. The identification of backcrosses demonstrates hybrids are viable, and all backcrosses but one involved a scalloped hammerhead. All hybrids but one possessed Carolina hammerhead mtDNA, indicating sex-biased gene flow between species. Repeated hybridization and backcrossing with scalloped hammerheads could lead to the loss of endemic Carolina hammerheads.

Guy, D. S., Ruck, C. L., Lopez, J. V., & Shivji, M. S. (2017). Complete Mitogenome Sequences of Smooth Hammerhead Sharks, *Sphyrna zygaena*, from the Eastern and Western Atlantic. *Mitochondrial DNA Part B-Resources, 2*(2), 806-807. https://doi.org/10.1080/23802359.2017.1390421

We report the first mitogenome sequences of the circumglobally distributed, highly mobile, smooth hammerhead shark, *Sphyrna zygaena*, from the eastern and western Atlantic. Both genomes were 16,729 bp long with 13 protein-coding genes, two rRNAs, 22 tRNAs and a non-coding control region. The two Atlantic shark sequences differ from each other by 13 SNPs, and by 43 and 44 SNPs from the published mitogenome of an *S. zygaena* specimen from the eastern Pacific Ocean. The cross-Atlantic mitogenome sequences reported here provide a resource to assist with population genetics studies of this widely exploited species of conservation concern.

Pinhal, D., Domingues, R. R., Bruels, C. C., Ferrette Bruno, L. S., Gadig Otto, B. F., Shivji, M. S., & Martins, C. (2020). Restricted Connectivity and Population Genetic Fragility in a Globally Endangered Hammerhead Shark. *Reviews in Fish Biology and Fisheries, 30*(3), 501-517. https://doi.org/10.1007/s11160-020-09607-x

Vagile, large-bodied marine organisms frequently have wide range dispersion but also dependence on coastal habitats for part of their life history. These characteristics may induce complex population genetic structure patterns, with resulting implications for the management of exploited populations. The scalloped hammerhead, *Sphyrna lewini*, is a cosmopolitan, migratory shark in tropical and warm temperate waters, inhabiting coastal bays during parturition and juvenile development, and the open ocean as adults. Here, we investigated the genetic connectivity and diversity of *S. lewini* in the western Atlantic using large sample coverage (N = 308), and data from whole mitochondrial control region (mtCR) sequences and ten nuclear microsatellite markers We detected significant population genetic structure with both mtCR and microsatellites markers (mtCR: ΦST = 0.60; $p < 0.001$; microsatellites: Dest 0.0794, $p = 0.001$, FST = 0.046, $p < 0.05$), and isolation by distance (mtCR $r = 0.363$, $p = 0.009$; microsatellites markers $r = 0.638$, $p = 0.007$). Migration and gene flow patterns were asymmetric and

female reproductive philopatry is postulated to explain population subdivisions. The notable population differentiation at microsatellites markers indicates low-levels of male-mediated gene flow in the western Atlantic. The overall effective population size was estimated as 299 (215–412 CI), and there was no evidence of strong or recent bottleneck effects. Findings of at least three management units, moderate genetic diversity, and low effective population size in the context of current overfishing calls for intensive management aimed at short and long-term conservation for this endangered species in the western Atlantic Ocean.

Quattro, J. M., Driggers, W. B., Grady, J. M., Ulrich, G. F., & Roberts, M. A. (2013). *Sphyrna gilberti* Sp Nov., a New Hammerhead Shark (Carcharhiniformes, Sphyrnidae) from the Western Atlantic Ocean. *Zootaxa, 3702*(2), 159-178. https://doi.org/10.11646/zootaxa.3702.2.5

Sphyrna gilberti sp. nov. is described based on 54 specimens collected in the coastal waters of South Carolina, U.S.A. Morphologically, *S. gilberti* sp. nov. is separable from *S. lewini* (Griffith & Smith 1834) only in the number of precaudal vertebrae. Due to rarity of specimens and the highly migratory behavior of most sphyrnids, the range of *S. gilberti* sp. nov. is unknown.

Quattro, J. M., Stoner, D., Driggers, W., Anderson, C., Priede, K., Hoppmann, E., . . . Grady, J. (2006). Genetic Evidence of Cryptic Speciation within Hammerhead Sharks (Genus Sphyrna). *Marine Biology, 148*(5), 1143-1155. https://doi.org/10.1007/s00227-005-0151-x

Surveys of genetic variation within cosmopolitan marine species often uncover deep divergences, indicating historical separation and potentially cryptic speciation. Based on broad geographic (coastal eastern North America, Gulf of Mexico, western Africa, Australia, and Hawaii) and temporal sampling (1991–2003), mitochondrial (control region [CR] and cytochrome oxidase I [COI]) and nuclear gene (lactate dehydrogenase A intron 6 [LDHA6]) variation among 76 individuals was used to test for cryptic speciation in the scalloped hammerhead*, Sphyrna lewini* (Griffith and Smith). CR and COI gene trees confirmed previous evidence of divergence between Atlantic and Indo-Pacific scalloped hammerhead populations; populations were reciprocally monophyletic. However, the between basin divergence recorded in the mtDNA genome was not reflected in nuclear gene phylogenies; alleles for LDHA6 were shared between ocean basins, and Atlantic and Indo-Pacific populations were not reciprocally monophyletic. Unexpectedly, CR, COI, and LDHA6 gene trees recovered a deep phylogenetic partition within the Atlantic samples. For mtDNA haplotypes, which segregated by basin, average genetic distances were higher among Atlantic haplotypes (CR: DHKY=0.036,COI: DGTR=0.016) than among Indo-Pacific haplotypes (CR: DHKY=0.010, COI: DGTR=0.006) and approximated divergences between basins for CR (DHKY=0.036 within Atlantic; DHKY=0.042 between basins). Vertebral counts for eight specimens representing divergent lineages from the western north Atlantic were consistent with the genetic data. Coexistence of discrete lineages in the Atlantic, complete disequilibrium between nuclear and mitochondrial alleles within lineages and concordant partitions in genetic and morphological characters indicates reproductive isolation and thus the occurrence of a cryptic species of scalloped hammerhead in the western north Atlantic. Effective management of large coastal shark species should incorporate this important discovery and the inference from sampling that the cryptic scalloped hammerhead is less abundant than *S. lewini*, making it potentially more susceptible to fishery pressure.

Ruck, C. L., Marra, N., Shivji, M. S., & Stanhope, M. J. (2017). The Complete Mitochondrial Genome of the Endangered Great Hammerhead Shark, *Sphyrna mokarran*. *Mitochondrial DNA Part B-Resources, 2*(1), 246-248. https://doi.org/10.1080/23802359.2017.1318682

We present the first mitochondrial genome sequence of the great hammerhead shark, *Sphyrna mokarran*. This species is of considerable conservation concern throughout its global distribution, and currently listed as Endangered on the IUCN Red List. The mitochondrial genome is 16,719 bp in length with 13 protein-coding genes, 22 tRNA genes, 2 rRNA genes and a non-coding control region. The gene arrangement is congruent with other shark and most vertebrate species. This *S. mokarran* mitogenome provides a genomic resource for assisting with population studies and conservation efforts for this highly depleted species.

Section II: Biology and Life History

Gallagher, A. J., Hammerschlag, N., Shiffman, D. S., & Giery, S. T. (2014). Evolved for Extinction: The Cost and Conservation Implications of Specialization in Hammerhead Sharks. *BioScience, 64*(7), 619-624. https://doi.org/10.1093/biosci/biu071

The interactions between the evolutionary history of species and contemporary changes in their environment can result in both positive and negative outcomes for fitness and survival. Sharks are one the oldest groups of all extant vertebrates but, today, are among the most threatened globally, primarily because of destructive fishing practices. Hammerhead sharks (Sphyrnidae) exhibit extremely specialized traits and complex behaviors that have increased their vulnerability to human exploitation, which impedes conservation efforts. By bringing together published data on aspects of hammerhead shark phylogeny, morphology, biology, physiology, and ecology, we argue that the same novel adaptations that have historically contributed to evolutionary success have become maladaptive under current levels and modes of exploitation. Therefore, we suggest that future management be made in light of rather than in spite of the unique evolutionary and ecological traits possessed by hammerhead sharks, because similar patterns are threatening other taxa with high extinction risk.

Gallagher, A. J., & Klimley, A. P. (2018). The Biology and Conservation Status of the Large Hammerhead Shark Complex: The Great, Scalloped, and Smooth Hammerheads. *Reviews in Fish Biology and Fisheries, 28*(4), 777-794. https://doi.org/10.1007/s11160-018-9530-5

Hammerhead sharks are among the most intriguing yet imperiled groups of large sharks globally. Until recently, our understanding of their biology, movements, diet, and life histories was challenged by a lack of studies. In recent years there has been a surge of published studies on this group of sharks, incorporating new information on age and growth, behavior, and the threats they face. Here we summarize and compare what is known on the biology and conservation of the three largest species of hammerhead sharks: the great hammerhead (*Sphyrna mokarran*), the scalloped hammerhead (*Sphyrna lewini*), and the smooth hammerhead (*Sphyrna zygaena*). We chose these species since they are the most well-studied of the hammerheads, and also because they are commonly captured in target and non-target fisheries worldwide. Thus, we also discuss population trends and the vulnerabilities of each species, and make recommendations for future studies on these fascinating and complex elasmobranch fishes.

Gallagher, A. J., Serafy, J. E., Cooke, S. J., & Hammerschlag, N. (2014). Physiological Stress Response, Reflex Impairment, and Survival of Five Sympatric Shark Species Following Experimental Capture and Release. *Marine Ecology Progress Series, 496*, 207-218. https://doi.org/10.3354/meps10490

In many fisheries, some component of the catch is usually released. Quantifying the effects of capture and release on fish survival is critical for determining which practices are sustainable, particularly for threatened species. Using a standardized fishing technique, we studied sublethal (blood physiology and reflex impairment assessment) and lethal (post-release mortality with satellite tags) outcomes of fishing stress on 5 species of coastal sharks (great hammerhead, bull, blacktip, lemon, and tiger). Species-specific differences were detected in whole blood lactate, partial pressure of carbon dioxide, and pH values, with lactate emerging as the sole parameter to be significantly affected by increasing hooking duration and shark size. Species-specific differences in reflex impairment were also found; however, we

did not detect any significant relationships between reflex impairment and hooking duration. Taken together, we ranked each species according to degree of stress response, from most to least disturbed, as follows: hammerhead shark > blacktip shark > bull shark > lemon shark > tiger shark. Satellite tagging data revealed that nearly 100% of all tracked tiger sharks reported for at least 4 wk after release, which was significantly higher than bull (74.1%) and great hammerhead (53.6%) sharks. We discuss which mechanisms may lead to species-specific differences in sensitivity to fishing and suggest that observed variation in responses may be influenced by ecological and evolutionary phenomena. Moreover, our results show that certain species (i.e. hammerhead sharks in this study) are inherently vulnerable to capture stress and mortality resulting from fisheries interactions and should receive additional attention in future conservation strategies.

Gulak, S. J. B., Enzenauer, M. P., Deacy, B. M., & Carlson, J. K. (2017). Allometric Relationships for Species Captured in Longline Fisheries from the Western North Atlantic. Retrieved from https://repository.library.noaa.gov/view/noaa/14192

Commercial landings data provide the platform upon which most research, assessments, and management plans are based. Data collection authorities obtain information from commercial records; however, commercial records are often in native units that are of limited use for data analysis. Conversion factors are used to convert landed condition weight or landed units of commercial seafood products to whole weight. Although many fisheries land product in whole form which does not require conversion, others record product in gutted, headed, carcass, fillet, tail, loins, fins or some other partial form of the fish. Conversion factors are also necessary for product landed in units other than weight in pounds, such as number, thousands, bushels or dozens. In addition, shellfish and crustacean fisheries generally land product as bushels, bags, baskets, numbers, shell on, shell off, or meat only. Conversion factors are then applied to these landed conditions or units with the resulting output of whole weight in pounds.

Jerome, J. M., Gallagher, A. J., Cooke, S. J., & Hammerschlag, N. (2017). Integrating Reflexes with Physiological Measures to Evaluate Coastal Shark Stress Response to Capture. *ICES Journal of Marine Science, 75*(2), 796-804. https://doi.org/10.1093/icesjms/fsx191

In both commercial and recreational fisheries, sharks are captured and released alive to comply with regulations or due to low economic value or voluntary conservation ethic. As a result, understanding the physiological and behavioural responses of sharks to capture stress is important for determining subsequent effects of fisheries interactions on a species-specific basis, as well as for identifying factors that influence mortality. Here, we employed a suite of conventional blood physiology endpoints (glucose, lactate, and haematocrit) integrated with assessments of reflex impairment on blacktip (Carcharhinus limbatus), great hammerhead (*Sphyrna mokarran*), nurse (Ginglymostoma cirratum) and sandbar sharks (Carcharhinus plumbeus) captured via experimental drumline gear. We documented a wide range of species-specific differences in all parameters assessed, with nurse sharks consistently having the lowest relative levels of physiological disturbance and reflex impairment; and with great hammerheads exhibiting the highest level of physiological disturbance and reflex impairment, suggesting higher vulnerability to fishing. In general, increases in lactate were positively associated with hook time and correlated with reflex impairment assessment. Moreover, reflex indices showed significant impairment with hook time, with the “jaw” reflex emerging as the most potential predictor of

disturbance. Our study results connect previously reported species-specific at-vessel and post-release mortality rates to their physiological disturbance and reflex impairment.

Lyons, K., Galloway, A. S., Adams, D. H., Reyier, E. A., Barker, A. M., Portnoy, D. S., & Frazier, B. S. (2020). Maternal Provisioning Gives Young-of-the-Year Hammerheads a Head Start in Early Life. *Marine Biology, 167*(11). https://doi.org/10.1007/s00227-020-03766-y

For species that do not provide parental care after birth, excess maternal provisioning during development, beyond what is required for embryogenesis, provides offspring with resources to increase their chances of survival. Maternally derived resources are expected to be important for buffering offspring against limited food resources at birth or time needed to learn how to properly feed. Young-of-the-year (YOY) cryptic Scalloped Hammerheads (*Sphyrna lewin*) and Carolina Hammerheads *(Sphyrna gilberti*) were sampled from nurseries along the US Atlantic Coast and compared for a number of biological condition metrics across three developmental stages. Large declines in liver lipid content and hepatosomatic indices were found in neonatal sharks, using umbilical scar healing as a proxy for time since birth. Feeding commenced quickly as 96% of sharks had prey remnants in their stomachs. The combination of rapid exhaustion of maternally provided resources and high occurrence of stomachs with prey contents indicate that nursery quality, with respect to prey availability, may be important for YOY hammerhead survivorship. While externally the two species are morphologically similar, longer length-at-birth in *S. lewini* and higher hepatic condition in neonatal *S. gilberti* suggest that aspects of reproductive biology, including physiology, may differ between species. While more information is needed to distinguish life history differences between these two species, data collected from YOY may serve as a useful proxy to inform management when adult samples of cryptic species are difficult to collect.

O'Connell, C. P., & Leurs, G. (2016). A Minimally Invasive Technique to Assess Several Life-History Characteristics of the Endangered Great Hammerhead Shark *Sphyrna mokarran*. *Journal of Fish Biology, 88*(3), 1257-1264. https://doi.org/10.1111/jfb.12900

A dorsal-fin photo-identification technique paired with a non-invasive parallel laser photogrammetry technique was used to non-invasively identify individual *Sphyrna mokarran* over time. Based on the data collected over a duration of 59 days, 16 different *S. mokarran* (mean ± s.d. pre-caudal length: 220·82 ± 13·66 cm; mean ± s.d. cephalofoil width: 71·38 ± 7·94 cm) were identified using dorsal-fin photo-identification, with a mean ± s.d. shark re-sighting frequency of 4·05 ± 3·06 at-sea days. The results illustrate a high *S. mokarran* sighting rate and therefore, the utilization of parallel laser photogrammetry and dorsal-fin photo-identification may be a plausible multi-year approach to aid in non-invasively determining the growth rate and inter-annual site fidelity of these animals.

Payne, N. L., Iosilevskii, G., Barnett, A., Fischer, C. P., Graham, R. T., Gleiss, A. C., & Watanabe, Y. Y. (2016). Great Hammerhead Sharks Swim on Their Side to Reduce Transport Costs. *Nature Communications, 7*(1), 12289-12289. https://doi.org/10.1038/ncomms12289

Animals exhibit various physiological and behavioural strategies for minimizing travel costs. Fins of aquatic animals play key roles in efficient travel and, for sharks, the functions of dorsal and pectoral fins are considered well divided: the former assists propulsion and generates lateral hydrodynamic forces

during turns and the latter generates vertical forces that offset sharks' negative buoyancy. Here we show that great hammerhead sharks drastically reconfigure the function of these structures, using an exaggerated dorsal fin to generate lift by swimming rolled on their side. Tagged wild sharks spend up to 90% of time swimming at roll angles between 50° and 75°, and hydrodynamic modelling shows that doing so reduces drag-and in turn, the cost of transport-by around 10% compared with traditional upright swimming. Employment of such a strongly selected feature for such a unique purpose raises interesting questions about evolutionary pathways to hydrodynamic adaptations, and our perception of form and function.

Rosa, D., Coelho, R., Fernandez-Carvalho, J., & Santos, M. N. (2017). Age and Growth of the Smooth Hammerhead, *Sphyrna zygaena*, in the Atlantic Ocean: Comparison with Other Hammerhead Species. *Marine Biology Research, 13*(3), 300-313. https://doi.org/10.1080/17451000.2016.1267366

The smooth hammerhead *Sphyrna zygaena* (Sphyrnidae) is a pelagic shark occasionally caught as bycatch in pelagic longline fisheries, but is one of the least studied of all pelagic sharks. Age and growth of *S. zygaena* was studied along a wide Atlantic region covering both the northern and southern hemispheres. Data from 304 specimens, caught between October 2009 and September 2014, ranging in size from 126 to 253 cm fork length (FL), were analysed. Growth models were fitted using the three-parameter von Bertalanffy growth function (VBGF) re-parameterized to calculate L-0 (size at birth). Growth models were fitted to the sample data and data from several back-calculation models. The model fit to the quadratic modified Dahl-Lea back-calculated data seems to be the most appropriate to describe growth in this species, with resulting growth parameters of L-inf = 285 cm FL, k = 0.09 year(-1) for males and Linf = 293 cm FL, k = 0.09 year(-1) for females. Compared with other species of the same genus, estimated growth coefficients for *S. zygaena* seem to fall in the low to middle range. Although further work is still needed, this study adds to knowledge of the vital life-history parameters of smooth hammerheads in the Atlantic Ocean, which can be used in the management and conservation of this species.

Wosnick, N., Niella, Y. V., Navas, C. A., Monteiro-Filho, E. L. A., Freire, C. A., & Hammerschlag, N. (2019). Multispecies Thermal Dynamics of Air-Exposed Ectothermic Sharks and Its Implications for Fisheries Conservation. *Journal of Experimental Marine Biology and Ecology, 513*, 1-9. https://doi.org/10.1016/j.jembe.2019.01.002

Body temperature is a crucial component of thermoregulation, being strongly linked to variables such as energy flow, metabolic rates, activity patterns and resilience. With exception of lamnid sharks, elasmobranchs are classified as ectothermic, depending on ambient temperature for heat modulation. Despite often being removed from the water during fisheries interactions, the known effects of air exposure on sharks are limited to the hypoxia experienced. Comparatively little is known about the potential effects of changing ambient temperatures and solar radiation experienced by sharks during air exposure, and if such scenarios may compromise their thermal dynamics and survival. Here we used infrared thermography (IRT) to measure external body temperature of 10 different shark species (N = 62), ranging in size from 106 to 340 cm total length, experimentally exposed to air. We tested the hypothesis that all individuals would exhibit body surface temperature increases when air-exposed, with temperature uniformly distributed across the body surface regardless of species. Our results did not support this hypothesis. Although ectothermic, sharks exhibited significant species-specific variations in

heat distribution and warming along the body surface. Moreover, these thermal patterns were significantly impacted by both environmental factors (water temperature at capture) as well as biological traits (shark size and body region). Multivariate analyses separated the 10-shark species into five groups according to the influences of shark body size, body region and water temperature on variations in the thermal profiles detected. We discuss the potential physiological, ecological and conservation implications of these findings.

Section III: Ecology

Brewster, L. R., Dale, J. J., Guttridge, T. L., Gruber, S. H., Hansell, A. C., Elliott, M., . . . Gleiss, A. C. (2018). Development and Application of a Machine Learning Algorithm for Classification of Elasmobranch Behaviour from Accelerometry Data. *Marine Biology, 165*(4), 1-19. https://doi.org/10.1007/s00227-018-3318-y

Discerning behaviours of free-ranging animals allows for quantification of their activity budget, providing important insight into ecology. Over recent years, accelerometers have been used to unveil the cryptic lives of animals. The increased ability of accelerometers to store large quantities of high resolution data has prompted a need for automated behavioural classification. We assessed the performance of several machine learning (ML) classifiers to discern five behaviours performed by accelerometer-equipped juvenile lemon sharks (*Negaprion brevirostris*) at Bimini, Bahamas (25°44'N, 79°16'W). The sharks were observed to exhibit chafing, burst swimming, headshaking, resting and swimming in a semi-captive environment and these observations were used to ground-truth data for ML training and testing. ML methods included logistic regression, an artificial neural network, two random forest models, a gradient boosting model and a voting ensemble (VE) model, which combined the predictions of all other (base) models to improve classifier performance. The macro-averaged F-measure, an indicator of classifier performance, showed that the VE model improved overall classification (F-measure 0.88) above the strongest base learner model, gradient boosting (0.86). To test whether the VE model provided biologically meaningful results when applied to accelerometer data obtained from wild sharks, we investigated headshaking behaviour, as a proxy for prey capture, in relation to the variables: time of day, tidal phase and season. All variables were significant in predicting prey capture, with predations most likely to occur during early evening and less frequently during the dry season and high tides. These findings support previous hypotheses from sporadic visual observations.

Calich, H., Estevanez, M., & Hammerschlag, N. (2018). Overlap between Highly Suitable Habitats and Longline Gear Management Areas Reveals Vulnerable and Protected Regions for Highly Migratory Sharks. *Marine Ecology Progress Series, 602*, 183-195. https://doi.org/10.3354/meps12671

Highly migratory species (e.g. sharks, tunas, turtles, cetaceans) present unique conservation management challenges due to their wide-ranging movements. Consequently, the extent to which management areas protect habitats for highly migratory species is often unknown. Within the southeast region of the USA's exclusive economic zone, highly migratory sharks are target and/or bycatch species in pelagic and bottom longline fisheries. Here, we developed maximum entropy habitat suitability models for great hammerhead sharks *Sphyrna mokarran*, tiger sharks *Galeocerdo cuvier*, and bull sharks *Carcharhinus leucas* within the southeast region based on satellite tag (n = 96) and remotely sensed environmental data. Modeled highly suitable habitats were compared to longline gear management areas to determine what proportion of these habitats are protected from, and vulnerable to, longline fisheries. The percentages of highly suitable habitats overlapping with longline management areas varied by species and season (78% warm, 36% cool season for great hammerhead sharks; 48% warm, 79% cool for tiger sharks; and 2% warm, 100% cool for bull sharks). Highly suitable great hammerhead and tiger shark habitats were relatively well protected from pelagic longline fisheries yet vulnerable to bottom longline fisheries. Additionally, both species were vulnerable to pelagic and bottom longline fisheries off southwestern Florida; thus, extending gear restrictions to this area may benefit both species. Bull shark highly suitable habitats were only well protected from longline gear during the cool

season. These results demonstrate how habitat suitability modeling can be used to help assess the efficacy of spatial management strategies and inform conservation plans for highly migratory species.

Calich, H. J. (2016). Identifying Suitable Habitat for Three Highly Migratory Sharks (Great Hammerhead, Tiger, and Bull) and Assessing Their Spatial Vulnerability to Commercial Longline Fishing in the Southwest Atlantic Ocean and Gulf of Mexico. Retrieved from https://scholarship.miami.edu/permalink/01UOML_INST/105q9vf/alma991031447329202976

Aquatic highly migratory species (HMS) are economically and ecologically important, however, their highly migratory nature makes them difficult to study and thus there are knowledge gaps relating to their movement and habitat use patterns. Highly migratory sharks are likely to interact with commercial longline fishing gear and be caught as target or bycatch, which can threaten their populations. Understanding the environmental factors that influence and drive the movements of highly migratory sharks may help researchers better predict their presence and subsequently identify areas where they are vulnerability to fisheries. Here I evaluated the overlap between habitat suitability and gear restricted zones for three co-occurring apex predatory sharks in the Southwest Atlantic Ocean and Gulf of Mexico (great hammerhead *Sphyrna mokarran*, tiger *Galeocerdo cuvier*, and bull sharks *Carcharhinus leucas*) to identify areas in this region where these species are vulnerable to and protected from commercial longline fishing. This research was accomplished in three integrated steps. First, I reviewed and summarized what is known about the environmental drivers of great hammerhead, tiger, and bull shark habitat use and movement patterns. Second, I used the results of this review to parameterize and subsequently generate habitat suitability models for these three species. Third, I used these models to spatially compare where each species' highly suitable habitat overlaps with longline gear restricted areas within the Southwest Atlantic Ocean and Gulf of Mexico, to identify regions where these species were both vulnerable to and protected from longline fishing gear. The results of this thesis have implications to the management of these species as well as for the conservation of other highly migratory aquatic species.

Das, D., & Afonso, P. (2017). Review of the Diversity, Ecology, and Conservation of Elasmobranchs in the Azores Region, Mid-North Atlantic. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2017.00354

A vulnerable species group, such as the elasmobranchs, in a data-deficient context presents a complicated management problem. Evidence suggests that the Azores islands, a remote archipelago on the Mid-Atlantic Ridge, serve essential functions in the life-history of species across taxa. The diversity of marine resources within its EEZ are exploited by local to international fleets, and the full extent of fishing pressure can often be underestimated. Although sharks and rays appear to be of minor importance in the fishery, the possibilities of illegal, unreported and unregulated fishing raises concerns about these threatened species. However, this group has failed to attract management attention, visible in the lack of regional studies focused on biodiversity, ecology or threats of elasmobranchs. Our work attempts to review and update the information on elasmobranchs of the Azores and identify potential threats, mainly by the local fisheries. We aim to highlight knowledge gaps that require further research and conservation actions. We 1) update the annotated checklist of elasmobranch species, 2) compare species distribution across a biogeographically similar section of the North Atlantic, and 3) analyze the interaction of elasmobranch species with local fisheries. We confirm 61 chondrichthyan species for the Azores (39 sharks, 17 rays and 5 chimaeras), adding 19 species to the previous annotated checklist of

1997. The Azores elasmobranch species assemblage most resembles Madeira, the neighboring Macaronesian archipelago. Biogeographic affinities between the chosen regions of the North Atlantic are reflected in the taxonomic structure of families. Although underestimated in the local fisheries, elasmobranchs constitute a regular but highly variable portion of total landings. Misreporting and misidentification is perhaps the greatest concern in the local fisheries records, further aggravated by few existing catch regulations for elasmobranchs. Local knowledge indicates that the Azores serves as essential habitat for at least a few species in coastal areas and shallow seamounts, and potentially so for a number of deep-sea elasmobranchs. The intersection of fishery threats and local essential habitat functions around the archipelago warrants greater research effort and studies.

Doan, M. D., & Kajiura, S. M. (2020). Adult Blacktip Sharks (*Carcharhinus limbatus*) Use Shallow Water as a Refuge from Great Hammerheads (*Sphyrna mokarran*). *Journal of Fish Biology, 96*(6), 1530-1533. https://doi.org/10.1111/jfb.14342

A refuge can be any space that keeps an organism safe from danger. Prey usually seek protection in the closest refuge available to minimize cost while maximizing survival. Aerial drone footage of blacktip sharks, *Carcharhinus limbatus*, along the coast of southeast Florida, USA, shows adult blacktips fleeing to the shallow water adjacent to the beach when confronted with or chased by a predatory great hammerhead shark, *Sphyrna mokarran.* To authors' knowledge, this is the first evidence of adult *C. limbatus* using shallow waters as a refuge.

Drymon, J. M., & Wells, R. J. D. (2017). Double Tagging Clarifies Post-Release Fate of Great Hammerheads (*Sphyrna mokarran*). *Animal Biotelemetry, 5*(1), 1-7. https://doi.org/10.1186/s40317-017-0143-x

Biotelemetry applications have advanced our understanding of many highly migratory species, but present a challenge for species that suffer high capture and/or post-release stress. Failing to accurately characterize post-release fate can obfuscate our understanding of animal movement patterns and complicate the development of effective conservation and management plans. The great hammerhead (*Sphyrna mokarran*) is a long-lived, highly migratory shark listed by the International Union for the Conservation of Nature as Endangered. Accordingly, we used a combination of tags designed to report horizontal position estimates and verify post-release fate, to examine movements of great hammerheads in the northern Gulf of Mexico. Between May and September 2016, three individuals (one male and two females) were equipped with both fin-mounted smart position and temperature transmitting (SPOT) tags and survivorship pop-off archival tags (sPAT) to provide information on post-release fate. Tagged sharks measured 187 (F), 203 (M), and 250 (M) cm total length. All three sharks surfaced daily, yet individuals showed variability in vertical habitat use, with maximum daily depths ranging from 5 to 98 m. A single fin-mounted SPOT tag, attached to the smallest of the three sharks, reported position estimates over an 81-day period and moved a straight-line distance of approximately 400 km; however, the other two fin-mounted SPOT tags failed to generate position estimates. All three sPAT tags indicated post-release survival. Final positions of the sPAT tags from the two largest sharks suggested restricted horizontal movements (< 35 km). Despite their demonstrated utility on other shark species that frequent the surface, fin-mounted SPOT tags may not be the best option for tracking great hammerheads. In addition, our findings illustrate the value of double-tagging animals under certain conditions; notably, over the short monitoring period of this study, one of the three sharks tagged may have been incorrectly presumed dead had only a fin-mounted SPOT tag been used.

Gallagher, A. J., Hammerschlag, N., Shiffman, D. S., & Giery, S. T. (2014). Evolved for Extinction: The Cost and Conservation Implications of Specialization in Hammerhead Sharks. *BioScience, 64*(7), 619-624. https://doi.org/10.1093/biosci/biu071

The interactions between the evolutionary history of species and contemporary changes in their environment can result in both positive and negative outcomes for fitness and survival. Sharks are one the oldest groups of all extant vertebrates but, today, are among the most threatened globally, primarily because of destructive fishing practices. Hammerhead sharks (Sphyrnidae) exhibit extremely specialized traits and complex behaviors that have increased their vulnerability to human exploitation, which impedes conservation efforts. By bringing together published data on aspects of hammerhead shark phylogeny, morphology, biology, physiology, and ecology, we argue that the same novel adaptations that have historically contributed to evolutionary success have become maladaptive under current levels and modes of exploitation. Therefore, we suggest that future management be made in light of rather than in spite of the unique evolutionary and ecological traits possessed by hammerhead sharks, because similar patterns are threatening other taxa with high extinction risk.

Gilman, E., Milani, C., Bach, P., Fennell, H., Hall, M., Musyl, M., . . . Song, L. (2020). Effect of Pelagic Longline Bait Type on Species Selectivity: A Global Synthesis of Evidence. *Reviews in Fish Biology and Fisheries, 30*(3), 535-551. https://doi.org/10.1007/s11160-020-09612-0

Fisheries can profoundly affect bycatch species with 'slow' life history traits. Managing bait type offers one tool to control species selectivity. Different species and sizes of marine predators have different prey, and hence bait, preferences. This preference is a function of a bait's chemical, visual, acoustic and textural characteristics and size, and for seabirds the effect on hook sink rate is also important. We conducted a global meta-analysis of existing estimates of the relative risk of capture on different pelagic longline baits. We applied a Bayesian random effects meta-analytic regression modelling approach to estimate overall expected bait-specific catch rates. For blue shark and marine turtles, there were 34% (95% HDI: 4–59%) and 60% (95% HDI: 44–76%) significantly lower relative risks of capture on forage fish bait than squid bait, respectively. Overall estimates of bait-specific relative risk were not significantly different for seven other assessed taxa. The lack of a significant overall estimate of relative capture risk for pelagic shark species combined but significant effect for blue sharks suggests there is species-specific variability in bait-specific catch risk within this group. A qualitative literature review suggests that tunas and istiophorid billfishes may have higher catch rates on squid than fish bait, which conflicts with reducing marine turtle and blue shark catch rates. The findings from this synthesis of quantitative and qualitative evidence support identifying economically viable bycatch management measures with acceptable tradeoffs when multispecies conflicts are unavoidable, and highlight research priorities for global pelagic longline fisheries.

Guttridge, T. L., Van Zinnicq Bergmann, M. P. M., Bolte, C., Howey, L. A., Finger, J. S., Kessel, S. T., . . . Gruber, S. H. (2017). Philopatry and Regional Connectivity of the Great Hammerhead Shark, *Sphyrna mokarran* in the U.S. And Bahamas. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2017.00003

A thorough understanding of movement patterns of a species is critical for designing effective conservation and management initiatives. However, generating such information for large marine vertebrates is challenging, as they typically move over long distances, live in concealing environments, are logistically difficult to capture and, as upper-trophic predators, are naturally low in abundance. As a large bodied, broadly distributed tropical shark typically restricted to coastal and shelf habitats, the great hammerhead shark *Sphyrna mokarran* epitomizes such challenges. Highly valued for its fins, it suffers high bycatch mortality coupled with conservative fecundity, and as a result, is vulnerable to over-exploitation and population depletion. Although there is very little species specific data available, the absence of recent catch records give cause to suspect substantial declines across its range. Here, we used biotelemetry techniques (acoustic and satellite), conventional tagging, laser-photogrammetry, and photo-identification to investigate; the level of site fidelity, and or residency for great hammerheads to coastal areas in the Bahamas and U.S. and the extent of movements and connectivity of great hammerheads between the U.S. and Bahamas. Results revealed large scale return migrations (3030 km), seasonal residency to local areas (some for 5 months), site fidelity (annual return to Bimini and Jupiter for many individuals) and numerous international movements. These findings enhance the understanding of movement ecology of the great hammerhead shark and have the potential to contribute to improved conservation and management.

Lauren, N. F., & Glenn, R. P. (2019). A Note on Associations Observed between Sharks and Teleosts. *Southeastern Naturalist, 18*(3), 489-498. https://doi.org/10.1656/058.018.0314

We report herein on novel observations of associations between 2 teleost species and a variety of shark species in the Gulf of Mexico. Using underwater video, we observed *Decapterus punctatus* (Round Scad) and *Chloroscombrus chrysurus* (Atlantic Bumper) associating with both *Carcharhinus limbatus* (Blacktip Shark) and *Carcharhinus brevipinna* (Spinner Shark). We also observed Round Scad associating with *Carcharhinus acronotus* (Blacknose Shark). Both Round Scad and Atlantic Bumpers schooled around and followed these sharks. We observed Round Scad in schools averaging 54 individuals that tended to stay posterior to the pectoral fins of the shark. These observations prompted a novel on-line image survey wherein we found that Round Scad were associated with 3 additional shark species. Online media platforms have not been commonly utilized for data collection, and to our knowledge, this is the first study to conduct a Google Image survey to obtain data supporting interspecific associations. This paper is also the first report of an apparent symbiosis between various shark species with Round Scad and with Atlantic Bumpers. There are few reports of associations with sharks aside from well-known examples, such as *Echeneis naucrates* (Sharksucker), *Naucrates ductor* (Pilotfish), and *Labroides spp*. (cleaner wrasses). These results provide additional information to the body of literature about symbioses between top predators, such as sharks, and teleosts.

Logan, R. K., Vaudo, J. J., Sousa, L. L., Sampson, M., Wetherbee, B. M., & Shivji, M. S. (2020). Seasonal Movements and Habitat Use of Juvenile Smooth Hammerhead Sharks in the Western North Atlantic Ocean and Significance for Management. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2020.566364

Upper trophic level predators dramatically impacted by fisheries include the large-bodied hammerhead sharks, which have become species of conservation concern worldwide. Implementing spatial management for conservation of hammerhead populations requires knowledge of temporal distribution patterns and habitat use, identification of essential habitat for protection, and quantification of interactions with human activities. There is little such information for the smooth hammerhead shark, *Sphyrna zygaena*. We used fin-mounted satellite tags to examine the movements and habitat use of juvenile smooth hammerheads, a demographic segment particularly threatened by exploitation. Six sharks were tagged off the US mid-Atlantic and tracked for 49–441 d (mean 187 d). Sharks consistently showed area-restricted movements within a summer core area in waters of the New York Bight and a winter core area off Cape Hatteras, North Carolina, with directed movements between them in autumn. There was high overlap of shark winter core area use and the Mid-Atlantic Shark Area (MASA) - a seven-month per year, bottom-longline fishery closure - indicating that this area closure offers seasonal reduction in fishing pressure for this species. Based on timing of shark movements and the MASA closure, protection for juvenile smooth hammerheads may be increased by beginning the closure period one month earlier than currently scheduled. Generalized additive mixed models revealed that area-restricted movements of sharks in their summer and winter core areas coincided with high primary productivity, strong sea surface temperature fronts and elevated sea surface temperature. Consistency in use of summer and winter core areas suggests that the coastal waters of the New York Bight and Cape Hatteras, North Carolina could be considered for Essential Fish Habitat designation for this species. This study reveals the first high resolution movements and habitat use for smooth hammerheads in the western North Atlantic to inform management planning for this population.

Moravec, F., Dalrymple, K. M., Galloway, A. S., Barker, A. M., & de Buron, I. (2020). First Record of Piscicapillaria Bursata (Nematoda: Capillariidae), a Parasite of Hammerhead Sharks Sphyrna Spp., in the Western Atlantic Ocean. *Diseases of Aquatic Organisms, 138*, 133-136. https://doi.org/10.3354/dao03458

Examination of 32 spiral valves from neonate specimens of hammerhead shark Sphyrna spp. (Carcharhiniformes: Sphyrnidae) captured between June and August 2018 off the Atlantic coast of South Carolina, USA, revealed the presence of the capillariid nematode *Piscicapillaria bursata* (Capillariidae) in the Carolina hammerhead *S. gilberti*, the scalloped hammerhead *S. lewini*, and their hybrids. This is the second find of this parasite originally described from hammerhead sharks off Australia, its first record from the western Atlantic Ocean, and its first record in a new host species and in hybrids.

O'Connell, C. P., Hyun, S.-Y., Gruber, S. H., & He, P. (2015). Effects of Barium-Ferrite Permanent Magnets on Great Hammerhead Shark *Sphyrna mokarran* Behavior and Implications for Future Conservation Technologies. *Endangered Species Research, 26*(3), 243-256. https://doi.org/10.3354/esr00629

The great hammerhead shark *Sphyrna mokarran* is an endangered species that is exposed to several sources of anthropogenic mortality, including beach nets. Although not a major contributor to *S.*

mokarran mortality, beach nets are utilized in several locations to minimize the potential harmful interaction between sharks and beachgoers. To address this mortality, permanent magnets have been employed to determine if these materials can deter sharks away from netted areas. The present study examined the effects of barium-ferrite (BaFe sub(12)O sub(19)) permanent magnets on *S. mokarran* behavior under several environmental and biological conditions. In the bait experiment, feeding frequency significantly decreased and avoidance frequency significantly increased with the magnet treatment, with exposure quantity yielding an increase in feeding frequency, although this effect was not statistically significant. For the barrier experiment, entrance frequency significantly decreased and avoidance and pass-around frequencies significantly increased with the magnet treatment, with heterospecific density also being a significant predictor of entrance frequency. The findings demonstrate how permanent magnets can modify *S. mokarran* behavior and how this behavior is modified based on situational context. Since several other sphyrnid species are caught in beach nets more frequently than *S. mokarran* (e.g. scalloped hammerheads *S. lewini*), the present results may serve as a model for these other sphyrnid species and illustrate the potential conservation implications of future magnetic deterrent barrier technologies.

O'Connell, C. P. (2018). The Utilization of Prey-Simulating Electrodes to Analyze the Predatory Behavior of the Great Hammerhead Shark (*Sphyrna mokarran*). *Zoology and ecology, 28*(2), 75-85. https://doi.org/10.1080/21658005.2018.1458964

A new observation of a great hammerhead shark (*Sphyrna mokarran*) natural predation on a southern stingray (Hypanus americana) is described in combination with two novel field experiments that investigate both: (1) the sensory cues that elicit *S. mokarran* foraging responses, as well as (2) the unique prey handling techniques that make this hammerhead such a specialized predator. This study is the first to demonstrate the importance of electro-sensory cues at close ranges for prey detection in *S. mokarran*. In addition, both the observed natural predation and field experiments provided visual evidence of the repeated prey manipulation technique, termed 'lateral headshake repositioning', that may maximize prey handling and foraging success. Further research using more accurate chemo-sensory cues (e.g. those from southern stingrays – *Hypanus americana*) or varying decoy manipulations (e.g. a buried decoy with active electrodes) is warranted to enhance our understanding of the sensory allocation and prey handling behavioral patterns in relation to the foraging success of this endangered predator.

O'Shea, O. R., Mandelman, J. W., Talwar, B., & Brooks, E. J. (2015). Novel Observations of an Opportunistic Predation Event by Four Apex Predatory Sharks. *Marine and Freshwater Behaviour and Physiology, 48*(5), 374-380. https://doi.org/10.1080/10236244.2015.1054097

Few data are available on interspecific elasmobranch interactions during predation events. This report describes and discusses empirical data from a single event in which four sharks (species: *Carcharhinus leucas, Galeocerdo cuvier*, *Sphyrna mokarran* and *Carcharhinus perezi*) competed for foraging opportunities on a fifth shark *(C. perezi*) caught on an experimental longline. Analysis of video footage suggested competition was enforced without agonistic behaviour and access to the resource was not governed by size. The singularity of the data set and the artificiality of the situation limit the strength of the conclusions. The rarity of such an observation warrants, however, a published description of the event to provide an example of the behaviour of apex predator interactions in the field.

Peterson, C. T., Dean, G. R., & Mickle, A. (2020). Trophic Ecology of Elasmobranch and Teleost Fishes in a Large Subtropical Seagrass Ecosystem (Florida Big Bend) Determined by Stable Isotope Analysis. *Environmental Biology of Fishes, 103*(6), 683-701. https://doi.org/10.1007/s10641-020-00976-7

Carbon and nitrogen stable isotope analyses were used to infer relative trophic structure and examine regional variation in trophic dynamics of fishes in the Florida Big Bend, an approximately 300 km stretch of relatively pristine coastline in the eastern Gulf of Mexico that contains over 250,000 ha of seagrass. The Florida Big Bend is home to a diverse assemblage of fauna; and the ecosystem is regionally important through its support of robust fishing (recreational and commercial) and eco-tourism industries. Stable isotope analyses suggest assemblages of fishes in the Florida Big Bend are trophically diverse, with considerable isotopic overlap across many taxa. Patterns of trophic structure corroborated the results of similar studies of these and related taxa and in other seagrass ecosystems, and there appear to be multiple channels of primary production. Large elasmobranch fishes were most enriched in δ 15N with values well above the teleost fishes sampled, while smaller and demersal elasmobranchs had δ 15N signatures comparable to several species of predatory teleosts. Results of stable isotope analyses suggested high trophic redundancy and overlap in resource use among both teleost and elasmobranch fishes. Comparisons of regional stable isotope values revealed some spatial variability and indicated the southern Big Bend is isotopically distinct, suggesting a distinct regional faunal zone in this region, potentially due to greatly reduced river influence in the southern portion of the system.

Phenix, L. M., Tricarico, D., Quintero, E., Bond, M. E., Brandl, S. J., & Gallagher, A. J. (2019). Evaluating the Effects of Large Marine Predators on Mobile Prey Behavior across Subtropical Reef Ecosystems. *Ecology and Evolution, 9*(24), 13740-13751. https://doi.org/10.1002/ece3.5784

The indirect effect of predators on prey behavior, recruitment, and spatial relationships continues to attract considerable attention. However, top predators like sharks or large, mobile teleosts, which can have substantial top–down effects in ecosystems, are often difficult to study due to their large size and mobility. This has created a knowledge gap in understanding how they affect their prey through nonconsumptive effects. Here, we investigated how different functional groups of predators affected potential prey fish populations across various habitats within Biscayne Bay, FL. Using baited remote underwater videos (BRUVs), we quantified predator abundance and activity as a rough proxy for predation risk and analyzed key prey behaviors across coral reef, sea fan, seagrass, and sandy habitats. Both predator abundance and prey arrival times to the bait were strongly influenced by habitat type, with open homogenous habitats receiving faster arrival times by prey. Other prey behaviors, such as residency and risk-associated behaviors, were potentially driven by predator interaction. Our data suggest that small predators across functional groups do not have large controlling effects on prey behavior or stress responses over short temporal scales; however, habitats where predators are more unpredictable in their occurrence (i.e., open areas) may trigger risk-associated behaviors such as avoidance and vigilance. Our data shed new light on the importance of habitat and context for understanding how marine predators may influence prey behaviors in marine ecosystems.

Queiroz, N., Humphries, N. E., Mucientes, G., Hammerschlag, N., Lima, F. P., Scales, K. L., . . . Sims, D. W. (2016). Ocean-Wide Tracking of Pelagic Sharks Reveals Extent of Overlap with Longline Fishing Hotspots. *Proc Natl Acad Sci U S A, 113*(6), 1582-1587. https://doi.org/10.1073/pnas.1510090113

Overfishing is arguably the greatest ecological threat facing the oceans, yet catches of many highly migratory fishes including oceanic sharks remain largely unregulated with poor monitoring and data reporting. Oceanic shark conservation is hampered by basic knowledge gaps about where sharks aggregate across population ranges and precisely where they overlap with fishers. Using satellite tracking data from six shark species across the North Atlantic, we show that pelagic sharks occupy predictable habitat hotspots of high space use. Movement modeling showed sharks preferred habitats characterized by strong sea surface-temperature gradients (fronts) over other available habitats. However, simultaneous Global Positioning System (GPS) tracking of the entire Spanish and Portuguese longline-vessel fishing fleets show an 80% overlap of fished areas with hotspots, potentially increasing shark susceptibility to fishing exploitation. Regions of high overlap between oceanic tagged sharks and longliners included the North Atlantic Current/Labrador Current convergence zone and the Mid-Atlantic Ridge southwest of the Azores. In these main regions, and subareas within them, shark/vessel co-occurrence was spatially and temporally persistent between years, highlighting how broadly the fishing exploitation efficiently "tracks" oceanic sharks within their space-use hotspots year-round. Given this intense focus of longliners on shark hotspots, our study argues the need for international catch limits for pelagic sharks and identifies a future role of combining fine-scale fish and vessel telemetry to inform the ocean-scale management of fisheries.

Roemer, R. P., Gallagher, A. J., & Hammerschlag, N. (2016). Shallow Water Tidal Flat Use and Associated Specialized Foraging Behavior of the Great Hammerhead Shark (*Sphyrna mokarran*). *Marine and Freshwater Behaviour and Physiology, 49*(4), 235-249. https://doi.org/10.1080/10236244.2016.1168089

Evidence suggests the great hammerhead shark, *Sphyrna mokarran*, is vulnerable to a variety of anthropogenic stressors, and is an understudied species of shark due to its cryptic nature and wide-ranging movements. While recognized as both a pelagic-coastal and a highly mobile predator, minimal anecdotal evidence exist describing shallow water habitat use by this species. This report describes six cases in which a great hammerhead shark utilizes an inshore shallow water flats environment (<1.5 m in depth), five of which involve prey capture. These observations permitted identification of two novel behaviors that may allow great hammerheads to inhabit these shallow habitats: a (1) prey-capture technique termed 'grasp-turning' that involves burst swimming at tight turning angles while grasping prey and (2) a post-predation recovery period whereby the shark maintains head-first orientation into the current that may facilitate respiration and prey consumption. These behavioral observations provide insights into the natural history of this species.

Royer, M., Maloney, K., Meyer, C., Cardona, E., Payne, N., Whittingham, K., . . . Holland, K. (2020). Scalloped Hammerhead Sharks Swim on Their Side with Diel Shifts in Roll Magnitude and Periodicity. *Animal Biotelemetry, 8*(1), 11. https://doi.org/10.1186/s40317-020-00196-x

Great hammerhead sharks (*Sphyrna mokarran*) routinely swim on their sides and periodically roll from side to side. A previous study used wind tunnel tests with a rigid model hammerhead shark to

demonstrate that the rolling behavior could improve swimming efficiency using the tall first dorsal fin as a lift-generating surface. Scalloped hammerhead sharks (*Sphyrna lewini*) also have proportionally taller dorsal fins compared to pectoral fins than most shark species and similar to that of great hammerhead sharks, and thus might exhibit similar rolling behavior. This was assessed by deploying multi-sensor accelerometer instrument packages on free-swimming adult scalloped hammerhead sharks to directly measure swimming depth, body orientation and swimming performance. Specific objectives were to (1) determine whether scalloped hammerhead sharks exhibit side swimming and rolling behavior, (2) characterize the patterns of these behaviors, and (3) evaluate the purpose of these behaviors. We obtained 196.7 total days (4720 h) of data from 9 free-swimming adult scalloped hammerhead sharks equipped with multi-instrument biologgers with deployment durations ranging from 7 to 29 days. All sharks exhibited rolling behavior throughout the entire period of observation. The roll angle magnitude and periodicity of rolling showed a clear diel pattern. During daytime, the sharks spent an average of 48% of the time swimming at a roll angle > 30°, with an average roll angle of 41° and rolling periodicity of around 4 min. At night, the sharks spent an average 82% of their time at an angle > 30°, with an average roll angle of 60° and rolling periodicity of around 13 min. In addition to an increase in degree of roll and roll duration, overall dynamic body acceleration (ODBA) also increased at night, and tailbeat frequency was more regular and consistent than during daytime. We observed rolling behavior in scalloped hammerhead sharks similar to that observed in great hammerhead sharks. The diel changes in roll angle and periodicity were accompanied by other changes in swimming behavior. These changes are possibly due to interplay between reducing cost of transport and social interactions with conspecifics.

Section IV: Population Abundance and Trends

Aguilar, C., González-Sansón, G., Hueter, R., Rojas, E., Cabrera, Y., Briones, A., . . . Baker, P. B. (2014). Captura De Tiburones En La Región Noroccidental De Cuba. *Latin American Journal of Aquatic Research, 42*(3), 477-487. https://doi.org/10.3856/vol42-issue3-fulltext-8

Sharks have been important as seafood source and fisheries revenue in Cuba. Nevertheless, current information about this group of fishes in Cuba is scarce and in the last decades they have not been the focus of any organized research. From October 2009 to June 2011, fisheries and biological (229 sharks examined) data were collected at four landing sites in the northwest of Cuba. At present, there is no organized fishery specifically targeting only sharks along the northwest coast of Cuba, but they are caught as a component of multispecies fisheries on the insular shelf and as bycatch in longline fisheries targeting billfishes. We registered a total of 17 species, six in the commercial fishery, dominated by *Carcharhinus perezii*, *Sphyrna mokarran*, and *Carcharhinus leucas*, and 14 in the sport fishery (i.e., small-scale artisanal, not recreational properly), dominated by *Isurus oxyrinchus, Isurus paucus*, *Carcharhinus longimanus, Carcharhinus falciformis, Galeocerdo cuvier* and *Prionace glauca*. Mean CPUE by months in sport fishing varied from 0.43 to 4.44 number of sharks caught per ten fishing trips. Most oceanic sharks caught in the Cuban sport fisheries are highly migratory species and their populations show great ecological connectivity throughout the Gulf of Mexico and adjacent waters. This fact and the presence of a high proportion of individuals of *C. longimanus* and *C. falciformis* below maturity size are important results to be considered for regional conservation of sharks and planning rational use of shark fisheries.

Braccini, M., Aires-da-silva, A., & Taylor, I. (2016). Incorporating Movement in the Modelling of Shark and Ray Population Dynamics: Approaches and Management Implications. *Reviews in Fish Biology and Fisheries, 26*(1), 13-24. https://doi.org/10.1007/s11160-015-9406-x

The explicit incorporation of movement in the modelling of population dynamics can allow improved management of highly mobile species. Large-scale movements are increasingly being reported for sharks and rays. Hence, in this review we summarise the current understanding of long-scale movement patterns of sharks and rays and then present the different methods used in fisheries science for modelling population movement with an emphasis on sharks and rays. The use of movement data for informing population modelling and deriving management advice remains rare for sharks and rays. In the few cases where population movement was modelled explicitly, movement information has been solely derived from conventional tagging. Though shark and ray movement has been increasingly studied through a range of approaches these different sources of information have not been used in population models. Integrating these multiple sources of movement information could advance our understanding of shark and ray dynamics. This, in turn, would allow the use of more adequate models for assessing stocks and advising management and conservation effort.

Cardenosa, D., Fields, A. T., Babcock, E. A., Shea, S. K. H., Feldheim, K. A., & Chapman, D. D. (2020). Species Composition of the Largest Shark Fin Retail-Market in Mainland China. *Scientific Reports, 10*(1). https://doi.org/10.1038/s41598-020-69555-1

Species-specific monitoring through large shark fin market surveys has been a valuable data source to estimate global catches and international shark fin trade dynamics. Hong Kong and Guangzhou, mainland China, are the largest shark fin markets and consumption centers in the world. We used

molecular identification protocols on randomly collected processed fin trimmings (n=2000) and non-parametric species estimators to investigate the species composition of the Guangzhou retail market and compare the species diversity between the Guangzhou and Hong Kong shark fin retail markets. Species diversity was similar between both trade hubs with a small subset of species dominating the composition. The blue shark (*Prionace glauca*) was the most common species overall followed by the CITES-listed silky shark (*Carcharhinus falciformis*), scalloped hammerhead shark (*Sphyrna lewini*), smooth hammerhead shark (*S. zygaena*) and shortfin mako shark (*Isurus oxyrinchus*). Our results support previous indications of high connectivity between the shark fin markets of Hong Kong and mainland China and suggest that systematic studies of other fin trade hubs within Mainland China and stronger law-enforcement protocols and capacity building are needed.

Chuang, P.-S., Hung, T.-C., Chang, H.-A., Huang, C.-K., & Shiao, J.-C. (2016). The Species and Origin of Shark Fins in Taiwan's Fishing Ports, Markets, and Customs Detention: A DNA Barcoding Analysis: E0147290. *Plos One, 11*(1). https://doi.org/10.1371/journal.pone.0147290

The increasing consumption of shark products, along with the shark's fishing vulnerabilities, has led to the decrease in certain shark populations. In this study we used a DNA barcoding method to identify the species of shark landings at fishing ports, shark fin products in retail stores, and shark fins detained by Taiwan customs. In total we identified 23, 24, and 14 species from 231 fishing landings, 316 fin products, and 113 detained shark fins, respectively. All the three sample sources were dominated by *Prionace glauca*, which accounted for more than 30% of the collected samples. Over 60% of the species identified in the fin products also appeared in the port landings, suggesting the domestic-dominance of shark fin products in Taiwan. However, international trade also contributes a certain proportion of the fin product markets, as four species identified from the shark fin products are not found in Taiwan's waters, and some domestic-available species were also found in the customs-detained sample. In addition to the species identification, we also found geographical differentiation in the cox1 gene of the common thresher sharks (*Alopias vulpinus*), the pelagic thresher shark (*A. pelagicus*), the smooth hammerhead shark (*Sphyrna zygaena*), and the scalloped hammerhead shark (*S. lewini*). This result might allow fishing authorities to more effectively trace the origins as well as enforce the management and conservation of these sharks.

Deacy, B. M., Moncrief-Cox, H. E., & Carlson, J. K. (2020). First Verified Record of the Smooth Hammerhead (*Sphyrna zygaena*) in Coastal Waters of the Northern Gulf of Mexico with a Review of Their Occurrence in the Western North Atlantic Ocean. *Southeastern Naturalist, 19*(1). https://doi.org/10.1656/058.019.0105

Sphyrna zygaena (Smooth Hammerhead) is considered a wide-ranging hammerhead species, though its distribution throughout its range is not well known. The occurrence of this species in the northern Gulf of Mexico is largely unknown, with only limited unverified records in this region. In September of 2017, a Smooth Hammerhead was collected from Florida coastal waters in the northern Gulf of Mexico, representing a confirmed record of this species in this region. To further understand the range of the Smooth Hammerhead, we reviewed available occurrence data throughout the western North Atlantic Ocean, which suggests this species may occasionally transit into the Gulf of Mexico.

Enzenauer, M. P., Deacy, B. M., & Carlson, J. K. (2015). Characterization of the Shark Bottom Longline Fishery, 2014. https://doi.org/10.7289/V58C9T6D

Observations of the shark-directed bottom longline fishery in the Atlantic Ocean and Gulf of Mexico have been conducted since 1994 (e.g. Hale et al. 2012 and references therein). Currently about 198 U.S. fishers are permitted to target sharks (excluding dogfish) in the Atlantic Ocean and Gulf of Mexico, and an additional 252 fishers are permitted to land sharks incidentally. Amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan implemented a shark research fishery, which allows NMFS to select a limited number of commercial shark vessels on an annual basis to collect life history data and catch data for future stock assessments (NMFS, 2007). Specifically, only commercial shark fishers participating in the research fishery are allowed to land sandbar sharks, Carcharhinus plumbeus, and must carry an observer on 100% of all trips (compared to a target coverage level of 5-10% outside the research fishery). Outside the research fishery, fishers are permitted to land 36 nonsandbar large coastal sharks per trip (including blacktip shark, *Carcharhinus limbatus*, bull shark, *Carcharhinus leucas*, lemon shark, *Negaprion brevirostris*, nurse shark, *Ginglymostoma cirratum*, silky shark, *Carcharhinus falciformis*, spinner shark, *Carcharhinus brevipinna*, tiger shark, *Galeocerdo cuvier*, great hammerhead shark, *Sphyrna mokarran*, scalloped hammerhead shark, *Sphyrna lewini*, and smooth hammerhead shark, *Sphyrna zygaena*). Herein, we report on fishing activities in the bottom longline fishery for the 2014 fishing season, including coverage of the 2014 Shark Research Fishery.

Enzenauer, M. P., Deacy, B. M., & Carlson, J. K. (2016). Characterization of the Shark Bottom Longline Fishery, 2015. https://doi.org/10.7289/V52J68WG

Observations of the shark-directed bottom longline fishery in the Atlantic Ocean and Gulf of Mexico have been conducted since 1994 (Morgan et al. 2009, Enzenauer et al. 2015 and references therein). Currently about 210 U.S. fishers are permitted to target sharks (excluding dogfish) in the Atlantic Ocean and Gulf of Mexico, and an additional 254 fishers are permitted to land sharks incidentally. Amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan implemented a shark research fishery, which allows NMFS to select a limited number of commercial shark vessels on an annual basis to collect life history data and catch data for future stock assessments (NMFS, 2007). Specifically, only commercial shark fishers participating in the research fishery are allowed to land sandbar sharks, *Carcharhinus plumbeus*, and must carry an observer on 100% of all trips (compared to a target coverage level of 5-10% outside the research fishery). Outside the research fishery, fishers are permitted to land other large coastal sharks (e.g. blacktip shark, Carcharhinus limbatus, and bull shark, Carcharhinus leucas,). Herein, we report on observed fishing activities in the shark bottom longline fishery for the 2015 fishing season, including coverage of the 2015 Shark Research Fishery.

Fields, A. T., Fischer, G. A., Shea, S. K. H., Zhang, H., Feldheim, K. A., & Chapman, D. D. (2020). DNA Zip-Coding: Identifying the Source Populations Supplying the International Trade of a Critically Endangered Coastal Shark. *Animal Conservation*. https://doi.org/10.1111/acv.12585

There is an urgent need for population-specific trade information for overexploited sharks, as international trade regulations are becoming an important tool for their conservation [i.e., listings on the Convention on International Trade in Endangered Species (CITES)]. We tested a genetic stock identification (GSI) workflow to quantify the relative contributions of different source populations of the CITES-listed scalloped hammerhead shark *Sphyrna lewini* to international trade hubs for products such

as dried fins. We grouped published mitochondrial control region sequences from wild-captured sharks sampled in 15 locations into 9 differentiated populations that provide broad coverage of the species global distribution. GSI simulations established that these populations are highly identifiable and we trialed this approach to assess the provenance of processed fin trimmings collected randomly from the retail market of Hong Kong, one of the world's largest shark fin trade hubs in 2014-2015 (N = 72). In this pilot survey, we found over 75% of scalloped hammerhead fin trimmings came from two Pacific Ocean populations, but mostly from the Eastern Pacific (61.4%, of all trimmings; se 7.1%) where this species is listed as 'Endangered' under the United States Endangered Species Act. Six of the nine populations were found in this sample of the market, indicating near global sourcing of scalloped hammerhead fins in Hong Kong. We suggest technical and sampling considerations for employing GSI at fin trade hubs in the future to investigate regional sourcing of scalloped hammerheads and other coastal sharks in international trade. Random GSI in trade hubs could revolutionize our understanding of global shark trade dynamics and provide critical information required to effectively implement shark fisheries management and trade restrictions.

Graham, F., Rynne, P., Estevanez, M., Luo, J., Ault, J. S., Hammerschlag, N., & Schoeman, D. (2016). Use of Marine Protected Areas and Exclusive Economic Zones in the Subtropical Western North Atlantic Ocean by Large Highly Mobile Sharks. *Diversity & Distributions, 22*(5), 534-546. https://doi.org/10.1111/ddi.12425

Study aim and location Many populations of highly mobile marine fishes, including large sharks, are experiencing declines. The benefits of spatial management zones, such as marine protected areas (MPAs), for such animals are unclear. To help fill this knowledge gap, we examined core habitat use areas (CHUAs) for bull (Carcharhinus leucas), great hammerhead (*Sphyrna mokarran*) and tiger sharks (Galeocerdo cuvier) in relation to specific MPAs and exclusive economic zones (EEZs) in the western North Atlantic Ocean. Methods Bull, great hammerhead and tiger sharks (N = 86 total) were satellite tagged and tracked in southern Florida and the northern Bahamas between 2010 and 2013. Filtered and regularized positions from Argos locations of tag transmissions were used to generate CHUAs for these sharks. Overlaps of CHUAs with regional protected areas and exclusive economic management zones were quantified to determine the proportion of each tracked shark's CHUA under spatial protection from exploitation. Results A total of 0%, 17.9% and 34.7% of the regional CHUAs for tracked bull, great hammerhead and tiger sharks, respectively, were fully protected from exploitation in the study area. Main conclusions Expansion of protected areas to include U.S. territorial waters would effectively protect 100% of the CHUAs for all tracked sharks in the study area. This finding is particularly significant for great hammerhead sharks, which are currently overfished, vulnerable to bycatch mortality and are the focus of strident regional conservation efforts. These findings also provide a means to inform decision makers and marine conservation planning efforts as to the types of management actions available and potential efficacy of spatial protections for these marine predators.

Gulak, S. J. B., de Ron Santiago, A. J., & Carlson, J. K. (2015). Hooking Mortality of Scalloped Hammerhead *Sphyrna lewini* and Great Hammerhead *Sphyrna mokarran* Sharks Caught on Bottom Longlines. *African Journal of Marine Science, 37*(2), 267-273. https://doi.org/10.2989/1814232x.2015.1026842

The scalloped hammerhead *Sphyrna lewini* and the great hammerhead *S. mokarran* are typically caught as bycatch in a variety of fisheries and are listed as globally Endangered by the International Union for

the Conservation of Nature. Due to very high at-vessel mortality for these species, research is needed on fishing methods to reduce mortality for longline-captured sharks. A series of fishing experiments were conducted employing hook timers and temperature–depth recorders on contracted commercial vessels fishing with bottom-longline gear to assess factors related to mortality. A total of 273 sets were deployed with 54 485 hook timers. Scalloped and great hammerheads had at-vessel mortality rates of 62.9% and 56.0%, respectively. Median hooking times for scalloped and great hammerheads were 3.5 h and 3.4 h, respectively, and 50% mortality was predicted at 3.5 h and 3.8 h. When these data are considered for potential management strategies to reduce the mortality of hammerhead sharks, a limitation on gear soak time would probably improve hammerhead shark survivorship. However, it may prove to be difficult for a fishery to remain economically viable if the soak time is limited to less than the median hooking time for the target species. Additional management options, such as time/area closures, may need to be explored to reduce bycatch mortality of scalloped and great hammerheads.

Martínez-Candelas, I. A., Pérez-Jiménez, J. C., Espinoza-Tenorio, A., McClenachan, L., & Méndez-Loeza, I. (2020). Use of Historical Data to Assess Changes in the Vulnerability of Sharks. *Fisheries Research, 226*, 105526. https://doi.org/10.1016/j.fishres.2020.105526

Shark populations have declined worldwide. However, the lack of data for most species makes it difficult to use conventional population assessments to estimate their status. The productivity and susceptibility analysis (PSA) has been recommended for elasmobranchs as it is a data-poor assessment that uses the best available information of the species and their fisheries to determine their vulnerability. A historical characterisation was performed to define the most important periods for the shark fishery in Campeche, southern Gulf of Mexico, and a PSA was conducted to determine the vulnerability of the eleven most important commercial shark species in each three periods. The periods were defined as: local commercialisation (1940–1979), when all species had their lowest vulnerability values, and Carcharhinus leucas, Negraprion brevirostris, and *Sphyrna mokarran* were classified as highly vulnerable; developed industry (1980–1998) when there was an increase of the fishing pressure, and most small species changed from low to moderate vulnerability and the large coastal sharks scored their highest vulnerability values; and declining industry (1999–2018), when all species had lower vulnerability values than in the developed industry period. However, *Carcharhinus brevipinna, Ginglymostoma cirratum, N. brevisrostris, C. leucas*, and *S. mokarran* were still classified as highly vulnerable and could be suffering the accumulative effects of decades of fishing pressure. This multidisciplinary approach serves to identify the most vulnerable species throughout the history of the fishery and to understand the vulnerability values within a historical context, avoiding the shifting baseline syndrome.

Mathers, A. N., Deacy, B. M., Moncrief-Cox, H. E., & Carlson, J. K. (2018). Characterization of the Shark Bottom Longline Fishery, 2017. https://doi.org/10.25923/f1n6-r841

Observations of the shark-directed bottom longline fishery in the Atlantic Ocean and Gulf of Mexico have been conducted since 1994 (Morgan et al. 2009, Mathers et al. 2017 and references therein). Currently about 219 U.S. fishers are permitted to target sharks in the Atlantic Ocean and Gulf of Mexico, and an additional 264 fishers are permitted to land sharks incidentally. Amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan implemented a shark research fishery, which allows NMFS to select a limited number of commercial shark vessels on an annual basis to collect life history data and catch data for future stock assessments (NMFS, 2007). Specifically, only commercial shark fishers participating in the research fishery are allowed to land sandbar sharks,

Carcharhinus plumbeus, and must carry an observer on 100% of all trips (compared to a target coverage level of 5-10% outside the research fishery). Outside the research fishery, fishers are permitted to land other large coastal sharks (e.g. blacktip shark, *Carcharhinus limbatus*, and bull shark, *Carcharhinus leucas*). Herein, we report on observed fishing activities in the shark bottom longline fishery for the 2017 fishing season, including coverage of the 2017 Shark Research Fishery.

Mathers, A. N., Deacy, B. M., Moncrief-Cox, H. E., & Carlson, J. K. (2020). Characterization of the Shark Bottom Longline Fishery, 2018. https://doi.org/10.25923/c9qc-f679

Observations of the shark-directed bottom longline fishery in the Atlantic Ocean and Gulf of Mexico have been conducted since 1994 (Morgan et al. 2009, Mathers et al. 2018 and references therein). Currently about 229 U.S. fishers are permitted to target sharks in the Atlantic Ocean and Gulf of Mexico, and an additional 190 fishers are permitted to land sharks incidentally. Amendments to the Consolidated Atlantic Highly Migratory Species Fishery Management Plan implemented a shark research fishery, which allows NMFS to select a limited number of commercial shark vessels on an annual basis to collect life history data and catch data for future stock assessments (NMFS, 2007). Specifically, only commercial shark fishers participating in the research fishery are allowed to land sandbar sharks, *Carcharhinus plumbeus*, and must carry an observer on 100% of all trips (compared to a target coverage level of 5-10% outside the research fishery). Outside the research fishery, fishers are permitted to land other large coastal sharks (e.g. blacktip shark, *Carcharhinus limbatus*, and bull shark, *Carcharhinus leucas*). Herein, we report on observed fishing activities in the shark bottom longline fishery for the 2018 fishing season, including coverage of the 2018 Shark Research Fishery.

Queiroz, N., Humphries, N. E., Couto, A., Vedor, M., da Costa, I., Sequeira, A. M. M., . . . Sims, D. W. (2019). Global Spatial Risk Assessment of Sharks under the Footprint of Fisheries. *Nature, 572*(7770), 461-466. https://doi.org/10.1038/s41586-019-1444-4

Effective ocean management and the conservation of highly migratory species depend on resolving the overlap between animal movements and distributions, and fishing effort. However, this information is lacking at a global scale. Here we show, using a big-data approach that combines satellite-tracked movements of pelagic sharks and global fishing fleets, that 24% of the mean monthly space used by sharks falls under the footprint of pelagic longline fisheries. Space-use hotspots of commercially valuable sharks and of internationally protected species had the highest overlap with longlines (up to 76% and 64%, respectively), and were also associated with significant increases in fishing effort. We conclude that pelagic sharks have limited spatial refuge from current levels of fishing effort in marine areas beyond national jurisdictions (the high seas). Our results demonstrate an urgent need for conservation and management measures at high-seas hotspots of shark space use, and highlight the potential of simultaneous satellite surveillance of megafauna and fishers as a tool for near-real-time, dynamic management.

Rigby, C. L., Wedding, B. B., Grauf, S., & Simpfendorfer, C. A. (2016). Novel Method for Shark Age Estimation Using near Infrared Spectroscopy. *Marine & Freshwater Research, 67*(5), 537-545. https://doi.org/10.1071/MF15104

Accurate age determination is an important component of assessing and managing fish populations, yet traditional ageing using growth bands is time-consuming and has limitations. In the present study, an alternative approach to shark age estimation using near infrared spectroscopy (NIRS) was investigated using two species. The ages of *Sphyrna mokarran* and *Carcharhinus sorrah* vertebrae that had been traditionally aged and validated were successfully predicted up to 10 years of age using NIRS. The correlations between the known ages of the vertebrae and their near infrared spectra were strong, with R^2 values of 0.89 and 0.84 for *S. mokarran* and *C. sorrah* respectively. The major advantage of the NIRS ageing approach was the rapid speed of age estimation, which could enable large numbers of sharks to be aged quickly. This would offer the fisheries management benefit of improving the reliability of age information for stock and risk assessments.

Santos, C. C., & Coelho, R. (2019). Distribution Patterns and Indicators of the Smooth Hammerhead Shark (*Sphyrna zygaena*) in the Atlantic Ocean. *Fisheries Research, 212*, 107-113. https://doi.org/10.1016/j.fishres.2018.12.015

The smooth hammerhead shark, *Sphyrna zygaena* , is a pelagic shark occasionally captured as bycatch by industrial pelagic longline fleets in the Atlantic Ocean. Data for this study were collected by fishery observers, between 2003 and 2016. Datasets analyzed included information on catches per unit effort (CPUE), size and sex of smooth hammerhead sharks bycaught by the Portuguese pelagic longline fishery in the Atlantic Ocean. A total effort of 2 523 288 hooks yielded 638 sharks, ranging in size from 123 to 275 cm fork length. Larger sharks tended to occur in open ocean habitats and smaller specimens in coastal areas. Results confirmed the wide latitudinal range of the species (45 °N–35 °S), although CPUE was higher closer inshore within the Tropical North and Equatorial regions. An overall sex ratio of 1.4 males for each female was observed, with more males in both inshore and offshore waters. Significant differences in CPUE and size distribution were found between regions, years and quarters of the year. Mean CPUE increased and mean specimen size decreased in the Equatorial region from 2012 onwards. In order to remove fishery-dependent effects from CPUE data, a Tweedie Generalized Linear Model (GLM) was used to create a relative index of abundance (standardized CPUE). The index showed some oscillations in the initial years (2008–2010), followed by a decreasing trend until 2013 and then an increasing trend in more recent years, until 2016. The distributional patterns and indicators presented in this study provide a better understanding of the smooth hammerhead shark's spatio-temporal dynamics and population structure in the Atlantic Ocean and can be used to improve management and conservation measures for this species.

Shiffman, D. S., Gallagher, A. J., Wester, J., Macdonald, C. C., Thaler, A. D., Cooke, S. J., & Hammerschlag, N. (2014). Trophy Fishing for Species Threatened with Extinction: A Way Forward Building on a History of Conservation. *Marine Policy, 50*, 318-322. https://doi.org/10.1016/j.marpol.2014.07.001

Trophy fishing occurs when anglers target the largest members of a species with the goal of obtaining an award with perceived prestige. The largest members of many species are also the most fecund, raising alarms about the disproportionate impact of removing the largest individuals of species of conservation concern. Presented here is the first systematic analysis of the conservation status of fishes targeted for world records by the International Game Fishing Association. Eighty-five species for which IGFA records have been issued are listed as Threatened by the International Union for the Conservation of Nature (IUCN) Red List. If the IGFA stopped issuing records that implicitly require killing the fish for IUCN Red

List Threatened species, it would immediately reduce fishing pressure on the largest individuals of species of conservation concern while still allowing anglers to target more than 93% of species that records have been issued for.

Weigmann, S. (2016). Annotated Checklist of the Living Sharks, Batoids and Chimaeras (Chondrichthyes) of the World, with a Focus on Biogeographical Diversity. *Journal of Fish Biology, 88*(3), 837-1037. https://doi.org/10.1111/jfb.12874

An annotated checklist of the chondrichthyan fishes (sharks, batoids and chimaeras) of the world is presented. As of 7 November 2015, the number of species totals 1188, comprising 16 orders, 61 families and 199 genera. The checklist includes nine orders, 34 families, 105 genera and 509 species of sharks; six orders, 24 families, 88 genera and 630 species of batoids (skates and rays); one order, three families, six genera and 49 species of holocephalans (chimaeras). The most speciose shark orders are the Carcharhiniformes with 284 species, followed by the Squaliformes with 119. The most species-rich batoid orders are the Rajiformes with 285 species and the Myliobatiformes with 210. This checklist represents the first global checklist of chondrichthyans to include information on maximum size, geographic and depth distributions, as well as comments on taxonomically problematic species and recent and regularly overlooked synonymizations. Furthermore, a detailed analysis of the biogeographical diversity of the species across 10 major areas of occurrence is given, including updated figures for previously published hotspots of chondrichthyan biodiversity, providing the detailed numbers of chondrichthyan species per major area, and revealing centres of distribution for several taxa.