BIOL 360 Climate Change Beneath the Waves

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Predicting High-Risk Elasmobranch Species Under The Pressure of Commercial Fishery and Anthropogenic Climate Change

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Large-scale commercial fisheries and rapid climate change have continuously altered the biotic and abiotic factors of the marine ecosystem. From 1970 to 2018, the global abundance of oceanic sharks declined by 71.1% (Davidson et al., 2016). Overfishing is the main cause for the decline of elasmobranch fishes: sharks and rays are landed both as bycatch and target catch (Pacoureau et al., 2021). Catches peaked in 2003 with 895,743 tons (around 63 - 273 million individuals); after the early 2000s, catches of elasmobranchs declined due to the population decline (Davidson et al., 2016). In addition to fishery loss, elasmobranchs face shrinking habitats due to global warming. Rising seawater temperature is a direct consequence of climate change; hypoxia and acidification of global oceans are also observed jointly with warming seawater. The low dissolved O_2 is caused by decreased oxygen solubility in water of higher temperatures; the decrease in ocean pH is caused by the dissolution of the overabundant atmosphere CO_2 into ocean waters. Nonetheless, sharks have experienced multiple climate changes: the elasmobranch group has diversified since the late Triassic or early Jurassic time, and different taxons have waxed and waned over the K.T extinction and numerous glacial movements (Kriwet et al., 2009). Given the combined impact of overfishing and rapid climate change, we predict that late-maturing pelagic sharks are under the highest risk, especially the obligate ram ventilators. Also, species-specific factors such as post-release mortality rates, population diversity, and the availability of nursery habitats need to be considered in conjunction to predict the future of a species.

Overfishing impacts late-maturing elasmobranchs most heavily because their long reproduction cycle and low offspring count lead to slow population recovery. Compared to other fishes, elasmobranchs are generally characterized by slow growth and low offspring count (O'Brien et al., 2013). For example, little skate (*Leucoraja erinacea*), whose adult size is around 60 cm, takes 7 to 8 years to mature and only produces around 8-20 egg cases per year (Frisk and Miller, 2009). In comparison, Atlantic cod (Gadus morhua), whose adult size is around 120 cm, takes only need 2-3 years to mature and can produce 3 to 9 million eggs per year (Fisheries, 2021). Sudden population loss–often due to fishing and extreme climate events–is more catastrophic to large elasmobranch species than small-medium species because large sharks need even more time to mature and recovery. The great white shark (*Carcharodon carcharias*) reaches sexual maturity around 30-year-old and produces less than 10 pups each year (Natanson et al., 2015). A more extreme example, the Greenland shark (*Somniosus microcephalus*) is estimated to mature no earlier than 134 years (Nielsen et al., 2020). The long life cycle of large sharks means that an overfished population needs decades or even centuries to recover, even as the habitat was to restore to the optimal condition. The size and wide migratory range of large sharks also make research on them more challenging. Without thorough research, it is much more difficult to find effective conservation strategies.

As difficult recovery combines with a lack of understanding, conservation and restoration of large shark species become very challenging.

It is important to keep in mind that fishing pressure varies greatly between shark species, both in target fishing and bycatch. Some large sharks are targeted for the economic values of their meat fin, gill plates, and liver oil (Pacoureau et al., 2021). In 2014, NGO journalists reported that hundreds of whale sharks (*Rhincodon typus*) were hunted annually due to the illegal trade in China (Hundreds of sharks killed in China, 2014). Before the 1990s, basking sharks (*Cetorhinus maximus*) were hunted worldwide for meat and oil, because an adult basking shark could yield 1 ton of meat and 100 gallons of oil (Cetorhinus maximus, 2017). However, some large sharks are never targets of commercial fishing and have little economic value, such as bull sharks (*Carcharhinus leucas*) and great white sharks. Many regulations and laws exist to protect large sharks and we are hopeful that more laws will be made to further prevent target hunting against elasmobranch fishes globally. However, all elasmobranchs are victims of bycatch regardless of their economic value. The loss of population due to bycatch is also highly variable among shark species. Laws may demand the release of bycatch of threatened species, but it has little ecological value if the captured sharks are already dead. Obligate ram ventilators (ORV) are a category of fish that rely on continuous swimming to allow water to pass through the gills. Whale sharks, sandbar sharks (*C. plumbeus*), and great white sharks are examples of obligate ram ventilators (Crear et al., 2019; Del Raye et al., 2013). Since fishnets restrain fishes from swimming, ORV species generally have low post-release survival rates (Ellis et al., 2017). However, among non-ORV elasmobranchs, the post-capture survival rate varied greatly, too–97% of tiger sharks (*Galeocerdo cuvier*) are reported to survive the capture, but only 33% of night sharks (*C. signatus*) can survive (Gallagher et al., 2014). Thus, depending on the economic value and the post-capture survival rate, the impact of fishing on sharks is highly variable between species, and species-specific research is necessary to assess the risk of a species.

While fishing pressure is local and can be managed through policies such as moratoriums, climate change is unlikely to be halted or reserved in the foreseeable future. Global warming is expected to pose a larger threat to cold water pelagic sharks because historically, these fishes were well adapted to a cold climate. DNA variance analysis of the population of 9 common shark species revealed that during the last glacial maximum (approximately 19,000 years ago), pelagic and deep benthic sharks were only slightly affected by the sudden drop in temperature and sea level (O'Brien et al., 2013). Shark species that were only slightly affected include pacific sleeper sharks (*S. pacificus*), salmon sharks (*Lamna ditropis*), bluntnose sixgill (*Hexanchus griseus*), great white sharks, and whale sharks. All of them except whale sharks live in the cold or temperate water. Contemporary climate change is characterized by rising temperatures and rising sea levels. The loss of the arctic ice cap and warmer water are expected to drastically reduce the habitat range of these once successful cold water sharks. However, even though the whale shark is a tropical/temperate fish, it is currently endangered because of overfishing (Pierce and Norman, 2016). Thus, either factor in fishing and climate change can severely impact a given species. On a positive note, since many large pelagic shark species thrived during the ice age, they always had a large effective population, rather than a recent bloom; as a result, previous studies have observed great genetic diversity in large pelagic species (O'Brien et al., 2012). Genetic diversity in a species is important given that the future climate is not only warmer but also more unpredictable and extreme. However, frequent extreme climate events can potentially reduce the total population size and the genetic diversity (Monroe et al., 2018), leaving the remaining populations vulnerable to future extreme events.

Aside from the historical trend, climate change expand the oxygen minimum zone (OMZ), which poses an imminent threat to pelagic sharks. Warmer surface water intensifies ocean stratification and prevent the mixing of oxygen-rich surface waters and oxygen-poor waters beneath it, thus expanding the OMZ. Among satellite-tracked blue sharks, the expansion of OMZ correlated with the migration from mesopelagic to surface waters; concurrently, fishery data also reported a positive correlation between that the number of blue shark bycatch and the size of OMZ (Vedor et al., 2021). Thus, the expansion of OMZ might push the habitats of pelagic sharks towards the shallow waters, exposing mid-water sharks to the danger of commercial fisheries and escalating the decline in shark populations. However, it is difficult to predict the size of OMZ in each ocean at a rising temperature, and the vertical migration patterns of sharks are highly species-dependent. Thus, the effects of OMZ expansion on shark populations also require species-by-species assessment.

In addition to commercial fisheries, climate change is also expected to heavily impact the obligate ram ventilators (ORV) because higher temperature causes an imbalance between rising metabolic activity and the availability of dissolved oxygen (DO). Most sharks, except lamniform (i.e. great white sharks), are ectotherms, so a higher environmental temperature increases the metabolic rate and oxygen demand. ORV can increase oxygen intake by swimming faster to allow more water passes through their gills (Crear et al., 2019). However, swimming faster also increases the metabolic rate, so the compound effect of hypoxia and increased oxygen demand can easily disrupt the metabolic balance in ORV sharks (Crear et al., 2019). Non-ORV sharks can rest on the seafloor during hypoxic periods, but ORV sharks lack the option to reduce movement to slow down metabolism. Combined with the high post-capture mortality rate, both climate change and fishery are expected to heavily impact ORV species.

Compare to more mobile adult sharks, embryos and juveniles are restricted to coastal nursery habitats, which are expected to experience extreme heatwaves and hypoxic environments. Although adult sharks can swim to cooler, non-hypoxic water, embryos and juveniles are forced to stay in shallow coastal waters for reasons including predator avoidance and limited mobility. In a control-variable experiment on embryo bamboo sharks (*Chiloscyllium plagiosum*), warmer water (+4, to 30°C) increased metabolic demand and higher CO_2 concentration (ΔpH = 0.5) decreased olfactory sensibility (Rosa et al., 2016); due to increasing nutrient demand and decreasing hunting ability, embryo sharks experienced slower growth in the end-of-century-simulated mesocosm. Another study on epaulette sharks (*Hemiscyllium ocellatum*) shows that warmer hatching temperatures (+4, to 31°C) led to smaller neonates with reduced metabolic performance (Wheeler et al., 2021). Many juvenile sharks can endure water over 30°C, but elevated metabolic rate reduces the amount of extra energy available for growth. High CO_2 hampers the juveniles' ability to detect and hunt prey, which further exacerbates the nutritional shortage. Thus, climate change is expected to make many nursery habitats unsuitable for embryonic development. Without reliable nursery areas and constant replenishment of the younger generation, a species will be in jeopardy.

However, individuals within a shark species often display highly variable reponses to warmer waters. For example, the juvenile Port Jackson shark (*Heterodontus portusjacksoni*) population from Jervis Bay had a critical thermal limit of 2°C higher than the population from Adelaide (Gervais et al., 2021). Both sites are in Southeast Australia, and Jervis Bay is 600 miles north of Adelaide. In addition to inter-population variations, some shark species also have huge inter-population variances among sharks captured from the same habitat. Among juvenile sandbar sharks captured from the eastern shore of Virginia, USA, some individuals show little changes in minimum routine metabolic rate (mRMR) in warmer water, even though overall, the mRMR of juvenile sandbar sharks is positively correlated with temperature (Crear et al., 2019). Thus, when evaluating impacts of climate change on elasmobranch species, we need to take into account phenotypical variations and adaptability within populations.

Overall, climate change and overfishing pose a grim future for large pelagic sharks, which are often apex predators in the ecosystem. Without top-down control from sharks, fast multiplying species of a lower trophic level can easily overpopulate, resulting in overgrazed sea vegetations and a destabilized ecosystem. Sea vegetation are large carbon sinks (Nowicki et al., 2021), and overgrazing releases carbon into the atmosphere and thus worsens the greenhouse effect. Conservation of elasmobranch is more than recovering the population: a balanced ecosystem is essential for the continuous eco-service to the local community. The identification of high-risk shark species is critical for conservation efforts, although risk assessments also need to account for interspecies and intraspecies differences. Given the limited resources for shark monitoring in open oceans, we think pelagic sharks, especially the obligate ram ventilators and sharks with long life cycles should be a priority in preemptive shark conservation.

References

Cetorhinus maximus (2017). *Florida Museum*.

Crear, D. P., Brill, R. W., Bushnell, P. G., Latour, R. J., Schwieterman, G. D., Steffen, R. M. and Weng, K. C. (2019). The impacts of warming and hypoxia on the performance of an obligate ram ventilator. *Conservation Physiology* **7**,.

Davidson, L. N. K., Krawchuk, M. A. and Dulvy, N. K. (2016). Why have global shark and ray landings declined: improved management or overfishing? *Fish and Fisheries* **17**, 438–458.

Del Raye, G., Jorgensen, S. J., Krumhansl, K., Ezcurra, J. M. and Block, B. A. (2013). Travelling light: white sharks (Carcharodon carcharias) rely on body lipid stores to power ocean-basin scale migration. *Proceedings of the Royal Society B: Biological Sciences* **280**, 20130836.

Ellis, J. R., McCully Phillips, S. R. and Poisson, F. (2017). A review of capture and post-release mortality of elasmobranchs. *Journal of Fish Biology* **90**, 653–722.

Fisheries, N. (2021). Atlantic Cod | NOAA Fisheries. *NOAA*.

Frisk, M. G. and Miller, T. J. (2009). Maturation of Little Skate and Winter Skate in the Western Atlantic from Cape Hatteras to Georges Bank. *Marine and Coastal Fisheries* **1**, 1–11.

Gallagher, A. J., Orbesen, E. S., Hammerschlag, N. and Serafy, J. E. (2014). Vulnerability of oceanic sharks as pelagic longline bycatch. *Global Ecology and Conservation* **1**, 50–59.

Gervais, C. R., Huveneers, C., Rummer, J. L. and Brown, C. (2021). Population variation in the thermal response to climate change reveals differing sensitivity in a benthic shark. *Global Change Biology* **27**, 108–120.

Hundreds of sharks killed in China (2014). *ABC News*.

Kriwet, J., Kiessling, W. and Klug, S. (2009). Diversification trajectories and evolutionary life-history traits in early sharks and batoids. *Proc Biol Sci* **276**, 945–951.

Monroe, A. A., Ziegler, M., Roik, A., Röthig, T., Hardenstine, R. S., Emms, M. A., Jensen, T., Voolstra, C. R. and Berumen, M. L. (2018). In situ observations of coral bleaching in the central Saudi Arabian Red Sea during the 2015/2016 global coral bleaching event. *PLOS ONE* **13**, e0195814.

Natanson, L. J., Skomal, G. B., Natanson, L. J. and Skomal, G. B. (2015). Age and growth of the white shark, Carcharodon carcharias, in the western North Atlantic Ocean. *Mar. Freshwater Res.* **66**, 387–398.

Nielsen, J., Hedeholm, R. B., Lynghammar, A., McClusky, L. M., Berland, B., Steffensen, J. F. and Christiansen, J. S. (2020). Assessing the reproductive biology of the Greenland shark (Somniosus microcephalus). *PLOS ONE* **15**, e0238986.

O'Brien, S., Gallucci, V. and Hauser, L. (2012). Effects of species biology on the historical demography of sharks and their implications for likely consequences of contemporary climate change. *Conservation Genetics* **14**,.

O'Brien, S. M., Gallucci, V. F. and Hauser, L. (2013). Effects of species biology on the historical demography of sharks and their implications for likely consequences of contemporary climate change. *Conserv Genet* **14**, 125–144.

Pacoureau, N., Rigby, C. L., Kyne, P. M., Sherley, R. B., Winker, H., Carlson, J. K., Fordham, S. V., Barreto, R., Fernando, D., Francis, M. P., et al. (2021). Half a century of global decline in oceanic sharks and rays. *Nature* **589**, 567–571.

Rosa, R., Pimentel, M., Galan, J. G., Baptista, M., Lopes, V. M., Couto, A., Guerreiro, M., Sampaio, E., Castro, J., Santos, C., et al. (2016). Deficit in digestive capabilities of bamboo shark early stages under climate change. *Mar Biol* **163**, 60.

Pierce, S.J and Norman, B. (2016). IUCN Red List of Threatened Species: Rhincodon typus. *IUCN Red List of Threatened Species*.

Vedor, M., Queiroz, N., Mucientes, G., Couto, A., Costa, I. da, Santos, A. dos, Vandeperre, F., Fontes, J., Afonso, P., Rosa, R., et al. (2021). Climate-driven deoxygenation elevates fishing vulnerability for the ocean's widest ranging shark. *eLife* **10**, e62508.

Wheeler, C. R., Rummer, J. L., Bailey, B., Lockwood, J., Vance, S. and Mandelman, J. W. (2021). Future thermal regimes for epaulette sharks (Hemiscyllium ocellatum): growth and metabolic performance cease to be optimal. *Sci Rep* **11**, 454.