Ecological Impacts of Declining Global Elasmobranch Populations Due to Anthropogenic Influences

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<u>Abstract</u>

In the past century, marine ecosystems worldwide have seen sharp declines in elasmobranch populations. Recent assessments by the International Union for Conservation of Nature (IUCN) revealed nearly 25% of elasmobranchs are vulnerable to extinction. They exhibit k-species characteristics which leave them highly susceptible to anthropogenic influences. Human influences, such as habitat degradation or loss, climate change, as well as fishing and finning, are the most likely causes of the steep population declines in elasmobranchs over the past century. Physical destruction of habitats leaves juveniles vulnerable to predation and starvation from low prey availability. Due to elasmobranchs' slower life history characteristics they are the most vulnerable to climate change effects, especially those residing in estuarine and reef habitats. With prices for shark fins increasing to nearly US\$400 per kilogram on the Hong Kong market and increased demand from the Asian markets, sharks are harvested for their fins alone. It is estimated that if fishing mortality rates increase to 20% of the initial population per year, some species could decline to 1% of their population in the next 10 to 39 years. There have been documented cases of trophic cascades and meso-predator release as marine ecosystems have seen sharp declines in large bodied elasmobranch populations.

Keywords: elasmobranchii, elasmobranchs, ecology, conservation, population decline, sharks, rays, climate change, habitat destruction, fishing, finning, apex predator, meso-predator, trophic cascade

Introduction

Elasmobranchii is a subclass of Chondrichtyes, or cartilaginous fishes, which include sharks, skates, and rays that debuted in the fossil record in the Devonian era nearly 400 million years ago (Fowler et al., 2005). In their evolutionary past, elasmobranchs have faced fived mass extinctions (Parker, 2008), however, recent assessments by the International Union for Conservation of Nature (IUCN) revealed nearly 25% of elasmobranchs are vulnerable to extinction (Magiera, 2014). Unlike bony fishes, which exhibit r-species characteristics, reaching sexual maturity guickly and have a high rate of reproduction or fecundity, sharks and rays exhibit k-species characteristics which can make them susceptible to changes in their environment (Fowler et al., 2005). They have long life spans with slow growth rates, reaching sexual maturity late in life, and usually have low fecundity (Chin, Kyne, Walker, & McAuley, 2010), which leave them highly susceptible to anthropogenic influences. Human influences, such as habitat degradation or loss, climate change, as well as fishing and finning, are the most likely causes of the steep population declines in elasmobranchs over the past century (Knip, Heupel, & Simpfendorfer, 2010; Ward-Paige et al., 2010). Dramatic population declines in elasmobranchs can have devastating effects on marine ecosystems (Baum & Worm, 2009; Heupel, Knip, Simpfendorfer, & Dulvy, 2014; Mumby et al., 2007).

Habitat Degradation or Loss

In 2010, it was estimated that 60% of the global population lived within 100 km of a coastline. By 2020 it's estimated that number will increase to nearly 75% (Knip et al.,

2010). As one may imagine, the increase in population comes with a price for the environment. The acts of dredging, construction, and deforestation, which go hand in hand with increased coastal development, are detrimental to nearshore areas (Knip et al., 2010).

While it is adult sharks who have been exploited in the fisheries markets, juveniles of some shark species are at the greatest risk for habitat loss due to the encroachment of humans through coastal development (Heupel et al., 2007). For many species, mangroves provide nearshore nursery habitats for juvenile sharks, offering safety from predation and an abundant food supply (Knip et al., 2010) (Appendix Figure 1). In the last 25 years, mangrove habitats worldwide have decreased by nearly 35% due to clearing, cutting for development, and lumber (Valiela, Bowen, & York, 2001). Around Bimini island in the Bahamas, juvenile lemon sharks (*Negaprion brevirostris*) (Appendix Figure 2) utilize mangroves to hone their hunting skills and to evade predators (Jennings, Gruber, Franks, Kessel, & Robertson, 2008). However, these mangroves have been threatened by recent resort development. A study of the region saw a direct correlation between the decrease of seagrass (*Thalassia testudinum*) and the decrease in survival rates of lemon shark juveniles (Jennings et al., 2008).

Not only does coastal development lead to direct removal of habitat space, but it also leads to increased terrestrial runoff. When terrestrial runoff in an area introduces an excessive amount of nutrient richness there is an increased risk of algae blooms which can smother other organisms by reducing the available oxygen levels. These eutrophication events cause dead zones in aquatic environments (Knip et al., 2010). Many species of elasmobranchs have been leaving regions during periods of anoxia, like leopard sharks (*Triakis semifasciata*) (Appendix Figure 3) (Carlisle & Starr, 2009). Terrestrial runoff can also cause health problems in other ways for elasmobranchs. Organochlorines, a pesticide containing chlorinated hydrocarbons used generously in the 1940's through '60's for mosquito control and agriculture, has been shown to cause infertility in bonnethead sharks (*Sphyma tiburo*) (Appendix Figure 4) in coastal waters (Delaware Health and Social Services, 2010; Gelsleichter et al., 2005).

Not all species of elasmobranchs are coastal. Many, like whitetip reef sharks (Triaenodon obesus), spotted eagle rays (Aetobatus narinari), bluespotted stingrays stingrays (Urobatis jamaicensis), (Taeniura *lymma*), yellow sharks nurse (Ginglymostoma cirratum), epaulette sharks (Hemiscyllium ocellatum) (Appendix Figure 5), and many others all inhabit coral reefs which are mostly found between 23.4°N and 23.4°S of the Equator between the Tropics of Cancer and Capricorn (Appendix Figure 6). While corals represent only 0.1% of the sea floor, corals are estimated to sustain 25% of life in the ocean (Riegl, Purkis, Al-Cibahy, Abdel-Moati, & Hoegh-Guldberg, 2011). As the global climate continues to rise each year, the ocean temperatures also rise and coral bleaching epidemics have spread across many areas (Riegl et al., 2011)., Available habitats for reef species dwindles as degradation of coral habitats continues (Chin et al., 2010). Elasmobranch reef species are often highly mobile, sometimes traveling hundreds, or even thousands, of miles every year to find food and mates (Hammerschlag, Gallagher, & Lazarre, 2011; Wilson, Polovina, Stewart, & Meekan, 2006; Wilson, Taylor, & Pearce, 2001). This can often require a network of reef habitats

to be available to them to make these journeys each year. As coral patches continue to die off, fewer networks become available for these migratory animals and they are forced to find new networks of reefs to make these journeys possible (Duncan & Holland, 2006; Robbins, Hisano, Connolly, & Choat, 2006). For some species of reef shark, even if new suitable coral habitats can be reached, it may be possible that they will be unable to establish a stable population due to competition or predation events (Duncan & Holland, 2006).

Climate Change

It has been estimated that by 2050, with minimal climate-warming changes, approximately 18% of terrestrial species will be committed to extinction due to rapid global temperature increases (Thomas et al., 2004). Species that express r-strategy life histories are generally able to respond and adapt the quickest to climate change (Perry, Low, Ellis, & Reynolds, 2005). However, k-strategy species, like elasmobranchs, are more vulnerable to climate change effects (Perry et al., 2005).

Climate change has been known to effect sharks and rays in two distinct ways: as direct effects and indirect effects (Chin et al., 2010). Direct effects influence the physiochemical environment which a shark or ray inhabits. These effects can include water temperature changes, freshwater input from streams or rain fall, and ocean acidification (Chin et al., 2010). Indirect effects influence the geophysical, ecological, and biological processes occurring within the habitats, as well as the health of the environment. Indirect effects can also include air temperature, ultraviolet radiation, ocean circulation, and severe weather events (Chin et al., 2010). Both direct and indirect effects can have significant impacts on elasmobranch populations. It has been suggested that round stingrays (*Urobatis halleri*) (Appendix Figure 7) and leopard sharks (*Triakis semifasciata*) (Appendix Figure 3) use behavioral thermoregulation, aggregating in warmer waters to optimize their physiological and metabolic processes including reproduction (Hight & Lowe, 2007; Hoisington IV & Lowe, 2005). If conditions are not met for these animals they will not be able to meet their physiological requirements necessary for reproduction which could have a detrimental impact on their populations (Hight & Lowe, 2007).

In a recent study of elasmobranchs in six ecological habitats along Australia's Great Barrier Reef (Appendix Figure 8), ocean circulation changes, temperature, and freshwater input were the greatest influential factors due to climate change that affected species in all six ecological groups (Chin et al., 2010). Of these groups, estuarine and reef species are considered the most vulnerable to the effects of climate change. The species within these habitats are more susceptible to changes in salinity due to rising sea levels or alterations in rainfall and increased physical disturbance by severe storms (Chin et al., 2010). Reef habitats are considered moderate to high vulnerability to climate change factors including rising temperatures, increased storm activity, ocean acidification, and increased UV and light radiation (Chin et al., 2010). Coastal, pelagic, shelf, and bathyal ecological groups are considered low vulnerability to climate change. For these species, temperature is the greatest climate change factor which influences their physiochemical environment. Pelagic and shelf sharks and rays may also be effected by changing ocean currents. These currents could alter upwellings of nutrient

rich waters which drive productivity and ultimately prey availability (Chin et al., 2010). In recent years changes in the El Niño cycles have had significant effects on primary productivity (Kingsford & Welch, 2007).

Climate change may pose the greatest threat to species which are constrained by habitat requirements, dispersal capabilities, or seasonal and oceanographic events (Perry et al., 2005). In Australia the aggregation of whale sharks (*Rhincodon typus*) (Appendix Figure 9) on the Ningaloo Reef has been correlated to seasonal temperature changes (Wilson et al., 2006; Wilson et al., 2001). With the ocean temperatures on the rise these seasonal oceanographic events may be altered by climate change which in turn may have dramatic impacts on the timing or magnitude of seasonal patterns of migratory species (Chin et al., 2010). At present coral bleaching events linked to rapid climate change and increasing water temperatures have been documented as the greatest threat to whale sharks (Stewart & Wilson, 2005), as whale sharks will travel thousands of miles to Ningaloo Reef in Australia to feed on spawning corals (Wilson et al., 2001).

Fishing & Finning

In fisheries management, the amount of fish harvested and reported where fish are brought onto shore is referred to as a landing (Blackhart, Stanton, & Shimada, 2006). In the past thirty years, elasmobranch landings have been on a steep increase worldwide. In the Gulf of Mexico in the 1980's shark landings nearly tripled (Ward-Paige et al., 2010). Since 1950, which marked the first year of elasmobranch fisheries data collection, landings have increased 227% globally to their peak year in 2003 (Davidson,

Krawchuk, & Dulvy, 2016). The driving force behind the increased landings has been the dramatic increase in demand for seafood, primarily in East Asia, which has a strong influence on the global market demand (Clarke, 2004). In developing third world countries, local resources are being exploited to supply international markets (Clarke, 2004).

Sharks are primarily harvested for their fins alone due to low demand for shark meat with fluctuating markets for skin, oil, liver, and teeth (Clarke, 2004). Sharks are pulled from the water, still alive; with their fins stripped from their bodies, their bodies dumped overboard, and they are left to drown (Appendix Figure 10) (Stewart, 2008). Shark fin, or *yu chi* as it is known in China, is considered a delicacy. It is served as a soup by removing the collagen fibers from between the cartilage in the fins and boiling them in a stock (Clarke, 2004). Hong Kong has been the capital of the shark fin trade for decades, importing from over a 125 regions and countries (Clarke, 2004). And the fins are highly profitable on the Hong Kong market, bringing in nearly US\$400 per kilogram (Clarke, 2004), making fins one of the most valuable seafood products in the world. In one Hong Kong market, an estimated 30 to 40 shark species fins were available for sale, including the whale shark (Rhincodon typus) (Appendix Figure 9) a CITES Appendix II protected species (CITES, 2001). Despite the increased demand for fins, since peak landings in 2003, by 2011, landings had declined by 15% (Davidson et al., 2015). Concerns have risen that elasmobranch populations are following predictable patterns of fisheries which in the past have been open-access and unregulated: populations which express serial depletion and collapse (Davidson et al., 2015).

In response to the increasing pressure from Asian markets to supply shark fins, the United States has issued a national ban on finning within its waters (Fowler et al., 2005). Other countries, such as Australia, Brazil, the European Union, South Africa, and Oman, have either prohibited or issued controlled shark finning within their waters (Fowler et al., 2005). Despite some limitation on finning there has been very little progress limiting the number of sharks which may be landed throughout the world each year (Clarke, 2004; Fowler et al., 2005). An examination of elasmobranchs in the Caribbean suggested that if the fishing industry were to remove 10% of the current populations per year we could see a decline up to 14% of some elasmobranch species in the Caribbean within the next 50 years (Ward-Paige et al., 2010). If fishing mortality rates were increased to 50% each year all examined elasmobranchs declined to less than 1% of their initial population size within the next 10 to 39 years (Ward-Paige et al., 2010).

Recent studies in the Caribbean suggest that shark populations occur in higher densities where human populations densities are lower (Ward-Paige et al., 2010). Sharks were largely absent in survey studies conducted between 1993 and 2008 in areas around Jamaica, Dominican Republic, Cuba, Puerto Rico, South and Central American, and the Antilles where human populations are high (Ward-Paige et al., 2010). However, sharks were found in high densities in areas around Florida, the US Virgin Islands, and the Bahamas where human populations are also high (Ward-Paige et al., 2010). These regions all have strong fishing regulations that help support strong elasmobranch communities, including establishing marine protected areas, prohibiting the use of gill nets, prohibiting of longline fishing, and prohibiting shark finning (Ward-Paige et al., 2010). High human population density in these regions alongside healthy shark populations suggest that while other anthropogenic influences may be affecting shark population decline, the main driving factor of population decline is likely overexploitation due to fishing (Knip et al., 2010; Ward-Paige et al., 2010).

Ecological Impacts of Elasmobranch Population Decline

To maintain a healthy ecosystem with abundant biodiversity, predators at all levels must be present in sufficient numbers. Elasmobranchs perform critical roles in marine ecosystems as apex and meso-predators. Apex predators occupy the top trophic position in their community (Heupel et al., 2014). These predators are specialized predators that exert top-down control over their prey species and can significantly effect ecosystem structure (Estes et al., 2011). Meso-predators make up any mid-level predator within the ecosystem (Heupel et al., 2014). Meso-predators provide a more diffuse predator-prey pattern within a community than a specialized apex predator and they have less of an influence over the behavior of other species within their community (Heupel et al., 2014). This means that while only a handful of sharks like the great white shark (Carcharodon carcharias) (Appendix Figure 11) are considered apex predators, the majority of elasmobranchs are actually categorized as meso-predators (Heupel et al., 2014). This means that those few species, like the great white shark, that are categorized as apex predators are exceptionally key in maintaining balance within their ecosystems.

As marine ecosystems have seen sharp declines in large bodied elasmobranch populations there have been documented cases of trophic cascades and meso-predator release (Heupel et al., 2014). Along the eastern coast of the United States, following the collapse of large bodied shark populations the cownose ray (*Rhinoptera bonasus*) (Appendix Figure 12) began to fill in the gap. The loss of the top predators released the rays from its position in the food web and allowed their population to increase due to lack of predation and competition (Baum & Worm, 2009). This is what is referred to as meso-predator release. The cownose ray population boom eventually led to the depletion of its prey source, the bay scallop (Baum & Worm, 2009). In the Caribbean the absence of reef sharks has led to an increase in grouper and snapper populations, which devastated herbivore populations (Roff et al., 2016). Without herbivores on reefs to maintain algae populations, algae can guickly overtake reefs and smother them (Grubbs et al., 2016; Mumby et al., 2007). These cascades are similar to the trophic cascades that happened in Yellowstone National Park when the wolves disappeared (Berger, K.M. Conner, 2008).

<u>Conclusion</u>

Sharks were once "expected anywhere at any time," (Baughman & Springer, 1950); but due to human encroachment and destructive tendencies, sharks today are "expected anytime almost nowhere" (Ward-Paige et al., 2010). As human populations expand and greater numbers inhabit coast lines each year, coastal development continues to decimate nearshore habitats (Knip et al., 2010). Physical destruction of habitats leaves juveniles vulnerable to predation and starvation due to low prey

availability (Heupel et al., 2007; Jennings et al., 2008). Terrestrial runoff increases pollution levels and reduces water quality (Knip et al., 2010) which has led to a series of documented health conditions among elasmobranchs including infertility (Gelsleichter et al., 2005).

As the global climate climbs, elasmobranchs, especially those residing in estuarine and reef habitats, will be the most vulnerable to climate change effects (Chin et al., 2010). These species exhibit slower life history traits than most bony fishes which prohibit them from responding quickly to rapid changes in their environment due to global climate changes (Perry et al., 2005). As global climate continues to shift, seasonal and oceanography events, such as temperature correlated seasonal spawning aggregations, may be dramatically affected, which may have traumatic impacts on highly migratory species such as whale sharks (Stewart & Wilson, 2005; Wilson et al., 2006; Wilson et al., 2001).

Perhaps the most likely driver for elasmobranch population decline over the last century has been fishing and finning pressures from the Asian seafood market demand (Clarke, 2004). The demand for shark fins on the Asian market has been increasing for decades as Hong Kong continues to import fins from over 120 countries and regions (Clarke, 2004). With prices for fins increasing to nearly US\$400 per kilogram on the Asian market and shark meat fluctuating, sharks are harvested for fins alone (Clarke, 2004; R. Stewart, 2008). The current rate of harvest is not sustainable. With a yearly fishing mortality rate of 20%, some species will see declines to less than 1% of the current population in the next 10 to 39 years (Ward-Paige et al., 2010).

Sharks have been keeping marine ecosystems in balance as meso and apex predators for over 400 million years. It is only now, in the last century, that their very existence, and the in turn the balance of the entire marine environment, is threatened due to anthropogenic pressures.

<u>Appendix</u>



Figure 1. Red mangrove habitat offers shelter from predators and abundant food supplies for juvenile sharks (Wikimedia Commons, n.d.).



Figure 2. Juvenile Lemon Shark (*Negaprion brevirostris*) in mangrove forest (Potenski, 2012).



Figure 3. Leopard Shark (*Triakis semifasciata*) in kelp bed in Monterey, California (Wikimedia Commons, n.d.).



Figure 4. Bonnethead shark (Sphyrna tiburo) (Javier, 2012).



Figure 5. Common reef dwelling elasmobranchs. Top left: Whitetip reef shark (*Triaenodon obesus*) Top right: Nurse shark (*Ginglymostoma cirratum*) Middle left: Spotted eagle ray (*Aetobatus narinari*) Middle: Yellow stingray (*Urobatis jamaicensis*) Middle right: Bluespotted stingray (*Taeniura lymma*) Bottom: Epaulette shark (*Hemiscyllium ocellatum*) (Whitetip reef shark, n.d.; Von Brandis, n.d.; Corbis, 2011; Yellow stingray, n.d.; Petersen, 2006; Oldfield, 2009). v



Figure 6. World distribution of reef building corals, the majority located between 23.4 degrees N and S of the Equator, the Tropics of Capricorn and Cancer (Wikimedia Commons, 2007).



Figure 7. Round stingray (Urobatis halleri) (Wikimedia Commons, n.d.).





Figure 8. Six marine ecological habitats investigated for climate change effects along the Great Barrier Reef in Australia: Freshwater/Estuarine, Coastal/Inshore, Reef, Shelf, Pelagic, and Bathyal (Chin et al., 2010).



Figure 9. Whale shark (*Rhincodon typus*) (Nautilus Cruises, 2010).



Figure 10. A hammerhead shark that has just been finned is thrown back into the ocean to drown, unable to swim to pass air over the gills (Bali Animal Welfare Association, n.d.).



Figure 11. The great white shark (Carcharodon carcharias) (Levy, 2014).



Figure 12. Cownose rays (*Rhinoptera steindachneri*) (Giebel, 2006)

Literature Cited

- Baughman, J. L., & Springer, S. (1950). Biological and economic notes on the sharks of the Gulf of Mexico, with especial reference to those of Texas, and with a key for their identification. *The American Midland Naturalist*, 44(1), 96–152. http://doi.org/10.2307/2421758
- Baum, J. K., & Worm, B. (2009). Cascading top-down effects of changing oceanic predator abundances. *Journal of Animal Ecology*, 78(4), 699–714. http://doi.org/10.1111/j.1365-2656.2009.01531.x
- Berger, K.M. Conner, M. M. (2008). Recolonizing wolves and mesopredator suppression of coyotes: Impacts on pronghorn population dynamics. *Ecological Applications*, *18*(3), 599–612.
- Blackhart, K., Stanton, D.G., and Shimada, A. M. (2006). NOAA fisheries glossary: NOAA technical memorandum NMFS-F/SPO-69. Retrieved from http://www.st.nmfs.noaa.gov/st4/documents/FishGlossary.pdf
- Carlisle, & Starr. (2009). Habitat use, residency, and seasonal distribution of female leopard sharks Triakis semifasciata in Elkhorn Slough, California. *Marine Ecology Progress Series*, *380*, 213–228. http://doi.org/10.3354/meps07907
- Chin, A., Kyne, P. M., Walker, T. I., & McAuley, R. B. (2010). An integrated risk assessment for climate change: Analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. *Global Change Biology*, *16*(7), 1936–1953. http://doi.org/10.1111/j.1365-2486.2009.02128.x
- CITES. (2001). Whale Shark. Retrieved March 26, 2017, from https://cites.org/eng/gallery/species/fish/whale_shark.html
- Clarke, S. (2004). Understanding pressures on fishery resources through trade statistics: A pilot study of four products in the Chinese dried seafood market. *Fish and Fisheries*, *5*(1), 53–74. http://doi.org/10.1111/j.1467-2960.2004.00137.x
- Davidson, L. N. K., Krawchuk, M. A., & Dulvy, N. K. (2016). Why have global shark and ray landings declined: Improved management or overfishing? *Fish and Fisheries*, *17*(2). http://doi.org/10.1111/faf.12119
- Delaware Health and Social Services. (2010). Organochlorine pesticides: What are organochlorine pesticides? Retrieved March 23, 2017, from http://dhss.delaware.gov/dhss/dph/files/organochlorpestfag.pdf
- Duncan, K. M., & Holland, K. N. (2006). Habitat use, growth rates and dispersal patterns of juvenile scalloped hammerhead sharks (Sphyrna lewini) in a nursery habitat. *Marine Ecology Progress Series*, 312, 211–221. http://doi.org/10.3354/meps312211
- Estes, J. a, Terborgh, J., Brashares, J. S., Power, M. E., Berger, J., Bond, W. J., ... Wardle, D. a. (2011). Trophic downgrading of planet Earth. *Science (New York, N.Y.)*, 333, 301–306. http://doi.org/10.1126/science.1205106
- Fowler, S. L., Cavanagh, R. D., Camhi, M., Burgess, G. H., Cailliet, G. M., Fordham, S. V., ... Musick, J. A. (2005). Sharks, rays and chimaeras: The status of the chondrichthyan fishes. IUCN- The World Conservation Union (Vol. 14). http://doi.org/10.2305/IUCN.CH.2005.SSC-AP.9.en
- Gelsleichter, J., Manire, C. A., Szabo, N. J., Cortés, E., Carlson, J., &

Lombardi-Carlson, L. (2005). Organochlorine concentrations in bonnethead sharks (Sphyrna tiburo) from four Florida estuaries. *Archives of Environmental Contamination and Toxicology*, *48*(4), 474–483. http://doi.org/10.1007/s00244-003-0275-2

Grubbs, R. D., Carlson, J. K., Romine, J. G., Curtis, T. H., McElroy, W. D., McCandless, C. T., ... Musick, J. A. (2016). Critical assessment and ramifications of a purported marine trophic cascade. *Scientific Reports*, *6*, 20970.

http://doi.org/10.1038/srep20970

- Hammerschlag, N., Gallagher, A. J., & Lazarre, D. M. (2011). A review of shark satellite tagging studies. *Journal of Experimental Marine Biology and Ecology*, 398(1–2), 1–8. http://doi.org/10.1016/j.jembe.2010.12.012
- Heupel, M. R., Carlson, J. K., & Simpfendorfer, C. A. (2007). Shark nursery areas: Concepts, definition, characterization and assumptions. *Marine Ecology Progress Series*, 337, 287–297. http://doi.org/10.3354/meps337287
- Heupel, M. R., Knip, D. M., Simpfendorfer, C. A., & Dulvy, N. K. (2014). Sizing up the ecological role of sharks as predators. *Marine Ecology Progress Series*, 495, 291–298. http://doi.org/10.3354/meps10597
- Hight, B. V., & Lowe, C. G. (2007). Elevated body temperatures of adult female leopard sharks, Triakis semifasciata, while aggregating in shallow nearshore embayments: Evidence for behavioral thermoregulation? *Journal of Experimental Marine Biology* and Ecology, 352(1), 114–128. http://doi.org/10.1016/j.jembe.2007.07.021
- Hoisington IV, G., & Lowe, C. G. (2005). Abundance and distribution of the round stingray, Urobatis halleri, near a heated effluent outfall. *Marine Environmental Research*, *60*(4), 437–453. http://doi.org/10.1016/j.marenvres.2005.01.003
- Jennings, D. E., Gruber, S. H., Franks, B. R., Kessel, S. T., & Robertson, A. L. (2008). Effects of large-scale anthropogenic development on juvenile lemon shark (Negaprion brevirostris) populations of Bimini, Bahamas. *Environmental Biology of Fishes*, 83(4), 369–377. http://doi.org/10.1007/s10641-008-9357-3
- Kingsford, M. J., & Welch, D. J. (2007). Vulnerability of pelagic systems of the Great Barrier Reef to climate change. *Climate Change and the Great Barrier Reef: A Vulnerability Assessment*, 555–592. Retrieved from http://elibrary.gbrmpa.gov.au/jspui/bitstream/11017/550/1/Chapter-18-Vulnerabilityof-pelagic-systems-of-the-Great-Barrier-Reef-to-climate-change.pdf
- Knip, D. M., Heupel, M. R., & Simpfendorfer, C. A. (2010). Sharks in nearshore environments: models, importance, and consequences. *Marine Ecology Progress Series*, 402, 1–11. Retrieved from

http://www.int-res.com/abstracts/meps/v402/p1-11/

Magiera, E. (2014). A quarter of sharks and rays threatened with extinction. Retrieved March 23, 2017, from

https://www.iucn.org/content/quarter-sharks-and-rays-threatened-extinction

- Mumby, P. J., Harborne, A. R., Williams, J., Kappel, C. V, Brumbaugh, D. R., Micheli, F., ... Blackwell, P. G. (2007). Trophic cascade facilitates coral recruitment in a marine reserve. *Proceedings of the National Academy of Sciences*, *104*(20), 8362–8367. http://doi.org/10.1073/pnas.0702602104
- Parker, S. (2008). The encyclopedia of sharks (2nd ed.). Buffalo, NY: Firefly Books Ltd.

- Perry, A. L., Low, P. J., Ellis, J. R., & Reynolds, J. D. (2005). Climate change and distribution shifts in marine fishes. *Science*, *308*(5730), 1912–1915. http://doi.org/10.1126/science.1111322
- Riegl, B. M., Purkis, S. J., Al-Cibahy, A. S., Abdel-Moati, M. A., & Hoegh-Guldberg, O. (2011). Present limits to heat-adaptability in corals and population-level responses to climate extremes. *PLoS ONE*, 6(9), e24802. http://doi.org/10.1371/journal.pone.0024802
- Robbins, W. D., Hisano, M., Connolly, S. R., & Choat, J. H. (2006). Ongoing collapse of coral-reef shark populations. *Current Biology*, *16*(23), 2314–2319. http://doi.org/10.1016/j.cub.2006.09.044
- Roff, G., Doropoulos, C., Rogers, A., Bozec, Y. M., Krueck, N. C., Aurellado, E., ... Mumby, P. J. (2016). The ecological role of sharks on coral reefs. *Trends in Ecology and Evolution*, *31*(5), 395–407. http://doi.org/10.1016/j.tree.2016.02.014
- Stewart, B., & Wilson, S. (2005). Threatened fishes of the world: Rhincodon typus (Smith 1828)(Rhincodontidae). *Environmental Biology of Fishes*, 74(74), 184–185. http://doi.org/10.1007/s10641-005-2229-1
- Stewart, R. (2008). Sharkwater. Montreal: Sharkwater Production & Diatribe Pictures.
- Thomas, C. D., Cameron, A., Green, R. E., Bakkenes, M., Beaumont, L. J., Collingham, Y. C., ... Williams, S. E. (2004). Extinction risk from climate change. *Nature*, 427(6970), 145–8. http://doi.org/10.1038/nature02121
- Valiela, I., Bowen, J. L., & York, J. K. (2001). Mangrove forests: One of the world's threatened major tropical environments. *BioScience*, *51*(10), 807. http://doi.org/10.1641/0006-3568(2001)051[0807:MFOOTW]2.0.CO;2
- Ward-Paige, C. A., Mora, C., Lotze, H. K., Pattengill-Semmens, C., McClenachan, L., Arias-Castro, E., & Myers, R. A. (2010). Large-scale absence of sharks on reefs in the greater-caribbean: A footprint of human pressures. *PLoS ONE*, *5*(8). http://doi.org/10.1371/journal.pone.0011968
- Wilson, S. G., Polovina, J. J., Stewart, B. S., & Meekan, M. G. (2006). Movements of whale sharks (Rhincodon typus) tagged at Ningaloo Reef, Western Australia. *Marine Biology*, 148(5), 1157–1166. http://doi.org/10.1007/s00227-005-0153-8
- Wilson, S. G., Taylor, J. G., & Pearce, A. F. (2001). The seasonal aggregation of whale sharks at Ningaloo Reef, Western Australia: Currents, migrations and the El Niño/ Southern Oscillation. *Environmental Biology of Fishes*, *61*(1), 1–11. http://doi.org/10.1023/A:1011069914753

Image Sources

Bali Animal Welfare Association (n.d.) Shark Finning [Digital Image] Retrieved from http://bawabali.com/our-programs/responsible-tourism/shark-finning/

Chin, A., Kyne, P. M., Walker, T. I., & McAuley, R. B. (2010). An integrated risk assessment for climate change: Analysing the vulnerability of sharks and rays on Australia's Great Barrier Reef. *Global Change Biology*, *16*(7), 1936–1953. http://doi.org/10.1111/j.1365-2486.2009.02128.x

Corbis. (2011). Spotted eagle ray [Digital image]. Retrieved from http://www.texascooppower.com/content/slideshow_1112_reef_ray.jpg

Giebel, T. (Photographer) (2006, April 28). Golden Cownose Rays (*Rhinoptera steindachneri*) [Digital Image] Retrieved from

https://commons.wikimedia.org/wiki/File:Rhinoptera_steindachneri.jpg Javier, L (Photographer) (2012 March 11). Bonnethead Shark at the Aquarium of the Pacific [Digital Image] Retrieve from

https://www.flickr.com/photos/lorenjavier/6831068402

Levy, E. (Photographer) (2014, August 13). Great White Shark [Digital Image]. Retrieved from https://www.flickr.com/photos/elevy/14730744390/in/photostream/ Nautilus Cruises (2010). Whale Shark at Gangehi Maavaru, inside the lagoon [Digital Image] Retrieved from https://www.flickr.com/photos/maldives-liveaboard/5178773258 Oldfield, M. (2009). A "walking shark" or epaulette shark [Digital image]. Retrieved from http://matthewoldfield.photoshelter.com/image?&_bqG=27&_bqH=eJxtT8tqwzAQ_Jr4b

BdMaUAHWbs2S2Kp0SPEpyVJWwKBhDxO_fpqTWhNW4FGM7M7kja1n.fnE58 b5vbtvih3G6i7blfvKz1_eplXZSk7IzEEo26H7fVYEAfQEWd10_ezGtTEABADYGI NeYkpZ7bxdxT_RvH_qKE4jI_FXBZiXLLRD0zBiXSe0OYaOSuSAntcog4ID_k61c H5qLy2i2KcjbUFdc88BfRMoJLMrVerzUd54eooH1iTj0kvWXdozSBNBZuGKV.co w.avqlvf2gvVJuobu_b6_5QrMd0N6IR_AJG7nCB&GI_ID=

Petersen, J. (2006, September 1). Taeniura lymma [Digital image]. Retrieved from https://en.wikipedia.org/wiki/Bluespotted_ribbontail_ray#/media/File:Taeniura_lymma2a.

jpg

Potenski, M. D. (Photographer) (2012). Juvenile lemon shark searches for a meal [Digital Image] Retrieved from

http://www.marinephotobank.org/resources/OIFcontestwinners2012_essays_Pot enski.php

Von Brandis, R. (n.d.). Nurse shark [Digital image]. Retrieved from

https://www.reference.com/pets-animals/many-teeth-nurse-shark-c6e4ea41671e79b0 Whitetip reef shark [Digital image]. (n.d.). Retrieved from

http://marinebio.org/species.asp?id=232

Wikimedia Commons (16 February 2017). Reef Building Coral Distribution Map [Digital Media] Retrieved March 25, 2017 from

https://upload.wikimedia.org/wikipedia/commons/5/58/Reef_building_corals.jpg Wikimedia Commons (n.d.). Leopard Shark [Digital Image] Retrieved from

https://upload.wikimedia.org/wikipedia/commons/0/07/Leopard_shark_%28Triakis_semi fasciata%29_01.jpg

Wikimedia Commons (n.d.). Red Mangroves [Digital Image] Retrieved from https://upload.wikimedia.org/wikipedia/commons/f/f0/Mangroves.jpg

Wikimedia Commons (n.d.) Urobatis halleri at the Frijoles dive site in Coiba National

Park, Panama [Digital Image] Retrieved from

https://upload.wikimedia.org/wikipedia/commons/thumb/e/e7/Urobatis_halleri.jpg/ 1200px-Urobatis_halleri.jpg

Whitetip reef shark [Digital image]. (n.d.). Retrieved from http://marinebio.org/species.asp?id=232