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Oceanic Top-Down Trophic Cascades and the Link to Anthropogenic Effects

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Oceanic Top-Down Trophic Cascades and the Link to Anthropogenic Effects

by

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Abstract

As the human population continues to grow, it has become obvious that we are changing Earth's ecosystems. These anthropogenic effects can create top-down trophic cascades throughout much of the Earth's ecosystems – including the oceans. The oceans and the species that reside there are of extreme importance to the human population because they provide food and are sources of income for much of the world. Due to this importance, there has been a growing interest in researching the anthropogenic effects on the oceans and their species. The purpose of this review is to examine the current understanding of some major species interactions in oceans and how declines in populations may affect the interaction dynamics between species now and in the future. Specifically, this review will examine how overfishing and climate change are generating top-down trophic cascades within the ecosystem. Finally, it will examine if there is anything that can be done to help stabilize cascades, such as implementing marine protected areas, allowing for the balancing of the ocean's ecosystems.

Introduction

Only about five percent of the earth's oceans have been explored, and even the parts that have been studied are far from being fully understood. It is known that the ocean is home to a wide variety of species ranging from plankton and other autotrophs to sharks and other top predators. The dynamics of many species interactions have only recently begun to come to light and are still challenging to observe. One major problem is that these interactions may be changing because of the rise or decline of certain species that are caused by various factors, many of which have anthropogenic origins. Many researchers have warned that inferences about natural trophic cascades could be hindered because many marine communities have already been overexploited

(Heithaus *et al*. 2008). Understanding not only how the ocean's many complex interactions function now, but how they may change in the future due to anthropogenic stressors is extremely important to understanding the balance and functioning of the ecosystem in the ocean.

Species interactions can be altered in several different ways, but two of the most dramatic are the relationship of the top predators or the primary producers with the rest of the food web. These changes are understood as top-down or bottom-up trophic cascades. Top-down effects produce a cascade in which the top predator (or a third or fourth-level consumer in the food web) is removed, causing a change in lower trophic levels of the food web. Bottom-up effects are those in which the primary producer or primary consumer population is altered, and this causes a change in higher trophic levels of the food web. The alteration of species population can happen in many ways. In many cases, however, humans and their actions are the cause of the changing populations. Overfishing and climate change are just a few anthropogenic effects that can change the ocean ecosystem.

Top predators have a major impact on controlling and maintaining a healthy ocean ecosystem. Without the ocean's top predators there to control growth, many other species would see a dramatic population increase, thus having a cascading effect on the ecosystem. This is the most common thinking behind top-down cascades, the idea of direct predation and prey release, where the reduction of top predators causes an increase in their prey's populations (Heithaus *et al*., 2008). However, another way that top predators can affect the environment is through risk effect, or the idea that a prey species will change its behavior (distribution, reproductive output, feeding habits) to avoid predation (Heithaus *et al*., 2008). Through both of these mechanisms, top predators play a key role in oceanic communities.

As of now, there has been very limited research into the consequences on food webs when the top predator is severely threatened or removed. Far fewer studies have been conducted on the gradual reduction of a species, which is much more realistic. In the studies that have been conducted, many focus on the effect of predator-prey interactions and how they are impacted when the top predator is declining or has been removed. This is partly because it is well known that the top predators are often the most affected and exploited species and that the top-down control they exert on prey species can significantly alter an ecosystem structure (Heupel *et al*., 2014). Within these studies, it is found that the removal of the top predator creates an almost direct pathway for the increase in its prey populations. Adam Rosenblatt and his colleagues said that, "The loss or diminishment of top-down control can have dramatic consequences on ecosystem structure and function because top predators help regulate population, community, and ecosystem dynamics through consumption of prey… (2013)" However, it has also been found that there is a non-consumptive effect of predators that may equal or exceed the impacts of direct predation (Heithaus *et al*., 2012). This is because direct predation results in direct mortality and therefore only removes a limited number of individuals from the population. Non-consumptive effects, in which predation has either a behavioral or physiological effect, can result in lower reproductive success or increased stress, and thus affect a larger proportion of the population (Heithaus *et al*., 2012). It has also been suggested that top predators may play a big role in ecosystem dynamics through nutrient cycling and transport and habitat connectivity (Rosenblatt *et al*., 2013).

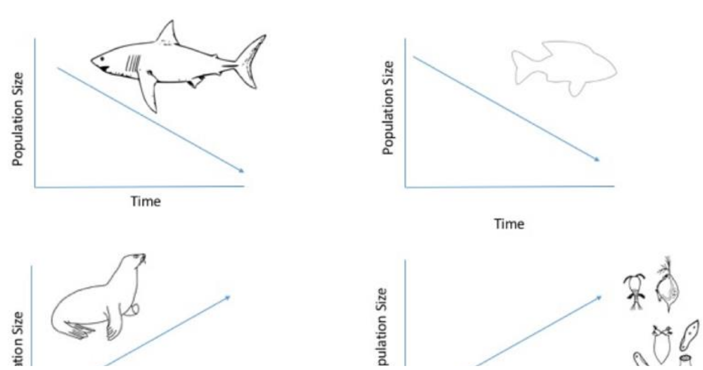


Image 1. Adapted from Heithaus et al, this image shows a top-down trophic cascade. Here the great white shark eats seals, the seals eat fish, the fish eat plankton. While not shown in the image, the plankton go on to eat zooplankton, and the zooplankton eat phytoplankton.

It has been found that the removal of top predators can not only affect the prey, but also consumer species at lower trophic levels as well (Heithaus *et al*., 2008; Image 1). The decline in top predators (in this case, sharks) causes an increase in mesopredators (seals), and thus a decrease in primary consumer species (fish), causing increase in plankton, which causes a decrease in zooplankton, and finally an increase in phytoplankton (one of the smallest organisms in the ocean). This example can be easily correlated to many other food webs, in which a top predator's population has declined, and the mesopredator therefore increases due to reduced predation, and the resource species declines because of increased consumption by mesopredators.

In many cases, the removal of top-predators, like sharks, is through overfishing by humans. Many large fish species are overfished because of their economic value, mostly being sold as a food source. Other large predators, such as sharks, are targeted for their fins or simply brought onboard fishing vessels as bycatch. Sharks and many other large fish species are seeing declines in population because of their slow reproduction cycle and the quick harvesting of their species (Stevens *et al*., 2000). Overfishing not only impacts the population size of the predator, but it also affects many other dynamics of the species. It is understood that an increase in mortality rate will favor an earlier sexual maturation at smaller sizes and an increase in reproductive effort (Jorgensen *et al.* 2007). These life-history traits are important for determining population dynamics and can systematically change predator-prey interactions, competitive interactions, and production of offspring over time (Jorgensen *et al.* 2007).

Climate change is another anthropogenic effect creating disruptions along the oceanic food web. It has been found that warming affects lower trophic levels and macro invertebrates much more than it does the upper trophic levels (Nye *et al*., 2013). However, it has been found that warming can induce body mass reductions in top-predators, which then go on to affect the body mass of lower trophic levels (Jochum *et al*., 2012).

This research paper will examine the following questions: does the removal of top predators, like sharks, create a trophic cascade in the oceans? How do anthropogenic actions alter the interactions of marine species? These questions will be answered by performing a literature review and meta-analysis. This review and analysis will provide the basis for understanding the importance of top predators in oceans and if/how humans are altering these ecosystems.

Methods.

Literature Review

A literature review will serve as the main source of information. A literature review is a widespread overview of prior research regarding a specific topic (Denney & Tewksbury, 2012). A synthesis will be completed containing research from various sources including: research papers, journal articles, textbooks, and other peer reviewed sources. The utilization of peer reviewed sources will ensure that the conclusions drawn from the research project are based on validated research and theories.

During the months of October-November 2016 the literature search was conducted using the bibliographic database, Web of Science. This aided in the identification of experiments and literature that dealt with trophic cascades in the ocean environment. Three separate searches were conducted looking at trophic cascades that may or may not have been induced by the removal of different top predators. The three searches were performed under the following conditions:

Search 1:
Condition: contains in title, abstract, or keywords: troph* casc* or top* effect* or pred* effect* and marin*, ocean* and shark*

Search 2:

Condition: contains in title, abstract, or keywords: troph* casc* or top* effect* or pred* effect* and marin*, ocean* and whale*

Search 3:
Condition: contains in title, abstract, or keywords: troph* casc* or top* effect* or pred* effect* and marin*, ocean* and tuna*

Within each of these searches, the articles were sorted based on relevance. Then the articles were examined manually to determine if the studies returned in the search were articles that examined trophic cascades within the ocean environment with the removal of the right top predator. For instance, some articles within Search 3 conditions did not examine what would happen to the ecosystem if tuna was removed, rather it looked at what was happening to tuna when there was an increase in bottom trophic levels (bottom-up cascade).

Meta-Analysis

A meta-analysis is a statistical tool that can be used to estimate the mean and variance of underlying effects from a collection of empirical studies addressing the same research question (Field & Gillett, 2010). The utilization of a meta-analysis will allow for conclusions to be made based from data that was collected across several different published studies.

For the purposes of this analysis, search 1 was the only one analyzed on the effects of top predator removal in the system, because the other two lacked sufficient data. Each article found under search 1 conditions were examined for the following information and the data was recorded: title, year, journal of publication, location of study, duration of the study, results (biomass of predator and prey), and anthropogenic effect (such as overfishing). Finally, the prey biomass was evaluated in control groups and experimental groups by estimating the effect of sharks on prey biomass using a log response ratio:

$$\ln(R) = \ln(X_e/X_c)$$

where X_e is the prey biomass in the presence of sharks, and X_c is the prey biomass in the reduced density or absence of sharks (Romero & Koricheva, 2011).

For the examination of whether trophic cascades were linked to anthropogenic effects, all three searches were analyzed.

Results.

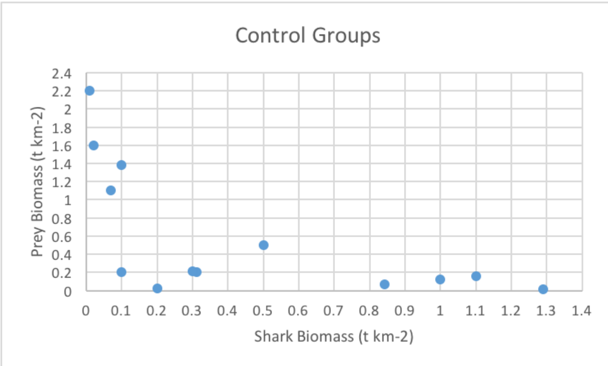
The three searches consisted of 33 articles, in which search one resulted in 13 studies, search two resulted in 11 studies, and search three resulted in nine studies. As previously mentioned, only the articles that were found in search 1 were used for the meta-analysis. While search 2 and 3 resulted in enough research papers, these papers lacked specific data that could be used for the statistical analysis, therefore no meta-analysis was conducted on those search conditions, but the research papers were still used for other data. Table 1 indicates the oceans that were studied in the 13 articles from search 1 and the sharks that were studied within these oceans.

Oceans Studied	**Sharks Studied**
Atlantic	Bull *(Carcharhinus leucas)*, Tiger *(Galeocerdo cuvier)*, Hammerhead *(Sphyrnidae)*, Mako *(Isurus oxyrinchus)*
Pacific	Tiger *(Galeocerdo cuvier)*, Great White *(Carcharodon carcharias)*, Pacific Blue

	(Prionace glauca)
Gulf of Mexico	Great White *(Carcharodon carcharias)*
Caribbean Sea	Blacktip *(Carcharhinus limbatus)*, Whitetip *(Triaenodon obesus)*

Table 1. Indicates the oceans and the sharks studied in all 13 studies from search 1.

It was found that when the biomasses of sharks were compared to the biomass of their direct prey in both the control groups and experimental groups there was a negative correlation (r = -0.36, p = 0.02 and r = -0.62, p = 0.21, respectively). This indicates that when the biomass of sharks increases, the prey biomass decreases, and vice-versa (Fig. 1). The control groups (Figure 1A) represent the biomass of sharks and their prey in their natural environment (the researchers took population samples from several locations varying naturally in shark population density). The experimental groups (Figure 1B) represent the biomass of sharks and their prey when the researchers manipulated population numbers either through laboratory experiments or through computer-generated models. The p-value for both the control groups and experimental groups were, 0.02 and 0.21, respectively. This indicates that the correlation coefficient (r = -0.36) found for the control groups ($p<0.05$) could not have been observed by chance. However, the correlation coefficient (r = -0.62) found for the experimental groups ($p>0.05$) may have been observed by chance.



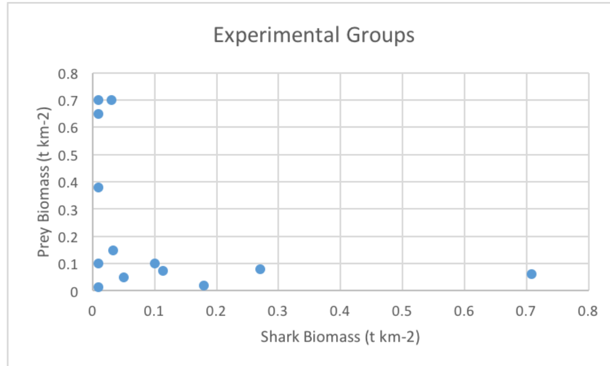


Figure 1A (left). Biomass of sharks and the biomass of their direct prey in control groups.
r = -0.36 and *p* = 0.02
Figure 1B (right). Biomass of sharks and the biomass of their direct prey in experimental groups.
r = -0.62 and *p* = 0.21

There was a difference in the average prey biomass before and after the reduction of shark biomass (Fig. 2). Within the 13 studies the average biomass of the shark's prey in the before was 0.24 t km-2, whereas the average biomass of the shark's prey in the after was 0.6 t km-2. This would indicate that when there is a decrease in shark biomass there is prey release, resulting in an increase in prey biomass.

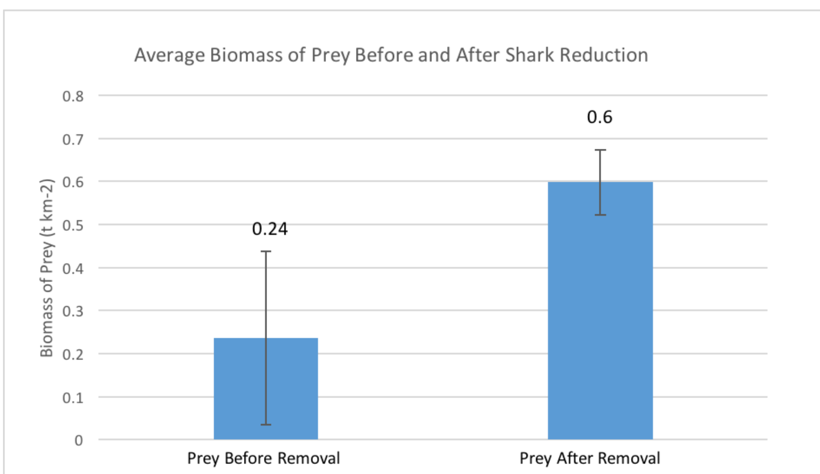


Figure 2. Average biomass of shark's prey before and after reduction of shark population densities.
Before Removal Standard Error = 0.2
After Removal Standard Error = 0.07

Finally, it was found that in 12 of the 13 studies, there was negative effect of shark predation on prey biomass (Fig. 3). This would indicate that shark predation has a negative effect on the fitness of shark's prey, it has a negative effect on the prey's biomass.

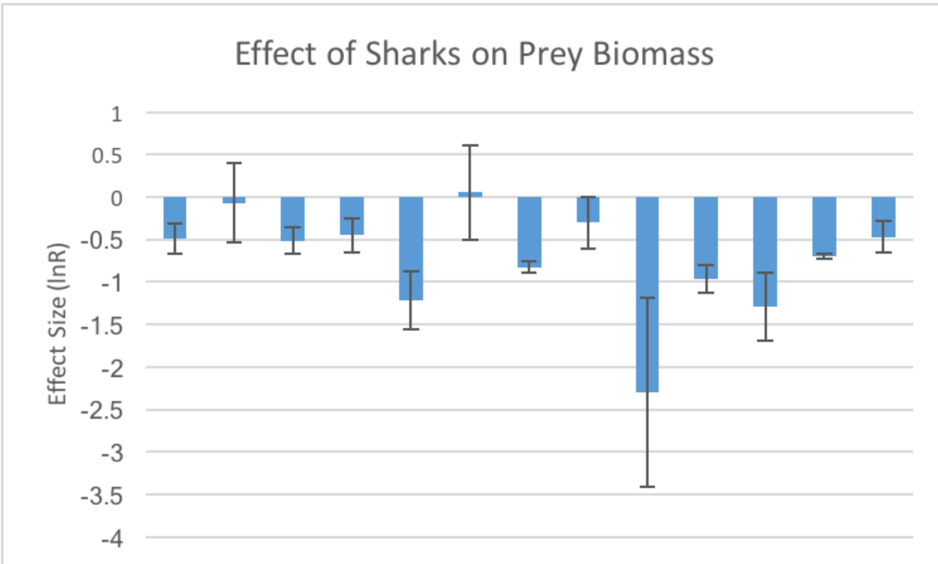


Figure 3. Effects (ln*R*) of shark predation on prey biomass from 13 trophic cascade studies.

An analysis of all 33 articles showed that 28 of these articles found trophic cascades that were produced by the reduction of the ocean systems' top predator and that these changes were the result of an anthropogenic effect, whether it was overfishing/overexploitation or climate change.

Discussion.

Overall, the evidence shows that top-down cascades occur when shark populations are reduced in oceans. This is indicated by the increase in prey biomass in the trophic level directly below the sharks (Fig. 1 & 2). While it was not examined in this research, it could be hypothesized that this, in turn, could cause population shifts in the trophic levels below. Similarly, while a meta-analysis was not performed on search conditions 2 and 3, there was a consensus in these papers that the removal of other oceanic top predators aside from sharks, such as whales and tuna, also induced a trophic cascade. For example, when killer whales are reduced within their system, there is an increase in the sea otter population. This increase causes a decrease in the sea urchin population which, in turn, causes an increase in kelp (Peckarsky *et al.*, 2008). Likewise, when tuna are reduced within a Pacific Ocean system, an increase in the squid population was seen (Hinke *et al.,* 2004).

Further support that top predators play a key role in the balancing of ecosystems can be seen by examining the effect of predators on their prey. It was seen in the analysis of sharks that there was a negative effect on prey. This means that the sharks are having a negative effect on their prey's fitness, or overall biomass. This could then be used to generate a hypothesis that when sharks are reduced within the system, there would be a lower negative or possibly positive effect on the prey biomass.

It can also be seen that this phenomenon is not held to just one specific location. As Table 1 shows, the studies analyzed show that this is occurring in many oceans with many different species of sharks. This indicates that anthropogenically induced trophic cascades are not restricted to one given area, but can span across many different systems.

A majority of these trophic cascades that are being seen in the oceanic environment are being induced by anthropogenic actions. Overfishing/overexploitation is the most common anthropogenic effect seen for these top predators. Many sharks are not necessarily fished for specifically - many are caught as bycatch meaning they are accidentally caught in nets and brought on board fishing vessels. This is not always the case though, it is also known that some species of sharks are specifically sought after for their fins, which then are sold for shark fin soup. Several species of sharks are also caught because of a general fear of sharks. In many countries that rely on the ocean for tourism, like Australia, there is legislation that allows for the killing of large sharks because it is thought this will lessen the case of shark attacks. Whaling is the largest problem in the past and currently for whale species (Ruegg *et al.,* 2010). Many whale species have already seen major declines in population size because of whaling in previous decades and while many countries have banned whaling, it is still a problem that is currently happening (Ruegg *et al.,* 2010). Overfishing can most clearly be seen for fish species like tuna. Tuna and many other fish species provide a vital food source to many communities and are sold commercially across the world. This has led to a large amount of fishing vessels overfishing several specific species. Tuna species are currently seeing major population declines because of the unsustainable amount of fishing that is occurring (Griffiths *et al.,* 2010).

Climate change is more of a problem for primary producers, but it still has effects on top predators. Higher temperatures have altered the timeframe for embryonic duration, hunting behavior, food consumption rates, and growth of some shark species (Pistevos *et al.,* 2015). This not only directly affects the predator population but also the prey population as well. It was found that in increased water temperatures, sharks increased their food consumption (Pistevos *et al.,* 2015). This would indicate that as the ocean warms due to climate change, sharks and potentially other predators, may increase the amount of prey they consume, thus lowering the overall biomass of that prey even further.

While some populations are heading towards mass extinction there are actions that can be taken to aide in the process of reestablishing these populations. For example, one way that humans can maintain the balance of the oceanic food web is through marine protected areas (MPAs). MPAs are boundaries of the marine environment that are partially managed for marine conservation (Edgar *et al*., 2007). These MPAs could be placed in important areas for certain populations, such as mating grounds or migration routes. This would create zones where fishing and recreational activities are not allowed and thus create an area where that species could flourish. Another action that could be taken is to establish fishing restrictions and/or subsidies. This would allow for the reestablishment of species that are seeing mass extinctions without hurting the fishing industry and the people who rely on it for a living. Finally, there will be a need for legislation to address climate change. Anthropogenic actions have ensured that effects of climate change will continue to be felt and likely worsen, and it is very challenging to undo what has already been generated. The best course of action is to now lessen the effect that humans are having.

Conclusion.

The evidence provided here indicates that the reduction of the ocean's top predators does induce a trophic cascade. When sharks are reduced from a system, prey biomass increases. This, in turn, could cause an increase and/or decrease in biomasses of other species throughout the food web. The evidence also supports the idea that many of these trophic cascades seen today are being induced by anthropogenic effects, such as overfishing and climate change. These problems need to be addressed through different means, whether that is establishing MPAs, fishing restrictions/subsidies, or enacting legislation. These various conservation efforts could become essential to the survival of many key ocean species and thus the balancing of the oceanic ecosystem.

Future studies should continue to observe the different interactions between predator and prey in the ocean ecosystem. This research could then extend into examining what would happen to these interactions if the predator were to be removed from the system. Understanding these possible interactions could allow for the protection of marine species now and in the future.

Maintaining the balance of the oceanic food web is critical to keeping a healthy ocean. This maintenance is important for several reasons. The balancing of the food web is important to humans because many of us rely on the ocean for food. Alterations of the food web can cause an increase or decrease in some species and thus create an imbalance. It is also important to maintain the oceanic food web simply because it is not fully understood. The changing of the species interactions may have cascading effects that we do not even know exist yet. As a whole, the human population will need to asses their impact on environments and then change their practices if they hope to continue to sustainably utilize these resources.

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