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Lily Haug
Portland State University

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**A review of current sea cucumber and *Apostichopus californicus*
knowledge and a proposal for future research and fishery
management**

by

Lily Haug

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requirements for the degree of

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Thesis Adviser

Dr. Susan Masta

Portland State University

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Abstract

The sea cucumber species *Apostichopus californicus* is fished in the Pacific Northwest region of North America and has the potential to be an economically beneficial fisheries species. An understanding of their population levels must be present to sustainably regulate their harvest. Current fisheries in North America vary in their methodology and level of regulation. The current regulations are presented and their strengths and shortfalls are described. This review gathers research done on tropical sea cucumber species and presents that knowledge alongside that regarding *Apostichopus californicus* to suggest future research and fishery management strategies. *A. californicus* takes four years to sexually mature and their juvenile survival rates are unknown, so fisheries need to implement strategies that allow adequate time for populations to recover and reproduce. Additionally, strict quotas on the total biomass that can be removed each fishing season need to be set by fisheries. A sustainable fishery can provide many jobs and serve as a sustainable alternative to unsustainable fished species.

Background

Sea cucumbers are eaten around the world, particularly in countries in Asia. In the Pacific Northwest of the US, the species *Apostichopus californicus* is fished, consumed, and exported (Whitefield and Hardy, 2019). Although this species is consumed both in the US and in other countries, very little research on their life history and population status has been done. The current understanding of this species is primarily inferred from research on tropical sea cucumber species. While that information is a useful starting point, it is important that further research on *Apostichopus californicus* is conducted to develop a better understanding of this economically important species.

While studies of the life histories of sea cucumbers are lacking, methodologies for how to study sea cucumbers have been published. Suggested methods for data collection involve photography analyses, weight and length measurements, and population density measurements in various habitats (Harper et al, 2020). This sort of study has been done in Alaska and in British

Columbia but not in the Washington area (Whitefield and Hardy, 2019). Conducting such studies will allow for better conservation and fishing of this species.

Research Objective

Few studies have been done on *Apostichopus californicus*. This review seeks to compile what is known about the species and about the broad category of sea cucumbers. Understanding their life histories and reproductive rates can allow for better conservation and more efficient fishing practices that protect populations and support coastal communities. This paper includes a wide range of what is known about sea cucumbers and the small amount that is known of *Apostichopus californicus*. The information presented includes life history, their history with humans, catch records from North American fisheries, study methods, and their economic benefit. This range of studies can be used to inform future research.

***Apostichopus californicus* Description and Biology**

Classification

Apostichopus californicus was first described in 1857 by William Stimson and was originally named *Holothuria californica* (Stimson, 1857, p. 84). It is in the phylum Echinodermata, class Holothuroidea, and family Stichopodidae. It was later placed in the genus *Parastichopus* (Lambert 1997) but has since been moved to the current accepted genus *Apostichopus*.

External Anatomy

Sea cucumbers generally look like cylindrical tubes lying on the ocean floor. Some species are covered in papillae or spine-like structures. Typically, they have five rows of podia (tube feet) along their length. The anus is located on the posterior end and the mouth and feeding

tentacles are on the anterior end. Sea cucumbers do not have skeletons. Instead, they have ossicles made of calcite that form a soft skeleton-like structure (Lambert, 1997, p. 3-4).

Apostichopus californicus is typical of its genus. Its shape is an elongated tube and it has five rows of podia. This sea cucumber is dark red with bright orange spikes dotting its body. These “spikes” are actually modified podia. The contrasting colors likely warn off potential predators (see figure 1). The feeding tentacles in a ring around the mouth have a pelate shape (see figure 2), acting as a mop that moves along the ocean floor.



Figure 1. *Apostichopus californicus* individual, photograph by pfly, distributed under a CC-by-sa-2.0 license.

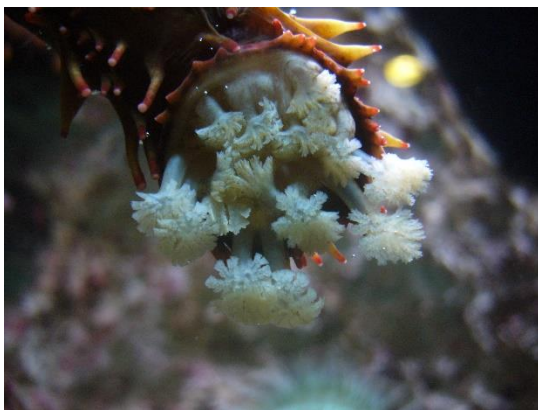


Figure 2. Pelate mouth tentacles of *A. californicus*, photograph by Fernando Losada Rodriguez, distributed under the Creative Commons Attribution-Share Alike 4.0 International license.

Internal Anatomy

Echinoderms are classified based on three characteristics: pentaradial symmetry, a water-vascular system for muscle movement, and an internal calcite skeleton (Lambert, 1997, p. 3). Sea cucumbers possess pentaradial symmetry that is evident when studying the five rows of podia. Their calcite skeletons are composed of ossicles that are secreted from sclerocyte cells, and they come in different shapes and sizes. These differences can be used to distinguish between morphologically similar sea cucumber species. *Apostichopus californicus* possesses “table-shaped” ossicles that are around 100 μm in diameter (see figure 3) (Lambert, 1997, p. 12). One suspected function of these ossicles is to protect the vulnerable juvenile sea cucumbers from predators when they float in the water column before settling. In many species, these ossicles morph into simpler forms as the animal matures.



Figure 3. Photo of *Temparena trouspetita* table-shaped wall ossicles, which are the same shape as *A. californicus*, photograph from Thandar’s 2018 paper “On some miscellaneous sea cucumbers (Echinodermata: Holothuroidea) in the collections of the South African Museum with three new species,” published in *Zootaxa*, distributed under the Creative Commons Attribution 3.0 Unported license, cropped to only show table-ossicles.

The one hard part of a sea cucumber is the calcareous ring around the neck area surrounding the esophagus. The ring is formed out of hardened plates and longitudinal muscles attach to it. This can be used to distinguish between different species and is generally the only part of the animal that fossilizes (Lambert, 1997, p. 10).

As is characteristic of echinoderms, sea cucumbers have five bands of longitudinal muscles as well as circular muscles. At the posterior end of the animal are muscles attached to

the cloaca and the respiratory tree. The circular muscles around the anus contract to push water through the tree to provide oxygen which is then transferred into the body fluids of the animal. Once the oxygen has been used, the circular muscles surrounding the anus relax and allow the water to flow out.

The esophagus is located just behind the mouth of the animal. It is surrounded by a ring canal which connects to five radial canals that connect to the five rows of podia. A nerve ring is present around these features and several ganglia sprout from it. A nerve net is present in the skin for chemosensing and tactile sensing (Lambert, 1997, p. 9-10).

Sea cucumbers do not possess hearts and therefore do not have circulatory systems. The movement of oxygen from the respiratory tree occurs via diffusion, and the movement of blood through the rete mirabile (blood channel system) occurs via the contraction and relaxation of circular muscles in the coelom. Sea cucumbers also possess hemoglobin which bring oxygen from the environment into the body cavity (Lambert, 1997, p. 10).

Locomotion

Apostichopus californicus is one of the sea cucumber species that must keep moving to find food. To accomplish this, it contracts and extends its longitudinal and circular muscles. This wave-like motion is common in other invertebrates and allows the sea cucumber to slide across the ocean floor. They can move up to 3.9 meters a day along the ocean floor in search of food (Lambert, 1997, p. 34).

Life Cycle and Reproduction

Apostichopus californicus is gonochoric and both sexes reach sexual maturity at four-years-old and approximately twenty-three centimeters in length. Reproduction occurs via

spawning into the water column. Individuals move to shallow water during their non-dormant months (April through August) and rise part way off the seafloor to release their gametes into the water column. These gametes are released through an external gonopore that is located near the mouth tentacles. Females release orange eggs and males release white sperm, and fertilization occurs when the gametes meet. The larvae that form live in the water column eating plankton for thirty-five to fifty-two days before settling on the seafloor where they mature (Lambert, 1997, p.34).

The eggs that are released by *Apostichopus californicus* turn into larvae via indirect development. The first step in this development is the auricularia stage. In this stage, the animals' organs are rearranged and they morph into juvenile larvae. Once the juveniles are big enough, they sink to the bottom and settle, developing into adults over time and behaving as adults do in terms of feeding and predation avoidance. The IUCN lists the lifespan of *Apostichopus californicus* as up to twelve years. This indicates a potential for many spawning events throughout an individual's lifetime.

Predators

The only known predator of *Apostichopus californicus*, other than humans, is the sunflower star (*Pycnopodia helianthoides*) (Lambert, 1997, p. 34). These seastars live in the Northeastern Pacific Ocean in coastal waters and prey on invertebrates with little discrimination (Brewer and Konar, 2005). In response to a nearby sunflower star, *Apostichopus californicus* will violently contract its muscles and rear up and occasionally roll away from the predator (Lambert, 1997, p. 18).

Food and Feeding

In their active months, *A. californicus* feed by moving through benthic environments using their pelate mouth tentacles to pick up food. These tentacles excrete mucus and the sediment sticks to them. The animal then retracts its tentacles and processes the organic matter out of the substrate in its digestive system, excreting the inorganic material like sand through the anus. The organic matter they consume includes bacteria and fungi (Lambert, 1997, p. 34).

History

Sea cucumbers have been consumed and used as medicine in Asian cultures for thousands of years. In China, they have been consumed since the Three Kingdoms Period which ended in the 30th century BC (Yang et. al, 2015, p. 7). It was believed that consuming their gonads and intestines regulates “heart, kidney, and lung activities; promotes spermatogenesis; cures impotence; enriches blood; normalizes menstruation; and strengthens waist and legs” (Yang et. al, 2015, p. 8). In folklore they have also been known to possess magical healing capabilities. These supposed benefits increased ancient Chinese demand for sea cucumbers and they became a mark of status. *Apostichopus japonicus*, a species from the same genus as the focus of this review, was deemed to be the most tasty and beneficial and was thus the most expensive in ancient dynasties.

Today, sea cucumbers are not seen as possessing magical healing qualities, but their health benefits are still appreciated in many Asian countries. Their gonads and intestines are marketed as high-end health food items and research continues to be conducted on their various medicinal and culinary benefits (Yang et. al, 2015, p. 9). Additionally, their harvest in developing countries supports local and national economies and creates jobs. Because of the high

demand for sea cucumbers, many countries are fishing various species to export, including the United States and Canada.

North American *Apostichopus californicus* Fisheries

In the United States, Alaska, Washington, Oregon, and California fish *Apostichopus californicus* commercially, as does British Columbia, Canada. Each state regulates their fishery differently and has different requirements for recreational versus commercial fishing. This section will describe the regulations put in place by each region and provide catch numbers when available.

British Columbia, Canada

There is a strong *Apostichopus californicus* fishery in British Columbia, Canada, that is regulated by the government under the Integrated Fisheries Management Plan. The fishing season is only eight weeks long to limit the number of individuals that can be caught in one year. Approximately thirty vessels are certified to fish them every year, and the required catch method is SCUBA diving to hand-pick them. To catalogue the number of sea cucumbers caught, fishermen are required to have licenses and report their numbers to the government. This is occasionally enforced by dock-side regulation (Government of Canada, 2021).

There are no limits on the number of sea cucumbers that can be caught every year, but the Government of Canada does keep a detailed record of the number of individuals and the total mass caught. From 2016 to 2020, the average total metric tonnes of sea cucumbers caught and recorded per year was 1,664.4 (~3,669,373 lbs), with the lowest year being 2015 with 1,582 metric tonnes (~3,487,713 lbs) caught and the highest year being 2017 with 1,736 tonnes (~3,827,225 lbs) caught (Government of Canada, 2016-2020). The numbers do not fluctuate

greatly between each year, but there are no quotas enforcing them. This could potentially lead to an increase in catches if the demand for sea cucumbers increases.

Alaska, United States

The regulations on sea cucumber fishing in Alaska are stricter than in all other locations described in this review. There are limits on who can fish, how sea cucumbers can be taken, how many can be taken, when they can be taken, and where they can be taken. Only those with permits can catch them and they must do so using the SCUBA diving and hand-picking method. The coastal regions in Alaska are divided into fishing zones. Each zone is only allowed to be fished for sea cucumbers once every three years to allow the populations to recover in the intervening years. Additionally, sea cucumber harvest can only occur between October 1st and March 31st of every year (Alaska Department of Fish and Game, 2005). The Alaska Department of Fish and Game reports the harvest guidelines and the actual landings, as well as the average price per pound of sea cucumber. Additionally, they report the average earnings each diver makes that year on the sea cucumber harvest.

Alaska reports their sea cucumber landings by fiscal year. From the 1988-1989 fiscal year through the 2019-2020 year, the total catch exceeded the guidelines all but eight years. Every year from 2015-2016 to 2019-2020, the guidelines were exceeded by the actual catch. The range was 1,295,802 lbs to 1,994,999 lbs, with a mean of 1,581,397.80 lbs. The price per pound of sea cucumber ranged from \$3.37 to \$4.41. Over the past thirty-two recorded fiscal years, the price per pound has generally increased each year with a few exceptions (Alaska Department of Fish and Game, 1988-2020).

Washington, United States

Washington also has regulations on sea cucumber harvest but does not catch as many as Alaska or British Columbia. The Washington Coast, Puget Sound, and Hood Canal are split up into zones for fishery management. Some zones are excluded during the harvest season to allow populations to recover. Fishermen are required to have permits to catch sea cucumbers and must do so via SCUBA diving. It is illegal to have a geoduck clam in one's possession at the same time as a sea cucumber, preventing the two from being harvested at the same time (Washington State Legislature, 2022).

The Washington Department of Fish and Wildlife sets quotas on annual sea cucumber harvest and reports those along with the actual landings by zone every year. In the 2021-2022 year, the total quota for all zones was 233,422 lbs and the actual landings were 233,518 lbs (Washington Department of Fish and Wildlife, 2022). Not all zones are available to fish every year, contributing to the relatively low number of sea cucumbers caught compared to other states.

Oregon, United States

While Oregon does have a sea cucumber fishery, it is small and regulated with the sea urchin fishery. Fishermen must possess a permit to possess or harvest sea cucumbers and they must be caught via one person from one boat SCUBA diving and hand-picking them. Additionally, they cannot be taken at a depth shallower than ten feet below the average water line (Oregon Secretary of State, 2012). The state does not report the number or weight of sea cucumber catches because it is so minimal every year (personal communication from Nadine Hurtado, Oregon Department of Fish and Wildlife, 2021). The Oregon Department of Fish and Wildlife recently drafted a sea cucumber fishery book submission and stated that from 1993 to

2021, 14 metric tonnes (30,864.7 lbs) were landed in total. This is less than the yearly catches for all other areas studied.

California, United States

Because California is a large state, different regions of coastline have different sea cucumber harvest methods. However, throughout the state the regulations are very minimal and the consequences for overharvesting are unknown. Hand-picking while SCUBA diving occurs in the Northern stretch of the coastline between Bodega Bay and Fort Bragg. They are caught alongside the halibut fishery so are harvested via bottom trawling from Point Conception to San Diego with a concentrated fishery off of Santa Barbara. Trawling is allowed year-round and there are no limits on the number of sea cucumbers that can be caught. Additionally, California does not have any methods in place to track the impacts fishing has on sea cucumber populations.

The annual commercial harvest of sea cucumbers is recorded on the California State Government website. From 1980 to 1986, only one commercial fisherman trawled for sea cucumbers. However from 1987 to 2019, this number has increased and fluctuated. The highest number of commercial fishermen participating in the sea cucumber trawling industry was seventy-one individuals in the year 1991 and they harvested 411,310 lbs. Landings eb and flow from year to year as populations are decimated and slowly recover, but overall there is a trend towards a more reduced harvest (California Marine Species Portal, 2020). This could be due to lack of participation or lack of sea cucumber availability.

Existing Research

Biology

A study was conducted in Alaska by Whitefield et al. in 2019 on *Apostichopus californicus* populations in Southeast Alaskan waters. The goal was to determine fecundity and the timing of reproduction of these animals in controlled fisheries settings versus natural settings (Whitefield et al. 2019). To do this, the researchers initiated strip spawning in the lab. In this process, sea cucumber gonads were soaked in a chemical that caused the release of gametes. Because the chemical breaks down the outer wall of the gonad, this causes all of the eggs to be released, even if they are not ready to be fertilized. This study compared fecundity from in-situ strip spawning and ex-situ natural spawning to determine which one would be more efficient in fisheries.

This study found that there was no statistically significant difference between the fecundity of females who were strip spawned versus those in which natural spawning occurred. However, those that reproduced via live-spawning yielded larger eggs. Additionally, it was found that the gonad weights were higher in April and June than any other month out of the year. This differs from a study done on *Apostichopus californicus* in British Columbia that found that the populations in that area spawned later in the Summer (Whitefield et al. 2019). This Alaskan study adds to the field of research on how sea cucumbers reproduce. In the past, fisheries of this species have been hindered by low fecundity of the sea cucumbers, so this knowledge could be used to make fisheries more sustainable and profitable (Whitefield et al. 2019).

Fisheries

Much of the research that has been done on sea cucumbers focuses on tropical species and their relationship to fisheries. One such study conducted by Li et al. (2020) focused on *Apostichopus japonicus*, a sea cucumber that has a similar shape to *Apostichopus californicus* and lives in benthic areas around Japan. The goal of the study was to determine the optimum amount of carbohydrates (CHO) this species should consume in fisheries. This was based on the growth rate as determined by mass and length and their tolerance to low salinity or high temperature stress. It was found that sea cucumbers fed with 192.5-316.8 kg/g of CHO over the course of sixty days were more tolerant to low salinity and high temperature (Li et al. 2020).

Another example of research done on a fisheries species was conducted by Harper et al. (2020) in Canada on the species *Cucumaria frondosa*. This species lives in the Atlantic Ocean along the North American coast from Cape Cod, Massachusetts to the Arctic and along the Western European coast (Harper et al. 2020). This study analyzed different data collection methods for this sea cucumber species. These include means of measuring mass, length and population density. The authors describe and test different methods and explain the advantages and disadvantages of each one. A method of data collection was considered advantageous if it was non-invasive to the animal and gave information related to the sexual maturity of the animal. They found that measuring the wet weight of the animal was more efficient for determining sexual maturity than measuring the split weight, which was measured by splitting the animal in half and draining it of fluids before weighing it (Harper et al. 2020). In addition, they found that using cameras with narrow beams while diving can be effective in measuring the length of individuals. The knowledge gained in this study can be applied to future research conducted on

Apostichopus californicus and on any other sea cucumber species to safely study these animals without disrupting their populations by killing them.

Economic Value

Various sea cucumber species are harvested around the world. It has been found that over seventy countries harvest sea cucumbers, and sixty-six known species are caught (Nishanthan et al. 2019). Generally, they are exported to Hong Kong who exports them to various other Asian countries where they are consumed. Sea cucumbers are commonly harvested by SCUBA or skin divers. A small percentage of harvested individuals are also collected via gleaning, the process of walking along a beach at low tide and picking up individual animals (Nishanthan et al. 2019). This method of harvesting requires a level of high employment in sea cucumber fisheries. Ninety percent of these fisheries are located in developing countries where well-paying jobs can be scarce, and it has been found that sea cucumber fishermen are able to sustain themselves and families on income from this trade (Eggertson et al. 2020). Therefore, there is a high economic incentive for maintaining healthy sea cucumber fisheries.

Most studies on the economic value of sea cucumbers have been conducted on Asian countries due to them being the predominant importers and exporters of sea cucumbers. One such country is Sri Lanka. While sea cucumbers are not consumed there, they are fished by many people as a primary income source (Nishanthan et al. 2019). A study was conducted in Sri Lanka by Nishanthan et al. (2019) to determine sea cucumber fishers' levels of satisfaction with fishery management and to understand how the industry has shifted due to management methods. The sea cucumber industry follows a chain of operations, beginning with the fisherman who sells sea cucumbers to a middle-man who sells them to an exporter. The study found that the exporters can make 200% more than the fishermen for the same amount of sea cucumbers (Nishanthan et

al. 2019). Despite this, many fishermen reported being satisfied with the buyers and management (Nishanthan et al. 2019). Based on the profit that individual fishermen make from their trade, this study determined that sea cucumber fisheries can be economically beneficial for all involved in the chain of operations. This heightens the need for sustainable management practices.

In addition to surveying fishermen to determine their satisfaction with buyers, the researchers asked them to describe the changes they have seen in sea cucumber populations and how management of the fishery has handled those changes. Those who harvest via SCUBA diving indicated that populations decreased in number and body mass and relocated to deeper waters farther offshore, resulting in more time and energy required to harvest sea cucumbers at the same rates as previous years (Nishanthan et al. 2019). When asked how satisfied these divers were with current management practices, they responded with “dissatisfied” (Nishanthan et al. 2019). The high volume of fishing and the low level of management has caused sea cucumber populations to become overexploited. Fortunately, Sri Lanka currently manages the fisheries on a regional rather than national level, meaning there is a possibility of concentrated management strategies that may curb the negative effects of overexploitation. Doing so would preserve healthy populations and allow fishermen to continue sustaining themselves on their income.

Another study compared two different sea cucumber fishery management methods in Mayotte and Zanzibar. In these two regions, three different sea cucumber species are fished under vastly different management strategies. The goal of the study was to assign economic values to the different species fished in each region and determine how management of fisheries could affect them (Eggertson et al. 2020). The fishery in Mayotte is more strictly managed than the one in Zanzibar due to the protected status of sea cucumber species in the large reef systems offshore. Because these reefs are protected, taking sea cucumbers from them is banned, lessening

the amount of fishing done in systems determined to be susceptible to overfishing. In Zanzibar, commercial fishing has occurred since the 1960s with little regulation, causing populations to be exploited (Eggertson et al. 2020).

Eggertson et al. (2020) determined that the value of an individual sea cucumber in regions with more regulations on sea cucumber fishing was over three-hundred times higher than the value of those in unregulated areas (Eggertson et al. 2020). Higher regulations increased the demand for sea cucumbers because fewer were taken, thus increasing their market value. In addition, well-managed fisheries were more sustainable in the long run. While there was room for improvement in the Mayotte management strategy, the authors noted that it better allowed for the recovery of overfished stocks than the less-managed Zanzibar fisheries. The authors identified several factors of sea cucumber individuals and fishing that determine the possibility of recovery from overexploitation. These include recruitment success, mortality of individuals, the connectivity of different populations, the time spent fishing, and the volume of fishing (Eggertson et al. 2020). Based on their data, Eggertson et al. (2020) stated that fisheries with sustainable management strategies were more economically beneficial in the long run than fisheries that allowed near-unlimited take of sea cucumbers due to the resulting increase in market value and long-term population stability.

Human Impacts

It has been alluded to that some sea cucumber species are being overexploited by fisheries because of their high demand in Asian countries. Humans have a long history of overexploiting natural resources, and the pattern continues with sea cucumbers. A 2019 study by Rawson and Hoagland analyzed the way market demand impacts sea cucumber values and fishing rates. The goal was to determine what factors motivate fishers to exploit sea cucumber

populations. They found that when the market value of a sea cucumber increases, the fishing rate and exploitation follows (Rawson and Hoagland, 2019). Combining the results of this study with those from the 2020 study by Eggertson et al. described in the previous section, it can be determined that the overexploitation of sea cucumbers causes a boom and bust pattern in market value and population size. This cycle begins with a demand for sea cucumbers and a high market value for them. This motivates a high rate of harvest. As this occurs, the market is flooded and the value of sea cucumbers goes down, causing the harvest of the to slow. Then, when fewer individuals of the species are present in the market, demand, and price increases again and the cycle continues. As the cycle continues, however, the same sites and populations of sea cucumbers get repeatedly exploited without adequate time for them to recover. This leads to what Rawson and Hoagland call “serial exploitation,” a pattern of human exploitation of natural resources that gets worse and worse over time (Rawson and Hoagland, 2019).

Aside from continual exploitation of sea cucumber populations, humans have also impacted the health of many species. With the increase in waste and pollution that humans produce on a global scale, more marine creatures are being negatively impacted by plastic. Little work has been done on how the ingestion of macro and micro plastics has impacted sea cucumbers (Coc et al. 2021). Because they are deposit feeders who ingest and process a large amount of inorganic material in order to consume nutrients, they are at a great risk of ingesting microplastics and other pollutants that have fallen to benthic ecosystems. Sea cucumbers are indiscriminate feeders so will consume whatever sediment or particles are before them in order to receive nutrients (Coc et al. 2021). A 2021 study by Coc et al. sampled the digestive tracts of *Holothuriidae floridana* individuals from a lagoon in Belize where solid waste is dumped directly into the water. They found that individuals had a mean of 8.4 with an error range of +/-

4.5 different plastic particles in their digestive tracts (Coc et al. 2021). Additionally, they found that some individuals had microplastics in the tissues of the digestive tract walls. This not only poses a problem to the health of the animals but to humans who consume them. Sea cucumber intestines are consumed in many Asian countries so there is a risk of consumers ingesting dangerous microplastics and chemicals.

Human Uses

In addition to studies on the economic value of sea cucumbers, research has also been done on the medical and nutritional benefits of various species. In past years, fungi from marine sources have been used in medical research because antibacterial compounds can be derived from some strains (Qi et al. 2020). A recent study conducted by Qi et al. (2020) isolated the *Trichoderma* fungus strain from a sea cucumber in the Yellow Sea and derived four antibacterial compounds from it. The researchers tested the four compounds against four different marine pathogenic bacteria and found that two of them were successful in warding off the pathogens (Qi et al. 2020). This research demonstrates the immense potential of sea cucumbers in the medical field.

The primary use of sea cucumbers by humans is as a food source. They are eaten in many Asian countries as both delicacies and street food. Studies that have been done on their nutritional value have focused on genera that are more commonly harvested than *Apostichopus californicus*. One such study focused on *Holothuria tubulosa*, a species native to the Atlantic Ocean (Zmemlia et al. 2020). Researchers analyzed the edible tissue of these animals and found that they are both nutritionally and pharmaceutically beneficial. They contain healthy levels of lipids, proteins, and omega 3, a substance that humans do not produce. Additionally, they contain

substances that can act as aspirin if isolated. They also contain EPA+DHA, a substance that has been known to prevent the spread of some cancers, cardiovascular diseases, and arthritis (Zmemlia et al. 2020). The biologists concluded that more research needs to be done on antioxidant potential of sea cucumbers but stated that they are nutritionally beneficial to humans.

Areas Where Further Research is Needed for *Apostichopus californicus*

The above section covers the scope of research done on sea cucumber species around the world. Most research focuses on species in Asia but should be replicated for *Apostichopus californicus*. Thanks to Lambert's work, the basic biology of this species is understood. However, recent research has focused on populations in Alaska or British Columbia and not in Washington, Oregon, or California. Such studies should be replicated with the populations there to determine if a fishery in those areas would be feasible. Additionally, studies that focused on the medicinal and nutritional benefits of tropical sea cucumber species should be replicated on *Apostichopus californicus*. Understanding their health benefits may incentivize the development of sustainable fisheries. Based on this, the pieces of data that are missing in the field of knowledge of *Apostichopus californicus* are their nutritional value, their medicinal value, their population dynamics in Washington, Oregon, and California, and their reproductive life histories in those regions.

Suggested Future Research

As described in the previous section, many studies have been done on sea cucumbers in tropical settings. Because they have been shown to be a successful and economically beneficial fisheries species, it is wise to study *Apostichopus californicus* in the Northeastern Pacific to determine if they are a viable and economically beneficial food source.

An important piece of data that is missing from the knowledge of *Apostichopus californicus* is the way populations in Washington, Oregon, and California reproduce. Understanding their reproductive timing is crucial for developing sustainable fisheries. The 2019 study by Whitefield et al. described in the previous section should be replicated in these regions. In addition, thorough population surveys should be done determine the health of *Apostichopus californicus* in the area.

Medical research and pharmaceuticals is another potential usage of sea cucumbers by humans. The study conducted by Qi et al. demonstrates the potential for sea cucumber individuals to contain fungal strains that can possess antibacterial properties. This study was conducted on a species in the Yellow Sea. Replicating it with *Apostichopus californicus* would identify the potential use for this species in the medical field. If it is possible to derive antibacterial compounds from them, fisheries or farms could be used for both consumption as food and medical research and development.

Sea cucumbers also have nutritional benefits. Throughout Chinese history, *Apostichopus japonicus*, a species in the same genus as *Apostichopus californicus*, has been viewed as nutritionally beneficial (Yang et al. 2015, p. 4). They contain high lipid and protein concentrations and omega 3. Different species have different levels of nutrients, so research needs to be done on *A. californicus* to determine if they are nutritionally beneficial enough to raise them as fishery animals.

Li et al's study demonstrated that the carbohydrate CHO can be a substitute for protein-based aquafeed in sea cucumber fisheries. It is cheap and has a high nutritional value and thus when given to sea cucumbers in the correct quantities can yield high growth rates and tolerance to environmental stressors (Li et al. 2020). This study should be replicated to determine the

quantities of CHO that can be given to *Apostichopus californicus* to ensure sufficient growth in fisheries. Understanding this opens the door for an economically viable way to run sea cucumber fisheries in the Pacific Northwest of North America.

Suggested Fishery Management Strategies for *Apostichopus californicus*

While sea cucumbers are generally not eaten in the US, *Apostichopus californicus* is exported to many Asian countries from West coast states. Because fisheries can bring in a significant amount of income to the economy, it is crucial that effective management strategies be put in place to ensure that sea cucumber fisheries are sustainable. As described in the previous sections, management strategies need to incorporate information based on the reproductive strategies and timelines of specific species. Ample time and space needs to be given to populations so they can recover and continue to reproduce at a rate higher or equal to that of the fishing rate.

The reproductive strategies of adult *Apostichopus californicus* are known. This knowledge can be used to establish healthy fisheries. However, the survival rate in juveniles is unknown, so further studies need to be conducted. With an understanding of population growth rates, fisheries can plan harvest seasons and locations accordingly. Best practices would include staggering where sea cucumbers can be harvested every year. Because this species reaches maturity after approximately four years, fisheries should institute a four-year cyclical system to allow populations to recover. Alaska does this with a three year cycle, though fishermen have suggested that the no-fish time period needs to be longer to allow stocks to adequately recover (Alaska Department of Fish and Game).

In addition to staggering the areas that can be fished each season, rigorous population surveys must be conducted in all regions with sea cucumber fisheries. As described previously, the estimated sustainable amount of sea cucumbers that can be harvested is approximately 5% of their biomass (Andersen et al. 2011). This number is based on tropical species so studies similar to the 2011 study conducted by Andersen et al. must be done on *Apostichopus californicus*. If the safe percentage of biomass to harvest can be determined, fisheries can set better catch quantity regulations. In order for this knowledge to be effective, however, rigorous population surveys must be done so fishery management teams have a baseline understanding of *Apostichopus californicus* population sizes and health.

While most regions in North America that fish *A. californicus* require fishermen to use the SCUBA method to harvest them, California allows bottom trawling. Not only does this practice take huge quantities of individuals, it also destroys benthic environments. Regulating sea cucumber fisheries should include specifying safe fishing methods. This will not only help protect *Apostichopus californicus* populations from overfishing, it will also keep benthic ecosystems healthy for other animals and fisheries.

Conclusion

Sea cucumbers have been shown to be a nutritional food source in many Asian countries and could thus be harvested for food in the US and Canada. In order to do this sustainably, more research needs to be done on the biology of *Apostichopus californicus*. If their reproductive strategies are known, fishing regulations that effectively protect them can be put in place. Best practices would be to stagger the location and times for allowable harvest areas every year. Additionally, population surveys need to be conducted along the Western North American coast

line. This will allow fisheries to set quotas that do not exceed a healthy capacity. If these animals can be fished sustainably, they could reduce the harvest of other, less sustainable animals and boost local economies.

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