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The Feasibility and Sustainability of Octopus Aquaculture: Exploring Operational Uncertainties and Challenges of Welfare Management

by

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ABSTRACT

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Aquaculture has become the world's leading source for seafood, surpassing production of wild-capture fisheries in 2014. In attempts to continue the expansion and diversification of the farmed seafood sector, octopuses have become relevant in discussion and experimentation due to fast growth rates and high nutritional value. Since the 1980s, worldwide demand for octopus as a food resource has increased, raising concerns for wild-caught octopuses. Predominantly, proposals of octopus aquaculture have surfaced in the Mediterranean, aiming for the development of both nearshore aquaculture and inland, closed system aquaculture. While there are standardized methods for developing finfish aquaculture, the unique physiological and behavioral traits of octopuses ensures the requirement of developing new aquaculture rules and regulations. Existing octopus fisheries and their sustainability, management, and profits were compared against proposed aquaculture plans to evaluate the feasibility and sustainability of the practice. A comprehensive synthesis on the viability of octopus aquaculture was created through a literature review, with identifications of consistent and considerable barriers through four categories: environmental, economic, policy, and welfare. Highlighted here are the outstanding barriers that continue to pose challenges and make octopus aquaculture development at any significant scale neither feasible nor sustainable given the uncertainty surrounding feed, seed, high operational costs, and a lack of proper management for octopus welfare.

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Chapter 1: Introduction and Overview

1.1 Introduction

Cephalopods – squids, nautiloids, and octopods – have captured the attention of the general public. Octopuses in particular are intelligent creatures often seen in aquariums, and they are able to solve puzzles, escape from tanks, and camouflage into any environment. Several species of octopus are commercially fished, with the most important being *Octopus vulgaris (*Common Octopus), *Octopus maya* (Mexican Four-Eyed Octopus), *Eledone cirrhosa* (Horned Octopus), and *Eledone moschata* (Musky Octopus) (FAO, 2024). Traditionally, octopuses are heavily consumed and relied upon in Mediterranean countries (i.e. Spain, Portugal, Italy, and Greece) as well as in Japan, Latin America, and South Africa (Sauer et. al., 2021). Wild octopus catch worldwide peaked prior to 2014, and has continued to decrease since (Pita et. al., 2021), but the demand for octopuses as a seafood has been rising due to the rapid growth and high nutritional value of the animal (Chappell, 2024). Aquaculture, or the farming of aquatic species, is a growing sector that has already overtaken wild-capture fisheries as the most common source of seafood (FAO, 2024) – and it has been proposed as a method by which to meet the demand for octopuses. Aquaculture can take a variety of forms, and within this thesis, the methods of aquaculture mentioned are referred to as per the definitions established by Buck et. al., 2024. For octopuses, two primary aquaculture methods are proposed: i) nearshore aquaculture, where a sea cage, either freestanding or suspended from a raft, is exposed to natural conditions and can be located at varying depths, and ii) onshore, or land-based aquaculture, where individuals are held in tanks with recirculating water systems (Buck et. al., 2024 & Olaniyi, 2022).

For potential octopus aquaculture, there are a variety of concerns, including seed – the acquiring of individuals – feed, and welfare standards. Animal welfare in the aquaculture sector can be defined as "the physical and mental state of an animal in relation to the conditions in which it lives and dies," (Barreto et. al., 2021), yet aquaculture regulations as they stand currently do not provide clear or direct management for octopuses. Octopus behavior is different from that of finfish – they are solitary, preferring to find a den, engage in consistent hunting – often of crabs – and transform their skin color and texture to the environment around them as a safety precaution and enrichment technique (Vaz-Pires et. al., 2004 & Andrews et. al., 2013). In captive environments, conflict and perceived stressors caused by nonideal conditions must be minimized in order to decrease the risk of cannibalism (Espinoza et. al., 2019). In addition, octopuses require enrichment, including environmental and cognitive types, to be in good health (Casalini et. al., 2023), which can pose challenges in a larger-scale aquaculture setting.

1.2 Research Question

In order to assess the potential of octopus aquaculture, research was guided by a question of whether or not the farming of octopuses for consumption can be feasible and/or sustainable given the unique physiological and behavioral traits of the Octopoda order. Octopuses differ in function and behavior from finfish and shellfish – many of their physiological traits are still unknown or require further understanding (Ponte et. al., 2019). They have the capacity to feel pain (Crook, 2021), and nonideal living conditions can induce stress-based responses that have the potential to harm both individuals and communities if multiple octopuses are being held together (Espinoza et. al., 2019). Harm lacks a consistent definition in octopus research, but can be evaluated via a threshold described as "any procedure which may cause pain, suffering, distress or lasting harm equivalent to, or higher than that caused by the insertion of a hypodermic needle in accordance with good veterinary practice," (Ponte et. al., 2019).

There is complexity in holding captive octopuses, and even more so in a potential aquaculture setting. There are concerns surrounding successful hatching and rearing as well as if octopus aquaculture can be done at a large enough scale to meet the demand and importance of the resource (Peng et. al., 2024). Additionally, there is a policy aspect – it is uncertain where octopus farming will be allowed to take place, and there is a rigorous series of steps to get a species approved for aquaculture. In some places, such as the states of California (Bill A.B. 3162) and Washington (H.B. 1153), the practice has already been banned – but considering the importance of octopus meat as a resource (Pita et. al., 2021), banning of the practice becoming more widespread could threaten wild octopus populations as companies attempt to bring in more animals from fishery efforts. If allowed, there must be a change to the regulations for octopus wellbeing – an area where there are currently few relevant restrictions. One of the only documents that clearly discusses octopuses and cephalopods is the European Directive 2010/63/EU, a legislation on animal welfare practices as it pertains to scientific research. While this is a step in the correct direction for octopus welfare, it does not cover the aquaculture gaps that are needed for further regulation in the seafood sector.

1.3 Research Importance

Cephalopod research as a whole is a prominent gap in marine biology and ecology. While other marine species have been extensively studied, often to a point of understanding how they experience pain or how their nervous systems work, these questions are still up in the air regarding cephalopods. Indeed, it has been observed in research that octopuses can experience lasting pain, understand where it is felt on their bodies, and evaluate the quality (i.e. intensity) of the pain felt (Crook, 2021). This begs the question of how an animal that is not fully understood can be successfully farmed on a large scale. Their complexity lies largely in two main areas: physiology and behavior.

Octopus physiology is vastly different to the commonly farmed finfish. They feel pain and experience stress from less-than-ideal conditions. Their health and stress levels can be measured using the fairly non-intrusive tactic of skin mucus sampling to assess hormonal indicators. (Vizcaíno et. al., 2023). When in pain or overwhelmed, they will retreat and tend to themselves, making them difficult to assess and maintain (Butler-Struben et. al., 2018). In addition to physiology concerns, they are also intelligent animals that require regular mental stimulation and entertainment, and without the appropriate conditions, they have been observed to partake in cannibalism if other octopuses are around or even begin self-harming behavior (Butler-Struben et. al., 2018 & Powell, 2022). Generally, intelligence and behavior are common reasons used to argue against octopus farming, with the basis that the practice would be cruel and should not be pursued. Despite this, two broad conclusions have been found in behavioral and physiological research: i) there is not enough information to come to a proper conclusion on the practice of octopus farming and ii) that it is likely possible, but should not be done. While each contributes to the further understanding of cephalopods and logistics of possible farming, having as much conflicting research as there is does not provide a clear path forward for the aquaculture industry – whether that is in the direction of successful octopus farming or the direction of possibly prohibiting their farming.

This leads to the two areas of concern within this thesis: feasibility and sustainability. Feasibility refers to the possibility of success for octopus farming, considering economic viability and ease of obtaining and feeding cultured individuals. Sustainability, on the other hand, is not a concrete concept across aquaculture (Osmundsen et. al., 2020), but here refers to environmental concerns such as the acquiring of individuals for culture, source of feed, required resource use, and pressures on local fishers. If feasible, the practice of octopus aquaculture is possible, but growth and reproductive success is reliant on culture conditions. It is possible to raise an octopus and maintain it in captivity in an ideal, enriching environment, (Vaz-Pires et. al., 2004), but with unique organisms such as octopuses, the risk that they cannot be raised in aquaculture and continue to be economically profitable, straightforward to keep running, and maintain high expectations of animal welfare regulations is present. When concerned with the keeping of captive octopuses under profitable and enriching environments, we can look to aquariums. It is important to note that aquariums are not producers of seafood, but the widespread holding of healthy octopuses shows that it is possible to raise and keep an octopus in enclosed captivity. In the case of possible economic success, the proposition of octopus farming becomes less of a possible task and more of a welfare dilemma. An overarching concern is the welfare and management restrictions – neither of which exist clearly for octopuses in an aquaculture setting. In addition, octopus is not a mainstream enough food source that it absolutely needs to be farmed – it does not feed a vast majority of the world as animals as land livestock does, and therefore would likely require too many resources to be continuously sustainable and profitable. The method of culling is another focus of inquiry within plans of octopus aquaculture, and whether a mechanical method or an anesthetic is best (Butler-Struben et. al., 2018). However, culling methods and the relevant uncertainties remain regardless of if focus is on octopus fisheries or proposed aquaculture.

For octopuses, there are several potential options. The first; follow in the steps of California and Washington, banning octopus aquaculture before it even truly begins. Such a task poses difficulty, as the proposals for octopus aquaculture, whether nearshore or inland, are being formed and experimented with in Mediterranean countries and territories rather than within the U.S. or North America. Another is to provide proper regulations for welfare and aquaculture management for octopuses to try and ensure the success of the practice. This, however, contains complexity in welfare distinctions, policy, economic success, and sustainability. Sustainability, as mentioned, covers population dynamics in the wild, particularly as pertains to the practice of capture-based aquaculture, or the taking of juveniles from the wild and placing them into a grow out period, within which increasing amounts of feed would be required.

This topic is important for the future of octopuses – both wild and perhaps farmed – but also for seafood sustainability going forward, especially as the farmed seafood market continues to diversify. As octopus aquaculture plans are currently existent in Mediterranean territories, the feasibility and sustainability of the practice is assessed in the scope of existing Mediterranean octopus fisheries and EU policies. In order to assess the sustainability and feasibility of octopus aquaculture, the following aspects are of great importance: i) current and historical octopus landings, ii) goals of existing octopus aquaculture plans, iii) relevant aquaculture management in the Mediterranean, iv) economics of fishing and farming, and v) how octopus physiology and behavior must influence welfare standards for the species. Entering into a practice without first knowing all of the impacts it might have on an environment, population, community, etc. runs the risk of causing more harm than good. Seeing as there is less known about octopuses than other already farmed species, any potential octopus aquaculture ventures require an understanding of the barriers as well as a proper, comprehensive evaluation of its viability.

1.4 Thesis Statement

The considerations of the complexities surrounding octopus farming lead back to the research question of whether or not the farming of octopuses for consumption can be feasible and/or sustainable given their unique physiological and behavioral traits. Given their differing behavior and biology from finfish and shellfish, octopus characteristics and complexity are likely to make the development of octopus aquaculture neither consistently feasible nor sustainable. Not enough is clearly known of the biological functions of these species, and they can be difficult to do experimental research on – which arises welfare concerns not just in aquaculture settings, but in research as well. Utilizing any species, environment, or ecosystem that is not fully understood for human purposes is likely to result in error and nonideal treatment – and octopuses are no exception.

1.5 Methods and Data

To assess the feasibility and sustainability of octopus aquaculture ventures, a systematic review as defined by Page et. al., 2021 was conducted on three methods of octopus harvesting, two of which are proposed aquaculture methods for octopuses: i) existing octopus fisheries, ii) nearshore aquaculture, and iii) inland, closed system aquaculture. In total, 96 papers were collected over six months via Google Scholar and Web of Science, deemed relevant based upon description of culturing method and outcomes for aquaculture methods, landings and management for fisheries, and location of operation for all methods.

Though octopuses are fished worldwide, the scope of the existing fisheries analysis was reduced to the Mediterranean Sea and the Gulf of Mexico. Proposals of octopus aquaculture are dominated by Mediterranean countries, and there is importance in understanding the impacts a potential aquaculture project might have on the established socioeconomic functions of a region; Gulf of Mexico octopus fisheries were added as to obtain a slightly wider perspective of how octopus fisheries are managed throughout the world.

Once the relevant methods were established, four categories were determined by which to evaluate sustainability of all and feasibility of aquaculture methods based upon the common concerns and restrictions. The categories are as follows: environmental, economic, policy and management, and welfare. Each of these areas are crucial in determining the feasibility and sustainability of the practice as well as informing future management decisions that will best support both populations and local communities. For each method of proposed octopus aquaculture, the concerns within each of the four categories were identified and discussed.

Chapter 2: Literature Review

2.1 Physiology and Behavior

The lack of information on octopuses creates problems as octopus aquaculture becomes a more pursued endeavor. The largest concern is response to possible captive environments, but there are also concerns surrounding food for these carnivorous animals. When it comes to octopus physiology and behavior that will guide management and welfare regulations, there have been a range of studies done. Some, done in labs on live octopuses – argue that with the right conditions and the continued sampling of indicators such as skin mucus to ensure good health, octopus farming is feasible (Vizcaíno et. al., 2023). Others have looked into issues when octopuses are in close proximity – the most prevalent being cannibalism, which is a concern when octopuses are stressed and in competition for food (Espinoza et. al., 2019). There have also been experiments that explore an octopus's experience with pain or discomfort, which was explored in one study through injection of saline into one of the animal's arms that showed evidence of discomfort through retreat and focus on the wound (Butler-Struben et. al., 2018). Intelligence and the need for enrichment is a highly important argument against octopus aquaculture – including reasons such as boredom and lack of stimulation, ease of trauma, and self-harming behaviors (Powell, 2022).

Octopuses are able to drastically change colors, patterns, and shades based on the surrounding environment and any threats that are around them. It is also suspected that these color and pattern changes can be a stress-based response; however this has not been confirmed in a wide enough range of species for it to be a consistently used diagnosis (Andrews et. al., 2013). Beyond the sensitivity and speed of changing of octopuses' skin, there is a mucus that covers them to assist in squeezing into small spaces, and as with other species of finfish and mollusk, provides a first defense against chemicals or toxins in their environment. Since a large concern in octopus farming is the creation of an adequate environment for them to thrive in whilst being raised, there need to be both behavioral observations and biological tests for these octopuses. The skin mucus that octopuses have could be used as a possible biomarker to test the octopuses' physical health and in turn make changes should there be indicators of problems. The mucus contains immune factors and enzymes, and the sampling of the mucus has been determined to be a relatively low-invasive method of identifying these biomarkers and thus the physical health of the octopuses (Vizcaíno et. al., 2023). While it is regarded as a method with low invasion levels to the animal, it is required that they are anesthetized to ensure minimal stress and decrease the potential of experiencing pain during the process, and so the mucus samples may be collected effectively and quickly. The requirement of anesthetization on octopuses during research efforts and physiological data collection brings up another issue that currently occurs during scientific studies and would likely be occurring in potential octopus aquaculture; what can be used to anesthetize octopuses. Two main options exist: magnesium chloride and clove oil. Magnesium chloride is used most commonly in cephalopods and is occasionally mixed with ethanol, while clove oil is more so being tested as an anesthetic but is producing results similar to those of $MgCl_2$. Therefore, each of these have been proven effective for placing octopuses in an ideal state of unconsciousness and do not provide only a neuro-muscular effect, which is a non-ideal situation in which the animal appears unconscious but can still experience pain (Andrews et. al., 2013).

While pain and suffering are largely studied in marine species, research on the manner in which octopuses experience such sensations has not yet been extensive. It can be believed that octopuses do experience pain, but the matter of how varies (Diggles et. al., 2024 & Crook, 2021). In other circumstances, authors argue that octopuses do not experience pain – leading to i) further confusion surrounding octopus functioning and ii) the need for more research. While the amount of evidence for cephalopod pain, suffering, and intelligence is far greater than against, it is important to acknowledge the reasons scientists might believe they lack the ability to experience pain. Unfortunately, the case against cephalopod (and more specifically, octopus) pain is a result of a bias towards human and mammal physiology and neural functions. A study done in Australia formed the conclusion that after investigating behavior and brain functions, there was no evidence for cephalopod suffering (Key & Brown, 2018) – an uncommon result.

2.2 Aquarium Captivity

When considering the requirements for successful octopus aquaculture that takes animal welfare into account, it is necessary to understand octopus captivity is already common – in aquarium settings. Although aquariums hold octopuses captive for vastly different reasons than aquaculture would, they prove that it is possible and sustainable. However, it is very important to understand that seafood production following aquarium welfare regulations and practices would produce little profitable material as they aim to recreate habitats and provide public education – which requires the animals to be as enriched and healthy as possible. Aquariums provide a baseline of understanding how to hold captive marine species while maintaining good health, but this perspective must be approached with the acknowledgement of the vast differences between aquariums and aquaculture.

Oftentimes, aquariums are helpful for conservation efforts and species recruitment – and if octopus farming is deemed unethical and unsustainable as a food source, perhaps it maintains the possibility of being a conservation tool should wild populations become more at risk. Effective octopus captivity requires the creation of ideal habitats that inspire typical behavior and sufficient enrichment for the animals in the tanks (Holmberg, 2022). They also require many dark areas – which often makes them difficult for aquarium visitors to spot, but is better for their wellbeing. Another aspect of enrichment in captivity is human interaction with the octopuses in which fish or other food items are offered to create tactile enrichment and therefore check the octopus's health (Holmberg, 2022). In events where more than one octopus resides in the same large tank, this tactile feeding occurs often to ensure the octopus knows it has a consistent food source and does not have to resort to cannibalism – a previously mentioned behavior that comes from stress. Feeding these animals is the largest challenge for aquarium caretakers as octopuses need regular food – and at the Vancouver Aquarium, the vast majority of the diet for a Giant Pacific Octopus is not live and is instead frozen, which is known to reduce the amount of vitamins (Holmberg, 2022). This provides proof that while possible to have a healthy captive octopus, diet becomes an issue in terms of both food with enough nutrients as well as the ongoing crisis of enrichment through food. The Association for Zoos & Aquariums (AZA) guidelines dictate sizes for captive areas –

and while the studied Vancouver Aquarium far exceeds the minimum tank size, there remains a debate about just how much space an octopus should have – the anecdotes of aquarium keepers differ from ecological routines and behaviors, making the presented argument that the vast majority of octopus captivity is unethical and based on anthropocentric needs (Holmberg, 2022). On the other hand, the argument for conservation remains. The Vancouver Aquarium's resident octopus was sold to them by a fisherman who caught her as bycatch and thought she would be "interesting for aquariums" (Holmberg, 2022). Such behavior raises the concern of octopus health and welfare within an aquarium – octopuses have been seen to experience skin damage and abrasions after being caught in the wild as long as they have been studied (Boyle, 1981). Skin damage is also a concern in captive environments because, as previously stated in the physiology discussion, octopuses can display self-harm behavior when stressed and not in ideal conditions. Although octopuses usually survive better than finfish or other marine species after being released back into the wild after being caught in fishing operations, it is likely that there is a higher level of safety in a well-run aquarium.

None of the challenges facing octopus captivity in aquariums are likely to vanish in octopus aquaculture – in fact, since the scale changes dramatically from one or two octopuses to perhaps thousands, the problems of nutritional food and stress reduction to ensure no damage on the animals become increasingly worse as the cultivated number of octopuses rise.

2.3 Economics

Octopus is eaten around the world, but is commonly fished in the Mediterranean, the Gulf of Mexico, the southern Atlantic (South Africa), and the western Pacific (Japan) (Gideran et. al., 2023 & Sauer et. al., 2021). Octopus is a global food source and practically its own sector of fishery, and there is already a sustainability concern for wild-caught octopus due to overfishing and climate change – leading to the rise of proposed octopus aquaculture. In addition, octopus is a fast-growing species, growing more than 5% of its body weight per day in the juvenile stage (García García & García García, 2011). Between its common use in seafood markets and fast rate of growth, the viability VS profitability is being weighed as wild octopus populations become more at risk and demand for the animal becomes higher.

One suggested benefit of octopus aquaculture as opposed to wild capture is the time between catch to market. Octopus is very receptive to changes in temperature or handling methods, which then influences its freshness, taste, and quality once on the market – particularly if it is being sold fresh and not processed. For octopus farming to be beneficial and marketable, there must be a balance between the economics, the conservation, and the treatment of the animals. A study in Mexico determined that community-based fisheries often lead to a higher amount of production and therefore a higher economic return, and a study on Greek octopus fisheries determined that quota-based management helped to maintain a stable population of wild octopuses (Gideran et. al., 2023). Although quote-based management does not play much of a role in aquaculture, the knowledge that it is successful for wild-capture fisheries is incredibly helpful should octopus aquaculture be banned, influencing a higher rate of wild fishing to continue to meet demand. For octopuses, like all other sold meat, food safety on the market is an ongoing demand.

A model was created in the Mediterranean to get an overview of the time and costs that octopus farming might require to determine the possible success of the practice. In the study, they evaluated octopus grow outs through the use of sea cages with juvenile specimens. Evaluation of octopus grow outs is the largest area of research done in terms of experimentation on feasibility – but as it is reliant on wild octopus populations, it is unlikely that it will remain the prominent method, as it depletes stock from wild-capture fisheries who, in part, rely on octopuses for their own profits. Through the economic evaluation of octopus grow outs, it was ultimately found that the highest costs went into feeding the animals (García García & García García, 2011) as octopuses are carnivorous and often require live prey to ensure they are sufficient stimulation. However, this was not their only discovered limitation – if the chosen method is a sea cage grow out, there are concerns with the range in off-shore ocean temperature and coastal human activities (García García & García García, 2011). The study used economic equations such as the NVP, or net present value, which is often used in agriculture to determine a hypothetical net (or total) value from a project – and when the final value is larger than zero, the project is financially viable. From the use of this equation, two things are determined: i) the existence of a very considerable investment to begin the process of octopus farming that is much larger than the costs of current grow out efforts in the Mediterranean and ii) there are many limiting factors even in the case where octopus farming is financially viable. The authors propose that in order to raise economic benefits from the practice of grow out octopuses in sea cages, simultaneous use of the cages to cultivate finfish species would ensure consistent use of the sea cages and therefore, less of the investment in setup wasted (García García & García García, 2011). This venture would also make the setup more attractive commercially, thus increasing profit and reducing overall production costs.

Existing experiments show that octopus aquaculture seems possible and has the potential to turn a profit. However, there are still considerable limitations when considering the creation of a consistent and profitable source of farmed octopus. The most prevalent limiting factors are the mass production of octopuses in a captive farmed setting and the ideal food for them to be fed (García et. al., 2014). Thus far, research and economic evaluations have been done with octopus grow outs in estuaries, open sea, and land-based tanks. It is possible that future methods of octopus farming might appear or even become more economically feasible, but have not been explored yet. A grow out is often done in nearshore areas, making the aquaculture system reliant on the natural aspects of a water system. Octopuses – specifically, *Octopus vulgaris* – are very sensitive to water temperature, with their ideal range being between 16°C and 21°C, while this can be maintained in the event of onshore tank aquaculture, open ocean water does not remain in the ideal range of temperature all year round, thus posing issues for continuous grow outs. It is proposed that given the ideal conditions, survival would average around 80% (García et. al., 2014). Finally, there is the economic concern of feeding. It has been determined that the ideal food for a captive octopus is a mixed diet of crab and bogue, a small finfish; this diet provides a high protein and energy content while offering the ability for octopuses to hunt and consume their food (Estefanell et. al., 2011). However, this means there is a much higher cost for the obtaining of octopuses' food because it is more than one item and is a live feed. While expensive, this diet would not only benefit octopus health as they are being raised, but also on the seafood market as higher prices are fetched for larger organisms (García et. al., 2014).

The background literature supports two ideas important to the research question of this thesis. First, it explores the unique characteristics of octopuses, both in a physiological and behavioral sense in order to illustrate their complexity and variance from other marine life. Second, it displays that octopus aquaculture is generally deemed possible and perhaps even economically viable, even if only on a small scale. Within physiological research, it is generally accepted and understood that octopuses feel a level of pain and discomfort – and though researchers have yet to discover the exact workings of an octopus nervous system, it is crucial to be aware that they have a more acute sense of feeling and perceiving the world around them than finfish. The general agreement of octopus physiological traits makes it possible to identify the exact characteristics that make them unfit as an aquaculture species, even if it can be successfully done and produce profit and a consistent supply. This thesis analyzes methods of octopus harvesting and evaluates the viability of octopus aquaculture as a potential addition to the sector. Additionally, potential regulations and restrictions for both octopuses in aquaculture and existing fisheries are discussed in order to provide improvements for the future of octopuses and fishery sustainability as well as relevant welfare restrictions and the socioeconomic reliance on the resource are considered.

Chapter 3: Background and Methods

3.1 Fishing Methods

The propositions for octopus aquaculture have arisen out of the growing demand for octopus meat and the concerns that wild-capture fisheries will not be able to keep up with demand or risk endangering populations of wild octopuses (Chappell, 2024). Many of the aforementioned concerns with octopus aquaculture such as culling methods and perceived stress to the animal are not absent in wild-capture fishery practices. Such similarities brings up concerns of if it is better to farm or fish an animal. Octopuses have been fished for centuries – particularly in Japan in years as early as 100 AD and in the Mediterranean during the time of the ancient Greeks; in modern times, octopus catch has almost doubled between 1980 to 2014, but still remain only 8-12% of the total cephalopods fished (Sauer et al., 2021, Figure 1). Modern octopus fisheries utilize an array of methods to capture these animals, including trawls, nets, lines, and pots or traps – most of which exist in the Mediterranean. Although octopuses are fished across the world, including locations such as Southeast Africa, Australia, Latin America, and Thailand, analysis of fisheries operations in Chapter 4 will focus primarily on the Mediterranean Sea and the Gulf of Mexico.

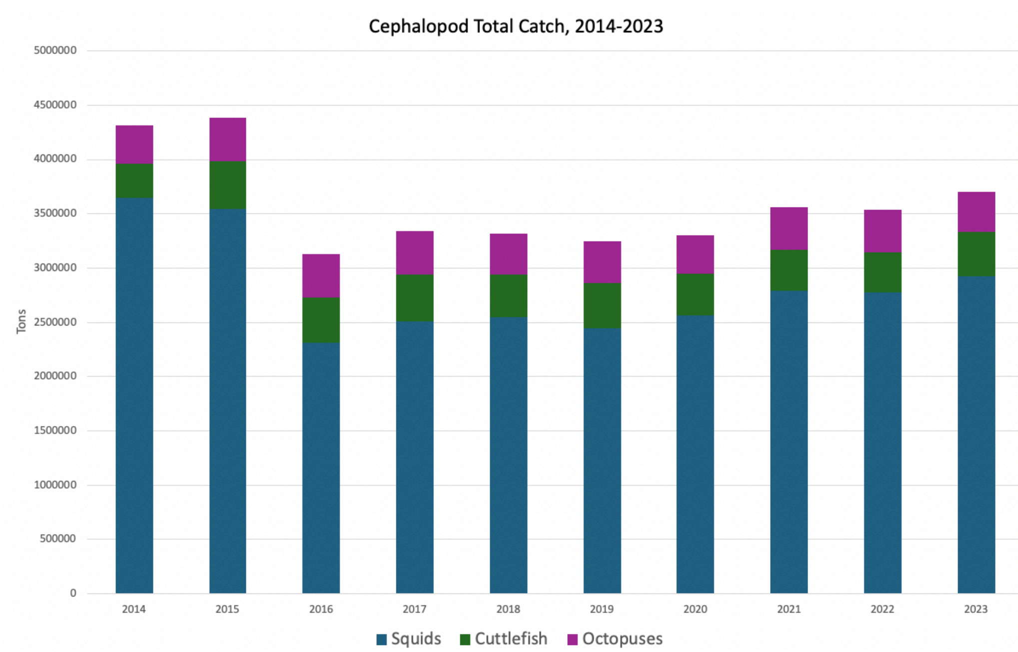

Figure 1. Total cephalopod landings (in tons) annually from 2014 to 2023. (FAO, 2024).

3.1.a Trawl, Trammel and Fyke Nets

Trawling, the method of dragging a large net along the seafloor, is most often used in the Atlantic Ocean and Saharan Bank and often fishes species of octopus as bycatch, thus rendering the method a nonselective catching technique (Zamuz et. al., 2023). Bycatch trawling species include *Octopus vulgaris* (Common Octopus), *E. cirrhosa* (Curled or Horned Octopus), and *E. moschata* (Musky Octopus) (Sauer et al., 2021). The capture of these species is beneficial to multi-species fisheries, but causes significant harm to the seafloor and can disturb the coloration of octopuses due to the amount of sand, mud, and debris that is moved from the dragging of the trawl nets. Nets are also used and kept stationary while being held up by floats and weights – such as the case of trammel and fyke nets, which are meant to entangle marine species and are common in both Japan and the Mediterranean. Japanese fyke nets catch *Octopus vulgaris* and account for 30% of octopus fishery yield as selective catching techniques (Sauer et al., 2021).

3.1.b Fishing Lines

Fishing lines are an uncommon way to capture octopuses, but exist for catching specific species such as *E. dofleini* (Giant Pacific Octopus) in Japan. These lines have one or more hooks placed along the line and are placed in locations where they can drift in a system of multiple lines stemming from a vessel (Zamuz et. al., 2023). However, drift and long lines have been deemed dangerous due to the immense amount of bycatch that becomes entangled in the lines. In addition, octopuses and other marine creatures have been known to struggle to escape, thus making these lines a source of injury and death even prior to removal (Fitzgerald, 2013).

3.1.c Traps and Pots

Traps utilized in octopus fisheries are often made to target octopuses and include a framed trap area that is baited and makes it easy for the octopus to enter, but not exit. They have significantly less impact on the seafloor and marine environment compared to trawl nets and are more efficient and sustainable for fisheries and the environment. Octopus traps are used in the Atlantic Ocean to capture *Octopus tetricus* (Common Sydney Octopus) and *Octopus vulglaris*, and in the Pacific Ocean to capture *Octopus minor*

(Longarm Octopus) and *E. dofleini* (Giant Pacific Octopus). Pots are very common in octopus fisheries and are made specifically for the capture of octopuses. Octopuses search for refuge on the seafloor to protect themselves and care for eggs, and in places where the marine habitat lacks natural shelter, octopuses will rely on man-made and placed pots where they can come and go from the pots (Sobrino et. al., 2011). The materials vary by location, some being true ceramic weighted pots and others being plastic – possibly even PVC pipes or old tires. Octopus pots are most common in Mediterranean fisheries such as Spain, where they are used to fish *Octopus vulgaris* (Sobrino et. al., 2011). The pots can be attached to lines in shallow waters – around 5 to 85 meters deep – such that they are able to be easily checked every 2-5 days (Leporati et. al., 2009). Octopus pots can be the least environmentally harmful (when made of clay) and the most ideal method for fishing octopuses. There is no bycatch involved, and because pots are often large, they capture adult octopuses rather than juveniles (Sauer et al., 2021). Octopus pots are able to be made to select for non-egg bearing females due to the opening of the pot being smaller than the average egg string size of the targeted species – meaning they would not be able to comfortably come and go from the pot, therefore encouraging them to avoid the pots when carrying eggs (Sauer et al., 2021). In addition to being the least harmful method of capture for the surrounding habitat, they provide minimal harm to the octopuses themselves – the animals are observed to have minimal stress and almost no marring on the skin. Though pots are viewed as the most beneficial to fishers, octopuses, and the environment, it must be noted that there is a risk of plastic pollution in locations where the pots' material is plastic rather than clay or wood.

3.1.d Fishing by Hand

In some places, octopus fishing is less industrial and is instead done by hand to catch select species. This is done at low tide and octopuses are baited out of their shelters using small finfish or crab and then hooked and removed from the water (Sauer et al., 2021). In some locations, such as Canada, irritants are put into the water instead of bait to flush the targeted octopus out of its den – but the irritant must be chosen carefully – some, such as chlorine bleach, are harmful both to the octopus itself and the environment, particularly small finfish within the den (Wright & Esmonde, 2000). The approach of fishing by hand is often used to obtain ornamental octopus species to be held in aquariums. These species include *Hapalochlaena lunulate* (Blue-Ringed Octopus) and *Wunderpus photogenicus* (Wonderpus Octopus), which are both fished in the South Pacific (Sauer et al., 2021).

3.2 Post-Capture Treatment

3.2.a Culling Methods

Prior to the treatment and processing of harvested octopus lies a key point of contention – the method of culling. Questions of death methods have been directed at experimental octopus aquaculture projects, but the suggested methods show little difference from that of fisheries. In wild-capture fisheries, the method of culling for octopuses is bludgeoning or decapitation – better described as clubbing the animals over the head – which has been believed to be the most efficient method (Gross, 2023). This method requires skill on the handler's part – and with the consideration of more recent research that supports the existence of a unique and decentralized nervous system, the continuation of the bludgeoning method in possible aquaculture brings up questions of welfare. Other experimental methods of culling are being explored – one being the submergence of the animal into ice water – a common method in aquaculture of other aquatic species (Gross, 2023). This method, however, is believed to be no more ethical than bludgeoning and does not account for the unique features of an octopus nervous system. Another experimental method is euthanasia, described as "overdose of an anesthetic" such as magnesium chloride ($MgCl_2$) in tandem with ethanol or clove oil (Andrews et al., 2013). While there has been some testing of these methods, it still requires further research to determine if it adheres properly to welfare regulations or is efficient enough to be implemented. It is supported that the method of euthanasia is in fact more harmful than direct mechanical culling methods (e.g. bludgeoning) as it is not fast-acting and requires further steps to confirm death (Andrews et. al., 2013). Euthanasia has been studied in salmon and crabs, and though there are many physiological differences between finfish, crustaceans, and octopuses, there has been success. However, it is important to note that there is still much research to be done in marine animal euthanasia, particularly how to monitor health trends in the long term and how to respond to indications of health problems (Neiffer & Stamper, 2009). Additionally, there are cases in which it is ill-advised to consume marine animals euthanized with chemicals such as ivermectin, which has been used to successfully euthanize blue crabs (Mones et. al., 2023). Many such studies display successful euthanasian, but do not explore in detail the welfare concerns or stress impact– a finding that should give pause when considering its widespread use.

3.2.b Processing

Once harvested, octopuses might be exported or sold to local markets. Because the meat is tough when raw and often difficult to prepare, many fisheries try and provide only to local sellers so they remain fresh and unfrozen (Zamuz et. al., 2023). For preservation, a rapid freezing process is used, which maintains most texture and flavor preservation while on its way to final destinations, which maintains quality (Gideran et. al., 2023). Rapid freezing of the animal must be done soon after capture to mitigate bacteria spread, which can be difficult for fisheries who may not have the most advanced freezing technology. This method also allows for longer distances to be traveled in the case of exported octopus, but there is a balance to maintain as too much time spent frozen can change the texture of the meat (Gideran et. al., 2023). While more uncommon, it is important to note that octopus meat can also be canned or fermented. These processes are less common than freezing, requiring a lengthier list of steps from capture to market.

3.3 Regularly Fished Octopus Species

While several species were discussed in Section 3.1 of the earlier background, identifying the importance of various octopus species in the seafood sector is important when considering i) octopus fishery sustainability, ii) most profitable octopus species, and iii) the octopus species with the most market potential in octopus aquaculture. On a global scale, the most commonly fished octopus species is *Octopus vulgaris*, the Common Octopus, followed by *Octopus maya*, the Mexican Four-Eyed Octopus (Figure 2). There is also significant fishing effort dedicated to *Eledone cirrhosa* (Curled or Horned Octopus), and *Eledone moschata* (Musky Octopus), though they are recorded with less certainty. Importantly, within the relied upon FAO fisheries data, the vast majority – 82% – of landed octopus species remain unidentified (Figure 3), posing significant uncertainty in the evaluation of fisheries sustainability and population levels. Understanding the most important fished octopus species will assist in the sustainable managing of populations in the event that octopus aquaculture begins as well as providing a basis on which to improve management of octopus fisheries.

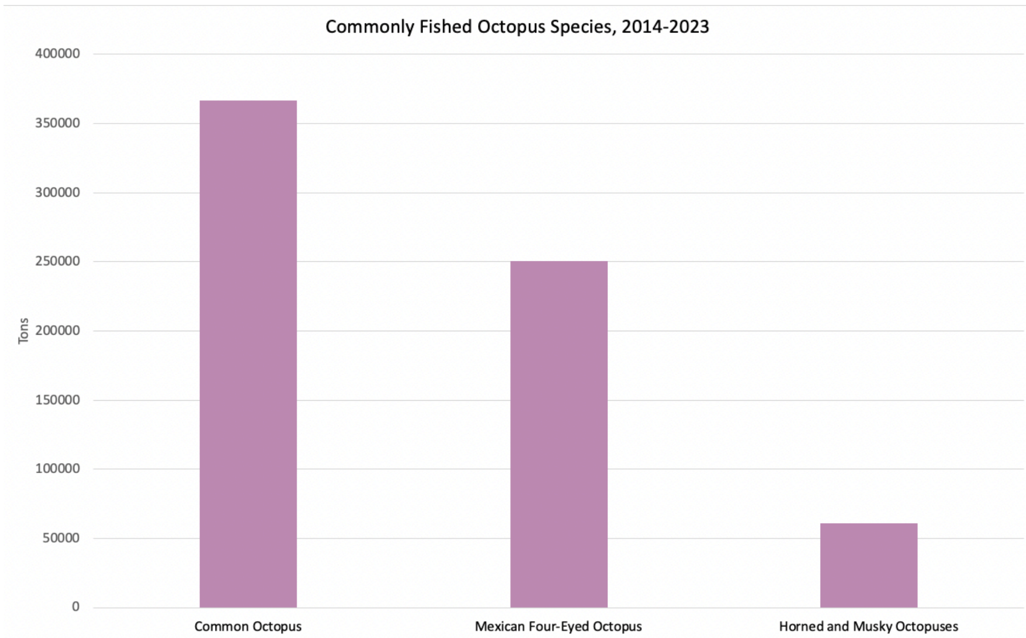

Figure 2. Most commonly fished and identified octopuses, aggregated from the period of 2014-2023. (FAO, 2024).

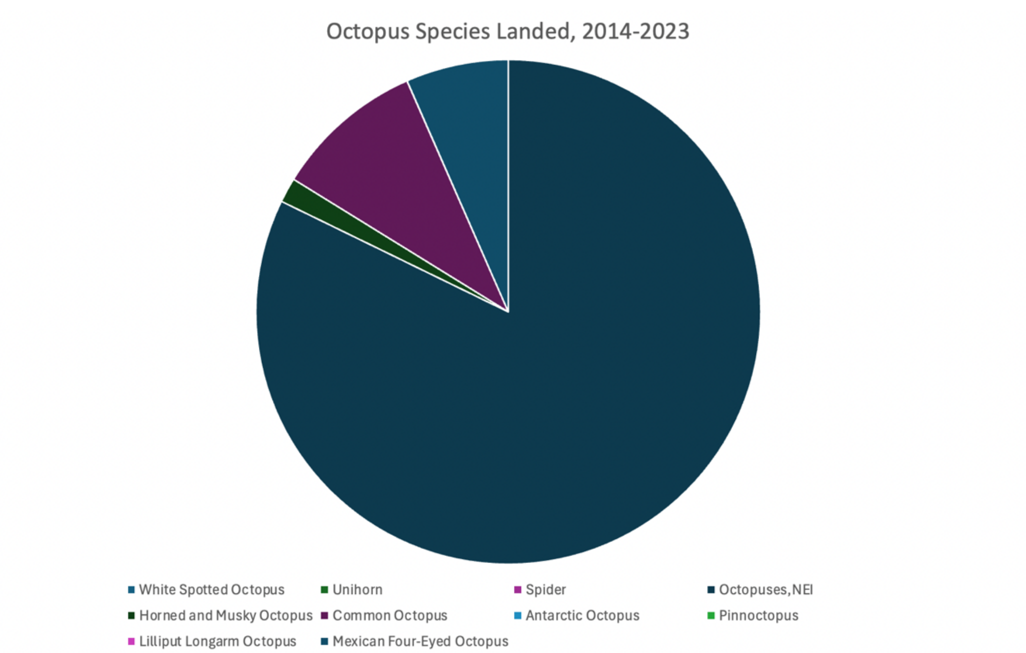

Figure 3. Recorded octopus species landed, aggregated from the period of 2014-2023. (FAO, 2024).

3.4 Methods

In order to conduct a cohesive analysis of the potential of octopus aquaculture, a systematic review as per Page et. al., 2021 and the PRISMA 2020 statement was conducted. All studies and journal articles were obtained through online searches via Google Scholar and Web of Science. The phrase "octopus aquaculture experiments" was used, resulting in the identification of two methods proposed for octopus aquaculture – nearshore and inland, closed system., Based on the information gathered in the literature review about octopus physiology, importance as a seafood resource, and welfare concerns for the Octopoda order, four categories were chosen through which to evaluate current and potential methods of octopus harvesting. These categories were chosen based upon reoccurring areas of concern mentioned within literature discussing octopus aquaculture projects, each having a level of impact upon environment, operation of aquaculture, and socioeconomic functions of a region. The four categories are discussed in detail in Section 3.5.

A total of 96 papers over a period of six months were obtained for the synthesis, and were grouped by i) method of harvest (i.e. wild-capture fishery, nearshore aquaculture, or closed system aquaculture), and ii) physiology, behavior, and biology. Among the gathered relevant studies, 32 on existing octopus fisheries were included predominantly based upon location – focus was placed on the Mediterranean Sea as it is home to a number of octopus-producing countries and several experimental octopus aquaculture projects, as well as the Gulf of Mexico in order to provide a slightly wider scope of understanding on the operation and management of existing octopus fisheries. 22 studies categorized into the nearshore aquaculture group were determined based upon method of culture, dictated largely by their locations in open water and potential barriers. 25 closed system studies were grouped more broadly, and included project proposals for inland octopus aquaculture, existing recirculating system impacts, and laboratory paralarvae hatching experiments. Finally, 17 studies on the topics of physiology, behavior, and biology were grouped based upon interaction with the inner functions and actions of octopuses. Beginning to evaluate the viability of octopus aquaculture was determined to be most effectively done by means of comparison across the aforementioned four categories – environmental, economic, policy and management, and welfare. Once established, each term was searched with “octopus aquaculture” and “octopus fisheries” in Google Scholar and Web of Science – including but not limited to “octopus fisheries Mediterranean,” “octopus fishery sustainability,” “octopus fishing impacts,” “octopus aquaculture economics,” “nearshore octopus aquaculture environmental impacts,” “captive octopus welfare,” and “closed system octopus aquaculture.” The relevance of studies to their established categories were decided based upon the following definitions of methods of capture and harvest, and information was gathered via the color-coding of categories within detailed notes on each method.

3.4.a Wild-Capture Fisheries

Wild-capture fisheries are the current method of gathering octopuses on a large scale for the seafood market. Reviewed in Section 3.1, wild-capture fisheries concerns octopuses extracted from the wild through various methods such as trawls, fishing lines, pots, etc., particularly by artisanal fisheries. Relevancy of a studied octopus fishery was determined based on its location as well as the inclusion of i) environmental impacts, ii) fisher behavior, and iii) existing management.

3.4.b Nearshore Aquaculture

Nearshore aquaculture is that which is located in open water and exposed to the natural variation of ocean system, with location based upon distance from the shore rather than depth of the water. Octopuses in nearshore aquaculture settings are located in stainless steel sea cages in benthic or floating apparatuses. The relevancy of nearshore octopus aquaculture was determined predominantly by the discussed method of obtaining octopuses, with particular focus on octopus grow outs and the setup of the sea cage. This method has been proposed in tandem with the raising of other marine finfish species to help supplement the aquaculture and improve profit margins (García García & García García, 2011).

3.4.c Closed-System, Recirculation Aquaculture

Closed system aquaculture, also known as inland or recirculating aquaculture systems (RAS), is located in a land-based facility, perhaps with water intake from a natural source, and holds captive aquatic animals in tanks rather than sea cages. The tank conditions are heavily monitored, offering a sense of control that is absent in nearshore aquaculture. This method can be envisioned similarly to an aquarium but on a much larger scale and for the purposes of food production. Studies for closed system aquaculture were determined relevant on a broader scale than for nearshore aquaculture, including i) those focused on impacts from other existing inland aquaculture (i.e. salmon), ii) laboratory breeding and hatching of octopus paralarvae, and iii) experimental inland octopus grow outs.

3.5 Areas of Evaluation

In order to draw conclusions on the feasibility and sustainability of potential octopus aquaculture, comparison of the three methods were done through the use of the four established categories: environmental, economic, policy and management, and welfare. This structure was determined during the process of Chapter 2's literature review, in which terms including "octopus aquaculture," "octopus fisheries," "octopus farming," "captive octopuses," "octopus physiology," and "octopus behavior" were searched in Google Scholar. Each of the four categories corresponds to a reoccurring concern in the holding and farming of octopuses, with the environmental impacts (i.e. population dynamics, pollution to the surrounding ecosystem) and welfare being consistently mentioned topics, therefore making them a clear metric by which to evaluate a method of rearing and harvesting. Economics and policy were established as categories due to i) the existing reliance on octopus as a fished species and the declining landings of wild-caught octopuses, ii) the need for profit in any seafood-related venture, and iii) appropriate management to ensure the health of populations and individuals. Each category's establishment and definition for the purposes of the thesis is discussed further.

3.5.a Environmental

The environmental category was defined as an overview of the impacts on natural systems, including resource requirements (i.e. water, energy, and footprint), concerns with feed and seed, and impacts on the surrounding environments and habitats. Information and findings within the relevant journal articles and studies were marked as environmental when there was mention of any of the following: octopus populations, climate change impacts, waste and/or disease management, pollution, energy usage, resource requirements, and open water conditions.

3.5.b Economics

Economics was defined here as any potential or existing profit as well as required costs and investments in regards to the fishing or farming of octopuses. Information relevant to the economics category included: landing weights, annual profits, aquaculture setup investment costs, and projected market prices of cultured octopuses. Within the economics analysis for each method of harvest, comparison between profits, cost of operation, and impact on local communities was evaluated, including potential supplemental efforts such as multi-species aquaculture.

3.5.c Policy and Management

Policy and management was defined here as any political and governance rules, regulations, and restrictions that manage coastal sectors, fisheries, and aquacultural welfare. An overarching theme throughout literature on octopus aquaculture projects is the lack of existing regulations for the species, especially in the case of welfare. Information was categorized as policy and management when these topics were mentioned: allocated aquaculture zones (AAZs), economic extractive zones (EZEs), co-management, top-down, welfare guidelines, and fisheries management.

3.5.d Welfare

Welfare was defined similarly to the previous definition in Section 1.1, and refers to the physical and mental states of an octopus, taking into consideration adequate enrichment, holding conditions, and treatment. Information within the relevant studies were categorized as welfare when physiology, sensitivity, enrichment, ideal feed, captive conditions, and stress were mentioned.

Chapter 4: Existing Octopus Fisheries

Preface

Prior to evaluating feasibility and sustainability of potential octopus aquaculture, an overview of the current method – wild-capture fisheries – must be conducted to come to a successful conclusion on aquaculture viability. For fisheries and aquaculture production, sustainability will be broadly defined as "the status of the exploited stock, [environmental impacts], efficiency of the management system, and animal welfare as well as the consideration of human health, food security, traceability of products, [and the social and economic benefits provided]" (Ainsworth et. al., 2023).

The analysis of existing octopus fisheries was conducted with a strong focus in the Mediterranean, a prominent producer of octopus, and supplemented with information on octopus fisheries in the Gulf of Mexico to get a wider view of how fisheries capture and manage their octopuses. This chapter and those that follow are mainly concerned with octopus-based activity in the Mediterranean, as the area is home to a vast array of octopus-reliant fisheries as well as the majority of octopus aquaculture and grow-on projects. Within these fisheries, the general methods of capture within existing octopus fisheries was outlined in Chapter 3's *Background,* and will be analyzed and discussed further within the categories of analysis.

4.1 Environmental

4.1.a Species, Range, and Region

The octopus fisheries of focus within this research target a small fraction of the worldwide octopus species. With a predominant focus on Mediterranean fisheries, the essential species of focus is the widespread *Octopus vulgaris*, or Common Octopus, which is the explored octopus species for aquaculture development and the target of the majority of octopus fishing efforts (Figure 4). In Mediterranean trawling fisheries, there is occasional capture of *Eledone moschata*, or Musky Octopus – though often not recorded in stocks and landings as a unique species to *O. vulgaris* (Quetglas et. al., 1998). In fisheries located in the Gulf of Mexico, three species are targeted - *Octopus maya* (Mexican Four-Eyed Octopus),

Octopus americanus (Common Octopus of North America), often identified as *O. vulgaris,* and *Octopus insularis* (Brazilian Reef Octopus) (Avendaño et. al., 2025).

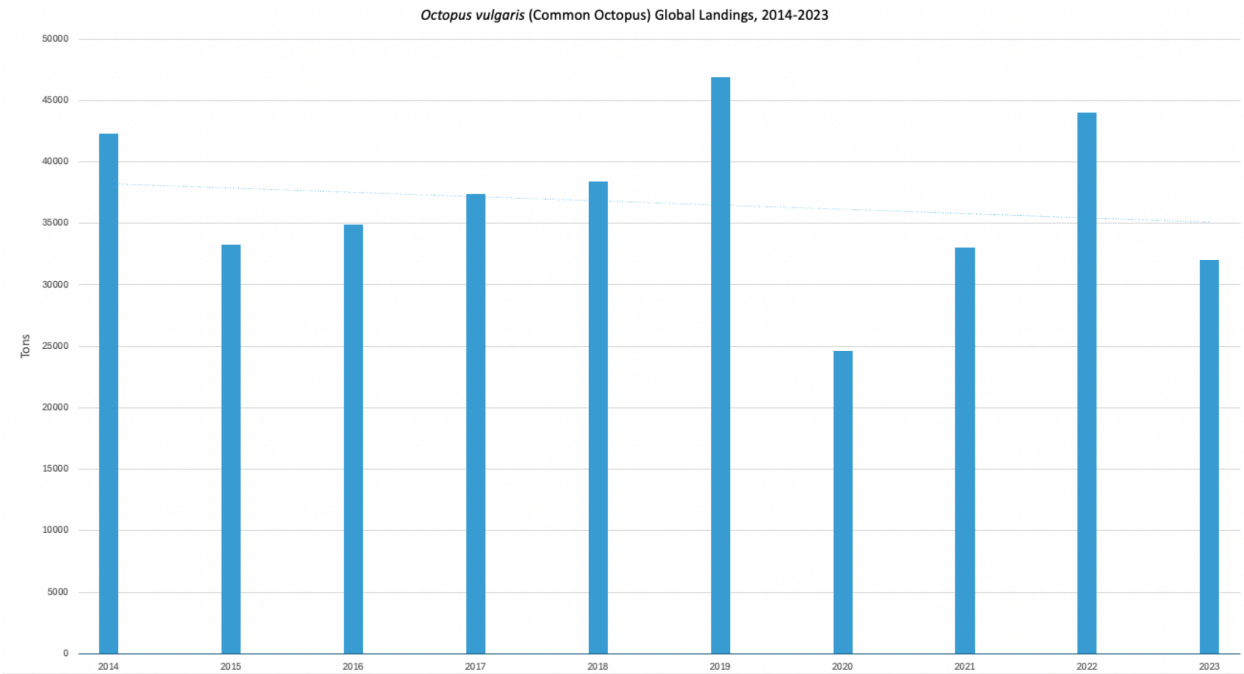

Figure 4. Global *Octopus vulgaris* landings annually, 2014-2023. (FAO, 2024).

4.1.b Methods of Capture

Throughout relevant octopus fisheries, there are three prominent methods of capture. These are trawlers, octopus pots, and traps. Due to the dominance of these three methods in the existing fisheries overview, only they have been chosen to receive full analysis; however, as stated previously, other methods of capture such as direct diving and baited lines do occur and contribute to landings, particularly in the North American fisheries of BC and the Gulf of Mexico.

Octopus catch and landings are dominated by octopus pots attached to lines, are not baited, and have the benefit of species selectivity given their ability to appeal to octopus denning behavior and (Sobrino et. al., 2011). Octopuses are also often captured in traps, which share the selectivity benefit of octopus pots, but the animal cannot come and go and is often baited in with fish or crab (Leitão et. al., 2023), located at the end of a long funnel to decrease escapes. Other methods such as hook and line or trawling are also relied upon, especially in the Gulf of Mexico (Avendaño et. al., 2025). These methods often capture octopuses as bycatch – particularly trawling, which might target shrimp species. In all Northern Hemisphere octopus fisheries, the abundance and importance of octopus landings increase in the spring, particularly in April through July (Quetglas et. al., 1998). Methods of capture vary by fishery; trawling is often used by industrial fisheries, while pots or traps are used by small-scale or 'artisanal' fleets (Diedhiou et. al., 2019).

Octopus catch via trawling occurs in the Mediterranean on the continental shelf, where octopuses are captured in deeper water as bycatch, but contribute to a significant percentage of total landings. On Mallorca, a Spanish island, although *O. vulgaris* is an extremely important species to the trawl fishery, the main target is finfish or lobster. Octopuses caught by trawlers are generally on the smaller side of captured octopuses given that they migrate away from open, sandy areas and into rocky substrates when maturing and preparing to mate or brood (Quetglas et. al., 1998). Despite the important contribution of trawling to the total amount of octopus landings, it is a fishing method known to cause significant environmental damage, particularly to open and benthic habitats given the dragging of large nets along soft and vulnerable areas of the seafloor. Trawling displaces sediments, causing them to disperse across marine habitats and impact areas that have not been targeted. Trawl nets are among the least selective fishing methods, so even species that have no reason to be fished or caught end up in landings. While this is beneficial to fisheries that capture the important percentages of octopuses as bycatch, there is harm done to habitats and species that are not of concern to the fishery. In the Spanish Mediterranean, the majority of octopus landings – around 36% – come not from trawls, but from octopus pots, a more selective method (Quetglas et. al., 1998, Figure 5).

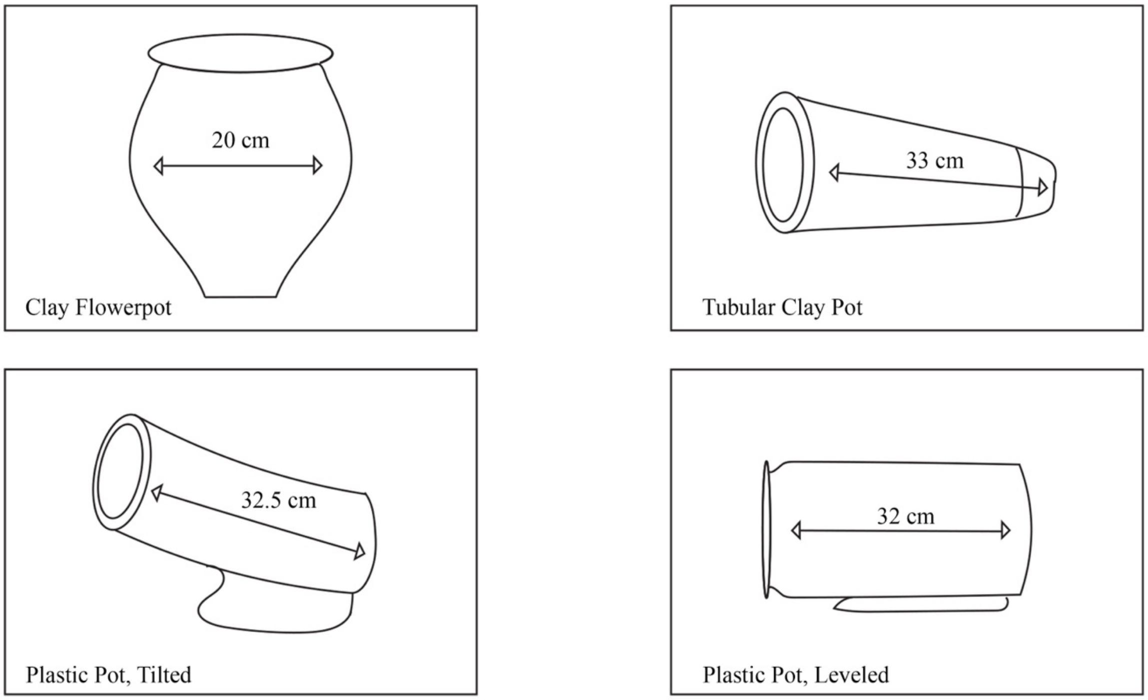

Figure 5. Various kinds of octopus pots used in Mediterranean octopus fisheries (Measurements from Sobrino et. al., 2011).

Octopus pots are among the least environmentally damaging method of capturing octopuses. They minimally disturb the seafloor on which they are placed and are able to increase the efficiency of fishers targeting various octopus species. Typically, pots on lines number 50-70 vessels and are checked several times a week. Selectivity enables fleets and fishers to not include mature females as they can return pots with these animals back to the water and leave them uncaptured (Sobrino et. al. 2011). Pots are made of either plastic or clay. Clay pots are typically old flowerpots or tubular vessels, whereas plastic pots can be PVC pipes, old tires, or specifically made vessels that are either flat or tilted. The most prominent issue in the Mediterranean octopus pot fisheries is pot loss, occurring when individual pots become detached from lines. With clay pots, this is less concerning as clay is a natural resource, but in the case of plastic pots, they contribute to the already large amount of plastic pollution, including microplastics, in seas and oceans. A case study in the Gulf of Cadiz – located in southwestern Spain – uses both clay and plastic vessels and had a partial focus on octopus fishery pot loss. The loss of lines or individual pots are typically due to strong storms or trawler interference, and in a total study time of 24 months, each month saw an average loss of 10 individual pots and one full line comprised of 100 pots (Sobrino et. al., 2011). Due to records and estimates such as this, the octopus pot fisheries' predominant environmental impact is based upon the material of pot or trap used. Unfortunately, the use of clay pots has been declining in favor of baited mesh traps, which are thought to be more efficient as a fishing method than passive pots (Sonderblohm et. al., 2017).

The final common method of octopus capture is a form of trap, which have increased in popularity in recent decades and are used alongside pots in much of the Mediterranean, resulting in capture of approximately 90% of octopus landings (Pita et. al., 2021). In Galicia, a region in Spain, octopus traps are the prominent method of capture and contribute to 80-90% of total octopus catch per year in the area (Bañon et. al., 2018). These traps are put out in shallow waters for capture of octopus and are made of iron wire and plastic (Figure 6). Trap loss is more uncommon than pot loss, and the vessels themselves contain less plastic material, and also impose minimal damage on the seabed due to their stagnant locations. Concerns surrounding octopus traps are based on regulation, and the predominant issue is that of bait – if it should be used and what kinds of bait are reasonable or ideal to use. Due to baited traps increased efficiency, there are worries about increased fishing pressure, octopus stocks, and potential bycatch. Baited traps in the Mediterranean display significant levels of bycatch, including crustaceans, finfish, cnidarians (jellyfish, anemones, etc.), and echinoderms (sea stars, sea urchins, etc.). The bycatch animals fall into three categories – landed bycatch, which is profitable, discarded bycatch, that which is thrown back to sea, and trapped bycatch, which is neither discarded nor sold as it has little value or is too much work to remove from the trap, such as sea urchins or scorpion fish (Leitão et. al., 2023). The largest concern with trap bycatch is that which is discarded and thrown back to sea – if non-profitable species are often being captured and thrown back, efforts should be made to try and reduce the numbers of these species caught. In many of these traps, particularly in ideal benthic areas for *O. vulgaris,* the majority of bycatch consists of invertebrates which sustain minimal damage if tossed back (Leitão et. al., 2023). Octopus traps are baited with fish or crab, and in Portugal, the use of crab as live bait has been banned due to the perceived risk of overfishing and increased bycatch levels, the manual task of placing a crab in each trap, and the cost of bait as an added fishery expense (Leitão et. al., 2023). However, a 2023 study resulted in the observation of slightly higher levels of octopus catch when using fish and an overall similar level of exploitation throughout the entire fishery regardless of the type of bait. The most important factor on catch rates is shown to not be bait type, but trap size (Leitão et. al., 2023). As a whole, these varying questions of bait type VS catch rates and overexploitation concerns are not only an environmental question, but a problem that has required management intervention and analysis of economic cost VS benefit.

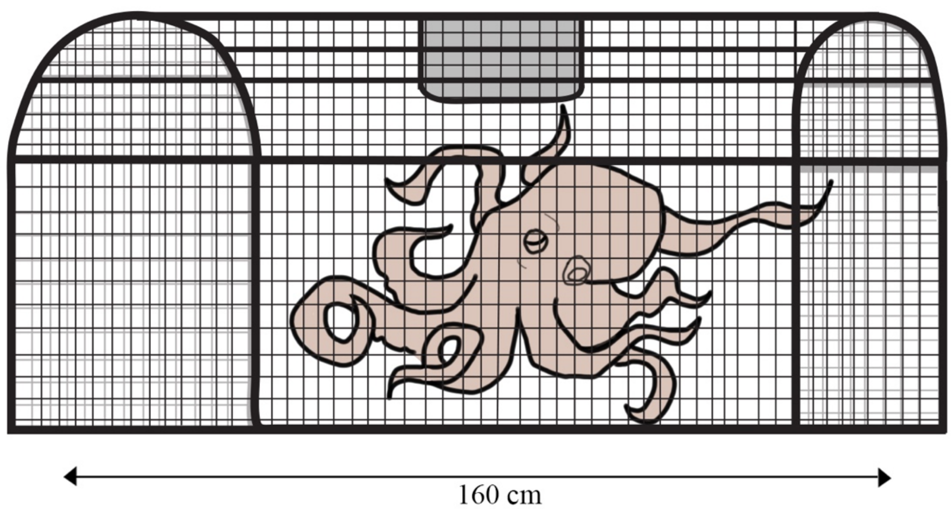

Figure 6. Depiction of an octopus trap.

4.1.c Life History

Existing wild-capture octopus fisheries are driven by an understanding of the octopus life cycle and behavior patterns. The semelparous nature of octopuses adds a complexity to their importance as a fished species – reproductive events are limited to the amount of mature females in the population, and species abundance is therefore dependent on the strength of recruitment (Emery et. al., 2016), which is subject to variability based on environmental conditions and exploitation levels. This variability and complexity makes population stocks difficult to assess, which eliminates the certainty of population health information and can lead to overfishing. In octopus populations, it is estimated that there are at least two generations present at one time given the average lifespan of 1.5 years and the approximate six-month spawning window (Leporati et. al., 2015). The small buffer between generations paired with the development of fisher knowledge of life cycle and behavior brings concern for the exploitation levels of a population – and without caution for the species and environment, this can threaten octopuses.

Octopuses, particularly the notable *Octopus vulgaris* of Mediterranean fisheries, display behavior closely linked to the life stage they are in. O. *vulgaris* spends the first months of the year and reproductive period close to the coast, then retreats to rocky areas for spawning and brooding (Quetglas et. al., 1998) so eggs are sheltered. Over time, fishers have learned these migration patterns, and in some locations has led to higher levels of fisher involvement in fishery regulation and species management. The octopus life cycle and behavior has influenced sustainability and management of the species, such as the implementation of a closure season, which occur when octopuses are mating and spawning (Sonderblohm et. al., 2017). The varying durations are based on the observed behavior patterns of the animals and the time they spend further from the coast in rocky outcrops. High percentages of octopuses are caught in the transitional seasons that border reproductive times. The sex ratio of captured octopuses is, on average, 1:1, but the numbers can vary based on capture method. In *O. tetricus*, another subtropical species, females make up 57% of pot catches and only 24% of trap catches (Leporati et. al., 2015), with the peak of landings typically occurring just before the summer months due to warmer sea temperatures. Although females are more common in pot catches, many fishers avoid taking mature females when they are found in traps or pots so they have the opportunity to reproduce and spawn, ensuring the continuation of the population. In addition, fisheries that predominantly use traps or pots are able to benefit from size selectivity, in which mature adults or brooding females can be excluded from landings.

Despite the best efforts of fishers and government to ensure octopuses will continue to be a reliable and important species for fishery landings, several environmental factors cause high variability in yearly octopus landings, freshwater input and temperature change, which can lead to paralarvae mortality and future recruitment failure (Sonderblohm et. al., 2017). Notably, temperature has a clear impact on growth – for subtropical species such as *O. vulgaris*, growth rates peak at 21°C and dramatically drop at 22°C (Leporati et. al., 2015). This drop in growth at a defined temperature is of great concern considering the warming oceans seen today as a result of climate change, possibly leading to future octopus landings decreasing dramatically in weight and size. Warmer seas are a concern for adult octopuses as well as paralarvae hatchlings, which are even more vulnerable to drastically changing environmental factors – such as temperature – but also intensity or freshwater input via storms or river drainage due to their small size. Paired with the reliance on octopus as a landing species, increased ocean condition and weather variability have the potential to threaten octopus populations, especially if market demand continues to increase.

4.1.d Overfishing Concerns

Octopus landings have seen a decrease over time. Four countries in the Mediterranean – Portugal, Spain, Italy, and Greece – make up 77% of the cephalopods landed in the EU – and markets in these locations as well as in the Americas are continuing to grow (Pita et. al., 2021, Figure 7, 8). Worldwide, cephalopod production has tripled in the past fifty years, reaching around 374 thousand tons by 2020 (Ainsworth et. al., 2023). The majority of fisheries that bring in these landings are small-scale, or artisanal fleets.

Figure 7. Locations of the most important Mediterranean octopus fisheries.

Figure 8. Locations of important octopus species and fisheries in the Gulf of Mexico.

In Algarve, Portugal, *O. vulgaris* is captured via pots and traps and is among the most valued species on the market. Over thirty years, the exploitation levels of the species nearly doubled – but have decreased recently and now sit below historical landing averages as market demand and fisher reliance on the species has grown (Pita et. al., 2021). In Spain, two prominent octopus fisheries are located in Galicia (Northern Spain) and Andalucía (Southern Spain). The country has high demand for octopus as a seafood and contributes heavily to EU landings. Many Spanish capture methods are traditional, passive gears, including gill or trammel nets and traps (Bañon et. al., 2018). These catch levels have seen decrease as well, with the total landed weight being cut in half from 2010 to 2019, dropping from around four-thousand tons to two-thousand (Pita et. al., 2021). This decrease results from environmental factors (overfishing, water quality), but predominantly management failure. Sardinia, an island off the coast of Italy, has no official octopus fishery; they are instead caught as bycatch in multi-species fisheries. The Italian production of octopus, as with the previous fisheries, has seen variability and a similar decline in landing weight, ranging from a high of around 5500 thousand tons to a low of around 1800 thousand tons over twenty years (Pita et. al., 2021). Sardinian artisanal fisheries draw their catch through the use of set nets (gillnets) and the more common octopus traps baited with crabs. In Greece, particularly the Thracian

Sea, there is a long history of octopus fishing and a wide variability in method of capture, including bottom trawl, traps, fyke nets, and seines (large walls of netting). In Greece, octopus landings peaked in 1992, when 3500 tons were captured with substantial contribution from Aegean Sea fisheries (Pita et. al., 2021), and since, overfishing of finfish species has led to the increased focus on octopus as a resource. Lastly, in the Gulf of Mexico, octopus fisheries exist primarily in the southern regions such as Yucatán, Quintana Roo, and Veracruz. Gulf of Mexico landings have increased from totals of 15,000 tons in the 1990s to 50,000 tons in 2018 due to the area's high octopus biodiversity (Avendaño et. al., 2025). These areas use an array of methods of capture – including but not limited to hooks and lines and baited traps, and contribute to substantial percentages of global octopus landings.

Overexploitation is a concern for many species, but octopuses are particularly vulnerable to the risks of overfishing – removing high percentages of a generation of adults, risks future recruitment. This is true if mature adults, especially females, are being captured before there is a chance for them to engage in their single reproductive cycle. Management of the species to ensure entire generations of recruits is challenging – many fisheries that capture octopuses are multi-species focused, which can be difficult to track accurately with traditional assessment methods (Emery et. al., 2016). While a fair amount is known about their life cycles, expertise on short-lived, semelparous species is lacking. Traditional methods of management or assessment such as seasonal closures based on assumed reproductive/brooding seasons or animal size evaluation are not particularly well-suited to benthic or holobenthic octopus species. This is due to the lack of ability to observe and record continued biological variation such as size or maturity which would assist efforts to decrease the exploitation of octopuses in life stages vulnerable to capture (Emery et. al., 2016), creating the need for improved understanding of how octopuses respond to overexploitation.

Octopuses are often fished in artisanal fisheries, and while these can often be more sustainable due to local ecological knowledge (LEK), cultural methods, and smaller landings compared to industrial fleets, the risk of overfishing is still present. This is especially true as small-scale, artisanal fisheries continue to change and develop, including the implementation of newer fishing methods. Artisanal fisheries are perceived to produce less bycatch – but in some places, reliance on octopus as a bycatch species paired with the willingness to throw back low-profit species can suggest otherwise (Lloret et. al., 2018). Many of these small-scale fisheries do not have the management restrictions that industrial fleets might, and due to their smaller nature and more widespread variability, what little regulation does exist is often not adhered to. This manifests as continuous and substantial fishing effort – closed periods or size limits might be disregarded for the sake of making a profit so fishers can continue to sustain their families or livelihoods (Lloret et. al., 2018).

Some fisheries, such as an artisanal fleet in Asturias, located in Spain, has taken steps to care for the local octopus population despite reliance on it, leading to eco-certification on the products at sale, which enable the fishery to continue to operate sustainably (Ainsworth et. al., 2023). Others in Galicia have begun to work with scientists and administration to share knowledge about life cycle and habitat so stock assessments and management plans can be more accurate and effective, especially with the variability and fluctuation in landings. In order to sustain octopus populations throughout the world, ecological knowledge-based management, developed methods of short-lived species stock assessments, and improved regulations and traceability might be solutions to the overexploitation and stark declines that have been seen in octopus fisheries (Ainsworth et al., 2023). However, a new solution has appeared on the horizon as well – the endeavor of octopus farming and aquaculture as a method to supplement and sustain existing octopus fisheries, which bring sustainability questions of their own.

4.2 Economic

4.2.a Demand and Market Proliferation

Octopus fisheries have grown immensely since the 1980s (Pita et. al., 2021). Since, many cephalopod and octopus landings have seen their peak, but continue to be a valuable resource. Average prices have risen from \$0.73/kg to approximately \$6/kg in a twenty-year period, despite the average weights of captured octopus being consistent (Diedhiou et. al., 2019). Octopus landings are likely higher than the yearly estimates published because, at least in the Mediterranean, artisanal octopus fisheries' landings are not as well documented – perhaps because of their smaller scale or the variability that comes with targeting *O. vulgaris.*

Octopuses in the Mediterranean sum to just below half of total cephalopod landings, and have seen considerable variability including peaks in the late 1980s to early 1990s and 2004-2007 (Sauer et. al., 2021). In Algarve, which houses the largest octopus fishery and fleet in Portugal, landings at first sale value account for approximately 50% of the total revenue from seafood (Sonderblohm et. al. 2017) and approximately 70% of total landed biomass (Bañon et. al., 2018). In the peak octopus fishing season, catch per unit effort (CPUE) for *O. vulgaris* in Algarve averages 220kg/boat/day compared with the low in the summer being approximately 180kg/boat/day (Sonderblohm et. al., 2017). In this region, *O. vulgaris* has become one of the most profitable species at market, rivaling the sardine and accounting for 28% of the region's landings and producing a total of $19.54 million as of 2020. In 2021, the region was responsible for 52% of national octopus landings (Leitão et. al., 2023). In Portugal, octopuses sell on average for $4.88/kg. Similarly, Galicia's octopus fisheries land slightly fewer octopuses, but *O. vulgaris* still makes up approximately 17% of the region's catch and produces a value of $18.28 million. (Pita et. al., 2021). Although these fisheries continue to land considerable amounts of octopuses, Galician octopus landings peaked in the mid-1960s, a period correlating with the introduction of new fishing technology such as trawl vessels and traps. The intense exploitation of *O. vulgaris* has resulted in new regulations, including a closure periods minimum catch size that benefits both fishers' profits and ideally, octopuses' ability to reproduce (Bañon et. al., 2018). Andalucía's fishery counts octopus as the fifth most important landing species, bringing in the second highest value of fished species at $17.49 million as of 2018 (Pita et. al., 2021). Of the primary octopus producing Mediterranean countries, Italy's marketed octopuses sell for the highest value and bring in the largest total profit of the relevant Mediterranean regions – in 2019, $38.4 million was made from octopus landings in Sardinia, and over half of recorded totals were brought in by the region's artisanal fishers (Pita et. al., 2021). Octopus fisheries in the Gulf of Mexico, despite being the largest octopus fishery in the Americas and contributing a third of the world's octopus production, have typical showings of lower CPUEs than those located in the Mediterranean – the Yucatan

Peninsula contributes about 90% of the region's octopus landings with average catches of 3-11kg/individual/day (Avendaño et. al., 2025 & Sauer et. al., 2021). The value of the Yucatan Peninsula's octopus fishery is valued between 40-100 million US dollars every year, exporting around a third of their landings, and providing employment to 90% of fishers in the area (Sauer et. al., 2021).

For all octopus fisheries, life cycle remains an important factor in not only the understanding of where and when to fish given sea temperatures and storm events, but also in the market sales of octopuses. In Portugal, lower sale prices are seen in the autumn months, where octopus landings result in an average price of $4.2/kg compared to the yearly average of $4.66/kg – but at auction, octopuses have sold for as much as $8.62/kg (Sonderblohm et. al., 2017). In the Gulf of Mexico, where there is higher octopus species diversity and generally warmer sea temperatures than in the Mediterranean, the fishing season typically spans the autumn season from August-December, when three fleets target different depths and varying habitats including plains and reefs (Avendaño et. al., 2025).

The importance of octopus continues to rise, which in part comes from the increasing levels of exportation from the Mediterranean's and Gulf of Mexico's fisheries. Exports from the Mediterranean countries go to other EU regions that do not fish octopus, and exports from the Gulf of Mexico are likely to travel through the Americas. As this continues, new and innovative management strategies based in octopus life cycle and behavior will need to develop alongside fishers who depend on these resources for their livelihoods.

4.2.b Socioeconomic Factors

Octopus fisheries are beneficial for the abundance and diversity of the seafood markets and are responsible for maintaining high levels of employment. In addition to the standards of living held by fishers that are reliant on employment from fisheries, there are variable costs involving possible bait and boat or gear maintenance. The largest expense is fuel, then food, then fixed costs of repair and maintenance (Diedhiou et. al., 2019). Fuel and energy is referred to as *fuel consumption per tide,* which considers distance to fishing grounds and the power of the boat's engine. Distance from port to target area is variable, and fishers typically bring around 10-30L of fuel per trip (Diedhiou et. al., 2019), which has highly variable costs depending on the year. Food expenses also play a significant but variable role, depending on the people per boat and the duration of time spent on the water. Costs of maintenance and repair tend to not have high variability.

Those who work in octopus fisheries have strong ties to the region, the culture, and oftentimes, the octopus itself as a historical resource. In the EU, there is no official management system for cephalopod fisheries, and each country or region is responsible for its own decision-making, creating variation in profit and exploitable stock levels (Silva et. al., 2019). Fishers have great local ecological knowledge when it comes to octopuses, which could help population management and regulation of sale – but acceptance of this is rare and slow to implementation.

Artisanal octopus fishery fleets vary by region, but Mediterranean fleets range from 358-1200 small boats, often supporting upwards of 1500 local, individual fishers who rely almost exclusively as octopus as a resource given its lucrative profit status (Pita et. al., 2021 & Silva et. al., 2019). While most individual, local fishers utilize methods like pots, fleets that rely on trawling have also seen an increased reliance on octopus species, around half of which is exported from Portugal to other Mediterranean countries like Spain or Italy, where the meat is typically frozen or processed (dried, canned, etc.) rather than sold fresh at market (Pita et. al., 2015). Tourism adds to the profitability of octopuses for local fishers, as tourists are likely to be interested in eating traditional meals and are willing to pay higher prices than those who live in the region full-time (Diedhiou et. al., 2019). This immense reliance on octopus landings for salaries has been the main driver of fishery pressure on governments to find ways to improve legislation and management of octopus fisheries. The majority of local fishers use small boats, most in limited ranges, which have an influence on their catch, profit, and their views on the fishery and its management as a whole (Silva et. al., 2019). The knowledge that local fishers possess is traditional and historical, but their preferences and knowledge must be understood in order to manage the octopus fisheries in a manner that is respectful and beneficial to the fishers' needs to make a living as well as the sustainability of the octopus populations.

As the landings of octopuses have begun to decline, various management tactics (see Section 4.3) have been implemented – but often unsuccessfully. Proposed and occasionally implemented strategies for managing octopus fisheries often are likely to have some positive benefit on the octopus populations, but may not be appreciated by fishers – who would have to take time off during closure seasons or adhere to a fishing schedule (Sonderblohm et. al., 2017). These restrictions would mean substantially decreasing time spent fishing and total landings brought in, meaning less profit for the fishers, which is just one reason why they might not support increased governmental improvement efforts for an octopus fishery. Closure periods or restricted fishing schedules has also seen a lack of compliance, often leading to illegal or black market fishing which results in especially high prices per individual octopus, thus further promoting the continuation of illegal fishing. Even those who respect the management that is set in place are still able to be hurt by decreased stocks on the next fishing trip or price variations at market. Alternatively, closure can also lead to increased fishing efforts, which not only negates the purpose of closure by further overfishing the species, but also creates lower profit margins over time and less beneficial landings (Sonderblohm et. al., 2018). Scheduling of fishing can also impact the sale time and profit margins of catch, as fishers tend to synchronize their landings with the times of auction or sale. Weekend fishing is generally non-ideal, given the closure of markets and the need to refrigerate or freeze catch until Monday, creating catch that is no longer fresh, and does not fetch the desired profit (Sonderblohm et. al., 2017). One idea for maintaining and improving the benefits fishers get from their landings is that of a certification of origin, which would ensure a higher sale price at market as well as provide economic incentive to sustainably harvest individuals and provide more transparency to customers (Silva et. al., 2019). Not only would a single octopus sell at a higher price, but it would be known that the individual was harvested at an appropriate time that does not interfere with vulnerable life stages such as recruit or reproducing.

Profit margins of octopuses are, overall, variable but increasing – which is beneficial for fishers until the possible point of overexploitation caused by the lack of proper management, increasing demand, or scarcity. Beyond the risk of declining populations of octopuses in heavily fished areas, the greatest risk to octopus fishers' livelihoods is illegal or black market fishing. Ideally, policy implementation and changes that involve increased co-management would solve these issues, but octopuses' inherent difficulty to manage makes keeping their populations at ideal, sustainable stock levels challenging.

4.2.c A Note on the Economics of Live Bait

Live bait is a variable fishery expense alongside fuel and crew food – but it is much more controversial than anything else. Bait for octopus traps is used worldwide, but has been a point of contention in the Mediterranean, particularly surrounding live crab bait in Portugal. This is a result of trap bycatch concerns as well as wonders of if the economic expense is truly worth the benefit it brings. A study by Leitão et. al. in 2023 has a heavy focus on how much difference crab VS fish as octopus trap bait makes in bycatch, landing, and operation expenses for artisanal fisheries.

Crabs, banned as a bait animal in 2010, are questioned and complained about based on the manual and detailed process it requires to secure a crab in a trap, taking up time that could be used targeting more areas or deploying more traps. It was also thought that crab collected a higher percentage of octopuses when used – which was not the case in the study. Crabs as bait created a higher diversity of bycatch in traps, but a generally lower total biomass of both bycatch and targeted octopuses, which results in less overexploitation of the marine habitat and fewer individuals thrown back into the sea if they are not deemed good enough or profitable enough for market (Leitão et. al., 2023). When fish were used as bait, traps needed to be replenished and deployed again every day, adding increased expense and labor (Sonderblohm et. al., 2017) as well as an increased pressure on finfish populations. The amount of fish required for bait each month is about 1/3 more in weight and price than is required for crab; it is more expensive but returns higher octopus landings (Leitão et. al., 2023). Bait will continue to be an expense for octopus fisheries, but choosing fish seems to increase operation costs while adhering to an implementation policy and resulting in higher landing weights – though evidently, the management strategy still needs work.

4.3 Policy and Management

4.3.a National and Regional Management

Octopus fisheries are difficult to manage due to the species' short lifespan and the immense dependance on the species. In Europe, there is no official regulation of cephalopod fisheries – so many countries in the Mediterranean rely on a combination of guidelines from general EU fisheries management, individual national laws, and local or regional rules. In many of the relevant countries, compliance is low, negating some possible benefits of implementing policies or management geared towards helping populations.

In the EU, all cephalopod fisheries are excluded from existing Total Allowable Catch and quota regulations created via the Common Fisheries Policy, leading to the national and local creation of management practices (Bañon et. al., 2018 & Pita et. al., 2021). Southern European countries – particularly those with fisheries discussed at length thus far – are the most active in the management of their octopus fisheries, a likely result of both historic traditional connections to octopus fishing and the heavy reliance on octopuses. Small-scale fisheries are often not as well documented or tracked as industrial fisheries, leading to fewer regulations and a likely inaccurate representation of true landings. Most of the fisheries in the EU are managed under EU-CFP, which is focused on long-lived finfish and shellfish; adding cephalopods to these regulations is difficult with the lack of knowledge and expertise on short-lived species, and many Mediterranean fisheries are multi-species focused (Pita et. al., 2015). In particular, these issues make the populations these fisheries rely on difficult to quantify.

The Spanish regions of Galicia and Andalucía have the most comprehensive management in place. Galicia's management is created by two entities: the Galician Autonomous Government (GAC), a regional authority, and the national government. The GAC regulates waters claimed by the region itself, the use of fishing gear used, and landing sizes (Pita et. al., 2021). Part of the GAC includes the Maritime Affairs Department (MAD), responsible for the management of the octopus trap fishery. The MAD provides rules on schedule and gear deployment for the regional fleet, which has 4534 vessels registered (Bañon et. al., 2018). Galicia employs a range of management tactics and a well-established participation of fishers in management due to the local governance format. Although the GAC places regulations on the fishery, they are mainly responsible for distributing and managing fishing permits and licenses, which are dictated by vessel and gear type (Bañon et. al., 2018). In Andalucía, there are also comprehensive national and regional regulations, though the national government enforces management for octopus fisheries and regulates small-scale fisheries (Pita et. al., 2021). National government enforces the Fisheries Management Plan, which includes guidelines for the octopus fishery, and the regional government implements regulation targeted to octopus fishing practices (Bañon et. al., 2018). In the last decade, regulation has been extended to offshore waters, around 2km from the shore and approximately 50m in depth (Holmer, 2013). The change enables regulations to be applicable to the fishery as a whole, including limiting total fishing effort.

Portuguese management is top-down, with most input coming from governmental research bodies and very little involvement of local fisher opinions or knowledge – which has been slow to change (Silva et. al., 2019). Fishery regulation comes from government legislation created by the Ministry of Agriculture and Sea, and the small amount of technical octopus management come from scientific research or governmental opinions. Since 2010, there has been increasing interaction between policymakers and fishers to make regulations that will benefit species populations and fishers alike (Pita et. al., 2015). In Italy, octopus fisheries that rely on trawling for their catch are subject to the European Mediterranean Regulation's rules on bottom trawling as of 2018, but there are no national policies and only occasional action on the part of regional governments in important fishing areas, such as brief bans on trapping for octopuses (Pita et. al., 2021). There are no specifications on minimum landing sizes or fishing techniques as are observed in other European fisheries, and spearfishing, a fairly common method of Italian octopus capture, is entirely unregulated (Maselli et. al., 2025).

Octopus fisheries in the Gulf of Mexico have more comprehensive regulations in place. National regulations in Mexican territories target octopus fisher behavior, including NOM-008-SAG/PESC-2015, enforcing closure periods, and NOM-008-PESC-1993, enforcing capture size and method for the *O. maya* fishery (Santamaría et. al., 2023). The Program for Promotion of Fisheries and Aquaculture Productivity in Mexico establishes limits and ever-growing quotes to promote sustainable fishing – but decisions made by fleets and fishers are based heavily on profit VS risk (Santamaría et. al., 2023). The *O. maya* fishery also utilizes total allowable commercial catch (TACC) limits, which are not common worldwide, but have seen moderate success in Mexico (Emery et. al., 2016).

4.3.b Overview of Management Tactics

All existing or proposed management for octopus fisheries are similar across fisheries. These management tactics, which are strategies of restriction, target fisher behavior and action to reduce total fishing efforts. These strategies are less widespread throughout the Mediterranean fisheries, and have more hold in the Gulf of Mexico.

A closure season is a common policy in octopus fisheries, whether it is a suggestion, an unofficial rule, or an enforced bill, as in Mexican octopus fisheries. Closure season overlaps with octopus brooding and spawning, lasting one to two months, and is also referred to as a biological break, though the duration of time of closure can vary based on year-to-year patterns and general octopus life cycle (Sonderblohm et. al., 2017). The purpose of a closure season is to protect young recruits and mature individuals from being fished and targeted, thus ideally boosting the population stocks and ensuring the health of the octopus population. During the closure season, no one is allowed to fish for octopuses – which is well enforced in the Gulf of Mexico, but has seen inconsistent results in the Mediterranean due to constraints on law enforcement and the inability to properly assess fisher behavior and market sales (Sonderblohm et. al., 2017). In 2024, the state of Quintana Roo along the Gulf of Mexico announced an eight-month closure and ban on the fishing of *Octopus maya*, the predominant octopus species in the region, in hopes of preserving the species and seeing increased reproduction (Riviera Maya News, 2024). Closure seasons, although favored as a method by fishers, requires proper enforcement and punishment, such as revoking licenses for a short time. When closures are implemented, it would likely be beneficial to also ensure the regulation of landing weights to at or below average, as it is often observed that fishers intensify their fishing efforts when the closure season ends. The result is high landings followed by a price drop due to smaller landings and an increased reliance on alternate species, leading to overfishing in a wider array of populations. Closure seasons must be implemented with the consideration of standard fisher behavior and the subsequent economic impacts. In addition, during closure seasons, the amount of black market octopus sales (do not pass through fish markets and are priced higher than at general sale or auction) is seen, (Pita et. al., 2021) which further harms the population and takes away profits from fishers who depend exclusively on the octopus fishery and employ their best efforts to fish sustainably.

Fishing schedules are another temporal strategy for octopus fisheries, and exist in Galicia. Scheduling times restrict the times and durations fishers would work, including hours or times of the day as well as frequency of outings. Currently, octopus fishing occurs mainly at night – fishers depart in the evenings, return at sunrise, and landings are often sold in the morning hours (Sonderblohm et. al., 2017). Fishers match their fishing times to the schedule of markets and auctions – which vary depending on the time of year due to weather and species landed. The suggested implementation of fishing schedules has more constraints than closure seasons. While closure seasons are based around the entire region's (i.e., the Mediterranean) octopus population dynamics, fishing schedules are port-specific and require attention to hydrology conditions, including tides, navigation practices, seafloor topography, etc.. Scheduling is not favored by fishers because it tends to cause loss in profits and ideal fishing days with good weather, thus reducing the number of potential fishing days and landings. Fishers are more amenable to official closures over the weekend, which is already a practiced schedule given the need to store catch until the new week begins. When fishing schedules are a chosen management strategy, they will need to be implemented with consideration of octopus behavior rather than only market schedules and dynamics, which are based on day VS night fishing (Sonderblohm et. al., 2017). The benefit of a fishing schedule is that it would be easier to enforce because of the ability to ensure all boats are docked during the off days or times.

Two management strategies often implemented in tandem are restrictions on the minimum landing weight of individual octopuses and the allowed gear. Three official policy decisions have been made in Portugal: Portaria n° 27/2001, regulating the minimum landing weight for *O. vulgaris* as 750g, while Decree Law 43/87 and Ordinance 1102-D/2000 provide gear regulations, including a limit of 3000 octopus pots for each vessel and an ideal mesh size for octopus traps (Pita et. al., 2015). The establishment of a minimum landing weight is implemented in the hopes of ensuring reproduction prior to catch, but in semelparous species, it is difficult to know if mating has occurred, making minimum landing weight a non-ideal method for managing octopus populations. In addition, minimum landing weights are not always adhered to, with estimated averages between 1300-1920g depending on sex (Sonderblohm et. al., 2017). Given that octopuses reproduce one time, unlike finfish or crustacean species, restricting the maximum landing weights is unlikely to benefit the population in the long term. Managing total landing weights or fishing locations would ideally ensure that more of the octopus population would be able to reproduce as fewer would be captured and sold if maximum landing weights were in regulated. Limitation of the number of traps and pots, which seems beneficial for sustaining healthy populations, is another disregarded restriction despite the existing legal management. Fishers are likely to deploy more traps than what is written into law to try and combat competition with other fleets or fishers. As a result, the existing ratios are limited by investment or how many traps or pots can fit onto a given boat size, which are under the discretion of fishers, not management. A potential remedy for this law is to regulate traps and pots not by numbers, but by vessel type and the number of crew members, leading to more equality and fairness when it comes to vessel size and gear ratios. There is also potential for trap tagging to reduce illegal fishing and competition, making it clear who the gear belongs to; this has a high price barrier, and fishers are more in favor of vessel-based regulation rather than more costly policies (Sonderblohm et. al., 2017).

As discussed previously, live bait has been among the most regulated and highly contested management approaches for octopus fisheries, especially in Portugal. Live green crabs, native to the region, are believed to increase bycatch and octopus capture rates. The use of these live crabs have been banned in favor of (more expensive) finfish, which require daily replacement and deployment. The consistent use of baited traps has brought up various perspectives where some fishers believe that crab leads to increased octopus and bycatch capture rates while others fear that finfish-baited traps will aid in overexploitation of the population. Some believe baited traps help the population, increasing biomass and yield over time (Sonderblohm et. al., 2017). Crabs used as bait in the Mediterranean are native to the ecosystem and last longer in traps, which decreases handling of traps and the travel time to trap locations, resulting in more time spent fishing and higher revenue – making them a more practical bait (Leitão et.

al., 2023). Restrictions on bait used in traps have the potential to reduce bycatch, but the focus that it has attracted is better spent developing other management tactics, such as a maximum landing weight or quota distribution. The impact that bait type has on octopus capture rates is not significant enough to base recruitment rates on, whereas other methods have the potential to have true positive impacts.

Mexican octopus fisheries utilize the closure season and the minimum landing weight, which is restricted by species and is on average 500g (Avendaño et. al., 2025). More importantly, they have implemented total allowable catch (TAC) and permitting. In 2001, the Fisheries Institute began putting out yearly TAC quotas for octopus fisheries on the Yucatan Peninsula based on estimates of abundance of the relevant octopus species (*O. maya, O. vulgaris*); conducted via visual surveying methods that utilize submarine transects and baited lines that assess relative abundance (Sauer et. al., 2021). Despite TAC regulations, there is still a lack of adherence, and individual quotas have never been implemented. Fishing in the Gulf of Mexico is regulated through permitting, which provide the right to fish a given species. In 2011, an official agreement focused on officially definition of a closure season in the waters surrounding Veracruz also distributed octopus permits, given to 227 fishers (Sauer et. al., 2021). This is a marine protected area and national park, giving it advantages in its management consistency and enforcement – a benefit that other regions in both the Gulf of Mexico and the Mediterranean do not have.

Management for octopus fisheries can be categorized into two areas: input or output. Input controls include gear and license limits; output controls include limiting individual weight or, ideally, the total landing weight (Pita et. al., 2021). Each are carried out by maritime police or harbor authorities, with occasional broad monitoring at sea or satellite tracking. Thee effectiveness of these monitoring entities varies and is often limited given the lack of resources required to patrol and enforce regulations, even if they are written into law (Pita et. al., 2015). On land, at seafood markets, landing weights are rarely enforced given the heavy economic reliance on seafood as a resource – and full compliance would likely have negative economic impacts on both fishers and community. The existing management in octopus fisheries is non-ideal and has not provided enough benefit to the relevant octopus populations, as evidenced by the consistent decline in landings and the large-scale closures in the Gulf of Mexico.

Management and policy for octopus fisheries needs to be developed separately from finfish and based solely upon the semelparous, short-lived nature of the species. It has been proven over the years that octopus populations do not respond as expected to the regulations that already exist (Pita et. al., 2015). There is also the concern of gathering adequate socioeconomic data that takes into account octopus ecology and the reliance of fishers in these regions on them, the necessary profits, and cultural ties to the resource. In future management efforts, fishing overcapacity and overexploitation need to be taken more seriously, especially since declines in octopus stocks could result in the annihilation of the populations and the mass unemployment and decreased seafood resources (Fall & Asiedu, 2024).

4.3.c Community and Fisher Involvement in Policy

Many octopus fisheries are artisanal, made up of locals who need fishing for their income. Despite immense reliance on marine resources, fishers are often excluded from management decisions. In some locations, fishers are beginning to be asked to provide their thoughts about current management.

Local ecological knowledge (LEK) is held by the majority of artisanal fishers, and includes understanding of the distribution and behavior of species, but is rarely implemented in management and stock assessment despite its use to optimize catch, minimize effort, and make daily decisions (Silva et. al., 2019). Many Portuguese fishers are middle-aged and have years of experience fishing, giving them LEK that might be unknown to government officials. While regional LEK will vary, fishers are aware of seasonal life cycle events and of recruitment areas or migration patterns. Fishers with this knowledge tend to depend on octopus as their primary resource – and the majority of them desire the development of a comprehensive local management plan for octopuses. Fishers hold a common opinion that the policies in place for the octopus fishery are unrealistic and that there is not enough understanding or respect for local fishers associations, leading to disagreement and blame between groups (Silva et. al., 2019). There is a general desire for more involvement in management and even suggestions of what might be the most beneficial for the fishery, therefore creating potential for co-management.

In the Mediterranean, biological closures are a favored strategy that is, to some degree, already implemented. There is a favorable view of creating a local certification of origin, which would increase profits while reducing fishing efforts. Fishers' suggestion of adding a certification to octopus sales or even increasing the severity and duration of biological closures displays two important points: first, displeasure with the management of octopus fisheries and concern for the populations, showcasing the need for considerable improvement in policy or management that will benefit all parties; second, there are enough fishers wanting to defend their interests and provide their thoughts (Silva et. al., 2019). These point to the potential for implementing co-management in Mediterranean fisheries, with a focus on strengthening connections and coordination and combatting illegal fishing through increased enforcement, promoting more octopus recruitment and increasing seafood profits (Peng et. al., 2024). Involving fishers with direct connections to the fishery and scientists, there is hope for the development of management that will fit into the socioeconomic scope of these regions while better evaluating stocks, health, and abundance of a short-lived octopus population.

4.4 Welfare

4.4.a Welfare in Fisheries

Octopus welfare in fisheries is less researched than octopuses in captivity. There is the concern of culling methods, an ongoing query in the ethical treatment of octopuses that has yet to have an agreed upon answer – and so it is important to note that while debated, it will not be answered here – only acknowledged as a concern. In addition, the time of holding in fisheries is much shorter than in any potential aquaculture setting, and holds less weight in the evaluation of existing fisheries than it will in an aquaculture system where individuals will be raised, grown, and held for extended periods of time.

4.4.b Stress Impacts of Fishing and Capture

Considering the widespread capture of octopuses in traps and pots, the overview of octopus welfare in wild-capture fisheries is based on stress indicators upon capture, including chromatophore patterns and hormone fluctuation. Wild-capture fishing methods in the EU often fail to comply with what little European cephalopod protection regulations exist, creating concerns about the sustainability of methods such as non-compliant gillnets, spearfishing, and specific artisanal traps (Maselli et. al., 2025). Gillnets are harmful to an array of marine species and result in increased levels of bycatch, while spearfishing remains unregulated and carries the concern of culling method and speed. Traps and pots, though typically less harmful to individual and environment, can result in octopuses with physical injuries, including mantle abrasions and arm mutilations – causing stress for the trapped animal (Maselli et. al., 2025). The majority of stress impacts upon wild-captured octopuses – although important when considering fisheries regulation – have more use in forming aquaculture regulation than they do in the venture of attempting to reform or add to existing octopus fishery management.

Generally, when octopuses are captured via pot or trap, they have low bruising or injury to their mantle or arms, although it is possible for arm injury to occur in baited traps. In fact, over 50% of captured octopuses bear some form of bruising, and over 40% have arm injuries (Maselli et. al. 2025). Physical injury, though moderately unappealing to buyers at market, is a rather minimal form of harm in comparison to the experience of stress in an octopus. The largest and most important concern when octopuses are stressed during an experience with fishing gear (or the later discussed non-ideal conditions) is the disruption of reproductive events (Maselli et. al., 2025). To manage this, most fishers avoid capturing mature females. There is an enzyme called *catalase,* crucial to defending against oxidative stress – an issue that might arise in trapped octopuses unable to move from their location to avoid decreasing salinity, temperature changes, or variable dissolved oxygen levels (Maselli et. al., 2025).

Welfare is less of a concern in fisheries than in potential aquaculture projects or the keeping of captive cephalopods, but there is still a responsibility for fishers to be aware of the treatment of the individuals they are fishing. They should be aware of the link between fishing-related stress and physiological or behavioral changes in octopuses, as it affects recruitment and the quality of the catch. For future fisheries management, increased population monitoring, as is annually done in the Gulf of Mexico, can be useful in determining stock levels and overall health of octopus populations given the consistent and intense fishing behaviors revolving around them.

4.5 Fisheries Discussion

Fisheries, despite their continued existence and importance, are not without their failings. Octopus fisheries in particular require a considerable reform if they are to continue to sustain healthy populations that can be extracted from in years to come – and much of this comes from improved management. The decline seen in octopus landings has not only opened a market for octopus aquaculture, but begs concern surrounding the sustainability of octopus populations worldwide. As demand for the resource increases, it is more important than ever to sustainably manage wild-capture octopus fisheries in a way that ensures reproduction and continued recruitment while not compromising the livelihoods and ways of life that people worldwide have come to depend on.

Octopus fishing can only continue sustainably if management becomes more commonly enforced, and if management and policy begins to take into account the nuanced, unique physiological and behavioral aspects of octopus life including short lifespans, single reproductive events, and life-stage-based-migration. For too long has fishery management been centralized around finfish while the importance of cephalopods has continued to grow. In addition, the environmental impacts of a changing climate upon octopuses must be considered, such as their temperature and salinity restraints in the events of reproduction and growth. Without sustainable, comprehensive, and enforced management, octopus populations will increasingly be at risk of overexploitation and endangerment. Aquaculture is perhaps a supplemental source of octopuses for the market, but the interaction with existing fisheries cannot go unnoticed, and the unique features of octopuses that dictate fishery intensity will become even more relevant as aquaculture is explored for the octopus species.

Chapter 5: Proposed Octopus Aquaculture Methods

Preface

Two methods are proposed for octopus aquaculture – specifically, *Octopus vulgaris* – the target of Mediterranean fisheries. The methods are nearshore aquaculture and inland, closed system aquaculture; each come with their own concerns of implementation and management.

Nearshore aquaculture is a method of operation that occurs in waters in the immediate vicinity of the coast, with animals raised in net pens or sea cages that are floating or submerged (Buck et. al., 2025 & Fry et. al., 2014). The majority of existing nearshore aquaculture is for finfish, and aquaculture regulations are dictated by fish life history and behaviors. Culture systems located in open waters are subject to the natural environmental functions of the region – weather, varying temperature and salinity, nutrient level change, etc., and have the risk of impacting local marine animals and habitats. All aquaculture systems located in marine waters, regardless of species, carry risks of harming habitats around them. Environmental impacts can vary depending by location; some sites might have stronger winds or currents, making transport of nutrients, chemicals, or waste more widespread. As a result, spatial constraints are a key issue in the planning of aquaculture. It is important to thoroughly plan when deciding where to implement a new aquaculture site, which can be done through the use of marine spatial planning (MSP) and allocated zones for aquaculture (AZA). Nearshore octopus aquaculture plans to utilize sea cages, which can be floating and suspended from existing rafts, such as those used for mussel culture, or fully submerged into benthic habitats. The kind of enclosures utilized in these projects are rigid sea cages made of metal containing stacked dens, which restricts use to calm waters, which means possible interference with navigation, tourism, and recreation (Estefanell et. al., 2021). Octopus sea cage size is, on average, 3 meters in length, 1.5m in width, and 1-6 meters in height with a volume of around $8m^2$ and made of iron or steel (Chapela et. al., 2006, Estefanell et. al., 2012, & García García & García García, 2011).

The second method is a closed system that does not interact directly with the natural environment and is located on land, relying on recirculated water (Bregnballe, 2022). Concerns with land-based aquaculture include managing of water resources and water quality (Bregnballe, 2022), required energy use, system maintenance, and waste discharge management. Closed system aquaculture relies on water intake, which can be intensified by the amount of space needed to raise a species, and water treatment, which can result in relocation of highly potent and nutrient-rich water being released (Piedrahita, 2003). However, the amount of water needed or recirculated can be highly variable, and the impacts are determined more by how water is treated. Land-based aquaculture requires similar spatial planning to nearshore aquaculture – where it will go, the environment or ecosystem its implementation will impact, and what other sectors it might cause conflict with. Closed system aquaculture carries the benefit of complete environmental control – water quality, temperature, oxygen content, circulation, and salinity can all be controlled and optimized for ideal growth levels (McGrath et. al., 2015), whereas aquaculture in the ocean is subject to natural impacts that come with life in the ocean. With the benefits of complete control come risks – increased energy use and emissions are an important issue when managing land-based aquaculture, and system failure can occur and result in total mortality of the cultured population. For octopuses, one closed-system project is proposed, located on the Canary Islands off the coast of Morocco under the control of Nueva Pescanova, an aquaculture company proposing not only land-based octopus aquaculture, but the breeding and hatching of octopuses to produce one million individuals per year (Chappell, 2024). An operation of this size would take not only years to get running successfully, but a large amount of resources that would impact the environment.

In each method, the risk of escape is present, as octopuses are notorious for escape of holding tanks and have been observed to travel between tide pools in the wild (Röckner et. al., 2024). There is a larger focus on escapes in a nearshore aquaculture system, as captive octopuses can return to the wild and perhaps transmit disease to wild populations or individuals. Escapes are a general concern in production of cultured marine animals, which can introduce or return animals to the wild and decrease profit margins. In nearshore cages or net pens, exposure and damage to the holding infrastructure can create opportunity for escape, and in finfish aquaculture, cause up to 25,000 individuals to be released (Holmer, 2013). The prominent concern with aquaculture escapees is a risk to genetic pollution of wild populations as a result of interbreeding between escaped and wild individuals (Alvanou et. al., 2023). In the early stages of octopus nearshore aquaculture, the concern of genetic crossover is less prominent given the current reliance on capture-based aquaculture. A case study on octopus escapes showed that out of eight species, *O. vulgaris* was the most likely to attempt escape (Wood & Anderson, 2004) – which might cause trouble in proposed aquaculture projects if not managed properly. In closed system environments, octopus escapes can lead to mortality if they remain out of the water for too long or have extended exposure with chemicals used to keep the laboratory facilities clean (Wood & Anderson, 2004).

5.1 Overarching Barriers and Concerns

Aquaculture as a whole has two prominent areas of focus – feed and seed. Feed concerns what the cultured animals will be eating and where it will be sourced from, and seed refers to the population of individuals and where they are coming from – the wild or a hatchery where they are bred in captivity. Both of these are of immense concern for octopus aquaculture given their carnivorous and semelparous characteristics. In addition, all aquaculture carries the risk of disease spread within a culture, and octopuses are no exception.

5.1.a Disease

For octopuses, the primary disease risk comes from secondary bacterial infection of abraded skin – the result of inter-animal conflict; in individuals, this can be treated through daily baths containing UV sterilized water and the relevant drug or through antibiotics contained in food sources (Forsythe et. al., 1988). Ulcers have been observed in the mantle during sea cage rearing, which come from "pathogenic agents [colonizing] the mantle through small wounds in the skin," (Chapela et. al., 2006). This is a result of contact with cage walls, and impacted individuals of all sizes. Another observed pathogen in octopuses is *Aggregata octopiana*, which is transmitted through the food web and is thought to impair development and growth through impacts on gastrointestinal function and tissue health (Gestal et. al., 2007). Individual treatment is unlikely to occur in an aquaculture setting. Disease treatment can vary by method, but among the best examples of disease management is that of salmon aquaculture, where *fallowing*, or the 'all-in-all-out' method, is used, where culture pens or cages are emptied and not restocked for a duration so the pathogen can clear out; in the case of nearshore aquaculture, nearby sites are placed under high surveillance (Werkman et. al., 2011). In the event that octopus aquaculture is feasible, cultures would house fewer individuals given their solitary, denning behaviors and their reproductive complexity – so fallowing would likely be easier to manage and coordinate. For both methods of aquaculture, though particularly nearshore due to its location in open, natural systems, consideration must be taken to ensure i) minimal interaction with sea cage walls, as abrasions are the leading cause of infection and therefore diseases and ii) feed choice, as crustaceans are able to carry *Aggregata octopiana*, the aforementioned octopus-specific virus.

5.1.b Water Quality and Culture Conditions

Temperature, salinity, and circulation strength are shown to have a strong impact on the growth of *O. vulgaris*. The issue of temperature is present in octopus fisheries and aquaculture projects, and was mentioned in relevance to growth rates and seasonal biology in the previous fisheries chapter. *O. vulgaris* shows an ideal temperature range of 20-21°C, which corresponds to high biological performance and distinct increase in growth rates that deeply decline at 22°C, particularly in juveniles and immature adults (Estefanell et. al., 2012 & Leporati et. al., 2015). Growth performance is higher during the spring and summer months than the winter, regardless of initial weight, and females experience higher rates of growth than males (Chapela et. al., 2006). Given the sharp declines in growth at higher sea temperatures, nearshore octopus aquaculture would have to face the concerns of rising ocean temperatures from climate change – making it a riskier venture than a closed system if consistent octopus growth rates are to be depended on. The water in the Mediterranean at present has a large range of annual temperatures, ranging from 10°C to 27°C (García García & García García, 2011), and benthic cages would provide an octopus rearing environment with more stable temperatures than the sea surface – which experiences higher variation in temperature (Estefanell et. al, 2012).

The lower limit of salinity should be 30psu (Practical Salinity Unit; 1g salt/1000g water) given the observation of high mortality rates at or below 29psu (Chapela et. al., 2006). In nearshore cultures, this decreased salinity can result from increased rainfall or increased water input from nearby rivers. In Spanish octopus fisheries, there are records of lower levels of octopus landings in correlation with increased rainfall (Sonderblohm et. al., 2014), suggesting that landings per unit effort are directly correlated to freshwater in the ecosystem. When octopuses are wild, they are mobile, and can avoid areas of lowering salinity; when they are in a stagnant captive location, they cannot seek ideal areas of water quality. In nearshore octopus cultures, regardless of cage location (i.e. floating VS benthic), site selection would have to be carefully planned so to avoid as much freshwater input as possible.

Circulation and current strength is also seen to have a strong impact on octopus growth. In experimental cultures utilizing rigid floating sea cages in the Mediterranean, there is a strong impact from wave action – even low wave heights of 0.4-1.2 meters have a negative effect on octopus growth (Estefanell et. al., 2012). Paralarvae are reliant on the productivity of the water column, which is correlated with upwelling events along Mediterranean coastlines, particularly in Spain (Sonderblohm et. al., 2014) – so the culture location must also be dependent upon ideal locations for upwelling if there is hope of breeding and paralarvae rearing in nearshore sites. Ideal water circulation in closed systems, particularly for paralarvae rearing, has been observed to be a gentle, circular movement to decrease stress and collision rates with the tank walls (Casalini et. al., 2020).

5.1.c Feed

The subject of feed for octopuses is an important consideration as they require high percentages of protein in their diets and use hunting of fish or crabs as a form of enrichment (Cooke et. al., 2019). Large-scale aquaculture operations such as salmon farming have defined, standardized diets – but there is no such commercialized diet for octopuses yet. Octopus feed source is a concern because of the protein requirement as well as an ideal food intake of around 5% of an individual's body weight (Chapela et. al., 2006). This is a high percentage compared to the requirements of the heavily cultured Atlantic Salmon, where daily diet is approximately 0.64% of body weight (Aas et. al., 2020). Feed conversion ratio, determined by ingested food over increase of weight, averages 2.69-3.66:1 depending on the density of the captive environment (Pham & Isidro, 2009). The diet demands of octopuses begs the question of where feed will come from – ideally, it should not have any immense impact on existing fisheries and inspire increased exploitation nor should it require creation of another marine culture system. In captive environments such as labs or aquariums, cephalopods are commonly fed crustaceans or small fish – frozen or live – but frozen food can affect growth and health of the individual; however the use of live food in production scale aquaculture is not economical nor is it practical (Sykes et. al., 2017). Crustaceans have a higher percentage of non-edible parts as compared to fish, and have the risk of contributing more waste and nutrient pollution in nearshore cultures or more debris to filter out of a closed system. Some crustacean species are intermediary hosts for an octopus pathogen, which suggests the need for comprehensive understanding of feed source and impact. In experimental octopus cultures, a mixed diet of fish and crustacean, both fresh and frozen, is common and results in higher growth rates (Estefanell et. al., 2012). A mixed diet provides adequate amounts of protein while maintaining a lower level of lipid consumption given octopuses' low digestibility and energy use of lipids (Chapela et. al., 2006, Estefanell et. al., 2011). A commercial octopus diet should also consist of species that do not have high demand by humans – such as bogue (*Boops boops*), often commonly discarded (Estefanell et. al., 2011). In previous octopus grow-on experiments located off the coast, bogue was seen to be an accidentally reared species (Estefanell et. al., 2012), creating potential for both self-sustaining octopus cultures as well as a new and profitable market for byproduct species that might increase the feasibility of octopus aquaculture projects.

5.1.d Broodstock & Seed

Seed and the obtaining of individuals for growout is another large concern in octopus aquaculture. In nearshore sea cage projects, octopuses are captured from the wild as juveniles and raised to maturity or ideal market size in captivity, referred to as a grow-out. This is the practice of capture-based aquaculture (CBA), and is done with other marine species and commonly seen in the practice of tuna ranching, developed in 1991 as a response to declines in total allowable catch quotas (Kirchhoff et. al., 2011). During the ranching grow-out, juvenile tunas (also a carnivorous animal) are captured and raised to ideal market size and weight, which has increased average individual prices and demand for CBA-raised tuna (Ellis & Kiessling, 2016). Management for all CBA is reliant on leaving enough mature, spawning fish in the ecosystem to provide future recruitment and ensure the next group of cultured individuals (Ellis & Kiessling, 2016). For tuna species, breeding and the establishment of hatcheries has been a barrier to domestic aquaculture, similarly to octopuses. In grow-outs and CBA, dependency on the environment needs to be emphasized due to the supply difficulties – fisheries are reliant on the same populations, and have concerns about the lowering of prices that might come from increased nearshore octopus grow-outs (García et. al., 2014).

Despite the reliance on CBA for the farming of various marine species (shrimp, lobster, tuna, eels) and its possible contribution to overfishing, estimation on the extent of CBA is almost non-existent (Clavelle et. al., 2019). In some cases, ranching and CBA can increase survival rates of juveniles – but without reproduction, the harm to the population is already done. Tuna ranching has become incredibly profitable, with 99% of bluefin tuna catch in the Mediterranean going into ranching cultures (Clavelle et. al., 2019), which not only removes a large percentage of individuals from the wild, but also relies on high percentages of food that can both intensify fishing efforts and existing farming practices. In cases such as tuna ranching or octopus rearing, the food required to feed these carnivorous animals is costly and can impact the wild populations of marine animals – leading to an imbalance between the economic or social benefits and the environmental impacts (Guillen et. al., 2024). CBA and its interaction with fisheries is reliant on communication and co-management between stakeholders; without, exploitation is likely to become unsustainable. The other option for the obtaining of seed for an aquaculture project is the establishment of a hatchery – which has proved difficult for octopuses. Young, larval individuals are vulnerable to habitat changes and water quality variability, making the creation of an optimal rearing habitat complex. In nearshore sea cages, octopuses are not seen to breed, and in closed systems, breeding and the hatching of eggs occurs with relatively low survival rates. Feed type, water circulation, and temperature all play critical roles in the survivability of octopus paralarvae. Typically, in octopus paralarvae rearing experiments in closed, recirculated water system tanks, survival rates average around 30% or lower (Iglesias et. al., 2007) – a number seen in a collection of differing studies with multiple iterations each. Survival rates for aquaculture, especially CBA, range from 20-95% (Froehlich et. al.,

2023) – providing a wide range of possibility. Considering the consistent octopus paralarvae survival averages of around 30%, there should be pause surrounding the viability of closed system octopus hatcheries for sustainable aquaculture production; in the case of survivability approaching the range of 50%, an octopus hatchery project would be increasingly viable when evaluated purely on survivability.

5.2 Environmental

5.2.a Nearshore Aquaculture

Nearshore aquaculture for any species has environmental risks and impacts, each of which should be considered carefully when choosing a culture site. Several have been discussed in the preface of the chapter. In addition, the physiological nature of octopuses may also restrict open water aquaculture locations given their sensitivity to changing environmental conditions (temperature, salinity, current strength). Open water aquaculture carries concerns of disease transmission, nutrient pollution, and risk of escape; if veterinary drugs are used, they can flow throughout the ecosystem and possibly incorporate into animal tissues (Fry et. al., 2014). Typically, the further away from shore an aquaculture site is located, the more susceptible it is to strong current movement and water column stratification, making it more likely for disease or pollutant to spread over a larger area (Holmer, 2013).

Disease management and mitigation for octopuses has been previously discussed, however, for disease mitigation within open water aquaculture sites, locations can be determined based on the maximum tide current speeds, leaving a minimum distance of 13km between farms (Werkman et. al., 2011) to help decrease hydrodynamic spread of waste or pathogens. The distance between sites must prevent at least 75% of pathogen spread to make eradication likely, and if sites are not owned by the same company, coordination and cooperation must occur to coordinate fallowing under high risk circumstances (Werkman et. al., 2011).

Nutrient overloading is a risk to areas surrounding nearshore cultures, and results from waste pollution, including the decomposition of uneaten feed. Close to the coastal zone, there is high competition for space among fisheries, maritime settlements, and recreation/tourism (Primavera, 2006).

Added nutrients to coastal areas already strained by their high development can disrupt the rates and success of primary production, and aquaculture efforts have added increased complexity to the planning and use of coastal sites. Waste pollution is predominantly nitrogen or phosphate, and the enhanced productivity they cause can create algal blooms, which float on the sea surface, cover beaches, and deplete oxygen levels (Sellner et. al., 2003); these issues can lead to marine animal mortality or skin irritation. Oxygen depletion, or *hypoxia*, is a particular concern in benthic habitats or areas of poor water exchange that might respond to enhanced nutrient enrichment by increasing production activity (Holmer, 2013). In these deeper waters, severity of nutrient impact is determined by the amount released from the source and transport rates of the surrounding currents. Water quality can vary by depth, and one method of octopus aquaculture is benthic sea cage rearing, which would reduce pressure on coastal sites and has shown improved growth rates compared to a floating sea cage (Estefanell et. al., 2012). For octopuses fed a mixed diet of crab (*Carcinus mediterraneus*) and bogue (*Boops boops*), the majority of nitrogen and phosphorus release comes from the non-edible parts of the animal – the shell for crabs, and spines, heads, and tails for bogue (Mazón et. al., 2007). The percentages released by animal waste are considerably lower, and is unlikely to have a significant impact on the environment – but non-edible parts, if not removed, can accumulate in sediment or spread through currents as it decomposes.

As more nearshore aquaculture sites have appeared in competitive coastal areas, ideal sites with good water quality have become more scarce (Holmer, 2013). This has led to two developments: the push to define and incorporate offshore aquaculture sites further from the coast than nearshore aquaculture, and the use of marine spatial planning (MSP). MSP is a multi-sectoral decision-making approach for reducing conflicts within ocean activities, weighing the production potential and potential profit margins against the environmental impacts, particularly on existing fisheries (Clavelle et. al., 2019 & Lester et. al., 2018). It has previously successfully determined a course of action to achieve the targeted levels of ocean use while ensuring costs and impacts remain as low as possible. Many of the decisions that go into MSP consider trade-offs rather than idealized function – which is important as dramatic tradeoffs are only unavoidable at high levels of development, which can be difficult to reach.

Continued development of nearshore aquaculture and the beginnings of offshore endeavors are an ideal way to integrate MSP on a wider scale as human use of the ocean expands – and it considers the unique concerns and attempts to mitigate conflicts between sectors within a location while considering the needs of a given species. Ideal plans for aquaculture via MSP include minimal impacts to existing fisheries, significant profit generation, consistent ecosystem health, and view quality of the ocean or coast (Lester et. al., 2018). For example, disease, which has an impact on nearly all of these, can be mitigated with the use of MSP. The understanding of ocean currents in a proposed site area can suppress the risk of disease spreading between cultures by avoiding areas with strong currents and connectivity – and maintains the generation of 88% of profit (Lester et. al., 2018). Octopus aquaculture would likely have a low to moderate relative value when assessed with the relevant factors – if benthic sea cages in areas of low current strength are used, visibility of the culture site would be low, as would spread of disease. Moderate levels of aquaculture are still able to generate substantial profits, and using MSP would not add negative consequences for planning or the environment (Lester et. al., 2018). For nearshore and offshore octopus aquaculture, MSP would assist in dictating the following: i) sites of minimal current strength, ii) sites of ideal stable temperatures, iii) areas least impacted by river runoff iv) where to situate floating VS benthic cages, v) potential overlapping sites with cultures such as mussel rafts for combined production, and vi) locations of minimal anthropogenic interaction so as to reduce conflict with navigation, existing fisheries, and tourism.

5.2.b Inland, Closed System Aquaculture

Closed system aquaculture is, in some instances, viewed as superior to nearshore or open water cultures due to the theoretical ability to reduce eutrophication impacts in neighboring environments, eliminate negative interactions with wild populations, and decrease water dependance (McGrath et. al., 2015 & Badiola et. al., 2018). A recirculating aquaculture system (RAS) can also decrease the potential for disease and higher feed conversion rations, where feed can be controlled more diligently and individuals are better observed (Bergman et. al., 2020). However, the ability to fully control a system and the decrease of eutrophication and disease spread come with different environmental concerns, including increased energy use. While perhaps better for local environments that experience lower levels of nutrient pollution or more open water, global-scale greenhouse gas pollution becomes a concern (McGrath et. al., 2015) given the need for 24-hour power supplies to maintain filtration, wastewater treatment, and light cycles. Therefore, in order to assess the viability and sustainability of a potential aquaculture system, a comprehensive assessment surrounding technique and lifecycle must be done.

In an RAS, tanks have connected filters and water treatment mechanisms, where post-treatment water returns to the holding tanks and the waste is converted into nitrate and gathered (Bergman et. al., 2020). Closed-system aquaculture relies on energy production, resource extraction, transportation, and manufacturing that ultimately result in an output of emissions. Their higher reliance on technical input and energy for the creation of suitable environments increases operational costs, which can decrease the sustainability of the farm. Energy source use, such as renewables, are highly dependent on farm location and accessibility (Badiola et. al., 2018). Some locations will have the ability to draw from an existing body of water, where treated water is released into as new, clean water is brought in, and the kind of treatment can require different amounts of energy – such as pumps or biofilters (Badiola et. al., 2018). In current land-based aquaculture, feed and general energy demand are the predominant areas of impact – where the feed comes from, how much is necessary, and what energy source is used to power the system (Bergman et. al., 2020). RAS systems powered on fossil fuels, such as coal energy, release 7.01kg CO_2 per approximately 0.5 kWh/kg, and those powered on a renewable source, such as geothermal, release 3.75kg CO_2 per approximately 3.6 kWh/kg, and operations running on nuclear energy in France released even less (Badiola et. al., 2018). In land-based, closed systems, energy is highly dependent on what is available in the selected location, and many places rely on a public utility, limiting options further. As a whole, although RAS can provide extreme control and fewer direct, local environmental impacts, it is more costly to manage and operate. Given the increasing climate crisis, it is necessary to integrate local energy sources into RAS aquaculture, which will need to be supported by farmers and stakeholders. In the case of closed-system octopus aquaculture, each of these energy and cost concerns will be present – and there is also the barrier of tank density, which must be less than in the case of finfish in order to prevent conflict and cannibalism to maintain welfare.

5.3 Economic

5.3.a Nearshore Aquaculture Tradeoffs and Cost Analysis

Areas for open-system, nearshore cultures must be located within Economic Extractive Zones (EEZs), created in the 1982 United Nations Convention on the Law of the Sea, and defined as an area beyond and adjacent to the territorial sea where coastal states have the right to explore, exploit, and manage the natural marine resources (UNCLOS, 1982). The mentioned allocated aquaculture zones (AAZs) have become increasingly important to ensure improved cooperation and coordination between industries. In the EU, aquaculture is strongly supported, and the use of methods such as MSP and Spatial Multi-Criteria Evaluation, a tool used to put together different scenarios and model their impacts helps to estimate uncertainty of profits and environmental impacts within AAZs in Europe (Porporato et. al., 2020). Defined areas and uncertainty evaluations help to ensure profit goals of developing aquaculture sites can be met, and conflicts that might arise have some level of solution planning already developed. One example of a highly profitable and strongly managed region when it comes to aquaculture is Rio Formosa, located in the Algarve region of Portugal. It is a marine protected area as well as Portugal's most productive aquaculture zone (Ferreira et. al., 2014).

The commercial viability of any aquaculture project is reliant on the start-up and maintenance costs being lower or balanced out by the profits made from the sale of the cultured species. In the case of octopus grow-outs, there are cost concerns with feed supply and the acquiring of juveniles (García García & García García et. al., 2011). For a grow-out (CBA) of *O. vulgaris*, a model was created to estimate costs, profits, and concerns. The situation included 150 sea cages with a total of 30,000 individuals and would consider 1-2 cycles per year with an assumed average mortality of 20% (García García & García García et. al., 2011). Goals of landing weight and market price are based on the current restrictions and profits made from wild-capture octopus fisheries. It is important to note that the study was based on models, and official octopus grow-out projects contain uncertainty and possible varying technology. Costs for the start-up of an octopus grow-out sea cage project include official licenses, the acquiring of necessary technology, permits, and environmental impact assessments (García García & García García et. al., 2011). Assuming a feeding schedule of once per day on a mixed diet of bogue and crab, feed results in the highest operational costs. Importantly, costs surrounding salaries, gear maintenance, and potential travel to aquaculture sites are relevant – but as they are not among the highest costs, they are not discussed here. As of 2011, feed costs were approximately $381,788.57 USD per growing cycle, obtaining juveniles was approximately $219,562.20 USC per cycle; total cost for production was $953,793.76 USD (García García & García García et. al., 2011). In order to 'break even' in the production of grown-out octopuses, selling price must be around $7.53/kg, which is on average about $3 higher than wild-caught octopuses (García García & García García et. al., 2011 & Pita et. al., 2021). Having one growing cycle a year creates a substantial portion of each year where sea cages go unused – leading to the potential of a joint cultivation of octopuses and a finfish species – which could both provide a source of feed for the reared octopuses as well as a potential supplemental source of profits to make the process more viable (García García & García García et. al., 2011).

5.3.b Inland, Closed System Tradeoffs and Cost Analysis

Economic and cost/profit information on land-based octopus aquaculture is less prevalent than for nearshore, sea cage octopus aquaculture. However, it is estimated that it would be a higher cost considering the energy needs, land use concerns, and water quality necessities. Several studies estimated that the cost per year of land-based octopus aquaculture operation ranges from approximately $2-2.5 million USD (García et. al., 2014). Ideal RAS for octopuses in this event relies on improved technology, where newly developed cages unique for octopuses could contain greater densities of individuals and perhaps have a lower relative investment to sea cages, which have a higher original cost but lower maintenance (García et. a., 2014). A study conducted on potential RAS octopus aquaculture displayed a production cost of $8.03/kg in 2004, or approximately $13.37/kg as of 2024 for intensive inland octopus culture efforts (García García et. al., 2004). Given these assessments, it is likely much more economically feasible and environmentally sustainable to conduct octopus grow-outs in nearshore sea cages – the high costs and increasing sale prices for closed-system cultured octopuses (despite the high levels of control) make it a less ideal method.

5.4 Policy and Management

In order to effectively create aquaculture policy, each method must have a proper legal definition. Nearshore aquaculture here is defined by Buck et. al., 2025 as operations that occur in waters in the immediate vicinity of the coast; "nearshore" thus refers to farming activities in water close to the coast, which may be shallower and closer to shore but can also include deeper waters depending on the region's topography. Closed system aquaculture is located on land and includes RAS. The development of aquaculture concerns four policy domains: public investments, aquaculture value support, regulation for environmental and social protection, and trade – and aquaculture is a business; one which must have an economic environment and secure property rights (Naylor et. al., 2023). In addition, the primary concern for increasing marine aquaculture is that of the uncertainty surrounding ecological and socioeconomic impacts on wild fisheries – without ecologically sound management, threats are likely to arise (Clavelle et. al., 2018). Overall targets of aquaculture policy are planning approaches, operational licenses, MSP, diversifying production, and multi-use (Falconer et. al., 2023). In addition, as briefly mentioned, there are no existing regulations or restrictions for the development of octopus aquaculture save for the two earlier mentioned bills in the U.S. (California and Washington) that have entirely banned the practice. Directive 2010/63/EU regulates proper practices for the use of cephalopods in scientific research – but aquaculture rules remain lacking and will need to be developed in entirely should octopus aquaculture become prevalent. Specifically, welfare and containment regulations need to be established as they are in finfish aquaculture. Management for the vast majority of concerns for nearshore and inland, closed system aquacultures are existent, and briefly discussed below.

5.4.a Existing Nearshore Aquaculture Management

Open water, marine aquaculture farms proposed for establishment must comply with the existing regulatory requirements of the country or area where they are located. These requirements can include location or production limits, license acquisition, and environmental impact assessments, which may also utilize MSP (Falconer et. al., 2023). As production of the culture continues, regular environmental monitoring often occurs to ensure the rules stated in the given license are followed. The finding of a suitable location is necessary for start-up, but is complex due to the large array of requirements that must be balanced with ensuring minimal environmental impacts; otherwise sustainability requirements will not be met. Despite these requirements, review and revision of established regulation is necessary and common – particularly in the EU, where there is a goal of creating guidelines for a more sustainable and competitive aquaculture process (Falconer et. al., 2023).

In the Mediterranean, where nearshore octopus aquaculture is being experimented with, there are allocated zones for aquaculture (AZAs), locations where aquaculture development has priority over other uses (Clavelle et. al., 2019). The creation alone of AZAs are not enough to promote sustainable development without significant environmental impacts – they must be used in tandem with MSP to properly account for the variation in space and impact that comes with different species. AZAs are currently considered mainly for finfish, but as development continues, policymakers have increasingly recommended marine spatial planning (MSP) to regulate the additions of aquaculture to highly used marine areas. Some plans created through MSP suggest that aquaculture should be developed in areas of lower anthropogenic impact, such as Mediterranean coastlines along Sicily and Calabria (Porporato et. al., 2020). For open water aquaculture, MSP and ecosystem-based approaches can be utilized to ensure no marine area becomes damaged enough that cultures must be abandoned or moved to new areas (Davies et. al., 2019). Indicators of ecosystem status should be evaluated – even if an area's operation is consistent and reliable at present, would the addition of a new activity push the ecosystem and its functions past its limits? This brings the idea of co-use – which has been suggested in octopus aquaculture projects in the form of attaching octopus sea cages to existing mussel rafts to decrease used space and efficiency (Chapela et. al., 2006).

5.4.b Existing Inland Closed System Management and Restrictions

Open water aquaculture has the benefit of already established economic extractive zones (EEZs) and in some locations, AZAs – but land-based aquaculture sites can be less clearly defined. Much of the policy and regulation for inland aquaculture is focused on land and water rights, sustainable resource use, pollution control, and animal health – leading towards (ideally) the expansion of environmental policy to regulate sustainable systems (Naylor et. al., 2023). Sustainable systems are those which have the necessary licenses, conduct regular environmental impact assessments, manage their resources and wastewater properly, and ensure the safety of their food product (Alexander et. al., 2015). In order to establish inland aquaculture sites, research on the energy impacts and targeted species must be conducted as well as the setup of proper infrastructure that is able to attract investment and meet seafood demands of consumers (Naylor et. al., 2023).

Among the requirements for an application for aquaculture development are a feasibility study and a document that outlines how waste shall be managed, the disposal of mortalities, and general hygiene practices (FAO, 2019). As a result, each aquaculture project must prove its viability prior to its possible authorization. The Canary Islands inland octopus aquaculture proposal is subject to the regulations and policies of Spain, as it is a Spanish territory despite its location off the coast of Morocco. Spanish law requires authorization or concession from the Fisheries Agency – and any facility that discharges into the sea must have the appropriate systems to prevent environmental harm, defined as the loss of activity/reproduction of species via the accumulation of harmful materials (FAO, 1984). The proposed location, near La Isleta, is home to a marine protected area in which seawater intake and release has the potential to harm seafloor animals end endangered species (Meader, 2024). Inland octopus aquaculture proposals, particularly that of the Canary Islands proposal – lacks a feasibility case on how the system will be run sustainably with sufficient survival rates, as well as an overview of how drastic environmental impacts will be and how to mitigate them – failing to adhere to both Spanish law and the FAO regulations of aquaculture.

5.5 Welfare

The state of captive octopuses in aquaculture environments, particularly given the lack of existing regulations, requires an evaluation of what the appropriate welfare standards are for holding them, regardless of if they will be in a nearshore sea cage or an inland, closed system RAS aquaculture setting.

As per Section 1.1, animal welfare is defined as: the physical and mental state of an animal in relation to the conditions in which it lives and dies (Barreto et. al., 2021). For octopuses, welfare regulations will inevitably vary from those for finfish as a result of their unique physiological and behavioral traits. One aspect of welfare is that of the capacity of an animal to experience pain and suffering, which in turn informs the legal regulations for how welfare is handled (Browman et. al., 2019). For octopuses in captivity, particularly in aquaculture settings, welfare concerns include skin wounds and abrasions that might cause pain, density of individuals per captive holding tank or cage, which can increase the risk of cannibalism, feed type, and enrichment (Sykes et. al., 2019, Casalini et. al., 2020, & Casalini et. al., 2023).

In order to create a suitable captive habitat for octopuses, understanding their physiological processes and the impact that external factors will have on them is crucial, especially in potential hatcheries that will house each life stage; cephalopod health and welfare have direct correlation to how they are housed and treated (Sykes et. al., 2017 & Sykes et. al., 2019). The majority of these (water quality, disease, etc.) have been discussed in Sections 5.1.a and 5.1.b. However, many of the necessary regulations that would need to be implemented to ensure ideal conditions for cultured octopuses would add to the costs of aquaculture operations, making the processes less feasible.

In addition to water quality and enclosure interaction, cannibalism is a topic of concern for holding large quantities of octopuses, which is caused by stress, nonideal habitat, and is an energy storage strategy in adverse food situations (Espinoza et. al., 2019). The main solution for decreasing or eliminating potential cannibalism is to decrease the amounts of octopuses held within one cage or tank and ensure adequate amounts of feed (Espinoza et. al., 2019) – but another is ensuring ample space for dens and artificial grasses to be present as shelter, especially for hatchings (Forsythe & Hanlon, 1980). This practice improves growth, but also ensures enrichment through exploration of habitat.

Enrichment is a broad concept, and involves techniques that facilitate and improve the biological functions of a captive animal through environmental modification and encouraging natural behaviors and includes physical enrichment, cognitive enrichment, nutritional enrichment, and occupational enrichment (such as introducing variety and opportunity) (Casalini et. al., 2023). In octopus welfare, enrichment is paired with water quality as the most important factor to consider considering the influence octopuses receive from their surroundings. Octopus health, stress levels, and enrichment ideals can be evaluated through growth rates and diversity of camouflage patterns – and when maintained in a less basic, more environmentally enriching place, there is less hostility, especially in RAS aquaculture (Casalini et. al., 2023). For octopuses and cuttlefish, camouflage is an aspect of enrichment given the environmental interaction; negative behaviors are reduced in tanks with substrate such as sand or seaweed when compared to bare tanks, which are likely to cause stress and unease as they cannot protect themselves as well (Tonkins et. al., 2015). These varying forms of camouflage and distinct behaviors are observed significantly more frequently in tanks with sand, natural-colored walls, the presence of shells, stones, and toys, and live food interactions (Casalini et. al., 2023). Individuals in enriching environments including more than just feed stimulation also see more consistent weight gain, as they are less stressed and feel more secure in their environments, thus being more motivated to hunt and feed – a high amount of diverse body patterns suggests a calm octopus condition (Casalini et. al., 2023). Given these environmental characteristics, it is suggested that captive octopuses in any setting require environmental enrichment rather than an average, empty cage or tank. Octopuses' intelligent nature and need for environmental enrichment display a unique management system and captive environment for potential aquaculture, especially RAS. However, the addition of environmental enrichment techniques such as live feed, diverse denning areas, and items to interact with as necessary factors for optimal growth and contentment add increased costs and sanitation issues (Casalini et. al., 2023) that are likely dissatisfactory to those planning octopus aquaculture. Not only would these additions increase the costs of maintenance and operation, they are also likely to increase the market prices of commercially-bred octopuses given the need to make a continuous profit from the operation.

<u>Chapter 6: Discussion and Conclusion</u>

6.1 Discussion

In the present state, the large-scale aquaculture of octopuses is neither feasible nor sustainable given the lack of reliable, non-environmentally damaging seed and the high costs and operational concerns associated with creating an environment that provides ample enrichment, exploration, and growth opportunities to ensure adequate welfare standards. Octopus aquaculture is not only constrained by the species sensitivity to environmental conditions, including temperature, salinity, and circulation; there are additional, larger constraints surrounding their environment and the stimulation within it. Octopuses thrive from the ability to hunt live prey, solve puzzles, establish dens, and explore their environment through interaction and camouflage. In sterile, confined captive environments, required kinds of enrichment do not exist, and therefore can increase stress and decrease growth rates due to an unwillingness to feed in nonideal settings (Casalini et. al., 2023). Ensuring the existence of these conditions in a large-scale, captive environment increases costs, especially in closed-system aquaculture where tanks must be cleaned, filtered, and maintained. Increased costs of production in turn drive up the sale price at seafood markets, which in many cases leads to lowered wild-capture octopus prices, harming the socioeconomic functions of the regions reliant on octopus fishing. Though octopus welfare and subsequent costs remain a considerable obstacle, the gathering of seed and establishment of an ideal, standardized feed are another source of increased costs and roadblocks for large-scale aquaculture establishment. In aquaculture operations, dramatic tradeoffs such as welfare VS costs of production, are only unavoidable at high levels of development – which can be difficult to reach. It is understood throughout literature on captive octopuses that a mixed diet consisting of crustacean and finfish is ideal for protein and lipid content, but specific percentages and sourcing remain a topic of further necessary research, especially considering increased reliance on fisheries to source live, protein-heavy species with which to feed octopuses. Current aquaculture stock sourcing is set to come prominently from capture-based aquaculture (CBA), with potential supplemental efforts occurring in hatcheries – though the low octopus paralarvae survival rates, hovering around 30% (Iglesias et. al., 2007), suggest a low chance of success for broodstock establishment and the continued reliance on wild populations of octopuses to supply grow-outs and aquaculture ventures.

The proposals for octopus aquaculture tend to not entirely consider the environmental impacts, particularly those surrounding CBA, nor do they full account for the welfare standards that are required by the complex physiology and enrichment needs of the species. Though CBA reliance is common throughout aquaculture in practices like tuna ranching, the interactions between fisheries and aquaculture are not widely understood. Resulting environmental impacts are not entirely evaluated or studied, such as influence on community disruption, life stage development, and fishery production (Froehlich et. al., 2023) – creating a potential need for studies on the influences of CBA during continued fishery exploitation of wild populations, especially octopuses given their semelparous nature. In the case that hatcheries are not feasible for octopuses, CBA reliance is likely to continue. Despite the aims to supplement wild octopus production with aquaculture and meet the increasing demand for the resource, CBA will instead cause further disruption of i) octopus populations and ii) the livelihood of fishers. As an approximate evaluation, a yearly landing of 2100 tons in Galicia as of 2019 (Pita et. al., 2021) with an assumed average landing weight of 1040g taken from averages of five weight trials (Arechavala-Lopez et. al., 2019), around 1.9 million octopuses are caught in the region per year. Therefore, octopus aquaculture proposals that aim to produce 30,000 individuals per year in a single set of nearshore installations or ambitious goals of one million octopuses in a closed system per year require environmental and ecosystem impact analyses and detailed socioeconomic analyses prior to attempted startup.

This study created a comprehensive evaluation of the physiological and behavioral barriers that stand in the way of feasible and sustainable octopus aquaculture efforts, encompassing both environmental influences on octopus growth (i.e. temperature, salinity, and circulation) as well as the behavioral and enrichment needs required for adequate to optimal captive conditions. However, the scope of existing octopus fisheries' management and operation was restricted predominantly to the Mediterranean, as this is where octopus aquaculture proposals are being developed and experimented with. In order to gain a fuller knowledge of how octopus as a resource is managed and how potential aquaculture might impact populations and existing policies, a more global analysis would be necessary. Additionally, there is uncertainty surrounding octopus landings and population assessments as a result of the data used to display important species and annual catches, and so there is potential for the creation of a more detailed and precise collection of octopus landing data so that fisheries scientists can appropriately evaluate octopus fishery sustainability. However, much of the information synthesized here provides a framework by which to make decisions on how to manage octopus populations and their welfare. In addition, the complexity of octopuses in proposed aquaculture projects and the considerations that are required outline general challenges of aquaculture as a sector as well as the obstacles faced when developing aquaculture processes for a newly proposed species.

The future of octopuses as a seafood resource is challenging and, in some ways, uncertain – aquaculture ventures are nonideal, and yet the demand for them remains while wild fishery landings are highly variable, and in a general state of decline. Reliance on CBA, particularly for the already-existent nearshore octopus grow outs, will only add pressure on fisheries and species populations, and without adequate welfare regulations and successful paralarvae survival rates, octopus aquaculture are bound for failure. Regulations and management plans for octopuses in the aquaculture sector must be established – whether in the form of a widespread ban, as in the U.S. in California and Washington, or with detailed, clear, and species-specific welfare regulations; some of which might restrict operations based largely on size and capacity. However, fisheries management and an assessment of aquaculture interaction with existing fisheries is a more well-rounded option. Despite reliance on the same manner of resources, fisheries and aquaculture have little interaction. The developing of a cooperative manner between the two sectors with which to evaluate potential species for aquaculture and existing ecosystem impacts is one possible way to maintain sustainability in the seafood sector; this is particularly important should capture-based octopus grow outs continue to occur in the Mediterranean, even on small scales. However, as noted by Froehlich et. al., 2023, this is a challenging task and is reliant on the politics, infrastructure, and social interests for cooperation in each region. In addition, though fisheries always have a limit, including the maximum that can be taken to remain sustainable (i.e. maximum sustainable yield), improving the ways in which they are managed can be extremely beneficial to both population and profit. In the Mediterranean octopus fisheries, researchers and locals alike noted that the current regulations are not ideal for managing the fisheries, nor are they particularly successful. Indeed, reforming octopus fishery regulations is also not a simple task – and would require similar levels of political involvement and social cooperation to increased interaction between aquaculture and fisheries. Despite this, reforms including co-management between government and fishers, quota systems, and more widespread enforcement are desired by local fishers and would have a positive impact on the fished octopus populations (Pita et. al., 2021). Sustainably fished octopuses can be determined by location and method of capture – though a thorough evaluation of if it is ever truly sustainable to heavily fish a semelparous species such as octopuses surely has a place in future octopus research, especially as it pertains to aquaculture and fisheries interaction.

6.2 Conclusion & Overview

Though aquaculture for a variety of new species will continue to develop as the practice continues to dominate the seafood sector, octopuses are unlikely to take a place among the high production, high profit species produced. With a full consideration towards their biological characteristics and welfare needs paired with the drastic tradeoffs present to hatch, rear, and produce octopuses in aquaculture captivity, the effort is neither feasible nor sustainable. Additionally, seed and feed for octopus aquaculture each provide immense concerns. Octopus fisheries are already less stable, seeing continual declines in landings, making capture-based aquaculture especially harmful, and hatching rearing and survival cannot yet be considered a success. In the event that increased paralarvae survival rates via hatchery could reach upwards of 40-50%, the feasibility of the venture would improve. However, an accomplishment such as it has not been seen reliably in aquaculture experiments, nor has it been seen consistently in research labs – and in nonideal captive environments, rates are unlikely to improve. As for feed in octopus aquaculture, the large amounts of feed required will have an impact on local fisheries, and a clear distinction in aquaculture regulations for optimal diet. Nutritional ratios, and sourcing would need to be identified. Finally, welfare is an equally large barrier – poor conditions can induce stress, leading to a risk of cannibalism and high mortality or a refusal to consume feed. Without adequate enrichment, octopuses are unlikely to experience their ideal high growth rates; the largest reason they have become such a focus for aquaculture. Each of these concerns means there is a corresponding tradeoff in execution, as tradeoffs are rarely unavoidable in aquaculture, and when managing complex creatures, the tradeoffs are likely to only increase.

Octopuses' future in the seafood market, especially aquaculture, is uncertain. The endeavor of farming the species for increased profit or larger amounts of them on the seafood market is ill-advised given the constraints, and existing fisheries have the potential for reform and co-management to improve the status of populations and maintain the socioeconomic benefits that come with them. This study provides a more comprehensive and widespread perspective of the impacts that both octopus fishing and aquaculture might have on various sectors, including environmental, economic, and political – and the ways that octopuses as a case study can be used to inspire communication and cooperation between fisheries and aquaculture as well as between local seafood consumers and government for the hopes of a more sustainable use of octopuses.

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Appendix A: Octopuses on the Santa Barbara Shores

During the writing of this thesis, I learned octopuses could be found in Santa Barbara tide pools – and so here are several images of California Two-Spot Octopuses (*Octopus bimaculoides*).

Top Right: California Two-Spot Octopus attempts to scare off the observer with its two bold spots. Seen May 3rd, 2025.

Top Left: What appears to be a California Two-Spot Octopus tucked into a tide pool crevice – not confidently identified. Seen May 2nd, 2025

Lower Left: A cautious California Two-Spot Octopus, who was sharing its tide pool with another. Seen May 16th, 2025

Above: A California Two-Spot Octopus, identifiable by two eye-like spots on its back, ventures out of a tidepool in curiosity. Seen May 16th, 2025.