LOCAL KNOWLEDGE IN EL JOBO: UNDERSTANDING THE PUNTA DESCARTES ARTISANAL OCTOPUS FISHERY

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Abstract

El Jobo is a small town on the Pacific coast of Costa Rica that economically depends on its tourism industry, conservation programs, and artisanal fisheries. While octopus are target species for fishing, little is known about the stock or its current state, leading certain community members to question the sustainability of the town's fishery. In an attempt to help community members and local fishers increase their shared understanding of the octopus fishery, a participatory research study was conducted that used a social-ecological systems approach. Interviews, Fuzzy Cognitive Mapping, and morphological species identification were all employed as tools to help address the community's main questions about the octopus and contribute to their existing knowledge base of the octopus' fishery system as a whole. Based on interviews conducted with local community members who rely on the octopus for their livelihoods, our study found that the population of octopus appears to be in a decline. Furthermore, we found that the octopus social-ecological system is heavily influenced by external social and environmental factors, which could be driving this population decrease. Lastly, we concluded that based on morphological characteristics, El Jobo has at least two distinct species of octopus inhabiting its shallow coastal waters. While this research acts as a key first step for increasing understanding of the local artisanal octopus fishery of El Jobo, more work is needed to address the community's concerns about its sustainability. This includes a larger interview sample size, genetic testing of octopus species for definite species identification, a stock assessment process, and the monitoring of external social and environmental factors that could be negatively affecting the octopus population.

Introduction

As of 2023, small-scale fisheries (SSFs) are estimated to account for at least 40% of global aquatic catches and are known to employ at least 60 million people worldwide (FAO, 2023). However, despite their longstanding economic and cultural importance, SSFs are understudied, underrepresented, and often left out of fishery decisions by central governments due to their unique challenges in areas such as management, sustainability, and resilience against climate change (Basurto et al., 2017; Biswal et al., 2017; Carrillo et al., 2019; Gianelli et al., 2021; Kittinger et al., 2013; Purcell et al. 2015; Smith & Basurto, 2019).

Small-Scale Fisheries often face different challenges than those typical of large-scale and more industrialized fisheries (Guyader et al., 2013). For example, SSFs often lack strong, central government institutions to manage a resource or enforce policies, thereby leading to potential overexploitation, increased illegal extraction, and eventual degradation of the resource for current and future users, such as the case for the artisanal bag net fishery of Saiyad Rajpara in India (Biswal et al., 2017). Examination of this fishery found that although a fisheries agency and various laws did exist in the fishing village, the weak presence of law enforcement led to little control within the fishery on both excludability (controlling access of resource users) and subtractibility (each resource users potential to take from the common-pool resource) (Biswal et al., 2017). Furthermore, SSFs are particularly vulnerable to climate change, as many fishers often rely directly on their catches for subsistence and livelihoods, especially in the developing countries, which are already experiencing disproportionate impacts from a warming climate. (Allison et al., 2009; Haji et al., 2021). SSFs have also been under-researched resulting in a large gap in the scientific literature surrounding their systems, drivers, and catch data (Purcell et al., 2015). Within the last two decades, however, research and the development of programs to better understand SSFs have been on the rise, with more published articles focusing on the presence of SSFs and organizations highlighting their role in global economics (FAO, 2023; Smith & Basurto, 2019).

Previously, it was assumed that extraction of a public resource, when not managed by a centralized government, as is the case with many SSFs, would ultimately end in overharvest (Ostrom, 2009). However, Ostrom's work elucidated examples where this was not the case, and described the factors that led to smaller communities being able to avoid resource collapse, such as the ability to self-organize to establish lasting sustainable management practices (Ostrom, 2009). Furthermore, Ostrom identified attributes of the resource system and its users that likely impact whether or not self-organization would happen. Resource systems where self-organization occurred and resource sustainability was achieved shared common attributes such as being moderate in size, witnessing some (not complete) depletion of the resource, the presence of respected leaders backing the attempts of self-organization, having users that depended heavily on the resource for livelihood, and the development of a shared knowledge base of the system and its attributes amongst resource users (Ostrom, 2009). Ostrom further notes that extraction and ecosystem dynamics such as harvest rates, spatial and temporal distribution of the resource, population of the resource, and replacement rate of the resource can all contribute to system sustainability and should help guide management strategies (Ostrom, 2009).

Examples of SSFs that lack centralized government yet support Ostrom's claim include the Seri and Peñasco benthic fishing communities in Mexico, where self-organization of stakeholders resulted in the implementation of successful management practices (Basurto et al., 2013). Attributes of these two fisheries that aided in their success include their high economic dependencies of the resource, high levels of trust in the community, and development of shared knowledge bases of the social-ecological system and the identification of influential human and ecological factors (Basurto et al., 2013). From their success in self-organizing, the Seri community was then able to establish Exclusive Fishing Zones as a way to manage their mollusk population, and was recognized by other communities as owners and managers of this fishing area (Basurto et al., 2013).

In Costa Rica, SSFs represent an important socio-economic sector, with an estimated 14,800 people participating in some form of artisanal fishing during the year 2022 (CoopeSoliDar RL 2022; Fargier et al. 2014). Additionally, over 75% of Costa Rica's fishery landings are attributed to artisanal fishers (Herrera-Ulloa et al., 2011). One sector of Costa Rica's SSFs includes the artisanal fishing of octopus, with estimated catches averaging 33 tons per year since the 2000s (Sauer et al., 2021). Despite its economic importance, little information has been published on artisanal octopus fishing practices and impacts of fishing throughout Costa Rica, including that of the Guanacaste area where the industry remains especially significant (Naranjo, 2010). Similarly, there is a paucity of information on species composition and more generally of the stock status and population dynamics of cephalopods inhabiting the Pacific waters of Costa Rica (Hochberg & Camacho-García, 2009). For fishing towns that reside on the Pacific coast of Costa Rica, the lack of information on species identification, ecology, and fishing of local octopus creates challenges for making informed policy and management decisions that promote fishery sustainability (SINAC et al., 2017). As such, enhancing the sustainability of octopus fisheries in Costa Rica would likely require a deeper understanding of the structure and functioning of its social-ecological system.

Social-Ecological Systems (SES) are "integrated systems of humans and environment," where humans are reliant on the environment for important ecosystem services, thereby creating an interdependent feedback loop of resource extraction and adaptation (Berkes, 2017). Stakeholders within an SES are the people who rely on or engage with the system to some degree, such as scientists, resource-users, NGO workers, policy makers, and resource harvesters (Gray et al., 2012; Villamor et al., 2014). Stakeholders often hold local or traditional knowledge about systems in which they regularly participate, which can manifest through years of lived experiences or cultural knowledge that is passed down from generation to generation (Latulippe & Klenk, 2020).

El Jobo is a small town of about 500 people located on the northern Pacific coast of Costa Rica that maintains an artisanal octopus fishery (*personal communication* with residents of El Jobo 2022). El Jobo relies heavily on both eco-tourism and their artisanal fishery that focuses on octopus, lobster, and various tropical fish (*personal communication* with residents of El Jobo 2022). The fishery and community are supported by a local non-profit, non-governmental organization (NGO) called Equipo Tora Carey (ETC) that focuses on conservation and ecotourism. Although members of the local NGO monitor and survey important native marine species such as sea turtles and stingrays, they have yet to do any research on local octopus. Many fishers attest to two distinct species in the surrounding intertidal waters of El Jobo, based on perceived morphological and habitat differences (*personal communication* with fishers, 2023). Still, no documented identification of the species has been conducted, and status and health of the octopus populations are not defined either.

Resource managers of the Guanacaste area, where El Jobo resides, have noted a lack of scientific studies conducted on the local octopus, with important information such as species identification and their ecology undocumented (SINAC et al., 2017). This gap in knowledge creates challenges for ETC educators to provide accurate information on the local octopus to local schools and international tour groups. Additionally, there is a growing concern surrounding the sustainability of the octopus fishery, as some octopus fishers and members of ETC have reported fewer catches and higher prices on the octopus over the course of the last three years (*personal communication* with fishers and NGO workers, 2023). A decrease in the octopus population would greatly impact the livelihoods of the fishers and the commerce of El Jobo as a whole.

In speaking with local ETC representatives and octopus fishers, they would like to begin research on the octopus and the fishery for purposes of conservation, education, and to gain a better sense of the status of the octopus population and fishery, as well as what factors may be affecting them. Some examples of possible effects that have influenced the stock of other octopus fisheries include seasonal variability of environmental conditions, changes in sea surface temperature, and increasing intensities of ocean upwelling, such as the case in Senegal and the *Octopus vulgaris* fishery (Thiaw et al., 2011). To assist these fishers and members of ETC, a participatory research study was conducted within the community of El Jobo to characterize the octopus fishery SES by using a technique known as Fuzzy Cognitive Mapping (FCM) (Gray et al., 2013).

FCM enables a visual representation of a person's knowledge of a phenomenon or experience (Gray et al., 2013). These maps are meant to showcase the relationships between multiple components, or factors, either directly or indirectly (Gray et al., 2013). Additionally, FCM enables quantitative analyses of SES functioning and structure such as calculating which factors drive the most influence within the system, comparing how different stakeholder groups perceive the same system, and running "what if" scenarios to reflect how the system could change overtime if certain factors were to increase or decrease in their intensity (Gray et al., 2012, 2013; Özesmi & Özesmi, 2004).

For this thesis, FCM was used to develop a foundation of local knowledge to be used in future studies or management decisions. The main objective of this study was to build a shared knowledge base that integrates local ecological knowledge to improve understanding of the octopus fishery SES in El Jobo, in order to inform future sustainable practices and management of the fishery and add to the ongoing conservation education of the area. This was completed through interviews with local community members, generation of fuzzy cognitive maps, and attempts at morphological identification of local octopuses.

Methods

I. Study Setting – Punta Descartes and El Jobo

El Jobo is located on Punta Descartes, which is the northwestern-most peninsula of Costa Rica located within the Guanacaste province (Figure 1). Punta Descartes is bordered by three different coasts and has an estimated 21.5 km of coastline, made up of a mixture of sandy, rocky intertidal beaches (Figure 1).

Figure 1: Location of the Punta Descartes Peninsula in Costa Rica. The orange line represents the total estimated amount of coastline (21.469 km). The town of El Jobo is located at the center of the peninsula.

The Guanacaste province, including Punta Descartes, experiences wet and dry seasons. The wet season extends from May to October, while the dry season runs from November to April. While fishers target octopus all year-round, catches are generally larger during the wet season, specifically throughout the summer months of May to August (*personal communication* with fishers 2022). One of the co-founders of the local NGO and longtime fisher from El Jobo attributes this difference in catches to the wind patterns of the season, stating that from May to August, the peninsula experiences less wind which produces better conditions for octopus habitat in the shallower areas of the coast (*personal communication* with fisher 2022).

El Jobo has an estimated population of 500 people (*personal communication* with fisher 2022). Within the El Jobo community, there are two main octopus stakeholder groups who are interested in the outcome of this research project: the members of the local non-profit research organization ETC and those involved in the town's fishery such as fishers and seafood receivers.

ETC was founded in 2016 through a collaboration between residents from El Jobo and a researcher from the University of San Jose. ETC works with El Jobo residents on local conservation initiatives such as by collecting data on the sea turtle populations and their nesting behaviors. Since its foundation, ETC has grown considerably, and has also influenced the local economy positively by creating jobs through eco-tourism. Eco-tours, research technician opportunities, student programs, and host-stays have made it possible for families to bring in extra income through ETC operations. Research and conservation impacts have also increased, with surveys now including three species of sea turtles, six species of stingrays, and one parrot species. One animal that ETC has yet to investigate, however, is the octopus of Punta Descartes.

About 1/5 of the El Jobo population relies on the artisanal fishing of octopus along the peninsula's coast, making a living by selling their octopus catches to local seafood vendors (*personal communication* with fishers 2022). Octopus are caught entirely through artisanal methods in El Jobo, both from free diving and hookah, or "compressor" diving. Free diving fishers typically only rely on fins, mask, snorkel, mesh bag, gloves, and a long rod with hook attachment locally known as "*bichero*" (Naranjo, 2010; Naranjo-Madrigal et al., 2015). Conversely, in addition to the gear associated with free diving, hookah diving requires more technologically advanced equipment, such as an air compressor, breathing hose, regulator, and small vessel to dive from (Naranjo, 2010). In El Jobo, free divers will walk or drive to their fishing grounds and dive directly from the shores. In both cases, fishers will dive and search for octopus among rocky areas, and extract octopuses from their dens using the "*bichero*" tool. Fishers will either keep their catch for personal consumption or sell to one of two local seafood buyers for roughly 8,000 Costa Rican colones per kilogram (about $15.21 in US currency as of August 22, 2024). Seafood buyers, which are local fish stores that buy octopus and other seafood products, process and ship them to markets and restaurants in larger cities, such as San Jose or Punta Reinas (*personal communication* with fisher 2024).

Octopus are an important part of the economy of El Jobo, yet there is uncertainty related to the status of the population and the factors that may impact fishery sustainability. To date, ETC knows little about the dynamics of the octopus fishery, thus limiting their ability to assist with conservation efforts and management plans. As such, this project sought to create a more comprehensive understanding of the octopus fishery SES through a combination of Participatory Modeling research and species identification. During interviews with community members who rely on the octopus for their livelihoods, participants were provided the opportunity to identify and discuss important factors that influence how or why the fishery may change over time. Additionally, the identification of candidate species for the octopus of Punta Descartes provided the basis for the local NGO to begin adding octopus to their list of researched species. Community benefits of both study goals are illustrated in the conceptual model (Appendix 1), and will continue to be explored in the following sections.

II. Participatory Research to elicit the local knowledge of fishery stakeholders

Participatory Research (PR) relies on the collaboration of community research to answer a question or address an issue that affects the community (Vaughn & Jacquez, 2020). Often this method is used to include stakeholders affected by the subject being studied, and employing the use of community perspectives and involvement for the betterment of the community (Vaughn & Jacquez, 2020). PR focuses on ethical research design via open communication and agreed-upon methods and cooperation with the focus community (Shalowitz et al., 2009). Furthermore, the

PR approach encourages a respectful, healthy relationship with the community participants, and that the results of the study are used for the benefit of the community such as suggested policy planning or implementation (Shalowitz et al., 2009). PR can be found in many disciplines, including environmental health, medicine, resource management, and conservation (O'Fallon et al., 2000; O'Fallon & Dearry, 2002; Twyman, 2000; Wiber et al., 2004). PR has also been successfully utilized in the study of stakeholders' perceptions and values towards an SES (Villamor et al., 2014).

Stakeholder knowledge can be valuable from both scientific and management perspectives as it can: (1) Provide a more holistic understanding of a system (Villamor et al., 2014); (2) Complement Western science (Murphy et al., 2021); (3) Provide a better contextual understanding of human involvement in an ecological system (Özesmi & Özesmi, 2004); and (4) Promote less rigidity and more adaptability in policy and conservation decision making (Gray et al., 2012). While there are many methods for documenting local knowledge, Fuzzy Cognitive Mapping (FCM) is a flexible research method that can capture complex systems and interactions by reconstructing a physical representation of a person's knowledge of a phenomenon or experience (Gray et al., 2013).

The 'maps' created through FCM showcase the relationships between concepts (Gray et al., 2013), where arrows are drawn between factors to illustrate the direction of influence. The term "fuzzy" refers to the addition of weighted values to these arrows that represent the relationship's strength (Gray et al., 2013). FCM provides social scientists with the opportunity to physically represent stakeholder perceptions of an SES, as told through the perspective, experience, and knowledge of stakeholders within a system (Özesmi & Özesmi, 2004). FCM has been successfully used to explore phenomena in various fields of research, such as conservation, risk management, public health, environmental policy, and large- and small-scale fisheries (Basurto et al., 2013; Gray et al., 2015; Halbrendt et al., 2014; Kontogianni et al., 2012; Özesmi & Özesmi, 2004; Singer et al., 2017). Often, FCMs are built around a central concept of interest such as the population of a fish stock (Aminpour et al., 2021). Cognitive maps can help develop a shared knowledge base surrounding the central concept, which can be used to inform stakeholders and managers on important policy and management issues (Gray et al., 2015; Singer et al., 2017). Additionally, multiple individual fuzzy cognitive maps can be combined to form a singular community map, illustrating which factors were mentioned most amongst stakeholders and which of them appear to hold the most influence over the central concept, according to the participants' perspectives (Aminpour et al., 2020).

For the purposes of this thesis project, the artisanal octopus fishery of the community living in El Jobo was defined as the primary SES of interest. Their connection to octopus and other marine species both as food and recreation showcases how their society depends on and interacts with the local biome and ecosystem services it provides. As such, FCM was used as a tool to illustrate the factors, both biotic and abiotic, that may affect the octopus population, and therefore the fishing that depends on it.

III. Species Identification

The accurate identification of a fishery species is a crucial step for designing and establishing effective management plans, as understanding its life history, biology, and population dynamics is fundamental for informed decision-making (Sauer et al., 2021). This is often the case for many octopus fisheries, where misidentification and poor range estimates are common (Magallón-Gayón et al., 2020). Lack of information on the identification and distribution of a species could mean potentially overfishing it without ever knowing the resource is being depleted (Pilar Sánchez, 2003).

There are believed to be two commonly spotted octopus species occupying the intertidal and shallow waters surrounding the peninsula of El Jobo. Fishers report that the main difference between the two species is their size, stating that one species grows to be significantly larger than the other. They typically focus on catching and selling only the larger of the two supposed species. Fishers note that the smaller species tends to inhabit the shallower parts of the coast, sticking to sandy areas with high densities of small rocks. Additionally, they report that the larger species is found more commonly, and typically at lower depths. Although octopus fishing remains an important economic activity throughout Costa Rica, and especially along the Pacific coasts of the Guanacaste province, little work has been dedicated to octopus species identification (Hochberg & Camacho-García, 2009).

One common method used to identify a species or genus is through the inspection of morphological characteristics, such as body color, shape, size, and other key diagnostic features (Jereb et al., 2016). Despite possessing the ability to change colors and skin textures, many octopuses have distinctive body patterns that can be used to set them apart from one another (Obrien et al., 2021). Common identifying patterns include the presence/absence of ocelli (false eye spots), body stripes, body spots, arm rings, eye bars, eye rings, and general/resting coloration (Caldwell et al., 2015; Huffard et al., 2008; Roper & Hochberg, 1988). Some patterns are more conspicuous than others, or may only appear under certain circumstances, such as hiding or hunting (Warren et al., 1974). Additionally, many body patterns and colorations are only detectable when the animal is alive; for instance, there are some examples of ocelli disappearing following death (Pliego-Cárdenas et al., 2014). Researchers have reliably used these colorations and body patterns for taxonomic identification both in laboratories and the field (Brusca, 1980; Jereb et al., 2005; Roper & Hochberg, 1988).

In addition to body coloration and pattern, certain body measurements and ratios can be used to distinguish between species of octopus. These include number of gill lamellae, weight, dorsal-mantle length, total body length, arm lengths, arm lengths in comparison to total body length, right arm 1 and left arm 1 lengths in comparison to the other 6 arms, hectocotylus and ligula size/shape, and proportion of right arm 3 length that is hectocotylus (Brusca, 1980; Jereb et al., 2005).

Part One: Interview and FCM Methodology

Data Collection

Prior to all data collections, all methods were approved by Alaska Pacific University's Institutional Review Board, approval number #2023-12-001 (Mod. 1) (Appendix 2 – 4). Interviews with local stakeholders in El Jobo were conducted during January and February of 2024 with the aid of a member of ETC and longtime octopus fisher from El Jobo.

A semi-structured questionnaire (open and closed questions) was developed to collect information regarding stakeholders' perceptions on the current status of the octopus fishery of Punta Descartes, the local octopus population, and the factors that may affect it. Stakeholders were defined as people involved in or with experience of the local octopus fishery. This included artisanal fishers, seafood processors (i.e., restaurants, seafood buyers), conservationists, and tourism industry workers (i.e., tour guides, hotel staff, etc.). Participants were located through snowball sampling and fishers were also approached by researchers at popular octopus fishing spots. This diversity of participants helped to deepen the understanding of the different factors that can affect the local octopus population through the different perspectives gained from various experiences and occupations within the local octopus SES.

The interviews began with introductions and a brief explanation of the study's purpose. An explanation and example of cognitive mapping was provided to help participants understand the exercise (Appendix 5). After the interviewee's consent, the interview was performed. During the interview, audio was recorded and notes were taken to summarize the general answers of the participants. Additional help with translation and clarification of the interviews was provided by an ETC researcher who was present during the interviews.

The interviewer first asked questions to obtain demographic information and to understand the experience, perceptions, and type of involvement of the interviewee in the octopus fishery (Appendix 6). These questions included: 1) Demographic information about the participant; 2) Perceptions of the octopus population and fishery according to the participant, asked in statements; 3) Perception of the octopus population in terms of species number and morphological descriptions; 4) For artisanal fishers, additional questions queried participants about their typical catches and the participation of women in the fishery.

Octopus population and fishery perceptions were assessed using the following statements:

1. "The octopus fishery of El Jobo is sustainable"
2. "The octopus population in El Jobo, Costa Rica is healthy"

3. “The octopus fishery in El Jobo, Costa could support more fishers”

Participants were then asked to choose their response from the following options: Strongly Disagree, Somewhat Disagree, Neither Agree or Disagree, Somewhat Agree, Strongly Agree, and I Do Not Know

Participants who identified their octopus experience as “Fisher,” were asked additional questions concerning the octopus fishery:

1. “Are women from El Jobo involved in the octopus fishery?" (Yes or No)
2. “During your time as a fisher, has the octopus population changed?"

The listed responses for the octopus population question included: Decreased a Lot, Decreased a Little, Has Not Changed, Increased a Little, Increased a Lot, and I Do Not Know.

Following the questionnaire, participants were next asked to create a fuzzy cognitive map, with “Local Octopus Population of El Jobo” acting as the central, starting concept. The participant was asked: 1) what factors affect the local population of octopus and 2) what does the local population of octopus affect? During the exercise, the interviewer drew the factors and their directions of influence on a page of a large sketch pad to provide the participant with a visual representation of their cognitive map. Participants were then asked follow-up questions pertaining to each factor they listed that included: 1) “What does the factor affect?”; 2) Intensity - “Is it a negative or positive effect?”; 3) Strength - “How much does *insert factor* influence *insert factor*? (a little, some, or a lot). Photos were taken of each cognitive map once the interview was completed.

Data Preparation – Individual Maps

Following the interviews, the physical drawings of all individual fuzzy cognitive maps were converted into digital maps using Mental Modeler (Gray et al., 2013). From these digital versions, Mental Modeler was used to translate the maps into adjacency matrices to be used in statistical tests run though RStudio (Posit team, 2024). All concepts were sorted into one of four dimension types: Environmental, Social, Economic, and Governance. The Environmental, Social, and Economic categories were chosen in reference to the Pillars of Sustainability (Waas et al., 2011), while Governance refers to one of the units from Ostrom's SES framework (Ostrom, 2009). Environmental concepts represent abiotic and biotic ecological factors, Social concepts represent stakeholders and resource users within the system, Economic concepts represent factors dealing with profit and monetary gain, and Governance concepts represent governmental or policy factors that influence the system (Waas et al., 2011; Ostrom, 2009). Concepts were sorted into dimension types by the researcher based on the context surrounding the concepts provided by the interview participant during the interviews. Using this categorical breakdown approach allowed for discussion on whether stakeholders of El Jobo perceived the octopus fishery system as more dependent on human or environmental factors, or perhaps an equal split between both.

Next, descriptive statistics were calculated for each individual map matrix. Descriptive statistics included: 1) Number of Concepts – total number of factors in a map; 2) Number of Connections – total number of relationships between factors in a map; 3) Connection Density – proportion of actual relationships to number of possible relationships; 4) Connections per Variable – average number of relationships per concept; 5) Number of Driver, Receiver, and Ordinary Concepts – total number of factors that only drive influence, factors that only receive influence, and factors that both influence and receive influence (Gray et al., 2013; Knox et al., 2023).

Data Preparation – Group and Community Maps

For the construction of the group and community maps, the Identity Diversity method was utilized (Aminpour et al., 2021; Knox et al., 2023). This multistep aggregation method follows the steps: 1) sort individual maps into groups based on the expertise of the maps' owners; 2) aggregate those sorted maps into group maps to represent expertise perceptions using the means of their connections; then 3) aggregate the newly formed expertise group maps into one community map using the median of their connections (Figure 2) (Aminpour et al., 2021; Gray et al., 2012; Knox et al., 2023).

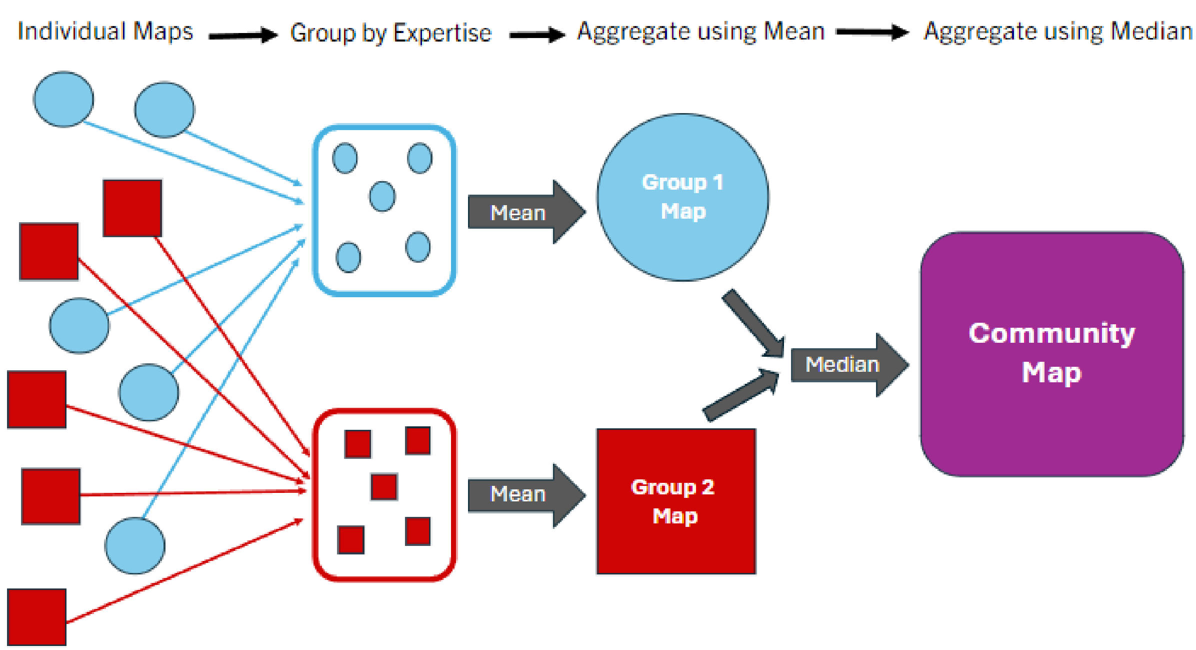

Figure 2: Diagram explaining the steps for multistep fuzzy cognitive map aggregation using the Identity Diversity method

By first aggregating expertise group maps using the mean, connections were better preserved, given that maps of similar expertise groups tend to have similar map outputs (Aminpour et al., 2021). Using the mean to aggregate maps from different expertise groups may create connections that do not accurately represent the majority and therefore produce misleading aggregated systems (Aminpour et al., 2021). Conversely, using the median to aggregate different expertise groups can conserve and create better representations of the majority's opinion (Aminpour et al., 2021). Therefore, when aggregating maps using the Identity Diversity method, it is advised to first create aggregated group maps based on expertise using the mean of connections, then aggregate the group maps into a community map using the median of connections (Aminpour et al., 2021).

In order to properly utilize the Identity Diversity method for map aggregation, first inconsistencies in spelling, grammar, and terminology were fixed across all individual maps. Next, concepts close in meaning were combined into one singular concept term across all maps (for example: "Fishing Exploitation" and "Fishing Effort" were recoded into "Fishing Pressure"). Individual maps were sorted into two groups based on the participant's answer to the question "What is your experience with the octopus of El Jobo?" Group One was constructed of all participants who have fishing experience with octopus, and Group Two was constructed of those without fishing experience. Once sorted, the means of the connections of each map in the groups were calculated and used to construct two group maps that represent the perceptions of each expertise group. Finally, the median of connections from the Group One and Group Two maps were calculated and used to construct the Community Map. The same five descriptive statistics used for the individual map analysis were then calculated for Group One, Group Two, and Community Map, plus an additional statistic of number of connections per individual concept.

Part Two: Species Identification Methodology

Data Collection

Octopus species were collected between January and February 2024 off three beaches in Punta Descartes: Playa Las Pilas, Playa Rajada, and Playa Rajadita. Pictures were taken of octopus catches, both before and after removal of the animal from the ocean. While free diving, live, underwater photos were taken of each octopus before it was captured to gather information on live body color and pattern. Next, the octopus was brought to shore for further morphological analysis.

Distinctive body patterns were notated, such as the presence/absence of ocelli, stripes, or spots. More pictures were taken of the specimen, including any of the distinctive patterns mentioned. Next, the octopus was measured for identifying features according to the most recent field guide for cephalopods, *Cephalopods of the world: an annotated and illustrated catalogue of cephalopod species known to date* (Jereb et al., 2016). Body measurements included Total Length (TL) and Dorsal-Mantle Length (DML). The sex was also determined, and for males, their Hectocotylus Length (HL) was taken and used to calculate the percentage of R3 arm that is their reproductive part, known as Hectocotylus Percentage (HP) (Jereb et al., 2005).

Lastly, octopus were sorted into two species groups (A and B): Species A was assigned to the bigger octopus that the locals are known to fish for, while Species B was assigned to the smaller octopus that the local fishers do not target in the fishery. The ETC researcher sorted the caught octopus into these groups based on their longtime experience as an octopus fisher in El Jobo.

Results

Interviews: Introductory Questions

A total of 12 participants from El Jobo were interviewed, where 10 identified themselves as male and 2 identified as female. The average age of participants was 39. Of the 12, 9 participants described their octopus experience type as "Fisher," while the other 3 were "other." The average amount of time participants reported their experience with octopus was 19 years. Nine of the participants were independent workers, 2 were employees, and 1 identified as being an independent worker, employee, and employer.

Based on interviewees' perceptions, most participants strongly agreed that the octopus fishery of El Jobo is sustainable (42%) and healthy (50%) and that it could support more fishers (42%). (Figure 3).

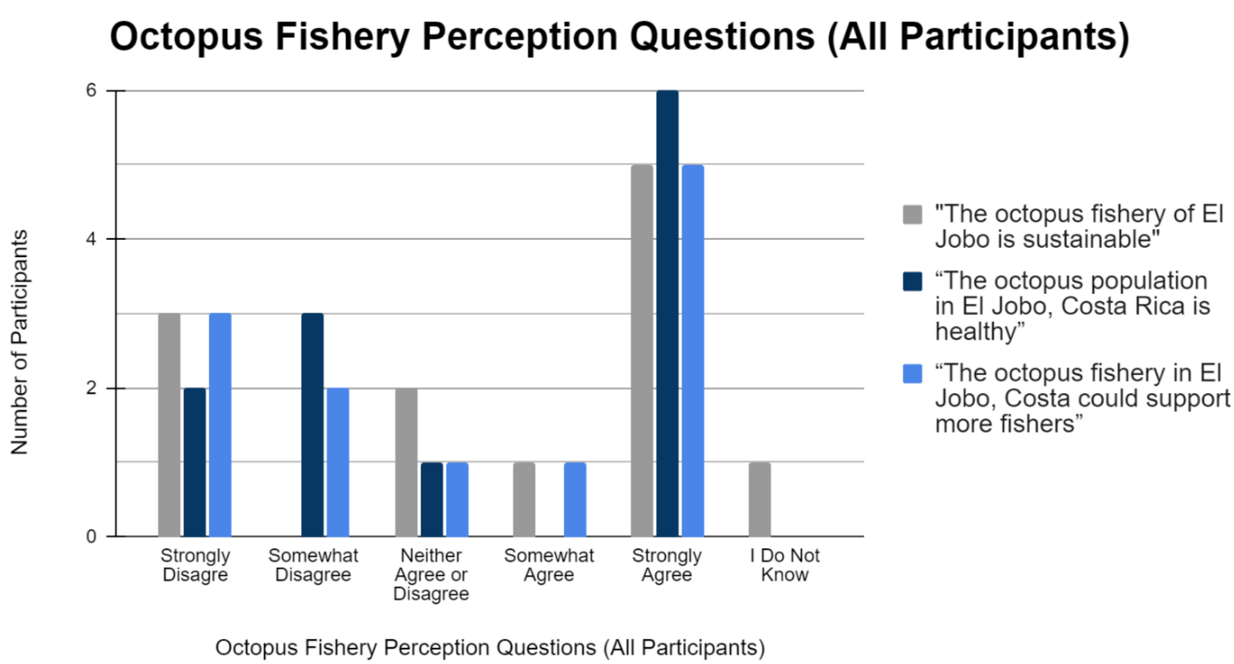

Figure 3: Participant answers to statements about the artisanal octopus fishery of El Jobo

As previously mentioned, participants who identified their experience as “Fisher” were asked additional questions pertaining to their perceptions of the octopus fishery. When asked about if women were involved in the El Jobo artisanal octopus fishery, 77.8% of the fishers responded with “No,” while 22.2% of participants responded “Yes.” Those who answered “Yes” said women were involved in selling the octopus and cleaning the gear associated with fishing for the octopus. When asked if the local octopus population had changed within their time as a fisher, 66% responded with “Decreased a Lot,” and 33% responded with “Decreased a Little.”

In relation to the fishing methods used, 56% of fishers free dive for octopus while 44% used hookah diving. For how fishers accessed their fishing sites, 55% of fishers reported accessing their fishing sites both by foot and motorboat, while the remaining accessed their fishing grounds by foot (11%), by car (11%), by motorboat (11%), and by foot and car (11%). When asked about their daily catch records, the majority of the fishers responded that catch amounts depended too much on external factors, such weather and fishing conditions, to be able to provide a single number. The average amount of octopus caught per fisher per day in kilograms ranged between 1 and 10 kg and the average size of individual octopus in grams varied between 250-500 g (Table 1).

Table 1: Octopus Catch Rates (per Day)

Participant Number	**Average Number of Octopus Caught**	**Average Amount of Octopus Caught (kilograms)**	**Average Weight of Individual Octopus Caught (grams)**
1	Depends	Depends	Depends
2	20	7	250
4	Depends	4	300
5	Depends	10	300
6	6	4	400
7	8 (Depends)	1 - 5 (Depends)	Depends
8	Depends	2 - 7 (Depends)	400
9	15 - 20	6	500
10	Depends	5 - 6 (Depends)	400 - 500

Interviews: Fuzzy Cognitive Maps – Individual Maps

A total of 12 individual fuzzy cognitive maps were constructed (Figures 4 – 15). The total number of unique concepts was 68, including the central, starting concept of "Population of Local Octopus in El Jobo" (Table 2, Table 3). Each concept (excluding the central concept) was sorted into one of four dimensions: Environmental, Social, Economic (Waas et al., 2011), and Governance (Ostrom, 2009). Each concept was color-coded to match its dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance. Arrows in each map are colored to represent their influence: blue for positive and red for negative. Additionally, the width of the arrows corresponds to their numeric absolute value between 0 and 1.

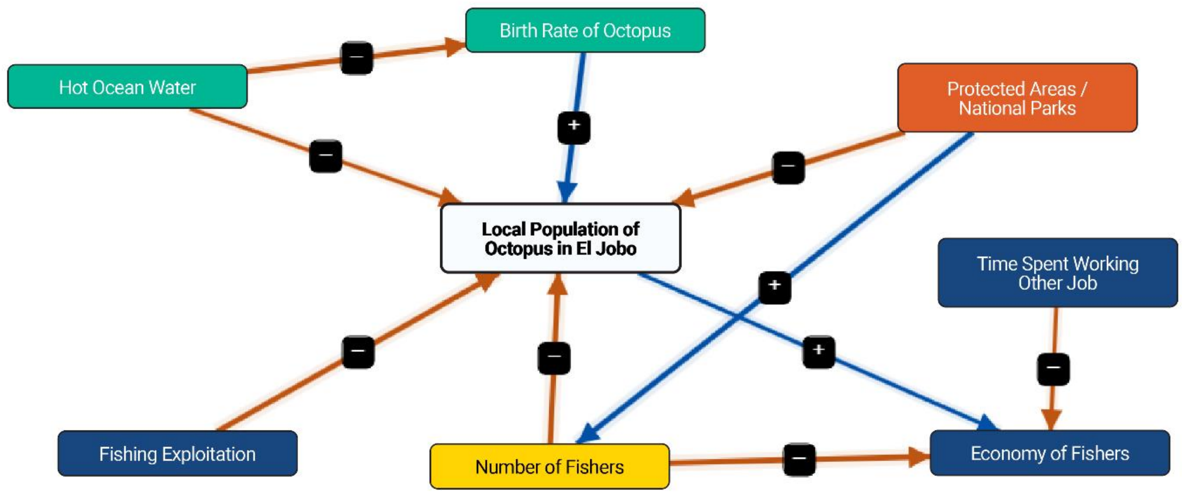

Figure 4: Map 1, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

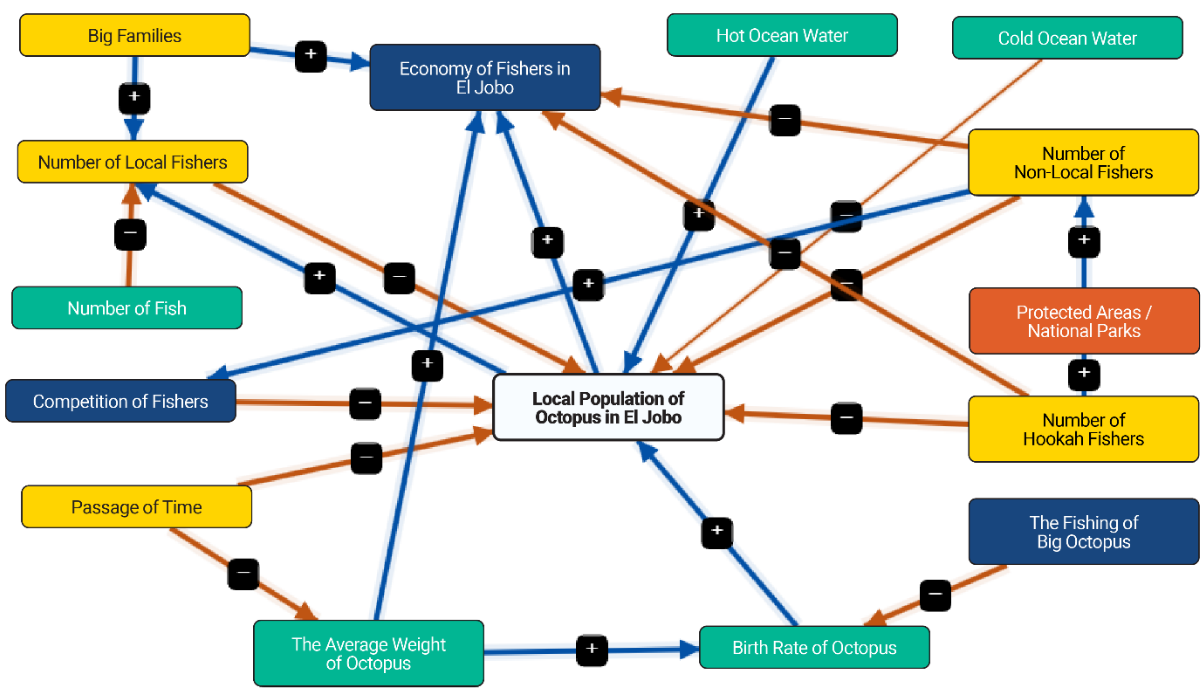

Figure 5: Map 2, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

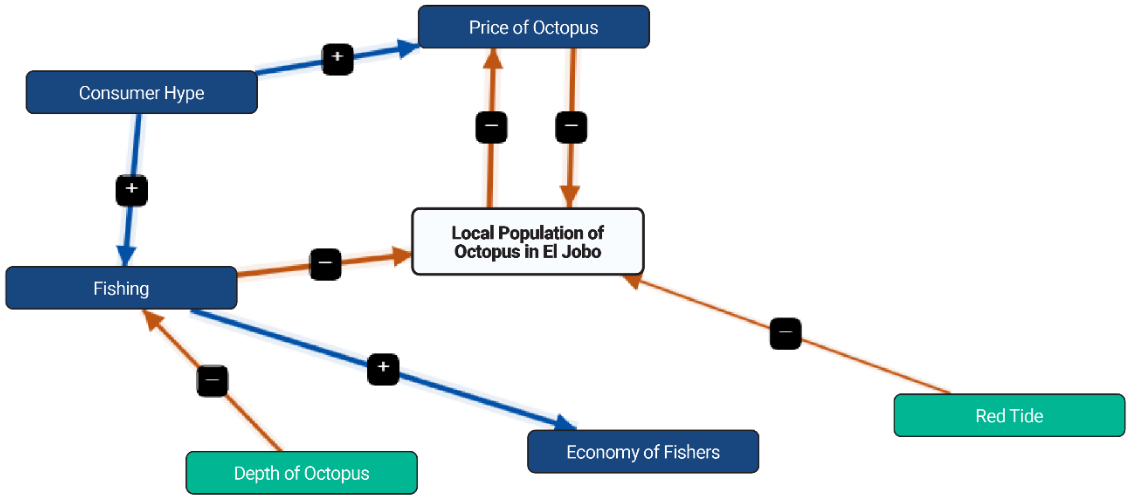

Figure 6: Map 3, belonging to a non-fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

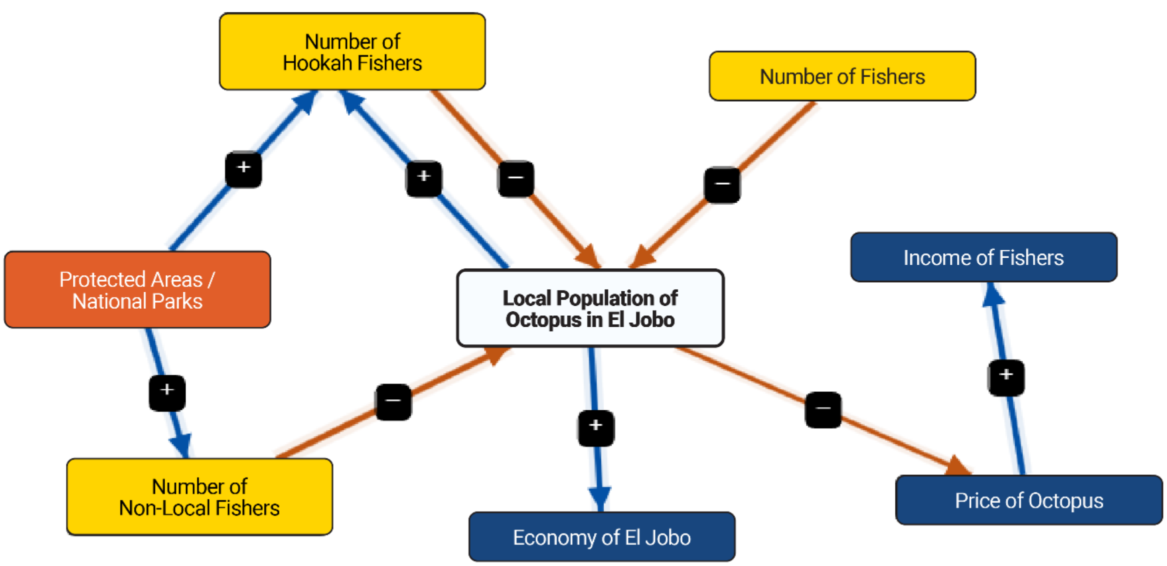

Figure 7: Map 4, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

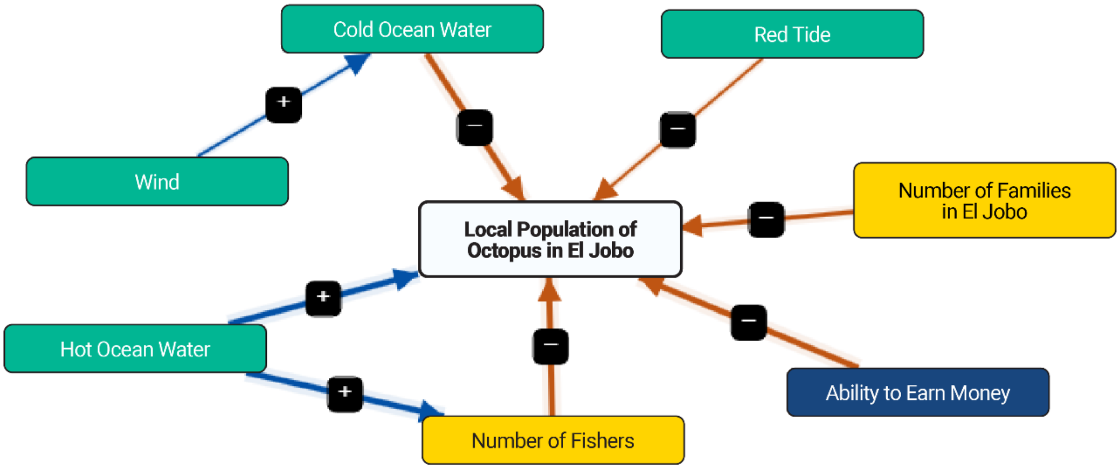

Figure 8: Map 5, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

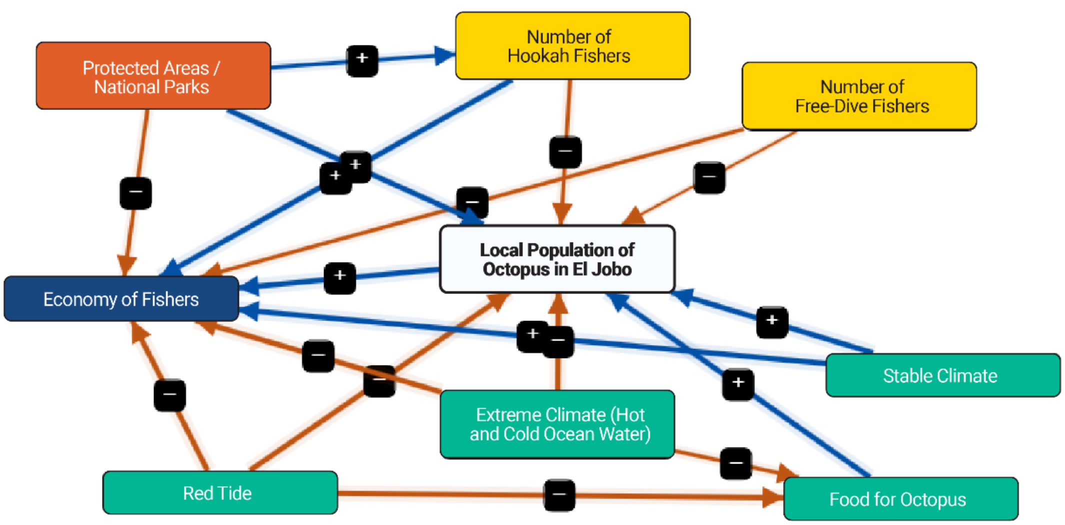

Figure 9: Map 6, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

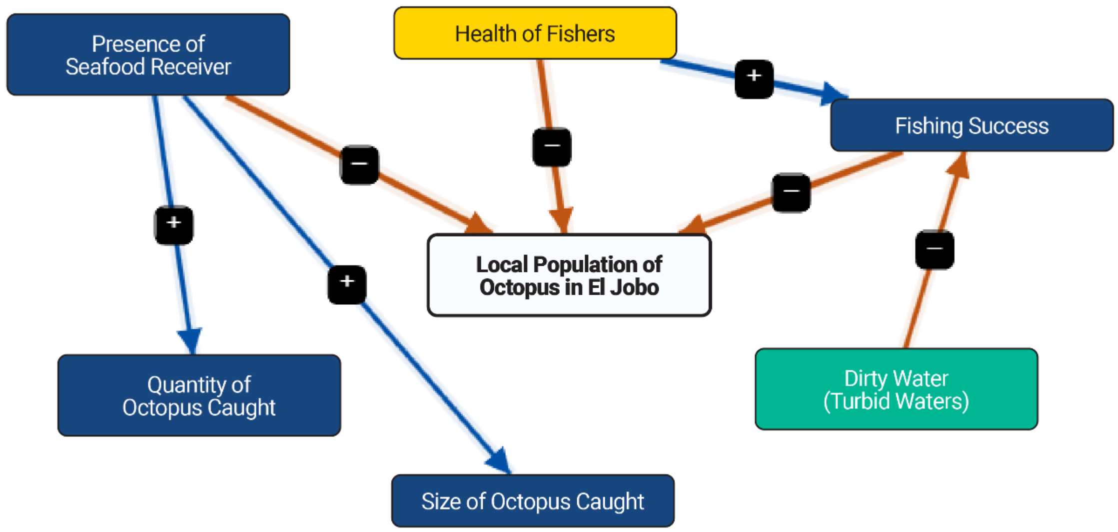

Figure 10: Map 7, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

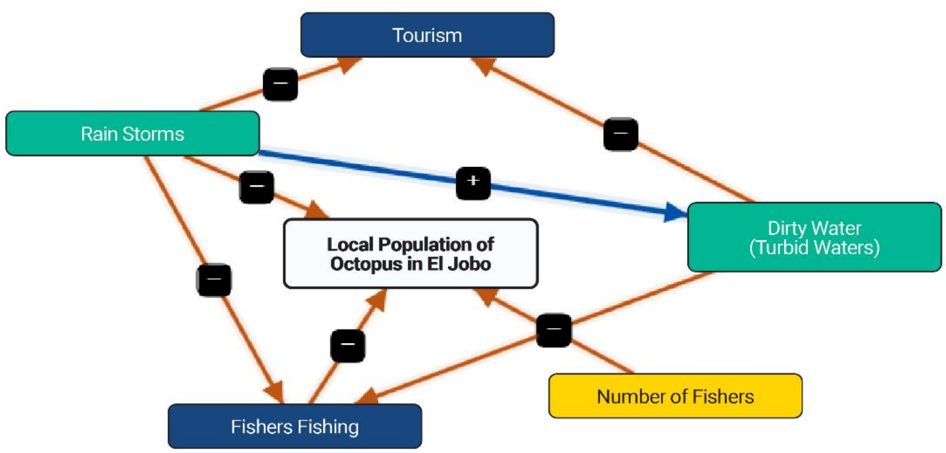

Figure 11: Map 8, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

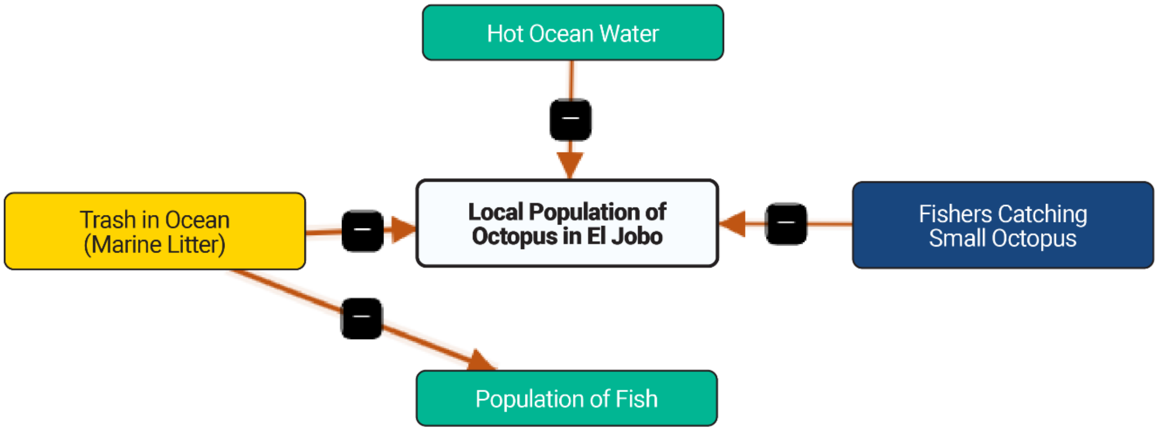

Figure 12: Map 9, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

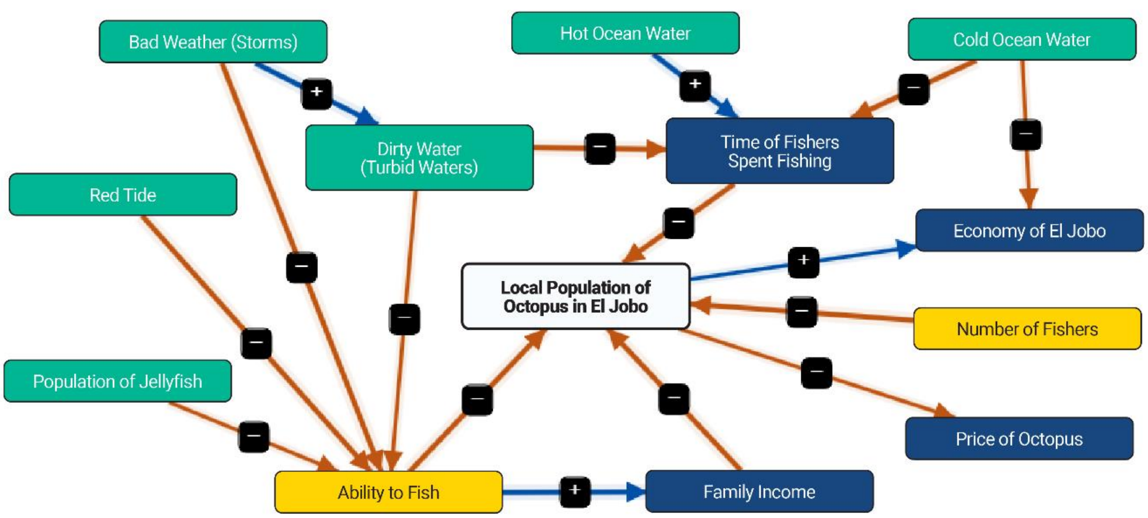

Figure 13: Map 10, belonging to a fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

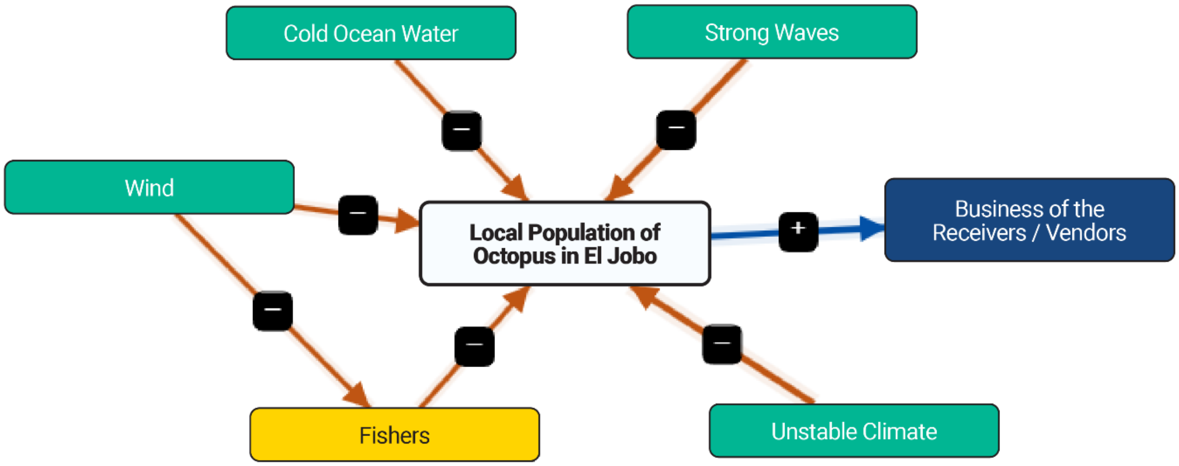

Figure 14: Map 11, belonging to a non-fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

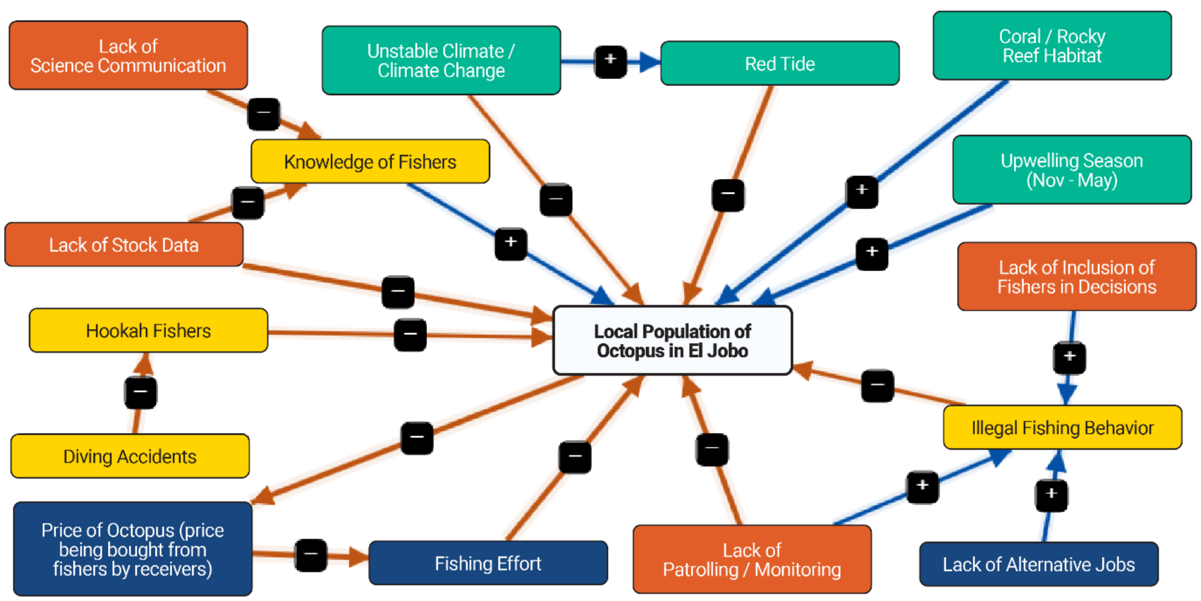

Figure 15: Map 12, belonging to a non-fisher. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

Table 2: Descriptive Statistics by Individual Map

Map Number	Number of Concepts	Number of Connections	Connection Density	Connections per Variable	Number of Ordinary Concepts	Number of Driver Concepts	Number of Receiver Concepts
1	8	10	0.2	1.3	3	4	1
2	15	22	0.1	1.5	7	7	1
3	7	8	0.2	1.1	3	3	1
4	8	9	0.1	1.1	4	2	2
5	8	8	0.1	1	2	5	1
6	9	17	0.2	1.9	3	5	1
7	7	7	0.1	1	1	3	3
8	6	8	0.2	1.3	2	2	2
9	5	4	0.2	0.8	0	3	2
10	13	16	0.1	1.2	5	6	2
11	7	7	0.1	1	2	4	1
12	16	19	0.1	1.2	7	9	0

A total of 97 concepts were mentioned by participants across the 12 individual maps. The majority of concepts were Environmental, followed by Economic, Social, and lastly Governance (Table 3).

Table 3: Concept Dimension Types by Individual Map

Map Number	Number of Environmental Concepts	Number of Social Concepts	Number of Economic Concepts	Number of Governance Concepts
1	2	1	3	1
2	5	5	3	1
3	2	0	4	0
4	0	3	3	1
5	4	2	1	0
6	4	2	1	1
7	1	1	4	0
8	2	1	2	0
9	2	1	1	0
10	6	2	4	0
11	4	1	1	0
12	4	4	3	4

TOTAL ACROSS ALL MAPS:	*36*	*23*	*30*	*8*

Interviews: Fuzzy Cognitive Maps – Group and Community Maps

Of the 12 participants interviewed, 9 identified their experience with octopus as “fisher” while the other 3 had different types of experience. Therefore, maps were sorted into two groups based on experience: Group 1 had fishing experience, and Group 2 did not have fishing experience. Like-concepts (such as “Number of Fish” and “Population of Fish”) were combined, turning the 68 concepts into 54. The two group maps and one community map have been included in this thesis (Figures 16 – 18) with the concepts once again color-coded according to their sorted dimensions. The descriptive statistics for each map have been provided in Table 4.

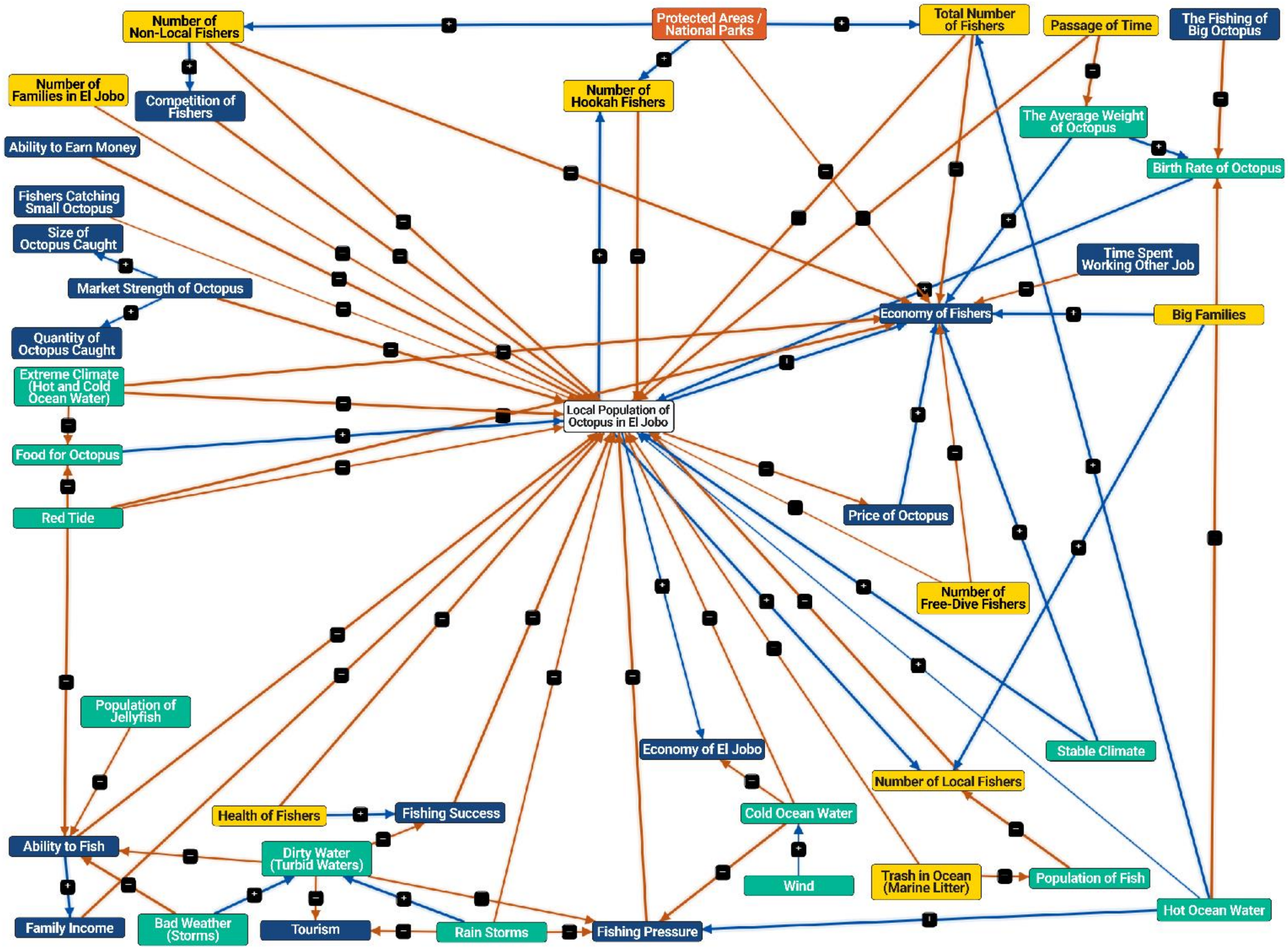

Figure 16: Group Map 1 – Fishers. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

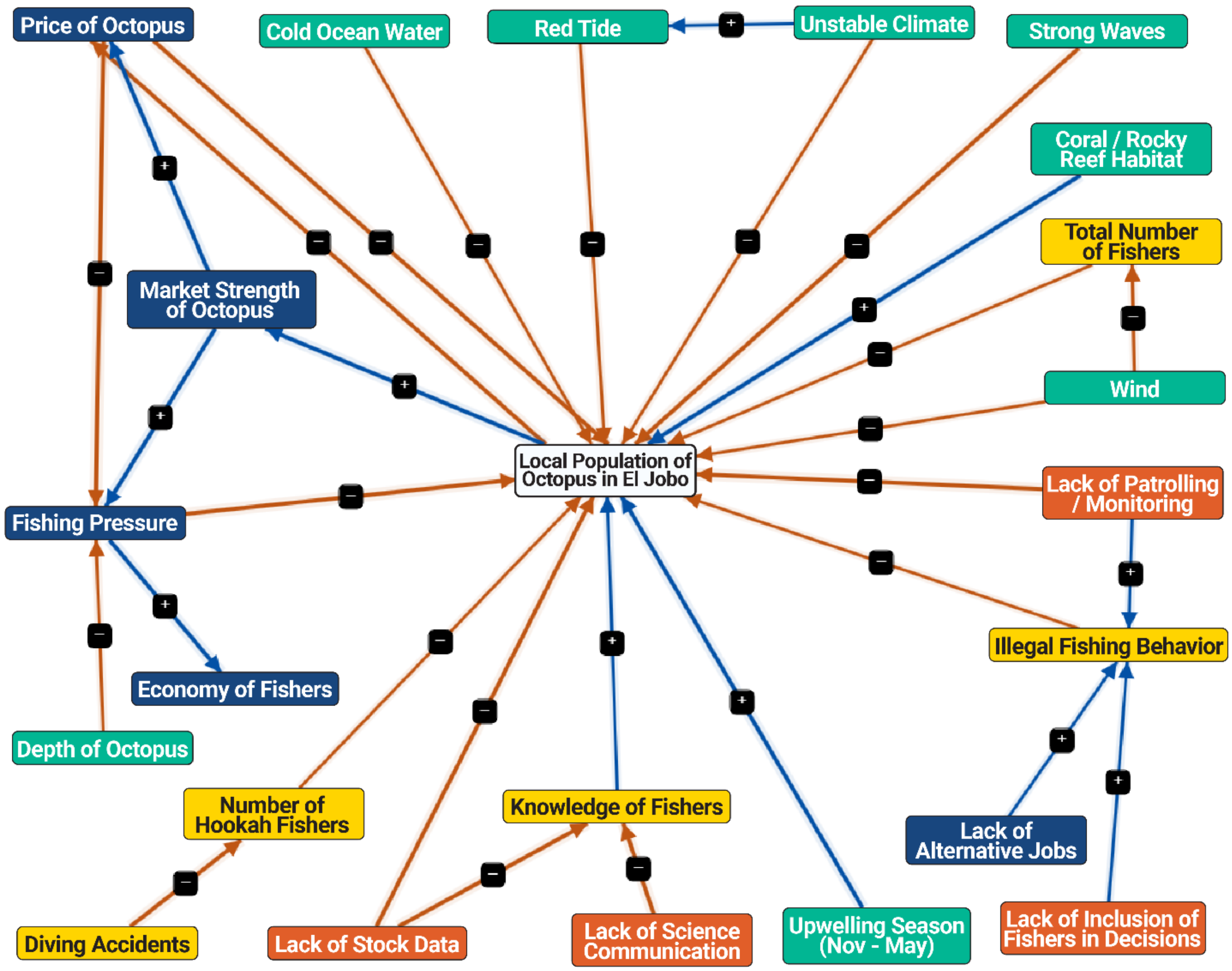

Figure 17: Group Map 2 – Non-Fishers. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

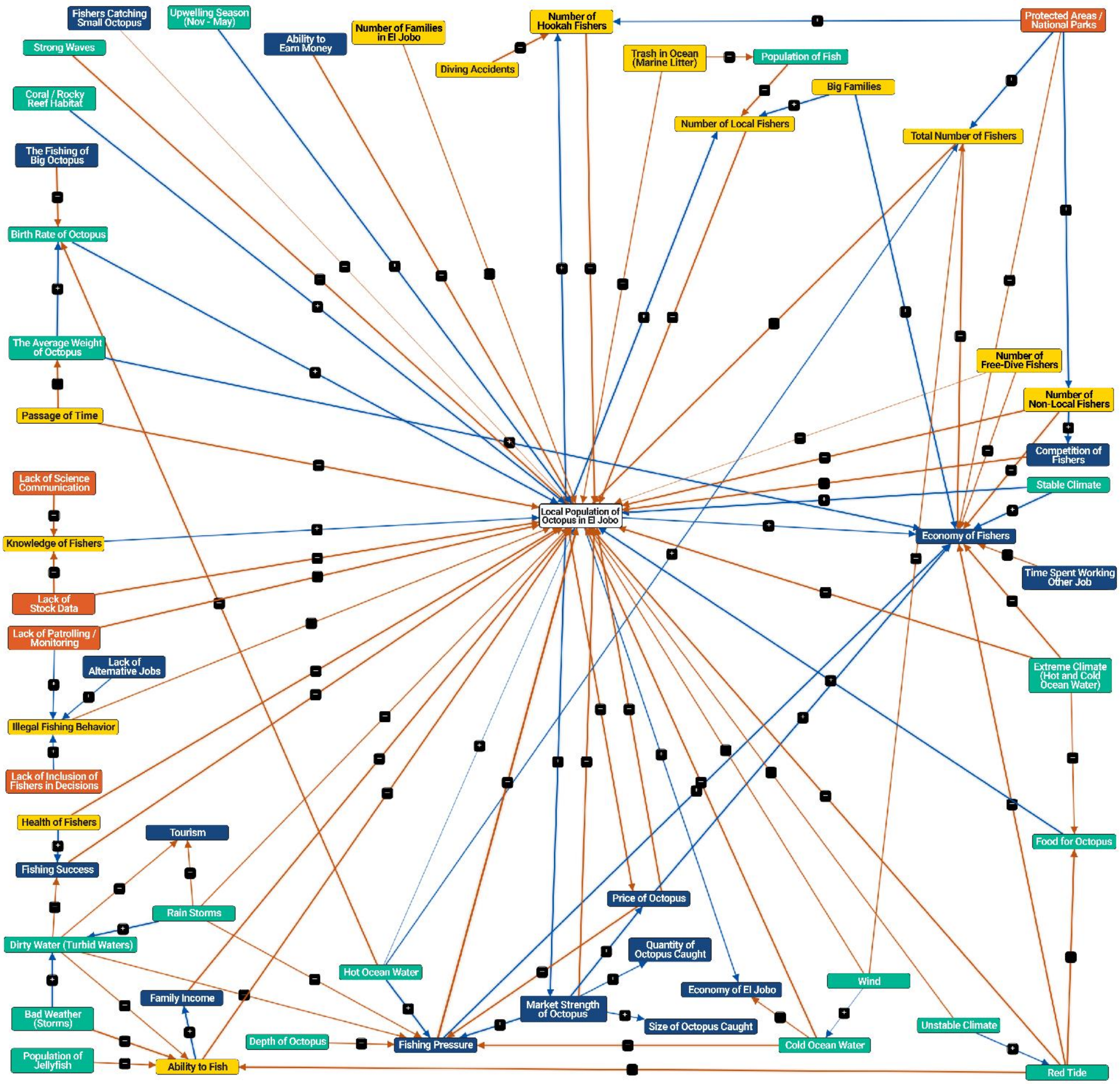

Figure 18: Community Map. Concepts are colored according to their dimension type: green for Environmental, yellow for Social, blue for Economic, and Orange for Governance

Table 4: Descriptive Statistics by Group and Community Map

Map Name	Number of Concepts	Number of Connections	Connection Density	Connections per Variable	Number of Ordinary Concepts	Number of Driver Concepts	Number of Receiver Concepts
Fishers (n=9)	42	74	0.04	1.8	17	20	5
Non-Fishers (n=3)	23	30	0.06	1.3	9	13	1
Community (n=12)	55	98	0.03	1.8	21	29	5

Table 5: Concept Dimension Types by Group Map

Map Name	Number of Environmental Concepts	Number of Social Concepts	Number of Economic Concepts	Number of Governance Concepts
Fishers (n=9)	14	10	16	1
Non-Fishers (n=3)	8	5	5	4

The concepts with the most connections (arrows) for each aggregated map were “Economy of Fishers” for the Fishers group map (12 connections), “Fishing Pressure” for the Non-Fishers group map (5 connections), and “Economy of Fishers” for the Community map (13 connections).

The five most mentioned concepts were Total Number of Fishers (6 mentions), Fishing Pressure (5), Red Tide (5), Hot Ocean Water (5), and Economy of Fishers (5). Table 6 provides a list of concept types that were mentioned more than once during interviews, along with the number of times they were mentioned.

Table 6: List of Concepts Mentioned More than Once Across All Interviews

Concept	Number of Times Mentioned	Concept Dimension Type
Total Number of Fishers	6	Social
Fishing Pressure	5	Economic
Red Tide	5	Environmental
Hot Ocean Water	5	Environmental
Economy of Fishers	5	Economic
Protected Areas / National Parks	4	Governance
Price of Octopus	4	Economic
Number of Hookah Fishers	4	Social
Cold Ocean Water	4	Environmental
Dirty Water (Turbid Waters)	3	Environmental
Market Strength of Octopus	3	Economic
Unstable Climate	2	Environmental
Number of Non-Local Fishers	2	Social
Economy of El Jobo	2	Economic
Birth Rate of Octopus	2	Environmental
Population of Fish	2	Environmental
Wind	2	Environmental

Species Identification

During the interviews, all participants were asked how many octopus species they believed lived in Punta Descartes. 42% of participants reported 5 species, 25% reported 3 species, 17% reported 4 species, 8% reported 2-3 species, and the remaining 8% reported 1 species.

A total of 16 octopuses were collected while free diving and measured (Table 7). Of these, 15 were identified as Species A, and 1 was identified as Species B. For the 15 Species A octopuses, the average Total Length was 35.3 cm, and the average Mantle Length was 8.1 cm.

Table 7: Octopus Specimen Measurements

Individual	Species Type (A=typical species, B=small species)	Total Length (cm)	Mantle Length (cm)	Age	Sex	Location
Pulpo_1	A	39	7.5	Juvenile	NA	Las Pilas
Pulpo_2	A	29	5.5	Juvenile	NA	Las Pilas
Pulpo_3	A	34	8	Juvenile	NA	Las Pilas
Pulpo_4	A	26	6.5	Juvenile	NA	Las Pilas
Pulpo_5	A	68	15.5	Adult	F	Las Pilas
Pulpo_6	A	50	12	Adult	F	Las Pilas
Pulpo_7	A	34	9	Juvenile	NA	Las Pilas
Pulpo_8	A	61	14	Adult	F	Las Pilas
Pulpo_9	A	42	13	Juvenile	NA	Las Pilas
Pulpo_10	A	26	8	Juvenile	NA	Las Pilas
Pulpo_11	A	24	5	Juvenile	NA	Las Pilas
Pulpo_12	A	29	4.5	Juvenile	NA	Las Pilas
Pulpo_13	A	26	5	Juvenile	NA	Las Pilas
Pulpo_14	A	20	4.5	Juvenile	NA	Las Pilas
Pulpo_15	A	21	4	Juvenile	NA	Las Pilas
Pulpo_16	B	26	4.5	Juvenile	NA	Las Pilas

The individual known as Pulpo_16 was the only octopus found that belonged to the Species B group, according to the ETC researcher. Pulpo_16 had distinctive blue spots (ocelli) that sat beneath each eye and can be seen circled in red in Figures 19 and 20. None of octopuses belonging to the Species A group had this distinctive identifying feature.

Figure 19: First photo of Pulpo_16, identified by ETC researcher as "Species B"

Figure 20: Second photo of Pulpo_16, identified by ETC researcher as "Species B"

Live and post-catch photos of Species A octopus individuals are available below (Figures 21 – 24).

Figure 21: Live, underwater photo of octopus identified as "Species A" by ETC researcher

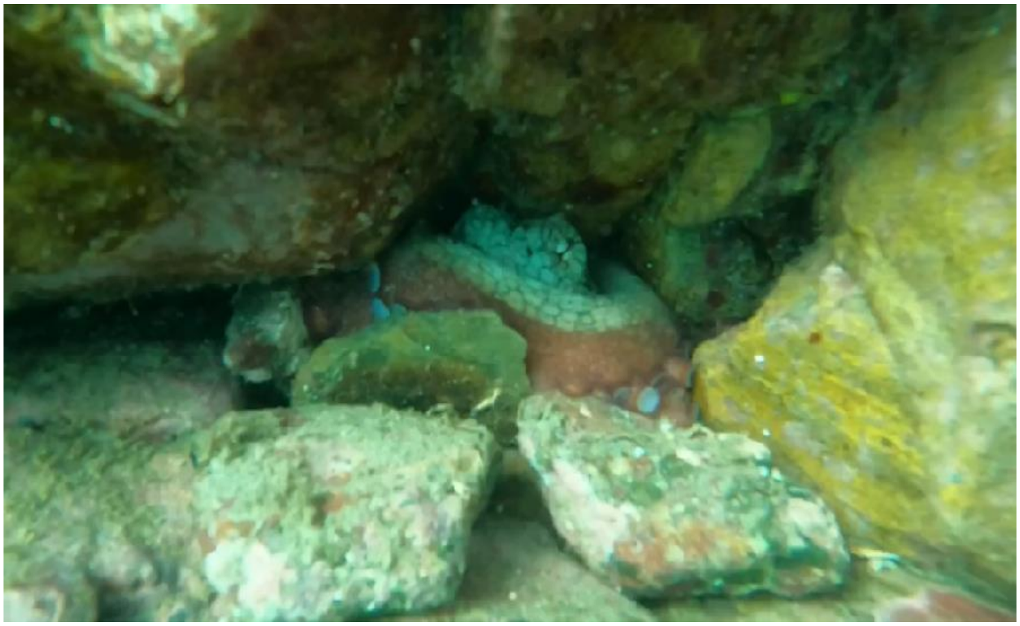

Figure 22: Live photo of octopus hiding in a den, identified as "Species A" by ETC researcher

Figure 23: Post-catch photo of octopus identified as "Species A" by ETC researcher

Figure 24: Post-catch photo of octopus with measuring tape, identified as "Species A" by ETC researcher

Discussion

Interviews and Fuzzy Cognitive Maps

In this study, interviews and fuzzy cognitive mapping were used as tools to represent and quantify the perceptions of participants toward the local octopus population that helps to support the economy and provide livelihoods for the community of El Jobo, Costa Rica. Participants' perceptions about the sustainability, health, and the capacity of the fishery were mixed, with most of them agreeing the fishery is sustainable, healthy, and could support more fishers. However, fishers generally believed that the local octopus population has been declining. While fishers note there is a declining octopus stock, they do not seem to view their fishing activity as the source of the issue. The fuzzy cognitive maps provide other possible explanations for causes of the decline, as perceived by the participants who crafted them.

According to the maps, environmental and economic concepts were perceived as having the greatest presence and influence on the octopus population and its corresponding resource system. This was evidenced by environmental and economic concepts being the majority both in terms of concepts created and total concepts across all maps. Conversely, governance concepts were much less commonly identified, which is not necessarily surprising given the limited centralized governance framework, lack of a management plan, and low participation of fishers in decision-making for the artisanal octopus fishery in El Jobo. Instead, social issues were perceived to have a greater influence on system functioning than governance. Research on small-scale fisheries suggests that social issues, like the number of fishers taking from the resource pool, create major challenges for management and conservation objectives (Basurto et al., 2017; Biswal et al., 2017). Similarly, the top three social concepts across all maps were "Total Number of Fishers," "Number of Hookah Fishers," and "Number of Non-Local Fishers," which aligns with research that found subtractibility to be a common management issue for small-scale fisheries (Biswal et al., 2017). The presence of hookah and non-local fishers could be contributing to the El Jobo octopus population decline, as these fishers increase the subtractibility and overall fishing pressure of the local fishery.

This research also revealed that environmental concepts, such as climate change-related concepts and the oft-mentioned “Red Tide,” were critically important to the SES functioning of octopus in El Jobo, and could potentially point to a source of the population decline. Red tide is a type of Harmful Algae Bloom (HAB), where the accumulation of various algae in ocean waters often causes large areas to be covered by a reddish-tinted algae bloom which can become toxic or hypoxic marine organisms (Sellner et al., 2003). Some participants who included “Red Tide” in their map also commented on the growing frequency of red tide events happening to El Jobo. Rising ocean temperatures have potentially contributed to an increase in the intensity of HABs as warmer waters promote maximum algae growth (Gobler, 2020). As such, the artisanal octopus fishery SES in El Jobo may be susceptible to climate change and the biotic consequences of a warming ocean, according to the perceptions of some community members whose livelihoods rely on the local octopus. Going forward, those involved with the octopus SES of El Jobo may want to consider monitoring the occurrences of red tide and other potential climate-related phenomena in order to increase their understanding of potential threats to the SES. Researching and recording these instances could help fishers and other community members craft effective and adaptive management plans that take into consideration a potential growing frequency or strength of red tide. Additionally, community members should also begin to consider other effects of climate change, such as warming ocean temperatures (Reid et al., 2009), changes in weather patterns (Reid et al., 2009), or shifts in migration and native ranges of target species (Thomas, 2010).

Although governance concepts were not as commonly identified as the other dimension types, the concept “Protected Areas / National Parks” was discussed frequently by fishers, and often acted as an important driver for other social concepts centered on the number of fishers in the system. The Punta Descartes peninsula does not currently encompass any type of Marine Protected Area, however, El Jobo is situated north of Santa Rosa National Park and the Santa Elena Bay Marine Management Area. One criticism of area closures is that they can reallocate fishing effort, thereby increasing fishing pressure outside of the closed area (Hilborn et al., 2004). This was the case for a Dutch beam trawl fishery of North sea cod *Gadus morhua*, where the implementation of an area closure had not appeared to benefit the cod, but may have negatively impacted other species who were affected by the increased trawl rates in areas outside of the closure (Rijnsdorp & Rivo, 2001). A similar situation could be occurring in El Jobo, given the propensity for fishers to discuss the influence of protected areas and national parks, and their perceived effect on the total number of fishers in Punta Descartes. Additionally, three of the four fishers who included “Protected Areas / National Parks” said they resulted in a rise in non-local and hookah fishers in El Jobo. An increase in hookah fishers could be concerning for local fishers, considering hookah-based fishers often have a greater catch rate than free diving fishers due to their advanced equipment (Pavlowich & Kapuscinski, 2017). The possible socio-economic and ecological effects of hookah diving are largely unknown, but there is some concern that their higher catch rates could promote overexploitation in artisanal fisheries (Barbosa-Filho et al., 2020; Pavlowich & Kapuscinski, 2017). For the octopus fishery of El Jobo, it would be interesting to know if an increase in non-local and hookah fishers could truly be attributed to the implementation of nearby closed areas surrounding El Jobo, and to understand the potential impacts they may be having on the environment as a result of their increased presence. It is recommended that a future study would include interviewing non-local fishers about how and why they started fishing in the surrounding waters of El Jobo.

Overall, the fuzzy cognitive maps created by the participants of this study often pointed to external factors as having strong negative influence over the local octopus population. Concepts such as “Red Tide,” “Protected Areas / National Parks,” and the number of non-local and hookah fishers were strong drivers in the community map and often the source for negative influence on the octopus population. It is possible that these external factors may be contributing to the population decline, however future monitoring efforts should be created to better understand the potential relationship between these drivers and the octopus. As described before, this could mean recording and researching incidents of red tide and other climate-related changes, interviewing non-local fishers about their allocation to El Jobo’s fishing waters, and monitoring and recording octopus catch rates and the number of active fishers in the system.

This research aimed to assess general catch rates of octopus in El Jobo by asking fishers about their daily harvest amounts. However, most of these questions were met with varying estimations and often just the term “depends.” Fishers who answered with “depends” often attributed the varying catch amounts to seasonal changes and heavy dependency on preferable weather conditions. In this case, it might have been more effective to have partnered with one of the local seafood buyers to either count the average number and weight of octopus brought in or interview the buyers about how much octopus they buy. In addition to this, interviews with local fishers about how much octopus they retain for personal consumption on a weekly basis would also be useful. This method is recommended for future research if more precise estimates of catch rates are desired.

While these interviews and maps provide a good starting point for understanding the artisanal octopus fishery of El Jobo and its associated SES, more work needs to be done to truly capture the SES from all angles and community perspectives. Limitations surrounding this research include the small number of participants, language barriers, and time constraints of the researchers. Continued research of this SES, such as gaining a better understanding of its value chain and identifying power imbalances within the system, will be an important next step to develop management plans to promote fishery sustainability.

Species Identification

The purpose of identifying the octopus species of the Punta Descartes area was to help community members with deepening their understanding of the octopus fishery, and act as a first step in crafting their management plan of the octopus. Although only 16 individual octopuses were found during dive surveys, the pictures provide evidence for at least two distinct octopus species in Punta Descartes. The single "Species B" octopus that was captured ("Pulpo_16"), had obvious blue spots ("ocelli") that were situated beneath both eyes, which were lacking in all other "Species A" octopuses that were caught. The presence of these ocelli combined with the mottled brown skin coloring could qualify Species B as being either *Octopus bimaculatus* or *Octopus bimaculoides* (Jereb et al., 2016). Both of the octopus species are known to reside in the Pacific Ocean, with their estimated distribution reaching from California to Mexico (Jereb et al., 2016). *O. bimaculatus* has a Mantle Length up to 20 cm and Total Length up to 110 cm while *O.*

bimaculoides has a Mantle Length up to 8.5 cm and Total Length up to 50 cm (Jereb et al., 2005). Pulpo_16 had a Mantle Length of 4.5 cm and a Total Length of 26 cm, meaning it could have been a juvenile for either *O. bimaculatus* or *O. bimaculoides*. There are two major distinguishing characteristics between these two species that would help with identifying Pulpo_16. First, *O. bimaculatus* produce small eggs which hatch into planktonic larvae (Hofmeister & Voss, 2024), while *O. bimaculoides* produce large eggs which hatch into benthic offsprings (Markaida & Castellanos-Martínez, 2024). Second, the blue ocelli of *O. bimaculatus* contain a "broken chain link" of smaller circles within the blue ring that creates sharp points, while the ocelli of *O. bimaculoides* have a more consistent chain link of smaller circles that do not create sharp points within the blue ring (Figure 25) (Jereb et al., 2016).

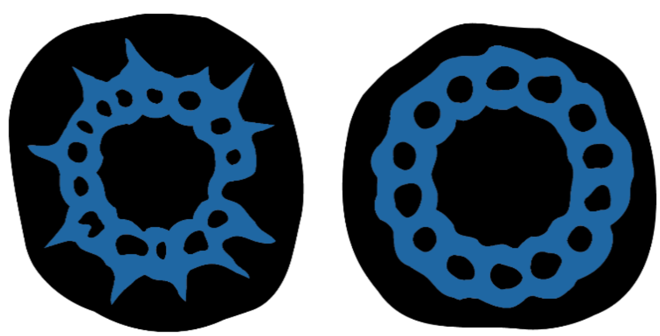

Figure 25: The ocellus of O. bimaculatus *(left) compared to the ocellus of* O. bimaculoides *(right)*

To definitively state whether Species B was either *O. bimaculatus* or *O. bimaculoides*, further study including better pictures of the ocelli, discovery and measurements of an egg clutch, and genetic sampling of the octopus is recommended. To date, there has not been any published work that has listed either of these species as being found in Costa Rica, which means it is possible that Species B could point to a range expansion for either *O. bimaculatus* or *O. bimaculoides*, or be categorized as a new species. Interviews with fishers about the egg sizes of

Species B, combined with genetic testing, would be recommended as the next step in this research process.

For the 15 remaining octopuses that were captured and labeled as “Species A,” there were no immediately noticeable, unique morphological characteristics as with “Species B.” The “Species A” specimen ranged in total length from 20 cm to 68 cm. They often displayed a reticulated grey to dark red dorsal coloration, combined with a light orange ventral coloration. This sample size did not include any mature males for hectocotylus assessment. Despite the lack of easily distinguishable body patterns, the literature does point to one possible candidate for “Species A,” which is *Octopus hubbsorum*.

Octopus hubbsorum is a medium-sized octopus that inhabits the shallow sub- and intertidal zones of Mexico’s Pacific coast (Jereb et al., 2016). They exhibit dorsal colors of black, purple, dark red, and gray, and possess an orange ventral color (Jereb et al., 2016). Their average total length is 55.45 cm, and their average mantle length is 12.06 cm (Domínguez-Contreras et al., 2013). Their males tend to reach maturity at 14 cm mantle length (Jereb et al., 2016), which would explain why none of this research’s specimen were identified as males since all the non-female specimen had mantle lengths less than 14 cm. Although *O. hubbsorum* has not been recorded south of Mexico, recently it has been suggested that *O. hubbsorum* may be genetically similar enough to another established species found in Ecuador, *Octopus mimus*, to categorize them as the same species (Pliego-Cárdenas et al., 2014). This would mean an increase in the estimated geographic range of *O. hubbsorum*, which would include Costa Rica’s Pacific coast. Both *O. hubbsorum* and *O. mimus* are heavily fished within Central and South American countries such as Mexico, Chile, Peru, and Ecuador, making these species likely candidates for being fished in El Jobo as well (Domínguez-Contreras et al., 2013; Pliego-Cárdenas et al., 2014).

Once again, the genetic testing of tissue samples is recommended for a more accurate identification of this heavily fished species.

The majority of interview participants believed at least two species of octopus inhabit the waters of Punta Descartes. The morphological identification portion of this research supports this claim. Naturally, more octopus study subjects would have been preferred and could have helped to further narrow down the list of species candidates, however this research was constrained by both the two-month time limit and undesirable weather conditions. Fishers informed the researchers of a major cold-water upwelling event that was happening at that time, which they believed resulted in fewer octopus for that season. Additionally, high winds produced strong waves during the month of February, resulting in many days of unsafe diving conditions.

Conclusion

In conclusion, this study provides a foundation for community leaders and fishery stakeholders to develop future research and conservation initiatives, and ultimately craft a fishery management plan. There are three key takeaways that this thesis uncovered, which will contribute to the shared knowledge base of this octopus SES. First, according to the artisanal octopus fishers of El Jobo, the population of octopus in Punta Descartes has declined significantly over the years. Second, that according to the individual and Community fuzzy cognitive maps created by octopus stakeholders in El Jobo, possible sources of this population decline are external factors such as red tide, changing ocean temperatures, and large-scale, non-local management decisions causing an increase in the number of hookah and non-local fishers in El Jobo. Third, that there are at least two distinct octopus species inhabiting the coastal waters of Punta Descartes. Possible species candidates for the smaller species with blue ocelli include *Octopus bimaculatus* and *Octopus bimaculoides*, while the possible species candidate for the larger species is *Octopus hubbsorum* (or possibly *Octopus mimus*, if the two are genetically the same as the research suggests).

In addition to these key findings, this thesis also examined potential steps for the community of El Jobo to take to continue deepening their understanding of the octopus fishery SES, with the purpose of contributing to future management plans based upon this new shared understanding. Recommendations included recording climate-related phenomena, recording catch rates and number of fishers in the system, and genetically sampling the two octopus species for more accurate species identification. There is more to learn about the social-ecological system of octopus in El Jobo, but this research acts as a solid starting point for building a shared knowledge base amongst those in the community that rely on octopus for their livelihoods. The hope is that more work will be done to add to this understanding and eventually aid in the crafting of informed management decisions and contribute to the ongoing conservation education programs of El Jobo.

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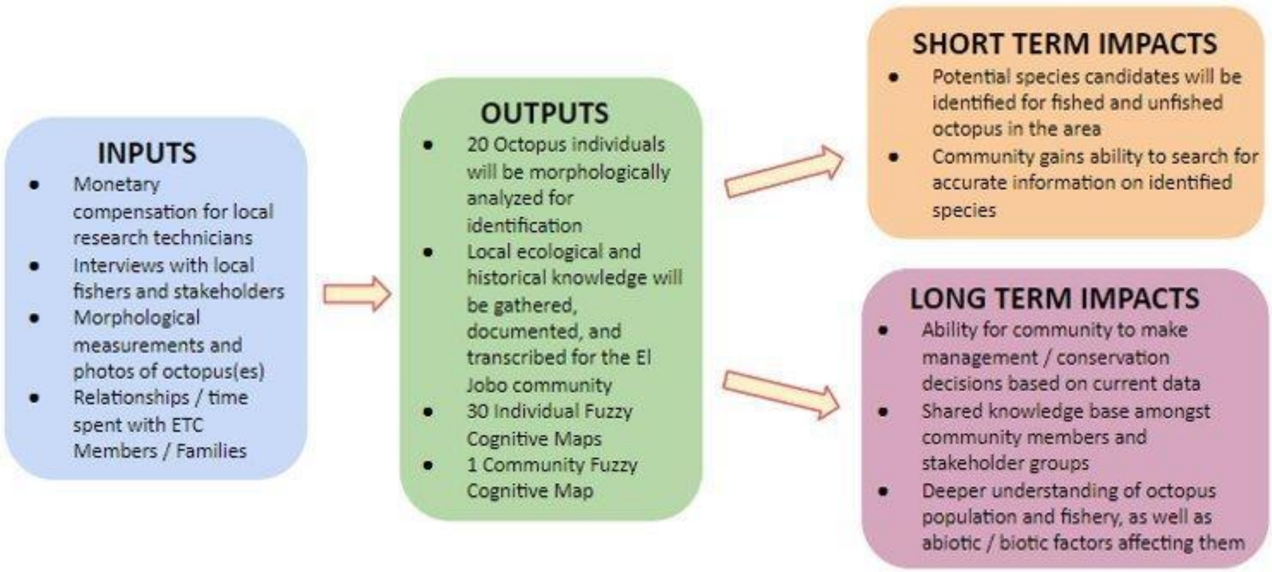
Appendix

Appendix 1: Community Benefits Conceptual Model



Appendix 2: Institutional Review Board Materials: Letter of Consent (English and Spanish)

LETTER OF CONSENT TO PARTICIPATE

Local Knowledge in El Jobo: Understanding the Punta Descartes Artisanal Octopus Fishery

I am Julia Steffens at Alaska Pacific University (APU) conducting a Master's Project over the coming dates of January 15th 2024 – February 29th 2024. I am requesting your voluntary participation in my research. You may choose to stop your participation at any time without penalty. I expect that your participation will take approximately 1 – 2 hours to complete.

The purpose of my research is to gather information about the local octopus population and fishery of Punta Descartes. By interviewing fishers and stakeholders, I hope to understand what factors may affect the octopus population. Interviews will be recorded, and translation assistance will be provided by Randall Mora, a member of the research group Equipo Tora Carey.

Your information will be kept confidential, meaning your name will not be associated with your responses. Your interview and all other data will be recorded via a physical recording device, researcher notes, and Excel sheets all locked behind a password protected file on my laptop. Only myself, Randall, and my research committee will be allowed to view the data. Any public reports or publications from this research will not identify you as being of this project.

This project has been reviewed and approved by APU's Institutional Review Board.

A copy of this letter is yours to keep. If you have any questions about how this investigation is to be conducted, please contact me at: Julia Steffens, phone number 1-314-799-3120, email jsteffens@alaskapacific.edu and mailing address 1610 Eastridge Drive Apt 301, Anchorage AK 99501. You may also contact my Faculty Advisor: Steve Rubinstein, 1-907-982-3122, srubinstein@alaskapacific.edu, 6404 N. Lossing Rd., Palmer, AK 99645, Care of Kellogg, Campus.

____ __________________

Investigator (print and sign) Date

I agree to participate in the project as described above.

____ __________________

Participant (print and sign)

CARTA DE CONSENTIMIENTO PARA PARTICIPAR

Los conocimientos locales en El Jobo: Comprendiendo la pesca artesanal de pulpos en Punta Descartes

Yo soy Julia Steffens de la Universidad de Alaska Pacific (APU) y estoy realizando un proyecto de maestría entre el 15 de Enero a 29 de Febrero 2024. Yo pido su participación voluntaria en mi investigación. Usted puede parar su participación en cualquier momento sin ninguna penalización. Yo calculo que su participación podría tardar aproximadamente de una o dos horas para finalizar.

El propósito de mi investigación es recolectar información sobre la población local pulpos y la pesca de Punta Descartes. Al entrevistar pescadores e interesados, yo espero comprender cuales son los factores que podrían afectar a la población de pulpos. Las entrevistas serán registradas, y la ayuda con las traducciónes será proporcionado por Randall Mora, un miembro del grupo de investigación Equipo Tora Carey.

Su información será confidencial, esto significa que su nombre no se conectará con sus respuestas. Su entrevista y todos los datos serán grabados por un dispositivo de grabación físico, las notas de la investigadora, y las hojas de Excel. Todos los archivos estarán guardados dentro de un archivo en mi computadora portátil con una contraseña. Solamente yo, Randall, y mi comité de investigación tendremos el permiso a ver los datos. Cualquier informe público o publicaciones de esta investigación no lo identificarán a usted como parte de este proyecto.

Este proyecto ha sido revisado y aprobado por la junta de revisión institucional de la Universidad de Alaska Pacific.

Una copia de esta carta es para que usted la conserve. Si usted tiene preguntas sobre como se realizará esta investigación, por favor contácte a Julia Steffens al número de teléfono +1-314-799-3120, al correo jsteffens@alaskapacific.edu, o la dirección postal 1610 Eastridge Drive Apt 301, Anchorage AK 99501. Usted puede contactar a mi consejero escolar: Steve Rubinstein, 1-907-982-3122, srubinstein@alaskapacific.edu, 6404 N. Lossing Rd., Palmer, AK 99645, Care of Kellogg, Campus.

____ ________________

Investigador/a (impreso y fírmalo) La fecha

Yo acepto a participar en este proyecto como se describió anteriormente.

____ ________________

Appendix 3: Institutional Review Board Materials: Human Part Form Answers

Project: Local Knowledge in El Jobo: Understanding the Punta Descartes Artisanal Octopus Fishery

Answers to Human Part Form

Date: 11/20/2023

A. What is the primary reason for this study? What are the anticipated educational or scientific benefits of the proposed project?

This project aims to directly inform octopus fisheries management in the town of El Jobo, Costa Rica. Specifically, Equipo Tora Carey, a local non-governmental organization (NGO), wants to better understand the status and functioning of the octopus social-ecological system. As such, Alaska Pacific University graduate researcher, Julia Steffens, with the aid of Equipo Tora Carey researcher Randall Mora will be conducting interviews with fishers and other stakeholders in El Jobo in an effort to expand our knowledge of the local octopus population and fishery. Conducting interviews with fishery stakeholders will provide the NGO with important information on how the fishery operates and what external factors, both biotic and abiotic, may affect it over time. As these interviews will be conducted in Spanish, which is not the native language of the graduate researcher, Julia Steffens, she may receive help from the above-mentioned ETC researcher in translating and interpreting the interviews of participants during said interviews. Randall Mora, the ETC researcher, will be signing a Research Contract that will also be submitted with this proposal package.

B. What is the proposed participant pool? If the participant pool includes minors (under 18 years old), prisoners, mentally challenged persons, or persons in residential institutional settings such as hospitals, clinics, or rehab centers, you must attach evidence of permission to work with these populations.

We aim to interview at least 30 and up to 60 artisanal fishers, seafood dealers (i.e., restaurants), several staff of Equipo Tora Carey, and other stakeholders of the octopus fishery (all over 18 years of age). Our primary goal is to interview fishers, but plan to interview others if time allows.

C. How will you recruit participants? If you are recruiting through a private or public institution, you must attach evidence of permission to recruit in that setting.

We will recruit participants through existing relationships with Equipo Tora Carey and via the snowball sampling approach. A signed research contract with the Equipo Tora Carey researcher will be sent to APU's IRB prior to data collection.

*D. Will participants **1)** be identified in this study and in the research report; **2)** be promised confidentiality (the final research report will not associate their responses with their names/other identifying information); or **3)** be anonymous (nobody, including the researcher, will know the identities of the participants)? Explain.*

2) Participant information will be kept confidential by default; we will not associate their responses with their names in the final research reports. Any public reports or publications from the researchers will not identify any individual as being of this project.

E. How will data be collected and recorded to ensure the level of privacy indicated in your
answer to item D, above? At the completion of the study, what will happen to materials (datasheets, videos, etc) that identify individual participants?

Data will be recorded via a physical recording device, researcher notes, and Excel sheets all locked behind a password protected file on the researcher's laptop. After completion of the study, participants will be assigned a random number using a random number generator and identifiable information deleted from all data files, which will continue to be stored in password protected files or folders.

F. Is there any pre-existing professional or personal relationship between the researcher and the participants? If so, explain.

The researchers do not have pre-existing relationships with the participant pool. However, Julia Steffens has met some of the potential participants previously, but this will not impact the risk associated with participation.

G. Does the study involve deception of the participants? If so, explain and justify.

No.

H. Will the study cause discomfort, harassment, invasion of privacy, risk of physical injury,
or threat to the dignity of participants, or be otherwise harmful to them? If yes, explain these potential effects and justify them. What measures will be taken to minimize these effects?

No.

Appendix 4: Institutional Review Board Materials: Research Contract

ALASKA PACIFIC UNIVERSITY

El contracto de investigación – La carta de la aprobacion

Este documento explica la investigación, recopilación de datos, y los procedimientos usados para compartir dichos datos que la Universidad de Alaska Pacific (APU) va a conducir en colaboración con un miembro de Equipo Tora Carey (ETC) - una NGO en El Jobo, Costa Rica. Esto se va a realizar para el proyecto que llamado "Los conocimientos locales en El Jobo: Comprendiendo la pesca artesanal de pulpos en Punta Descartes." Este proyecto está financiado por "The Explorer's Club" y "At-Sea Processor's Association." Los investigadores de APU para este proyecto incluyen al Prof. Steven Rubinstein y la estudiante de posgrado Sra. Julia Steffens, y un miembro de Equipo Tora Carey: Randall Mora. Al firmar este documento abajo, un representante de APU (*Investigador*) y ETC (*Co-Investigador)* reconocen las responsabilidades de ambos partidos en esta investigación.

El propósito de la investigación:

El objetivo de la investigación descrita aquí es crear una fundación compartida de conocimiento sobre la población local los pulpos y la pesca de Punta Descartes. Este proyecto se propone incorporar y combinar el conocimiento ecológico local de los pescadores artesanales y los interesados de El Jobo, en un esfuerzo para crear una comprensión más unificada de los pulpos de Punta Descartes. Con la ayuda de los pescadores y los interesados, nosotros esperamos obtener una mejor idea de los factores ecológicos y antropogénicos que pueden afectar a la población de los pulpos, así también afectando el trabajo y el medio de vida de los pescadores locales y los miembros de la NGO.

La recopilación y diseminación de los datos:

Para lograr los objetivos de la investigación mencionados anteriormente, los datos se juntarán a través de entrevistas en persona donde el *Co-investigador* podría asistir con la traducción del español al inglés durante y después de cada entrevista. El *investigador* y *Co-investigador* hablarán de todos los procedimientos de la recopilación de datos y estudiarán metodologías antes de implementarlas. Las personas mencionadas anteriormente de las organizaciones de *investigador* y *Co-investigador* podría estar presentes durante de las entrevistas y el *investigador* es responsable de recopilar y guardar los datos. Ambas organizaciones obedecerán los contratos de la confidencialidad que fueran descrito en las formas de consentimiento de participantes del estudio.

El / la Investigador

Como un representante del *Investigador*, yo acepto las condiciones del plan de investigación que fue mencionado en

este documento.
El nombre completo con letra de imprenta: Julia Steffens ________________________________
Firma su nombre : ____
La fecha: _________________________________

El / la representante de la entidad
Como un representante del *Co-Investigador*, yo acepto las condiciones del plan de investigación que fue mencionado en este documento.
El nombre completo con letra de imprenta: Randall Mora ____________________________________
Firma su nombre : ____
La fecha: _________________________________

ENGLISH TRANSLATION:

Research Contract – Letter of Approval

This document outlines the research, data collection, and data sharing procedures to be conducted by the Alaska Pacific University (APU), in collaboration with the Equipo Tora Carey (ETC) - a community-based NGO in El Jobo, Costa Rica, for the project titled 'Local Knowledge in El Jobo: Understanding the Punta Descartes Artisanal Octopus Fishery' funded by the Explorer's Club and the Alaska Sea Grant. Researchers for this project at APU include Prof. Steven Rubinstein and graduate student Ms. Julia Steffens, and at ETC include Randall Mora. By signing the document below, a representative from APU (*Investigator*) and ETC (*Co-Investigator*) acknowledges the responsibilities of each party in the proposed research.

Research Purpose:

The goal of the research described herein is to create a shared base of knowledge about the local octopus population and fishery of Punta Descartes. This work aims to incorporate and combine the local ecological knowledge of artisanal fishers and stakeholders in El Jobo, in an effort to create a more unified understanding of the octopus of Punta Descartes. With the help of fishers and stakeholders, we hope to get a better sense of what factors, both ecological and anthropogenic, may affect the octopus population, thereby affecting the work and livelihoods of both local fishers and NGO workers.

Data Collection and Dissemination:

To achieve the research goals above, data will be collected via in-person interviews whereby the *Co-Investigator* may assist in translation from Spanish to English during and after each interview. The *Investigator* and *Co-Investigator* will discuss all data-collection procedures and study methodologies before implementation. The personnel listed above from *Investigator* and *Co-Investigator* organizations may be present during the interviews and the *Investigator* is responsible for collecting data and storing data. Both organizations will abide by confidentiality agreements described in the study participant consent forms.

Investigator

As a representative for the *Investigator*, I agree to the terms of the research plan outlined in this document.

Print Name ____

Sign Name

Date _______________

Entity Representative

As a representative for the *Co-Investigator*, I agree to the terms of the research plan outlined in this document.

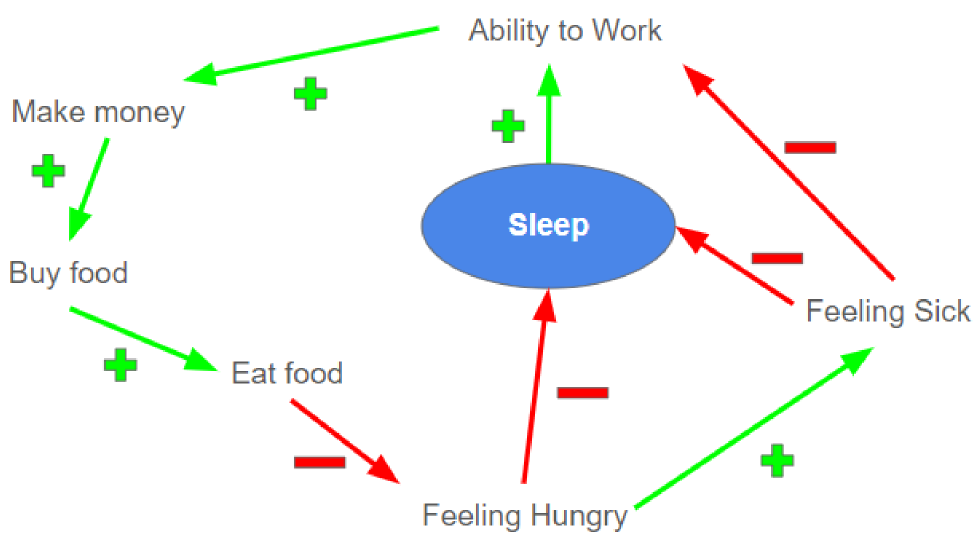
Print Name ____

Sign Name

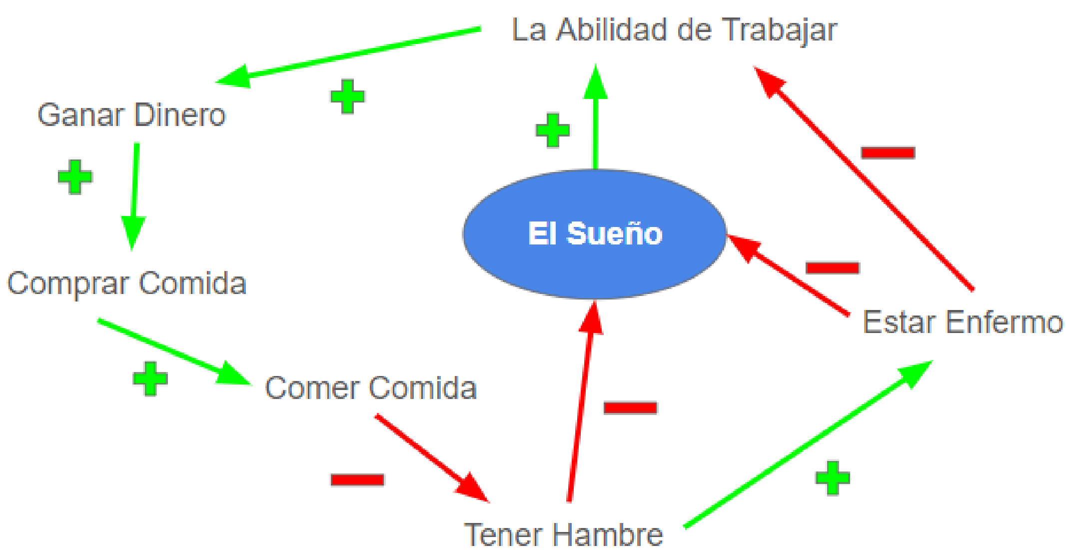
Date ______________

Appendix 5: Example of FCM for Participants (English and Spanish)

Example of a Fuzzy Cognitive Map



Un Ejemplo de un Mapa Cognitivo



Appendix 6: Interview Questionnaire

Conocimiento local en El Jobo: Entendiendo la pesca artesanal de Punta Descartes

Entrevistador(a): ________________________________ # Entrevista: ________________

Fecha: ___________________________ Ubicación: ______________________________

Hora de início: _____________________ Hora de fin: ______________________________

Hola, me llamo Julia, yo soy una estudiante de los estados unidos. Estoy investigando los pulpos de El Jobo y la industria de pesquera del pulpo aqui. Yo quiero aprender sobre los pulpos por las entrevistas con pescadores o otras personas con experiencia con pulpos aqui. Gracias por ayudarme con este proyecto! Hay dos partes de esta entrevista. En la primera parte, voy a preguntarle sobre usted y sus conocimientos de la pesca. En la segunda parte, vamos a construir un representación visual de su perspectivo de la poblacion de los pulpos en El Jobo y los factores que la afectan. Este es un metodo para comprender un concepto y los factores que lo afectan. Voy a explicar mas el processo despues de la primera parte de la entrevista. Esta entrevista podría tardar aproximadamente una o dos horas. Voy a grabar esta entrevista, y su información será confidencial, esto significa que su nombre no se conectará con sus respuestas. Cualquier informe público o publicaciones de esta investigación no lo identificarán a usted como parte de este proyecto.

Usted tiene preguntas sobre este proyecto o el processo?

Sección 1: Información Sociodemográfica

¡Comencemos! En esta sección, me gustaría saber más sobre usted. Las siguientes preguntas están relacionadas con su condición sociodemográfica. Por favor, recuerde que todas sus respuestas serán totalmente anónimas.

<u>1. Experiencia con Pulpos</u>

1.1.1 "Que es su experiencia con los pulpos en El Jobo?"

( ) Pescador ( ) Operador de turismo ( ) Conservación
( ) Vendedor
( ) Otro. Por favor, explique: ____

____

1.2.2 "Cuantos anos lleva usted trabajando como _________?"

<u>2. Ocupación</u>

2.1.3 "Cual es su ocupacion?

( ) *Pescador* ( ) *Operador de turismo* ( ) *Conservación*
( ) *Vendedor*
( ) *Otro. Por favor, explique:* ____

2.2.4 ¿Cuántos años lleva usted trabajando como un ________?

<u>3. Situación laboral</u>

3.1.5 ¿Cuál es su situación laboral actual?

( ) *Trabajador independiente* ( ) *Empleador* ( ) *Empleado*
( ) *Trabajador familiar no remunerado* ( ) *Jubilado*
( ) *Otro:* ____

<u>4. Edad</u>

4.1.6 "Cuántos años tiene?" ___________

<u>5. Género</u>

5.1.7 "Cuál es su género?"

( ) *Masculinocho* ( ) *Femeninoina* ( ) *Prefiere no responder*

Sección 2: Percepción de la Pesquería de Pulpo

En esta sección, voy a preguntar sobre su percepción en relación a la pesquería de pulpo. No hay respuestas ciertas ni erradas. Apenas diga lo que usted piensa. Voy a leer unas afirmaciónes y yo quiero que usted me dice si usted es en desacuerdo o en acuerdo.

<u>1. Sostenibilidad</u>

1.1.8 La pesca de pulpos en El Jobo es sostenible.

( ) *Totalmente en desacuerdo* ( ) *Algo en desacuerdo*
( ) *Neutro, ni en desacuerdo o de acuerdo* ( ) *Algo de acuerdo*
( ) *Totalmente de acuerdo* ( ) *No sé*

<u>2. Salud de la población</u>

2.1.9 La población de los pulpos en El Jobo está sana.

( ) *Totalmente en desacuerdo* ( ) *Algo en desacuerdo*
( ) *Neutro, ni en desacuerdo o de acuerdo* ( ) *Algo de acuerdo*
( ) *Totalmente de acuerdo* ( ) *No sé*

<u>3. Contribución socioeconómica</u>

3.1.10 La pesca de pulpos en El Jobo puede apoyar más pescadores

( ) *Totalmente en desacuerdo* ( ) *Algo en desacuerdo*
( ) *Neutro, ni en desacuerdo o de acuerdo* ( ) *Algo de acuerdo*
( ) *Totalmente de acuerdo* ( ) *No sé*

Sección 3: Percepción de la población de pulpos en términos de número de especies y descripciones morfológicas

Ahora, me gustaría saber más sobre las características de los pulpos en Punta Descartes.

1. Especies de pulpo

1.1.11 ¿Cuántas especies de pulpos usted cree que viven en Punta Descartes? ______________

1.2.12 Descripción de las especies - ¿Qué aspectos tiene los pulpos que usted mencionó? Mencione cualquier diferencias en rango de peso/tamaño, si el ocelo está presente, diferencias padrones de color, entre otros. Si hay diferencias en los hábitats donde se encuentran esas especies, o si tienen hábitos de vida diurnos o nocturnos, por favor, especifica.

____
____
____
____
____
____

1.3.13 Especies pescadas - ¿Cuáles especies de pulpo usted cree que se capturan en la pesca?

____
____

PARA PESCADORES SOLAMENTE - Sección 4: Apenas para Pescadores Artesanales - Cuestiones extras sobre la Pesquería

En esa sección, me gustaría saber sobre sus actividades en la pesquería de pulpo.

1. Método de pesca

1.1.14 ¿De qué manera usted pesca por los pulpos?

( ) *Buceo libre (en apnea)* ( ) *"Hookah"*
( ) *Otro. Por favor, explique:* ____

1.2.15 Acceso a la zona de pesca - ¿Cómo usted va al sitio donde pesca?

( ) *A pie* ( ) *En una canoa/barco sin motor* ( ) *En un barco con motor*
( ) *Otro. Por favor, explique:* ____

2. Pulpo pescado

2.1.16 Cantidad de pulpo pescada - "En general, cuántos pulpos captura al día?" ______________

2.2.17 El peso de pulpo pescada - En general, ¿cuántos kilogramos de pulpo captura al día? ________kg

2.3.18 El peso de pulpo individual - En general, ¿cuál es la talla más comúnmente pescada en gramos? __________g

<u>3. Participación de las mujeres</u>

3.1.19 "Las mujeres de El Jobo están involucradas en la pesquería de pulpo? (las opciones: si o no – si si, en que actividades: pesca, transporte, procesamiento, tranformacion, venta, prepare y limpieza de los materials de pesca y/o barcos, gestion de la pesqueria/toma de decisions, o otras actividades: por favor especifique ____)"

<u>4. Cambios en la población de pulpos</u>

4.1.20 "Durante su tiempo como un pescador, la población de los pulpos han cambiado?"

( ) *Ha disminuido mucho* ( ) *Ha disminuido un poco* ( ) *No ha cambiado*
( ) *Ha aumentado un poco* ( ) *Ha aumentado mucho* ( ) *No sé*

Sección 5: Mapa cognitivo de la población de pulpos

Ahora, vamos a construir una representación visual. Es un metodo para comprender un concepto y los factors que lo afectan. Es como un diagrama de una sistema. El objectivo es crear una visual que represente sus ideas o perspectivos sobre un concepto y todos los factors que lo afectan. Este es un ejemplo. En este ejemplo, el central concepto es el Sueno, y estes son todos los factores lo afectan el sueno o son afectados por el sueno. Un factor que lo afecta es "estar enfermo." Porque cuando una persona esta enferma, esta persona no puede dormir bien. Entonces el factor de "estar enferma" afecta el concepto central del "sueno." Entonces yo dibuje una flecha desde "estar enfermo" a "el sueno." Y en este caso el efecto es negetivo porque la influencia de "estar enfermo" es negativa. Finalamente, yo quiero saber la fuerza de esta influencia. Si el factor tiene un poco influencia, algo de influencia, o mucha de influencia. Tiene sentido?