Fishing for alternatives

Bait and pot trials in the upper Gulf of California

MASTER THESIS IN AQUATIC SCIENCE AND TECHNOLOGY
TECHNICAL UNIVERSITY OF DENMARK – DTU

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s162895

Fig. 1 Vaquita porpoise (*Phocoena sinus*) trapped and drowned in a gill net intented for totoaba (*Totoaba macdonaldi*) (Rojas-Bracho et al., 2006)

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1. Abstract

As the world realised that the smallest porpoise in the world – the vaquita porpoise (*Phocoena sinus*) had almost been driven to extinction by accidental catches in gill nets, the Mexican government completely banned the use of gillnets in the entire distribution range of the vaquita porpoise in April 2015, which was in full effect in May 2015. This led to instant unemployment among fishers in the area, and the compensation from the government was not scheduled to go on forever. A project revolving fishing with vaquita-friendly baited pots was set in motion by ECOFT[1] supported by the government and in collaboration with WWF Mexico. The aim was to create an alternative to gillnet fishing in the no-gillnet zone of the upper Gulf of California (UGC). To ensure the best performance of the baited pots, an experiment was conducted, testing the different baits available to the fisherman. Three baits were selected and tested in a 10-day survey in the area of San Luis Gonzaga, Mexico. Bait station activity was recorded using GoPro cameras in water sealed steel and plexiglass cages. The attraction of the bait was measured as 'most commercial species in a frame per 30 minutes'(MaxN). Bait attraction was tested in daylight and in the night with light assistance.

Flat-iron Herring proved to be the best bait in daylight, whereas the results from the night were inconclusive, probably due to the bias of light attracting fry and smaller fish.

The results from the pot trials indicated that a bottom standing pot design is prefered. The area of fishing had an impact on the species composition. In trial 2, the catch per fishing journey in weight was on average 24,8 kg. By increasing the number of pots the fisherman are fishing with per day and changing the bait from the expensive Monterrey sardine to the cheap flat-iron herring, the catches can be increased and the pot fishery could turn out profitable and be a viable alternative to gillnets in the Upper Gulf of California. However, more trials are needed to conclude this.

[1] ECOFT : the Expert Committee on Fishing Technologies

[2] (International Committee for the recovery of the Vaquita)

Table 1 Used terms and acronyms

Term	Explanation
CPUE	Catch per unit effort. In this thesis: Catch in numbers per pot hauled
WPUE	Weight per unit effort. In this thesis: Catch in weight per pot hauled
UGC	The Upper Gulf of California. Also known as the upper Sea of Cortez
GAMM	Generalized additive mixed model. A mathematical tool to interpret data statistically. It is structurally a response variable and a number of predictors.
Response variable	Is the variable you want to know more about. What affects the variable and how?
Predictor	A predictor is also called explantory variable and is a variable that can explain the variation in the response variable. To emphasise that I am referring to a predictor from the analysis. it figures with citiation marks. I.e. ”Pottype” and ”Soaktime”
INAPESCA	The national institute of fisheries and aquaculture in Mexico
Totoaba	A large fish in the croaker family (Scianidae). Famous for its large and high-value svimbladders that is being fished illegally and sold to China.
Vaquita porpoise	The smallest porpoise in the world. It only lives in the Upper Gulf of California and is facing extinction
CIRVA	International Committee for the Recovery of the Vaquita. An international team of scientists set up by the Mexican government to advice and monitor the vaquita population and management.
ECOFT	Expert committee set up by the Mexican government to advice on alternative gear selection. Members are alternative gear expers from all over the world.
PACE vaquita	A management plan formed by the Mexican government to decrease the fishing pressure in the UGC to slow down the bycatch of Vaquita.
Pot	A baited cage with entrances, designed to attract and catch marine creatures. Also called : baited traps
WWF	World Wide Fund for Nature. WWF is an NGO operating in the whole world.

2. Background

2.1 The Gulf of California

The Gulf of California is unique. Jaques Cousteau once labeled it ”The aquarium of the world”. This semi-enclosed sea lies between the Baja California peninsula and the Mexico mainland. The Gulf is 150 km wide and 1100 km long, with an average depth of 200 meters and a maximum depth of 3600m. It is affected by both the mainland on each side, the Pacific Ocean tidal currents and the monsoon winds (Ripa, 2003).

Many papers indicate that the Gulf of California is one of the most biologically productive marine regions in the world. The strong tidal mixing, thermohaline circulation, and coastal upwelling ensure an exceptionally high primary production and by that: an ecosystem that is among the most fertile on earth hosting remarkably high biodiversity (Zeitzschel, 1969, Mercado-Santana et al., 2017, Brusca et al., 2017). The biggest freshwater outlet into the Gulf used to be the Colorado River.

Starting with Hoover Dam in 1937, the intensive damming and regulation of the Colorado River in the USA for irrigation purposes has completely soaked up the main natural freshwater discharge in the Gulf and eventually dried out the river delta. The last 160 km of the river hasn’t been flowing steadily since the 1960s (Zamora et al., 2013). Consequently wiping out the foundation of the culture of the native Cucapá tribe (people of the river), not to mention disturbing the myriads of different life forms present in the river delta (Brusca et al., 2017).

By impeding the flow reaching the mouth of the river, the lack of freshwater discharge altered the once brackish water to a state of hypersalinity due to evaporation.

As both the totoaba(*Totoaba macnoldi*) and white seabass *(Atractoscion nobilis)* are spawning in the Colorado River mouth, the lack of river discharge has diminished the spawning and nursery grounds for at least the two species (Rowell et al., 2005).

In the past, Mexican legislators have tried to use the lack of river flow as leverage to explain the decline in the vaquita porpoise (*Phocoena sinus*) population (Brusca et al., 2017). This, however, is in disagreement with nearly all scientific research on the area that states, that fisheries bycatch, including the illegal fishery for totoaba, is the main culprit of the vaquita's decline. (Norris & Silber, 1991, Vidal et al., 1999, Rojas-Bracho et al., 2006). Unfortunately, the notion of the Colorado River discharge being the reason for the decline of the vaquita has more or less intentionally hauled out and delayed any serious attempts by the Mexican government to save the vaquita before 1997 where CIRVA[2] was established by the government of Mexico(Erisman et al., 2015).

The fisheries in the upper Gulf of California that is or has affected the vaquita population, roughly consist of a large fishery with small artisanal boats with outboard engines – *pangas,* fishing with gillnets, a fleet of bottom and pelagic trawlers that are fishing for shrimp and lastly an illegal fleet of pangas fishing for the totoaba croaker to export their unusually large swim bladders to the Chinese illegal market, for medicine use (Pennisi, 2017).

The legal artisanal boats are for the most part using gillnets for catching primarily Sierra Mackerel *(Scomberomorus sierra)* and Corvina *(Cynoscion othonopterus*) in the surface. Deeper down in the water column the targets are mainly blue shrimp (*Litopenaeus stylirostris)*, Chano (*Genyonemus lineatus)* and different species of sharks and rays. A small number of those pangas fish for rooster hind *(Epinephelus acanthistius)* with longlines or take divers out to collect bivalves from the seabed (D'Agrosa, C., Cody-Lennert, C.E., & Vidal, 2000).

Bottom – and pelagic trawlers are primarily targeting shrimp and the fishing fleet only in the Gulf of California consisted of 1456 vessels in 2005 (FAO & Aguilar & Grande-Vidal, 2008). Known reports of vaquita bycatch by trawlers is few (Norris & Prescott, 1961).

Attention has therefore been directed towards the issue of acoustic disturbances to the vaquitas due to trawling activity (Rojas-Bracho et al., 2006). Bottom trawlers fishing deeper than 200 meters are thought to have no physical impact on the vaquita as the vaquita has only been spotted in shallow waters.

The illegal fishery for totoaba typically happens at night with the strictly forbidden totoaba gill nets - *totoaberos* (20-30.5 cm in mesh size,(Vidal, 1995)). Needless to say, the fishery is damaging to the threatened totoaba population but has since the gillnet ban been the biggest threat to the

[2] (International Committee for the recovery of the Vaquita)

remaining members of the vaquita population. As the totoaba and the vaquita share similar sizes, the vaquita is getting caught as bycatch in the same type of net (A. Jaramillo-Legorreta et al., 2017).

The illegal but profitable fishery for totoaba, has made it very difficult to keep fishers with gillnets on shore. Prices for a kilo of totoaba swimbladder in 2014 exceeded 8500$ on the black market in Mexico, which is the equivalent to half a year of legal fishing (CIRVA V). Combined with little enforcement in the area it is unfortunately well worth the risk to go out fishing for totoaba (Brusca et al., 2017).

The illegal fishery for totoaba reached new heights in 2013, where demands and prices for totoaba swimbladders suddenly skyrocketed (Valenzuela-Quiñonez et al., 2016). Since then the illegal fishery has increased and with the prospect to earn up to 60000 $ for a kilo of swim bladder if smuggled to China, organised crime syndicates are involved, making the illegal fishery even harder to control (Valenzuela-Quiñonez et al., 2016). The totoaba does not only reach similar sizes as the vaquita but is also found in roughly the same area as the vaquita, which is endangering this porpoise population even more.

2.2 Vaquita biology

The Vaquita porpoise (fig. 2) was first described in 1958 by Norris and McFarland much to the surprise of scientists around the globe who had never heard of it and the villagers living near the coast of the upper Gulf of California, who had, for the most part, never seen one.

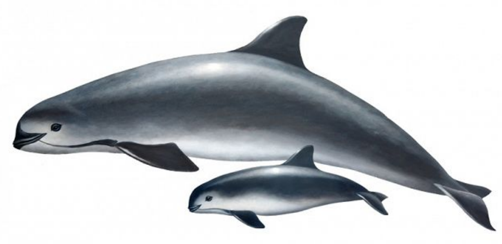

Fig. 2 Sketch of Vaquita with calf. Females grow to a maximum of 150 cm

Norris and McFarland had based the description of this new species on three sunbleached skulls they had collected close to the city of San Felipe in Mexico (Orr, 1969, Vidal et al., 1999).

Norris and McFarland were discussing the ancestry and suggested that the vaquita porpoise, or the California Gulf porpoise as it was called at that time, would be closest in ancestry to the Burmeister porpoise (*Phocoena spinipinnis*) by observing phenotypic traits of the skulls. This was confirmed 37 years after with genetic and molecular analysis (Rosel, 1995).

The vaquita is endemic to the upper golf of California and habituates an area of about 4000 km^2 or roughly the size of the island of Mallorca (Rojas-Bracho et al., 2006). Sightings out of this area have been extremely scarce, which leads to the conclusion that the vaquita is in the area year-round. This makes the vaquita the most range-restricted marine cetacean in the world (Vidal et al., 1999, Rojas-Bracho et al., 2006). They have a close affinity for turbid conditions and are most likely preferring areas with murky waters and low visibility possibly as a strategy to stay clear of any predators (Rojas-Bracho & Jaramillo-Legoretta, 2009). Female vaquitas are not breeding every year and by comparisons with the harbour porpoise *(Phocoena phocoena)* the vaquita reproduction rate is estimated to be lower than that of the harbor porpoise, at 4% a year (Hohn et al., 1996).

In 1995 Rosel et al. sequenced mitochondrial data from 43 different vaquitas and compared the control region sequence variability to gain insight in the overall genetic variability of the species. In humans as well as other mammals, the MtDNA control region is a hotspot for polymorphism and visualising genetic variance in a population (Stoneking et al., 1991). Rosel found, contrary to what anyone expected, the sequences in the MtDNA control region to be identical, meaning no genetic variability at all (Rosel, 1995).

A low genetic variability can be caused by rapid declines in the population, as seen in the New Zealand fur seal and cause populations to collapse due to inbreeding depressions and the fixation of deleterious mutations (Dussex et al., 2016). Nevertheless, it is generally accepted that inbreeding depression is not the case for the vaquita porpoise who presumably always has had a population with low genetic variability. (Rosel, 1995, Rosel & Rojas-Bracho, 1999).

The population size alone makes the vaquita vulnerable to changes in environment or anthropogenic threats but also the lack of genetic variation would suggest that the genetic plasticity is low, giving little room for adapting to environmental changes or other threats.

2.3 Chronological Scientific and Management Efforts in the upper Gulf of California

Already in 1955 in an effort to reduce fishery in totoaba and white sea bass spawning areas, a reserve in the mouth of the Colorado River delta was declared. In 1975 a complete prohibition for all totoaba fishing activities in the entire Gulf of California was announced after a population collapse due to high fishery efforts. These initiatives were however primarily to secure the yield in fisheries in the long term, rather than the notion of securing ecosystem sustainability (Caddy & Cochrane, 2001).

1975 was also the year where scientists from the IWC[3] scientific committee had concerns about the vaquita getting entangled in gill nets in the upper Gulf of California.

As a result of growing concern, the vaquita was listed as *vulnerable* by the IUCN in 1978(Brownell, 1983), and following some attempts to count the population linked with more and more intelligence about dead vaquitas in gillnets, the assessment changed to *endangered* in 1990 and then *critically endangered* in 1996.

No direct management was implemented to save the vaquita before 1993, when the upper Gulf of California and Colorado River Delta Biosphere Reserve was declared. Gillnetting was limited (>15 cm in mesh size, knot to knot) and artisanal boats, or *pangas*, was limited to 2100 boats inside the reserve, which partly covered the vaquita range, thus decreasing the fishing effort (fig. 3). Despite this being a positive initiative, the action came late compared with the fact that the scientific community was well aware of the vulnerability of the vaquita porpoise almost twenty years before (Rojas-Bracho et al., 2006).

[3] International Whaling Commission

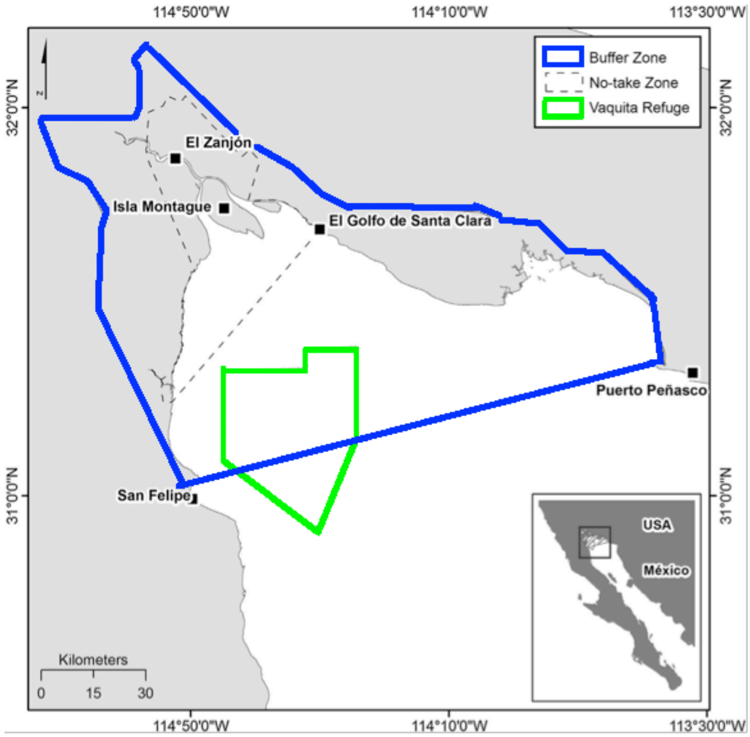

Fig. 3 The Upper Gulf of California and Colorado River Delta Biosphere Reserve declared in 1993 (No-take Zone). The Vaquita refuge or core-zone (the polygon in green) was declared in 2005, banning gillnets inside it. (Erisman et al., 2015)

In 1997 The International Committee for Saving the Vaquita – CIRVA, was appointed by the Mexican government and by the recommendation of this committee a survey cruise to estimate the vaquita population was realised and became a joint Mexico-USA venture. Acoustic surveys were concurrently initiated and by 1999 an estimate of the population was made public. 567 individuals (95% CI 177-1073) which CIRVA endorsed in 1999 (A. M. Jaramillo-Legorreta et al., 1999, Rojas-Bracho et al., 2006).

In 2000 D'Agrosa and her team measured the bycatch of vaquita in nets to a staggering 39 individuals in a year from one single port (D'Agrosa et al, 2000). The same year the National Fisheries Chart, an advising subunit under the fishing authorities, stated that the vaquita bycatch should be zero (D'Agrosa, C., Cody-Lennert, C.E., & Vidal, 2000).

In 2005 the vaquita refuge was implemented (fig. 3), by the Mexican government which banned gillnets entirely inside the vaquita refuge. However, this prohibition was widely ignored by the fishers as no enforcement was present (Rodríguez-Quiroz et al., 2012).

In 2011 a paper on a major survey combining acoustic, visual and aerial data was published, estimating the population of the vaquita to be at least halved between 1997 and 2008. Only 200 animals were estimated to be left (Gerrodette & Rojas-Bracho, 2011).

The PACE Vaquita management plan was launched in 2008 and the aim of this initiative was to enforce the already existing gillnet bans in the vaquita refuge while offering the fishers compensation for changing or even stopping their fishing activities (SEMARNAT, 2008)[4].

The success of this effort was announced three years after by the Mexican minister of environmental issues, who proclaimed that the vaquita was "on the path to recovery" (Avila-Forcada et al., 2012).

This statement is cringe-worthy if seen in the light of the population today, where the vaquita population is estimated to be 12 individuals by NGO's in the area("Mongabay news," 2018) and the actual success of PACE vaquita, may only be measured as having slowed the accidental killing of the vaquita (CIRVA, 2014). The PACE vaquita compensation system only bought out 247 *pangas,* out of a registered fleet of over 1200. The actual fleet may have been as large as 1800 due to a growing illegal fleet of pangas fishing without permits (Cantú-guzmán et al., 2015). Moreover, no efforts were made to control whether fishers actually fished with vaquita friendly gear under the switch-out program. (Cantú-guzmán et al., 2015).

In 2014 CIRVA held it's fifth meeting and concluded that management efforts had not worked and the vaquita was bound for extinction as early as 2018, with the decline rate at that point (18.5%). The recommendations were clear: Gillnets are not compatible with vaquita survival and must be banned in the total range of the vaquita. The illegal fishery for totoaba must be stopped and increased efforts should be made to introduce alternative fishing gear with zero bycatch (CIRVA, 2014).

These recommendations from CIRVA sparked a series of events. With below 100 vaquitas left, gillnetting in the entire range of the vaquita was banned in 2015 and compensation was given to all the fishers who had a permit. Which as previously stated, weren't all the fishers. A trial to test if pot fishery could be profitable in the UGC was conducted by INAPESCA in San Felipe and Santa Clara. Results were inconclusive despite good catch rates.

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[4] In PACE vaquita the fishers were offered three voluntary options. Switch-out, Rent-out or Buy-out. Switch out was switching to less effective vaquita friendly gear. Rent-out compensates the fisher for not fishing in the refuge area and the fishers are being paid for taking part in the conservation programme. Buy-out option can compensate a fisher if he turns in all gear (boat included) and permits.

ECOFT (Expert Committee on Fishing Technologies) was founded in 2016, a committee whose members are international experts on alternative gear, to assist in the Mexican governmental decision making on the alternative gear priority as recommended by CIRVA(5). ECOFT released a report. In 2016 the official number of the vaquita population had dropped to 30 (CIRVA 9, 2016). In 2017 the vaquitaCPR stole the headlines. VaquitaCPR was a huge last effort project revolving around the goal of catching vaquitas to breed in captivity to save the species. By acoustic monitoring, the vaquitaCPR team could localise the vaquitas and go out in the specific area to seize them. They captured the vaquitas in encircling nets and tried to transport them to an ocean pen, where they would be safe from the bycatch of gillnets. Unfortunately, one of the two vaquitas caught died in the arms of the scientists and volunteers, who tried to save them. The project was immediately shut down by a unanimous panel of experts, who deemed the vaquita unfit to be under the care of humans (Pennisi, 2017).

In 2018 the population of the vaquita is continuously dwindling and the latest guesstimate (March 2018) from NGO's is as few as 12 remaining individuals ("Mongabay news," 2018). While the IUCN still has it to 18 individuals.

In April, board members from ECOFT, in collaboration with WWF, performed a 10- day test together with the fishers from San Felipe to launch a trial to test baited pots for finfish to substitute gillnets in the Upper Gulf of California (UGC).

2.4 Gillnets

Set gillnets are usually sheets of nylon twine netting, held open by a floating line in the top and a sinking line in the bottom of the net. Set gillnets are usually designed to fish on the bottom, catching demersal species. In each end, there is typically a device that either holds the net to a fixed point, such as an anchor or mooring or a floating device such as flag buoy or similar, so it is possible to find and retrieve the net again (Northridge et al., 2017). On small boats, gillnets are usually hauled by hand and are widely used in the small scale fisheries of the world as they require no special equipment. They can be left fishing for an infinite amount of time before being retrieved. Soak times vary from region to region. In the UGC each of the 755 legal pangas was in 2015 equipped with two set gillnets of 800 meters each on average (Herrera & ECOFT., 2017).

Driftnets are attached to the boat in one end a buoy in the other end but are otherwise similar in structure to set gillnets. Differences are usually place of deployment as driftnets are typically in deeper waters, aimed at pelagic species. The depth of the netting panels can be as deep as 30 meters. They are drifting with the current and length of driftnets for big commercial vessels could be as long as 60 km, before it was set to a maximum of 2.5 km in 1991 by law of United Nations. Driftnets are typically deployed at night to avoid being detected by target species and are notorious for catching mammal bycatch (Society for Marine Mammology, 1991).

Encircling gillnets are custom made to catch schools of fish in a small area. The float line is on the surface and when the catch is surrounded by the encircling net, the fishers splash, shout or revs the engine to scare the school of fish to flee in order to entangle the scared fish in the gillnet, prior to retrieval of the net.

Encircling nets for corvina are mentioned as an alternative to set gillnets and driftnets as they have no bycatch of cetaceans and operates primarily in a small area near the Colorado River in specific times of the year. Despite strict management on corvina encircling net, some fishers have used them as a cover up for illegal fishing for totoaba (CIRVA 9, 2016).

The main problem is that gillnets, in general, are catching a lot of unwanted catch: Unwanted fish, turtles, birds, sharks (Dayton et al., 1995) and in the UGC also the vaquita porpoise (Rojas-Bracho et al., 2006).

2.5 Alternatives to gillnets in the UGC

The gear alternatives to gillnets that have been tried in the UGC have been chosen as they have little risk of mammalian bycatch and have been proved profitable locally or in other parts of the world. The trials and tests, that has for the most part been funded and conducted by the Mexican government, have been summarised by the working group ECOFT in 2016 (Herrera & ECOFT., 2017)

Suripera

Suripera nets use large sails to drag their nets through the water column in order to catch shrimp (fig. 4) The shrimp are caught in the additional bags that work as a fyke, when they try to escape by swimming to the surface (Amezcua et al., 2009). The fishery is seasonally effective and has very low fuel consumption, but was readily discarded in 2008 by INAPESCA (The national institute of fisheries and aquaculture), who deemed them ineffective. However recent trials from 2017 have shown good results and the fishery as an alternative are being considered and supported once again (Herrera et al, ECOFT., 2017).

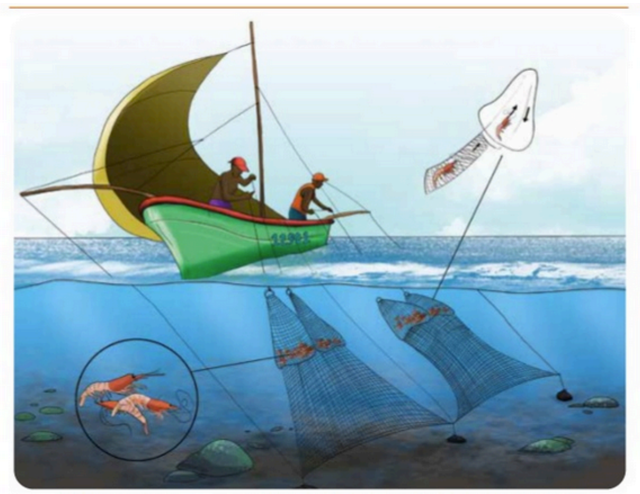

Fig. 4 Suripera nets catching shrimp. (Source: MarVIVA)

Small trawl / light trawl

The small trawl is an alternative to the shrimp gillnet, used in the UGC. A trawl is dragged over the bottom usually with trawl doors to widen the net to increase catches. This is perhaps the most studied alternative gear in the UGC. Promising and profitable, but varying results have been made from 2008-2015. Under the PACE-Vaquita the fishers were declined permits for trawling when they tried to switch out their gillnet license for a trawler license. Furthermore, a gill-net free area was promised for the small trawls to operate, but not delivered. This signaled conflicting interest in the Mexican government on whether the fishers should implement the switch to small trawls or not (CIRVA V, 2014). On top of that, some trials have shown, when testing small trawls versus gillnet, a 30% increase in fuel use per kg catch, 2,7 times more bycatch, and likely a bigger impact on the seabed than gillnets (Smith & Lopez-sagastegui, 2017).

Stow Nets

Stow nets are stationary nets, that work well in areas with strong currents. The precondition is usually that the current is one-directional, however a slightly changed design was imported from North Carolina to test in UGC, taking advantage of the strong tidal regime in the area. Stow nets were originally a part of the alternative gear arsenal but unfortunately, trials have been paused due to reports of porpoise bycatch in Korea (Kim et al., 2013).

Longline

Longline fishing is operated with a mainline and multiple baited hooks attached to it. The fishery is considered environmentally friendly in some areas (Pham et al., 2014) and in other areas infamed for shark and turtle bycatch (Ovetz, 2005). Longline fishing was tested in 2013 by Pronatura-Noroeste, an NGO operating in the area. The outcome of the test was positive regarding profitability, but about 10% of the catch was elasmobranchs, which is problematic from a management perspective, as some of the species caught were threatened species.

Pots for shrimp and finfish

Pots for shrimp has been tested in the UGC already in 2004 in a collaboration between WWF and the Memorial University of Newfoundland but failed to be profitable (CIRVA V, 2014). Pots for finfish was tested in 2015 and the results were overall discouraging regarding profitability (Felipe et al., 2016). Furthermore, no records were made on which models of pots used. Another issue was that the gasoline for the fishers was subsidised, allegedly causing the fishers to go on fishing journeys they otherwise would deem unprofitable (Herrera et al. ECOFT, 2017).

Table 2 Competition-like trials in San Felipe and Santa Clara, showing best catches with traps(=pots) in San Felipe (source: (Felipe et al., 2016) **and ECOFT.**

Type of gear	San Felipe			Santa Clara		
	Num. of journeys	Catch (kg) Per journey	Catch (kg) Total	Num. of journeys	Catch (kg) Per journey	Catch (kg) Total
Fish trawl	21	6.9	145	33	5.7	188
Stow net	13	0.4	5	18	0.4	8
Traps	64	34.3	2,197	23	7.3	169

Later in 2015, a competition-like test was performed between pots, stow nets and small trawls (Table 2. Traps=Pots). In that trial, fishers from San Felipe caught an average of 34,3 kg of fish per journey over 64 journeys which is very impressive and could at first glance easily be profitable. The same trial was made from Santa Clara but the average catch was only 7,3 kg per journey. According to catches only, pots should be the most efficient alternative gear. Despite this,

according to ECOFT, only the best pangas produced a profit of 32$ per journey, whereas the rest produced negative results.
This lack of profitability was estimated to be partly because of the cost of Monterrey sardine as bait which, despite being expensive, was preferred.
Future recommendations from the 2015 trial suggested researching for local and inexpensive bait to substitute Monterrey sardine (Herrera & ECOFT., 2017).

2.6 This thesis

This master thesis was a part of a cooperation with WWF Mexico, WWF Schwitzerland, DTU AQUA in Denmark and Swedish University of Agricultural Sciences (SLU) in Sweden, and the ECOFT working group.
The purpose was to test alternative gear to gillnets in the UGC in an effort to reduce the pressure on the nearly extinct vaquita, create a viable alternative to gillnets and thereby support the fishing communities in the area while minimizing the impact on the environment.
In this thesis, it is my aim to test the catch efficiency of different pot types statistically by comparing the catches of different pot types. By using statistical modelling I determine which of the several predictors described best explain the catch variability of the different pots. This is done in order to approximate a final design for the pot fishery for finfish in the UGC.
I will measure and statistically test the attraction of three locally used baits to determine the best bait option in these, for this region, novel fisheries. Furthermore, I will discuss the profitability perspective by comparing the results from these trials to the 2015 INAPESCA pot trials in San Felipe and Santa Clara and from that perspective advice on improvements of the fishing process.

3. Introduction

The vaquita has been declared critically endangered due to bycatch from both illegal and legal fisheries. Since May 2015 the majority of the UGC has been declared a no gillnet zone (A. Jaramillo-Legorreta et al., 2017) (fig. 5). This has left fishers in the region without any income besides the presumably time-limited compensations from the government. For some fishers the temptation of easy money from illegal totoaba fishing together with the area restrictions and the lack of choice for gear have been the last straw that has pushed them into illegal gillnet-fishing and thereby jeopardising the survival of the vaquita as a species on this planet.

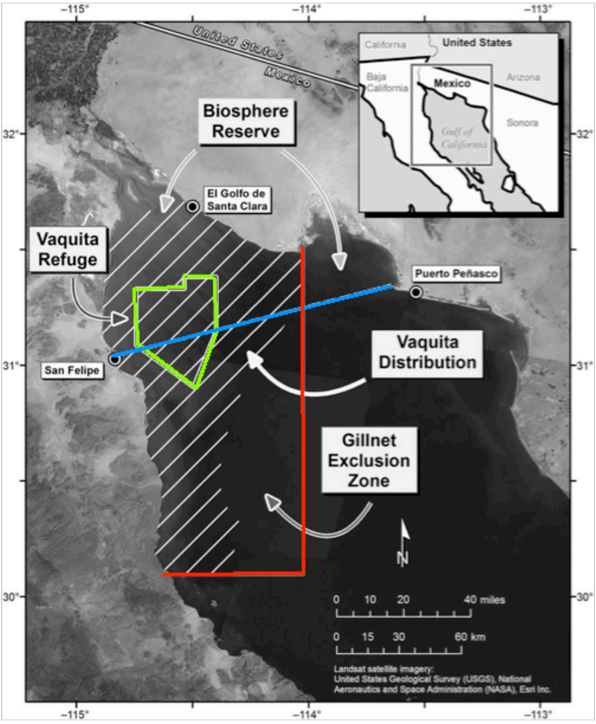

Fig. 5 Gillnet exclusion zone in the UGC, marked with red, covering the entire vaquita distribution range, (the hatched area)(A. Jaramillo-Legorreta et al., 2017)(see fig. 3 for reference) .

Therefore, it is crucial to develop alternatives to gillnetting in the upper Gulf of California to ensure a sustainable legal income to the fishers. One alternative to gillnets is fishing with pots.

Fishing with Pots for finfish is considered a low impact and fuel efficient capture technique (LIFE) (Suuronen et al., 2012) and has proved profitable in especially the Gulf of Alaska fishery for sablefish *(Anoplopoma fimbria)* and for Pacific cod (*Gadus macrocephalus)*. Pots are a valid alternative to gillnets in the grey seal-affected fishery of Atlantic cod *(Gadus morhua)* in the Baltic Sea (Königsson et al., 2015) and are used in the small, but very lucrative fishery to catch live wrasses to the Norwegian salmon aquaculture industry, where wrasses act as cleaner fish to remove sea-lice from the farmed salmon (Blanco Gonzalez & de Boer, 2017).
The pot fishery for finfish is versatile and can be deployed in very shallow areas up to 370m deep waters (Hughes & Hipkins, 1970), on hard substrate bottom where other types of gear are

restricted and even in some marine reserves (Coleman et al., 2013). Pots can be deployed individually or in strings of many pots. The pot size can be as tiny as a few liters up to several cubic meters (D. Furevik, 2010). The catch is alive when caught, which can fetch higher prices at the market and returned bycatch has evidently low mortality (D. Furevik, 2010). Combined with the low fuel consumption characterised by passive gear and the limited impact on the seabed it is considered an environmentally friendly form of fishing (Suuronen et al., 2012).
Downsides are low catch rates compared to many other gear types (Suuronen et al., 2012) along with continued ghost-fishing if a pot is lost at sea (Bullimore et al., 2001). This issue can easily be remedied by incorporating biodegradable material, usually where the fisher empties the pot or in the selection panel if present.

3.1 Factors affecting CPUE[5] or WPUE[6]

Several studies have described how the catch of pot fishery can be affected by features and design of pots in both size and numbers (D. M. Furevik & Løkkeborg, 1994, Hedgärde et al., 2016, Jørgensen et al., 2017, Königsson et al., 2015). Catches can also be affected by abiotic factors such as current, wind, light levels, depth, soak time, stimuli, season, temperature, while biotic factors such as prey density and target species abundance are also important. According to Stoner (2004), the abiotic factors should be given more weight, as they can affect the behaviour of the target species more, than the sheer number of target species available (A. Stoner, 2004). The catch process of pot fishery can be divided into several steps (D. Furevik, 2010), where this thesis will attempt to cover the following: Attraction, Ingress and Retaining the catch

3.2 Attraction

In the Carribean pot fisheries the pots are fished unbaited, but for the vast majority of pot fisheries, the bait constitutes an important role as one of the main attractants together with visual presence of the pot (D. M. Furevik & Løkkeborg, 1994).

[5] In this thesis, CPUE = Catch in numbers per pot hauled

[6] In this thesis WPUE = Catch in weight per pot hauled

The properties of a good bait are usually that they maintain their consistency and scent as to attract fish in the longest period possible. Scavenging fish follow the odour of the bait by chemoreception and olfactory senses (Lokkeborg, 1995) and the attraction over time is to be correlated with the duration of the odour which is believed to be influenced by the content of lipids and shedding of amino acids (Busdosh et al., 1982). A study to assess the attractants of bait in seawater over time, concluded, using amino acids as a proxy for attractant, that the first 1.5 hour has the highest decrease in amino acid shedding, after which a much slower decrease is observed, proposing that baited gear, such as pots, should be most effective shortly after it is deployed (Løkkeborg, 1990). To strengthen that result, Furevik (1994) reported, in a study, that most fish were most attracted to the baited pot within the first two hours after setting.

When a pot with bait is deployed the bait attractants disperse downcurrent in what is labeled a odour plume (Løkkeborg et al., 2014). Fish approach the bait in zig-zagging motions usually following the plume downcurrent from deployment, when a certain level of attractants has triggered the olfactory senses an individual response level is reached and the fish pursues the bait (D. M. Furevik & Løkkeborg, 1994, Løkkeborg et al., 2014). Furthermore, types of bait and amount result in varying total catches (D. M. Furevik & Løkkeborg, 1994, Whitelaw et al., 1991)

The visual appearance of an object can attract fish, even without bait, as described by Furevik (2010) Antillean pots in the Carribean (fig. 6), is exploiting that phenomenon. Fish will be attracted to the pot because of other reasons than fouraging. Those reasons can be shelter, social interaction or curiosity. Conspecific attraction has also been documented (Renchen et al., 2012) and in the Carribean, the more complex the visual outline of the pot/trap, the larger the attraction and subsequently the ingress rate (Munro, 1974).

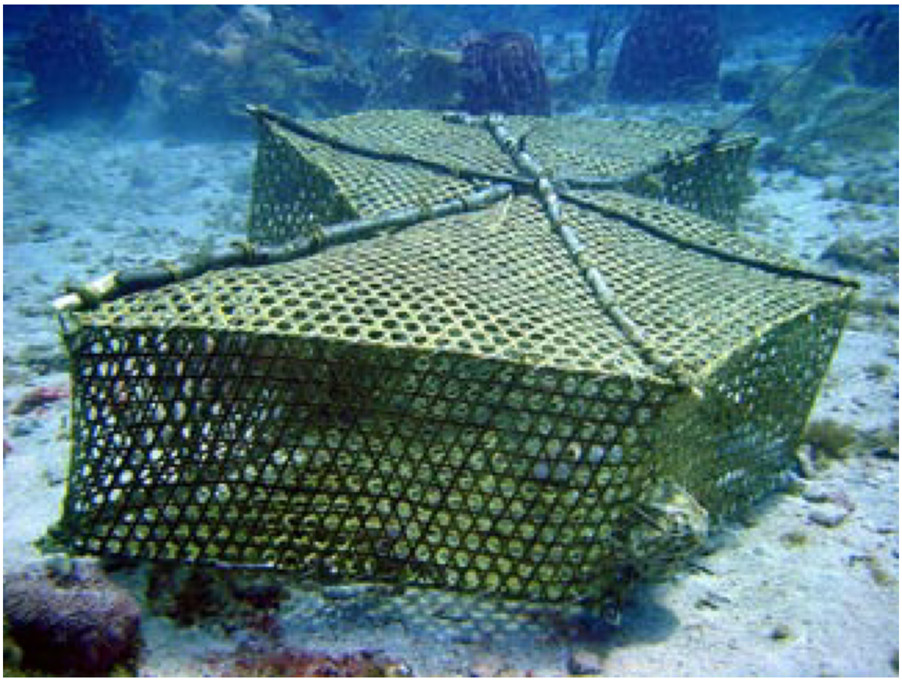

Fig. 6 No-baited Antillean Z-pots. Pots Are deployed near coral heads and soak time is usually 5-6 days. Antillean pots depend on their conspicuous look, conspecific attraction and that some fish has an affinity for small spaces to take shelter.

3.3 Ingress

As the fish approaches the pot, the trick is to persuade them to swim inside. This is harder said than done. According to the literature on the subject, many fish arrive at the pot, but the catch rates remain comparably low. The oldest reports show that only 1.5% of gadoids enter when attracted to the area by pots, suggesting that only a fraction of the fish in contact with the pots are caught (Valdemarsen & Johannessen, 1977). Another study from the Japanese pot fishery for pufferfish (*Lagocephalus wheeleri)*, suggested a 2% of the fish in contact with the gear, made it inside (Hirayama et al., 2011). In one study an acoustic camera field around a pot was activated between 2000-5000 times for every 10 sablefish caught (Rose et al., 2005).

The critical moment is when the fish moves into the entrance area (D. M. Furevik & Løkkeborg, 1994). An entrance where it is easy to enter will also make it easy to escape. Designing the best entrance to increase the ingress rate is probably one of the most important parts to pot fishing (D. Furevik, 2010). Unfortunately many species have a different affinity towards different openings which make it difficult to design an entrance that works for multiple species.

As an example: Atlantic cod and Wolffish *(Anarchicas lupus)* have no issue moving through a net panel of polyethylene, whereas Ling *(Molva molva)* and Haddock *(Melanogrammus aeglefinus)* are more cautious when searching and refrains from entering if resistance is met (D. Furevik, 2010). Stoner(2004) reported that any environmental factor that has an effect on fish activity could have an effect on any part of the catch process. With most fish being ectotherm, water temperature has an impact on the total catch (Gjøsæter, 2002). Changes in water temperature have therefore an effect on activity and by that on feeding behaviour (A. W. Stoner et al., 2006). All fisheries have seasonal peaks, often correlated with water temperature, but it seems that the effect of season in pot fishing is exacerbated due to the need for fish activity to actually catch anything. Another circumstance that relates to ingress behaviour is that of pot saturation. When a certain number of fish is in the pot, relative to the pot size, the ingress rate tends to go down (High & Beardsley, 1970).

3.4 To retain the catch

There is a whole suite of different entrance approaches; inclination angle of the funnel (Li et al., 2006), length of funnel, no funnel (Ljungberg et al., 2016), triggers ; plastic/metal fingers attached to the entrance that bend when the fish enters but can't be bend in trying to escape, funnel material and shape and size of entrance. All made with the same purpose; It should be easy to get in and difficult to get out. That is the Gordian knot of entrance design. However, there are other ways to lower escape rates than fiddling with entrances. Guiding fish to extra chambers in the pot to make it more difficult to find the way out (Ljungberg et al., 2016, Anders, 2015) or having two entrances in line (D. M. Furevik & Løkkeborg, 1994).

Munro (1971) found that the escape rate is inversely correlated with the size of the pot, with entrances being constant. Furthermore, larger pots have higher catch rates for many species (Collins, 1990). Unfortunately, the larger the pot the more space it is taking up and extra space is usually not a characteristic of most fishing vessels not to mention boats of small scale fishers.

4. Methods

4.1 Methods for Bait trials

The sampling took place predominantly in the protected bay of Bahia de San Luis de Gonzaga from the 12th of April to the 20th of April, approximately from lat. 30.002715 long: 114.380032 to lat: 29.781343 long: 114.284123 (fig. 7). Sampling was conducted on both sandy and rocky bottom and the depth range was 5-15 meter. In figure 7; the aprroximate placement of bait stations is marked with green dots, while the purple dots are approximate placements for where the pots where deployed.

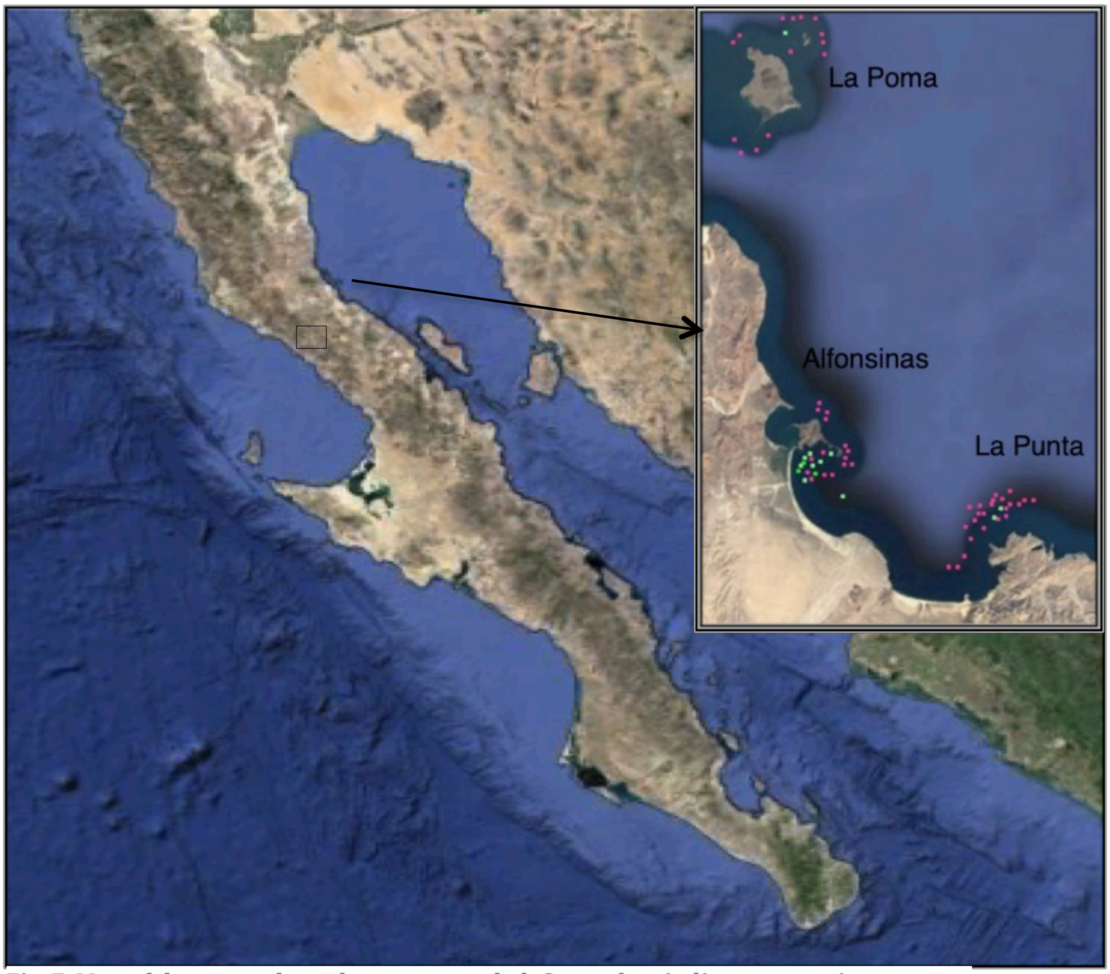

Fig. 7. Map of the area, where data was sampled. Green dots indicate approximate placement of video bait traps and magenta dots indicate the approximate placements of pots from the pot trial. A purple dot can be both a single pot or a pot string of five pots. The areas of interest is divided in Alfonsinas, La Punta and La Poma

4.2 Experiment setup

To observe the fish being attracted to the specific baits, bait stations were constructed, using concrete blocks as base and weight (fig. 8) and a water-sealed custom-made camera house made out of stainless steel and plexiglass pointing around 20 degrees upwards towards the bait bag. A steel rod was attached to the camera house. The purpose of the steel rod is not only to have a point on which to secure the bait bags position, approximately one meter in front of the camera, but also to ensure that the bait bag is in the middle top of the frame when recording video, to ensure full visibility of the fish approaching. The cameras were GoPro cameras set on the lowest resolution (720), with at least a 64GB sd-card. In the camera house we put two additional power banks in order to keep recording for at least 24 hours.

Approximately 400g of bait was inserted in the bait bag in an ordinary tennis sock to keep fish from eating the bait as the fish couldn't access the bait inside the sock.

To be able to register fish approaching the bait bag, light was attached to the bait stations during night time. Torches for the night trials were fisheye fix Neo DX 800/1200 torches and were set to 12% of full power that usually gave around 12 hours of light, enough for a full night. They were fastened with cable tiers.

Fig. 8 The bait stations constructed for the purpose of attracting fish to the bait bag while filming them. Note that the bait was put in a tennis sock to last the longest and keep fish from eating the bait. Steel rod (A) Steel and plexiglas cage (B) brick (C) Bait bag(D)

4.3 Bait

Three baits were chosen that the fishers had previously used.

Sierra mackerel *(Scomberomorus sierra)* (fig.9) is a member of the mackerel family and in the tribe scomberomorini, the Spanish mackerels. It is an oily fish with an oil content usually between 2-4 % (Murillo et al., 2014). The meat is reddish and firm and the price is around 2$/kg.

Fig 9 Baits used in the bait trials. From left to right: Sierra mackerel (*Scomberomorus sierra),* Flat-Iron Herring *(Harengula thrissina), and* Monterrey Sardine *(Sardinops sagax caeruleais)*

Flat-iron herring *(Harengula thrissina)* , is found throughout the Sea of Cortez. Oil content in the herring family is known to be very dependent on the season, but they can in peak seasons average around 21%. (Iverson et al., 2002). Price is around 1$/kg or can be caught by the fishers themselves.

Monterrey sardine *(Sardinops sagax caeruleais)* was the preferred bait of the fishers we worked with. The fishers buy it in Ensenada over 300 Kilometres away, receive it half-frozen and the sardines can easily be ripped over to a mince with the bare hands. Monterey sardine has an oil content of 8,4 to 11.1 (Ramirez-suarez & Mazorramanzano, 2000). Price is around 2$/kg

4.4 Video analysis

The video was analysed using the program Quicktime player with playback speeds between 1x – 30 times of normal speed. Playback speed was dependent on the fish present. Size of fish is not possible to determine from the recordings as no scale was present and no stereo frames could be taken. Various species were observed but the main focus was commercial species, thus a frame with more commercial species (cabrilla, croaker, corvina, flounder, triggerfish) was selected over a frame with equally or more non-commercial species (pufferfish, cinto, ray, angelfish, catfish)(see fish list in Appendix I).

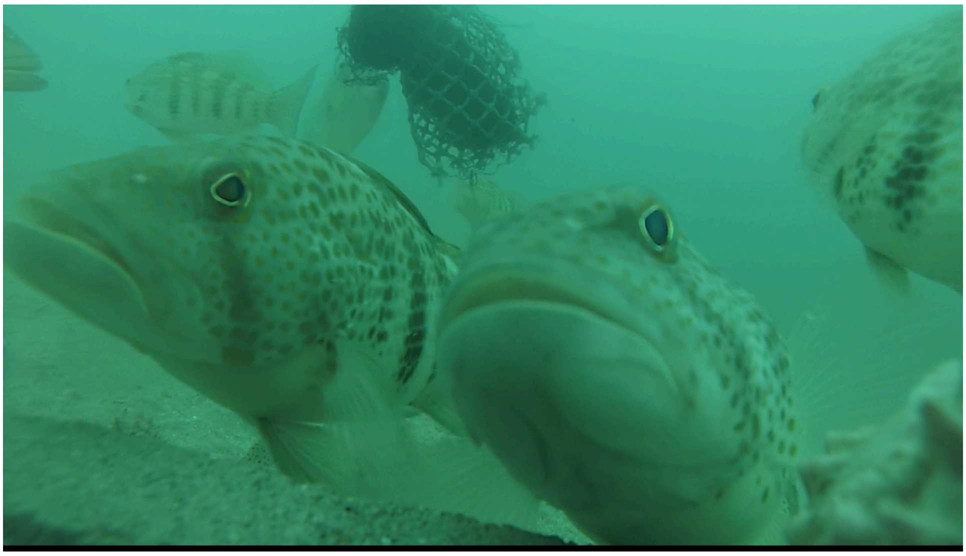

Fig. 10 Frame captured from one of the bait trap samples. Cabrillas (*Paralabrax maculatofasciatus)* inspecting the bait station.

4.5 Methods for Pot Trials

Trial 1 was conducted from the 10th to the 18th of April 2018 in the area around San Luis de Gonzaga.

- In trial 1, soak time and area of fishing was decided by fishers and researchers.
- In trial 2 soak time and area of fishing was decided by the fishers based on experiences and catches from trial 1.
- Trial 2 commenced on the 19th of April an ended the 15th of May and was carried out in the same area as trial 1.
- The fishing grounds for both trials were approximately from lat. 30.002715 long: 114.380032 to lat: 29.781343 long: 114.284123 (fig. 7)
- The depth was between 10 and 110 meters.
- Three fishers took part in the trials.

4.6 Experiment setup

The pots were made of stainless steel rods welded together to a cube (approx. 0,8 mm thickness) whereas the bottom, top and sides were green polyethylene (2.5mm twine and 30 mm mesh size).

A selection panel to allow undersized fish to escape was sowed in each pot with square mesh and with 5 cm distance knot to knot. Approximately 400g of bait was stuffed in a water bottle with multipe small holes in and then inserted in the bait bag (fig. 11) This was done to keep trapped fish from eating the bait and thereby maintain attraction.

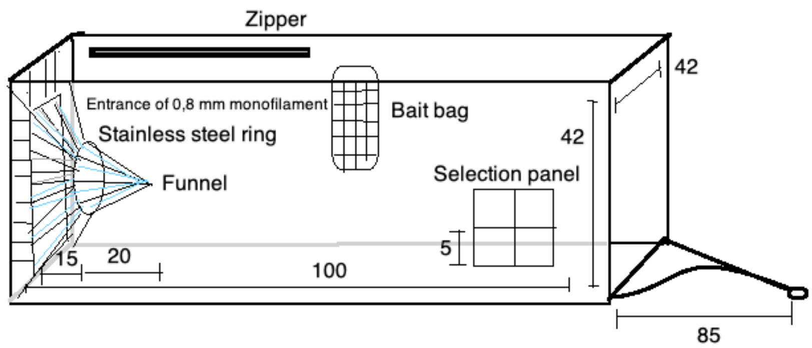

Fig. 11 Sketch of the basic pot design we used for the trial. The features depicted (except funnel) are common for the three different types we used. You open the zipper to empty the pot. The bait bag should be centered in front of the entrance. All measures are in centimeters(cm).

A number of five pots in each string and the placement of the pots in the string were randomly selected. Each panga had a total of two strings with them equaling ten pots. In trial 1 three different pot designs were tried (fig. 12 & table 3). A floating pot with one entrance and one chamber (A), a sinking type pot with two entrances and one chamber (B) and a floating pot with one entrance but with two chambers and without funnel in the entrance (C).

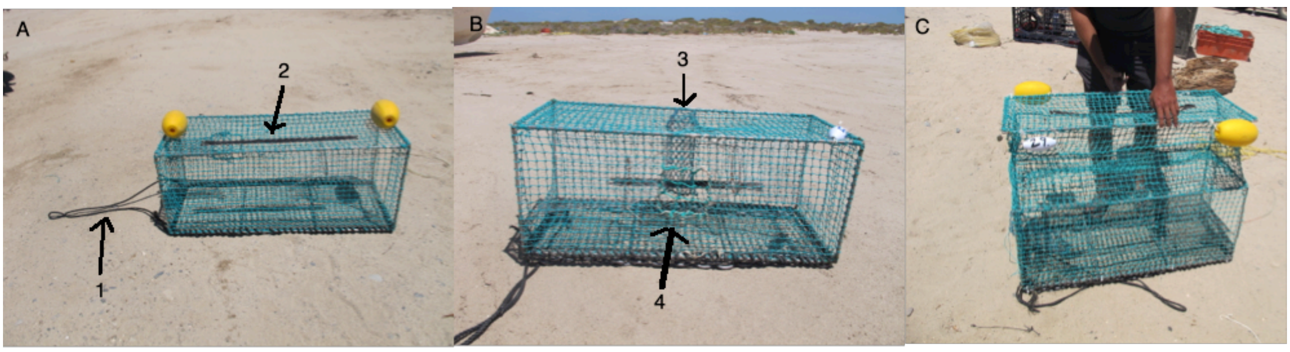

Fig. 12 A floating type pot with one entrance and one chamber. B: Sinking type pot with two entrances and one chamber. C: A floating type pot with one entrance but with two chambers, no funnel.
NB: On the floating pots, weight is attached to the bridle in order to keep them fixed at one point at the bottom. The current will swing the pot around so that the entrance is oriented away from the current.
1. The bridle that is attaching the pot to the mainline. 2. The zipper for emptying the pot. 3. Baitbag compartment. 4. Selection panel to avoid undersized fish.

After trial 1 was conducted, a meeting was held with the fishers to discuss the results. The two types of floating pots had the lowest catch rates and the fishers preferred the bottom standing pots. It was decided that all pots should be made bottom standing by tying chain to the bottom frame and detaching the floats and all should have funnels. This was agreed to be an immediate change. Thus, in trial 2, all the pots were bottom standing pots with either one or two monofilament entrances with funnels. All pots were checked by an additional observer. Monterrey sardine was used as bait in trial 2 as that was the fishers preference. See table 3 for pot description.

Table 3 Pot description. The different type of pots in the first (10-18th of April) and second part of the trial(19th April -15th of May. L=Length, H=Height, W=width. Funnel sizes are between 12-20 centimeters. Measures are in centimeters (cm) and "~" means approximated.

Name	Trial	Used period	Description	Size	Funnel	Depth of entrance before funnel
A	*1*	*10-18th April*	*Floating with one entrance, one chamber*	*L=100 H= 42 W=42*	*Yes*	*~30*
B	*1 & 2*	*10th of April- 15th of May (Entire period)*	*Bottomstanding with two entrances, one chamber*	*L=100 W=42 H= 42*	*Yes*	*~14*
C	*1*	*10-18th April*	*Floating with one entrancs, two chambers*	*L=100 H=42 W=72*	*No*	*~30*
D	*2*	*19th of April- 15th of May*	*Bottomstanding with one entrance, one chamber*	*L=100 H= 42 W=42*	*Yes*	*~30*
E	2	19th of April- 15th of May	*Bottomstanding with one entrance, two chambers*	*L=100 W=42 H= 72*	*Yes*	*~30*

4.7 Data collection

The data collected came in the form of protocols that the fishers filled out. All fishers had a GPS to write the position down. From the beginning, the fishers were involved in plotting location, pot type, date and time, depths, among other types of data, together with us. In trial 2 a skilled observer from WWF Mexico; Pablo Curiel, was there to help the fishers fill out the gaps in the protocols. All fish were counted and the catch was weighed or estimated by the fisher or the observer. Subsamples were taken to generate length-weight relations for the different species.

5. Statistical analysis

A GAMM (Generalised additive mixed model) approach was chosen to analyse which predictors (explanatory variables) could explain the response variables in the pot trials and bait trials respectively, the CPUE/CWUE and the MaxN.

The statistic modeling software R was used to compute the model. A GAMM is a non-parametric method to analyse data, that utilize smoothers to smooth the curves of the data, approximating a mean function of the data, which is used to determine which predictors affect the response variable (Beck & Jackman, 2016).

To build the final model the statistical significance and the deviance is analysed for the predictors. Stepwise removing the least significant predictor one by one until the remaining predictors are statistically significant resulting in the final model.

5.1 Bait trials

To estimate the effectiveness of Sierra mackerel, Flat-iron Herring and Monterey Sardine as bait, we measured the attraction as MaxN. MaxN is the maximum number of fish present in a single frame per 30 minutes, similar to the work of Cundy et al. (2017).

A GAMM analysis was performed with MaxN as the response variable and bait type, time and soak time as predictors (table 4). One analysis for daytime and one analysis for night. An AIC (Akaike information criterion) analysis was performed on the suggested models and showed that on both models the Poisson distribution was the best fit.

Table 4 The predictors used in the GAMM model to explain MaxN variation.

Predictors	Description
Soaktime	**For how long have the stations been submerged.**
Bait	**What type of bait. Monterrey Sardine, Herring, Sierra or ”no bait”**
Time	**Time and date of bait station deployment**

5.2 Pot Trials

In both trial 1 and 2, The GAMM analysis was performed on both of the two response variables CPUE and WPUE separately to evaluate which predictors could affect the catch. Predictors included were ”Soaktime”, ”Location”, ”Fisherman”, ”Date & Time”, ”Depth”, ”Entrances”, and ”Bait” (table 5).

Table 5 Predictors used in the GAMM model, explaining the variation in numbers and weight of the catch.

Predictors	Description
Soaktime	**For how long have the pots been submerged before hauling.**
Location	**The three main locations where we fished. Alfonsinas, La Punta, and La Poma**
Date&Time	**Date and time for setting and hauling.**
Fisherman	**Which fisherman is fishing. Javier, Will or Armando.**
Depth	**At which depth are the pots deployed**
Entrances	**Number of entrances of the pot**
Bait	**What type of bait. Monterrey Sardine, Herring, Innapesca Cookie, or Sierra**
String	**String Id and Date in one predictor to account for spatial and temporal fish abundance.**

As the response variable is count data the distributions selected reflect this. A Poisson distribution was selected for the model of the WPUE and a negative binomial distribution proved a better fit for the model of the CPUE. This was determined from running AIC analysis. This was the case in both trial 1 and trial 2.

6. Results

6.1 Bait trials

A total of 119,5 hours of video footage constituted the final database for the bait trials. Most of the sampling took place in the protected bay of Alfonsinas(fig 7). The species recorded (fig. 16) were also reflected in the species composition observed from the pot trials in the area (see fig. 21)

Table 6 Hours of filming with each type of bait in the bait trials, for nighttime and daylight.

	Hours filmed Sierra	Hours filmed Herring	Hours filmed Monterrey Sardine	Hours filmed no bait
Day	**18**	**21**	**6**	**-**
Night	**14**	**33**	**11**	**11**

The GAMM model analysis found differences between the three bait types in daylight. In the night trials, the statistical difference is inconclusive in regards to which performed the best (fig. 15). Soak time was not significant. The final model for both the bait trials – day and night:

$$MaxN \sim Baittype + s(Time)$$

The ”Bait type” predictor is a factor with 3 levels for the day trials and 4 levels for the night trials due to tests of only light, described in the model as the level: ”no bait”.

The statistical model for the bait trial during daytime showed a significant difference between Flat-Iron Herring and the other two types of bait: Sierra Mackerel and Monterrey Sardine(fig. 13). It can also be graphically visualised, as the 95% confidence intervals were not overlapping between Herring and the two other types of bait. From the results of the model, it can be concluded that Herring is statistically positively different from Sierra and Monterrey Sardine at the 5% significance level.

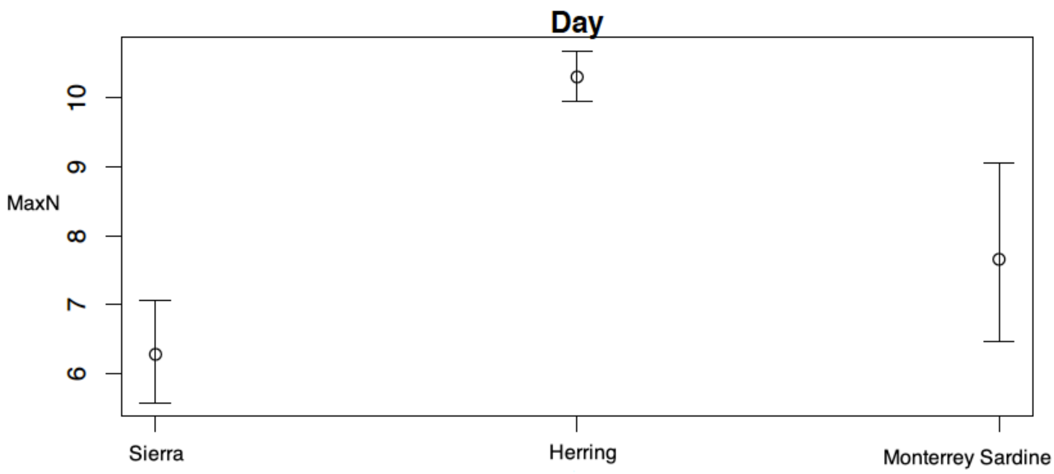

Fig. 13 Graphical illustration of the difference in the estimate of MaxN (no. of fish) in daylight with 95% Confidence intervals. Sierra and Monterrey Sardine has overlapping confidence intervals, whereas Herring has no overlapping confidence intervals meaning that Herring is statistically different from Sierra and Monterrey Sardine.

By looking at the raw data a graph showing the observed MaxN during daytime (fig. 14). It shows that activity is constant over the span of a day and that no pattern appears convincing. The gap in the late afternoon data corresponds with the time they were taken out of the water, battery and SD-cards changed and light attached for the night trials. Even when the bait had been soaked for over 12 hours there was still activity around the bait station and at no time do we see a drop from measured activity to zero activity.

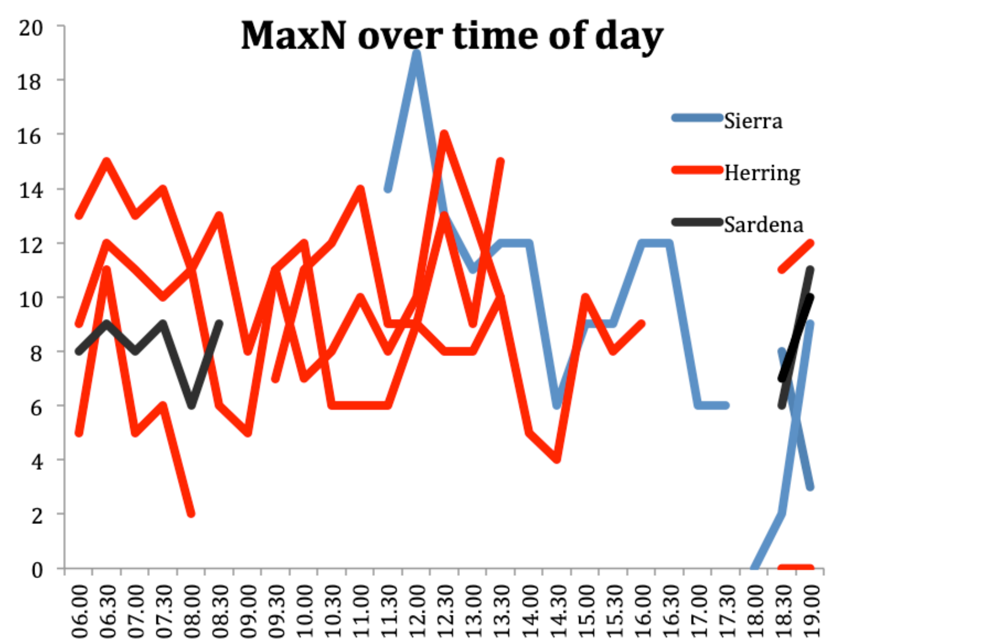

Fig. 14 The MaxN (no. Of fish) over time of day fra raw data. No real pattern is visible. The bait stations continue to attract fish a long time after being set.

Looking at the model estimates of the average MaxN (the small circles) revealed that Monterrey Sardine performing the best at a MaxN average of 7.2 (C.I -1.9+4.1), whereas Herring has a MaxN average of 3 (C.I. ± 0.5). The MaxN of “No bait” is just as high as every other bait tested at night based on the results from the model, the average and the confidence intervals.

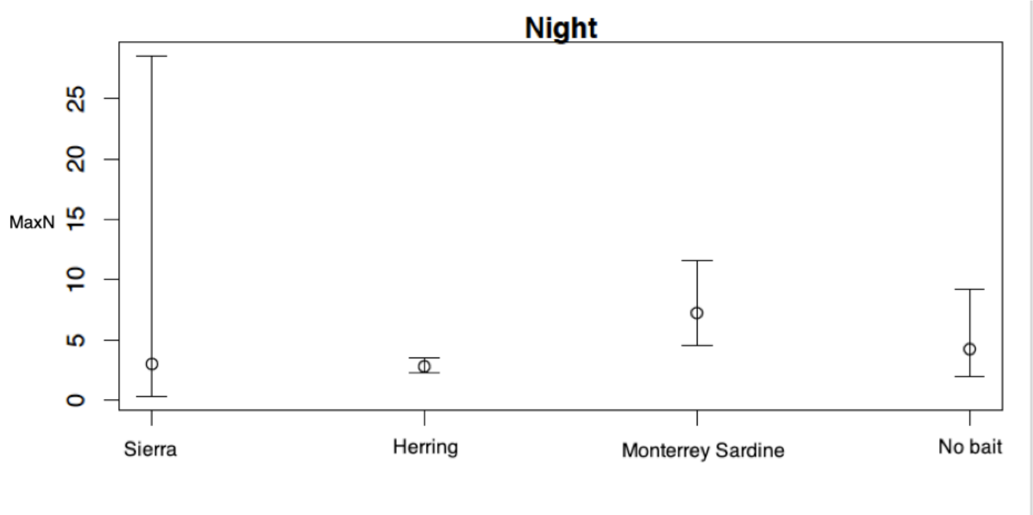

Figure 15 Graphical illustration of the difference in MaxN with 95% Confidence intervals. Monterrey Sardine is statistically different from Flat-iron Herring at the 5% significance level. Other than that confidence intervals are overlapping among the other types of bait, including ”no bait”

A total of 196 hours of filming revealed 13 species attracted by 3 different baits or ”No bait”. For a distribution of the species for night and day, see fig. 16.

No corvinas were recorded during the daytime despite being the most abundant species at night. Cabrillas (*Paralabrax maculatofasciatus)* were the most abundant species during daytime followed by fine-scale triggerfish (*Balistes polylepis)*.

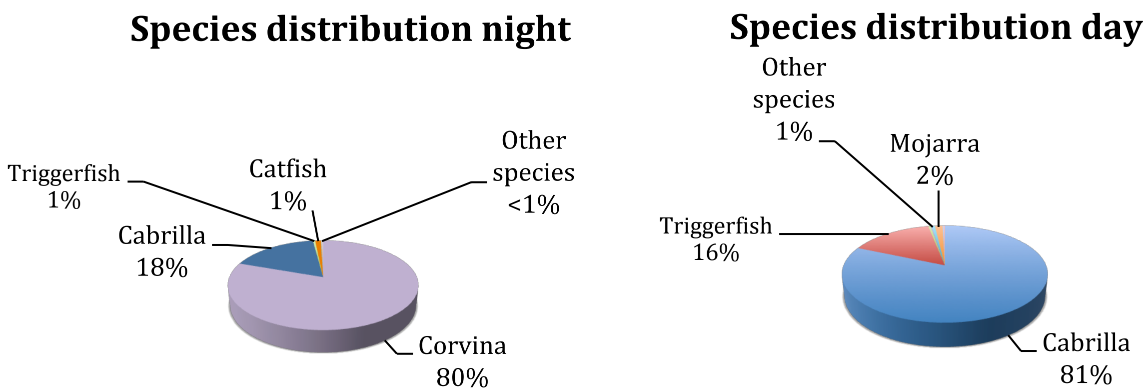

Figure 16 Distribution of species presence during day and night. See fish list App I.

6.2 Pot Trials

During trial 1 and trial 2, a total of 673 pots were emptied. The mean number of fish per pot and the mean weight per pot can be seen in table 7.

A twofold increase in mean CPUE and WPUE is observed from trial 1 to trial 2 (table 7).

Table 7 Results from trial 1, trial 2 and Total. The number of pots emptied, Mean number of fish per pot and mean number weight per pot(kg).

	Sample size/ Number of pots emptied	*Mean number of fish per pot (Mean CPUE)*	*Mean weight of fish per pot in (kg) (Mean WPUE)*
Trial 1	**199**	**2,23**	**0,63**
Trial 2	**474**	**4,69**	**1,67**
Total	**673**	**4**	**1.4**

6.3 Trial 1

The GAMM model analysis revealed that in trial 1, the predictors: ”String”, ”Location” and ”Pottype” significantly explained the variation in CPUE and WPUE. Deviance explained for WPUE was 57,5% (n=160) and 67,5% (n=160) for CPUE.

The final models for trial 1 is seen in table 8.

Table 8 The final models in trial 1. The ”String” predictor is smoothed by a random effects smoother (bs = re)

Model	*Variance explained*
$\boldsymbol{GAMM(WPUE \sim s(String, bs = "re") + offset(\log(Soaktime)) + Location + Pottype}$	***57,5%***
$\boldsymbol{GAMM(CPUE \sim s(String, bs = "re") + offset(\log(Soaktime)) + Location + Pottype}$	***67,5%***

This suggests that the area of fishing ”Location” and the design of the pot ”Pottype” has an impact on the catch, besides from ”String” and ”Soaktime”. ”String” is used to account for spatial and temporal variations in abundance of fish and thereby the catch. It is a combination of the date and string number. The predictor is smoothed by a random effects smoother.

Even though ”Soaktime” isn’t significant it is important to keep in the model to account for the hours of fishing. If not present it would be difficult to assess the actual effect of the pots as the single pot/observation would have no reported fishing time. The assumption is that catch is proportional to soaktime. This assumption was also statistically tested for and direct proportionality couldn’t be refused. CPUE and WPUE is a log link and to match ”Soaktime” linearly with the response variable it is with a log function in the model. The offset function in R simply offsets the estimation of the predictor even though it is present as data in the model.

The GAMM model revealed that CPUE and WPUE were affected by both the fishing location and the type of pot in trial 1. There is no statistical difference between pot type B and A, whereas pot type C had a lower catch rate than pot type B and A.
Fig 17 shows the model estimates and the partial effect of pot types A, B, and C.
Notice B and C are relative to A, which therefore is without error bars. Error bars show 95% confidence intervals.

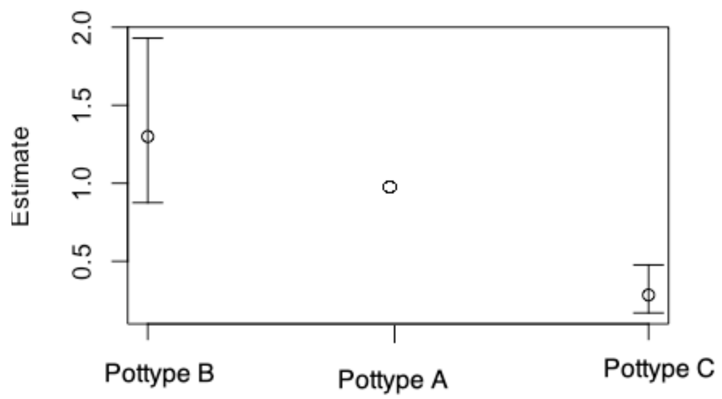

Fig. 17 Model estimates of the partial effect of pot type on WPUE in trial 1. The effect is relative to pot type A. The model results showed that pot type C was significantly different from pot type A & B. Note pot type C and pot type B is relative to pot type A, which for that reason has no error bars. Error bars show 95% confidence intervals.

The location of fishing had a significant effect on CPUE and WPUE (fig. 18) Similar catches were observed in La Punta and Alfonsinas whereas La Poma showed a significant higher catch rate. In fig. 18 La Punta and La Poma are shown as relative to Alfonsinas which for this reason has no error bars. Error bars show 95% confidence intervals.

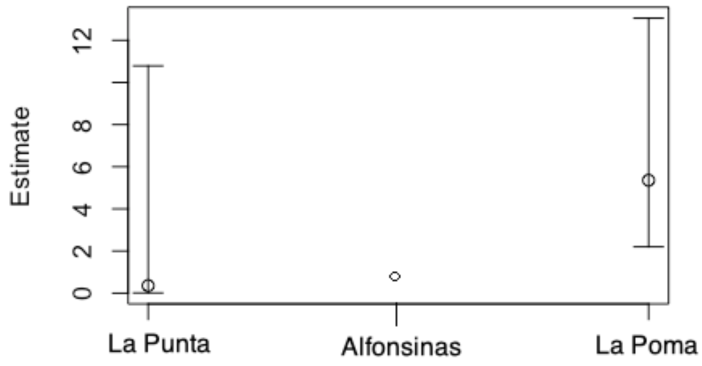

Fig. 18 Model estimates of the partial effects from "Location" on WPUE in trial 1. The effect is relative to Alfonsinas, which therefore has no confidence intervals. Error bars are 95% confidence intervals.

6.4 Trial 2

The GAMM model analysis revealed that the only significant predictor that had an impact on CPUE and WPUE was the predictor "String", accounting for spatial and temporal fluctuations of fish abundance. Deviance explained for WPUE was 74,4% (n=474), and for CPUE 76,2%(n=474). The final models for trial 2 (table 9).

Table 9 The models selected in trial 2

Model	*Variance explained*
$GAMM(CWUE \sim s(Link3, bs = "re") + offset(\log(Soaktime))$	***74,4%***
$GAMM(CPUE \sim s(Link3, bs = "re") + offset(\log(Soaktime))$	***76,2%***

It is meaningful for the interpretation of the results to visualise the model estimates and how they affect catch. As seen in fig. 19 the model estimates for pot type B is higher than both pot type E and pot type D but the difference is too weak to be significant statistically.

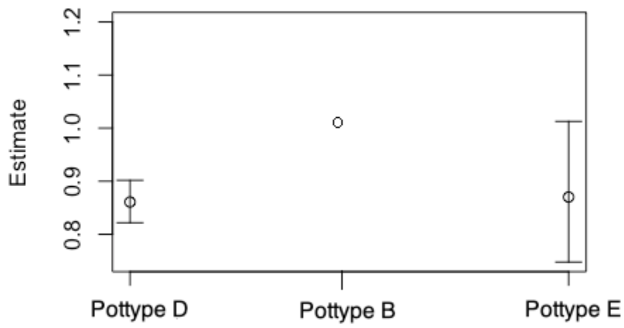

Fig. 19 Model estimates on the partial effect of pot types on the WPUE from trial 2. The effect is relative to Pot type B, which for that reason doesn't have error bars. Error bars show 95% Confidence intervals. The predictor "Pottype" didn't show any statistical significance.

Similarly the predictor "Location" has differences in the model estimates but are too weak to be statistically significant (fig. 20) . La Poma and La Punta, the areas in open water, show model estimates that are higher than that of the bay of Alfonsinas.

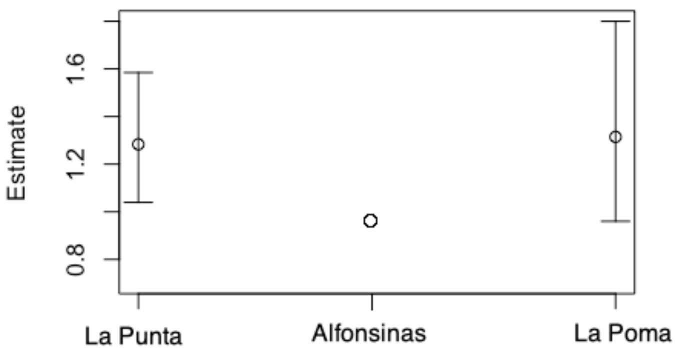

Fig. 20 Model estimates on the partial effects of Location on WPUE in trial 2. The effects "La Poma" and "La Punta" are relative to Location "Alfonsinas" which is therefore without confidence intervals. Errors bars show 95% Confidence intervals. The predictor "Location" was not statistically significant.

6.5 Calculations of total catches

In table 10, the total number of journeys, weight of catch per journey, total catch and WPUE(catch in weight per pot per journey) is depicted. The WPUE/h for trial 1 is at 0,15 and 0,73 for trial 2. The average fishing time pr. journey is from shore to shore and it shows that an average of 6.7 hours was spent per journey in trial 2.

Table 10 Data from trial 1 and trial 2 and in total. Number of journeys, weight of catch per journey and total catch of the trial and WPUE/h (Catch in weight per pot per hour) from raw data. Innapesca trials included for comparison. WPUE/H and avg. Fishingtime are not available from the INAPESCA trials.

	No. of journeys	Weight of catch per Journey (kg)	Total catch (kg)	Avg. Fishing time pr. journey (hours)	WPUE/h (kg)
Trial 1	**18**	**7**	**126**	**5,6**	**0,15**
Trial 2	**32**	**24,8**	**793**	**6,7**	**0,73**
Trial 1 & 2	**50**	**18.4**	**919**	**6,3**	**0,55**
Innapesca					
San Felipe	**64**	**34,3**	**2197**	**-**	
Santa Clara	**23**	**7,3**	**169**	**-**	

6.6 Species composition

An overview of species caught in the three areas was derived from the total catch data (Trial 1 & 2). The higher priced extranjera, a nickname given to both the gold-spotted sand bass (*Paralabrax auroguttatus)* and parrot sand bass *(Paralabrax loro)*(Aburto-Oropeza & Erisman, 2008)*,* is almost exclusively found in the open waters of La Punta and La Poma. On the other hand, the lower priced cabrillas are notably fewer in La Punta and La Poma than in the bay of Alfonsinas, where they dominates catches.

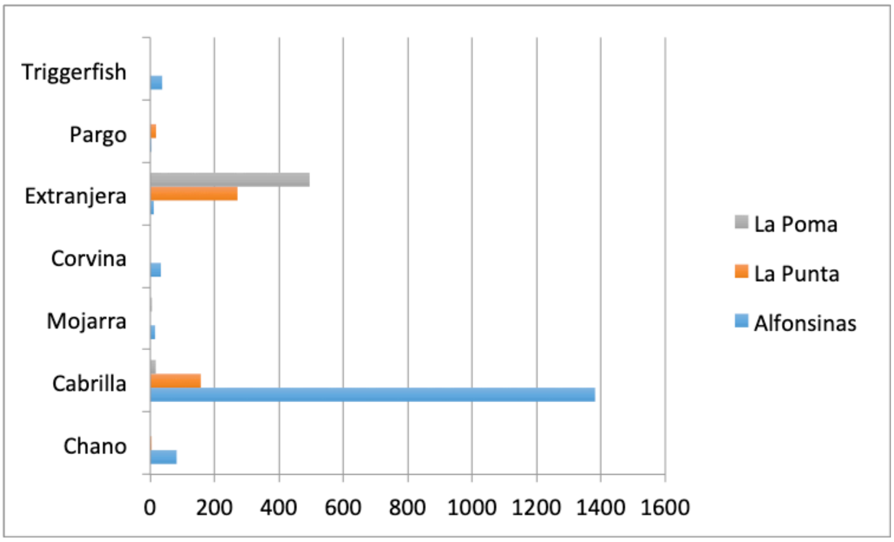

Fig. 21 Species composition by area. It clearly shows that there is differences in the species composition by area. The higher value species Extranjera is almost exclusively found in open waters of La Punta and La Poma.

Finally, the species composition for trial 1 and trial 2 in the pot trials shows that 59% of the total catch numbers are cabrilla followed by extranjera (32%). In the weight department, cabrilla still constitutes the majority of the catch with 54%, while the weight of extranjera is 40% of the total catch.

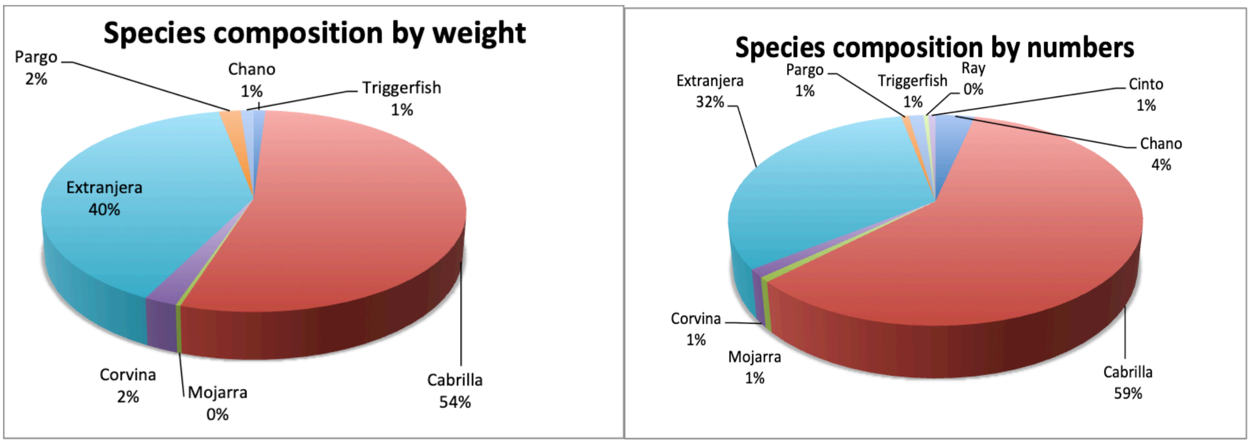

Fig. 19 Species composition from the pot trials. To the left is the distribution of the species by numbers caught in the pot trials, labeled in percentage. To the right is the distribution of the species by weight caught in the pot trials, labeled in percentage.

7. Discussion

The bait trials and pot trials in this thesis were the first of their kind, with international assistance, in the area of San Luis de Gonzaga. The trials went according to what was planned, with only a few minor set-backs. Mostly related to the remote area and the correspondence with the fishers and the net maker. The results of the trials is an important component in designing a viable fishery with pots in the UGC.

7.1 Bait Trials

In the daylight trial, flat-iron herring proved to be the choice of bait.
Why the flat-iron herring performs better as bait can from this study only be hypothesised. The oil content, which is seasonally higher than Monterrey sardine could have an impact.
This result indicates that the fishers should consider changing to a bait more easily available in their local waters, namely the flat-iron herring, rather than transporting Monterrey sardine from Ensenada at higher prices.
As such this trial is in line with the suggestions from the 2015 pot trials conducted by INAPESCA[7] on finding suitable bait alternatives to the expensive Monterrey sardine – the bait mostly used by the fisherman.
It must be noted that the optimal experimental design would include all three baits being tested on the same days to observe a possible difference under the same environmental circumstances. This was not a possibility, due to a shortage of bait from the fishers. Furthermore, to strengthen the result of flat-iron Herring, more replicates in the areas of La Poma and La Punta should have been conducted to test among other species. From the above-mentioned reasons, some caution towards the outcome of these bait trials should be taken.

The night trial results proved inconclusive. To highlight this; we observe the MaxN for ”no bait” has a similar average including confidence intervals than both the baits; Sierra mackerel and Flat-iron herring.

[7] INAPESCA is the National fisheries institute of Mexico

The images from the sampling in the night visibly show that corvinas and cabrillas gather to feed on the fry and small fish attracted to the light, rather than feeding on the bait in the bait bag. When daylight comes and the fry and small fish disperse, interest is again directed at the bait bag. From these observations, it seems that measuring the attraction of different types of bait at night is heavily biased by the artificial light we mounted on the bait stations. This result combined with the observed images gives doubt that the measure of attraction at night; MaxN, is dependent on the bait, but is a result of the gathering of fry and small fish attracted by the artificial light, similar to the studies by Humborstad et al., 2018.

The composition of species also gives insight in which species are attracted to the bait stations in what area. As most of the bait trials are in shallow waters in a protected bay, the higher value commercial species such as extranjera, weren't observed in the bait trials but constituted 40% of the catch in the pot trials.

7.2 Pot trials

In trial 1 three different pots were tested, each with a different number of entrances and chambers. For the purpose of evaluating the catch rate between pots while present in the area, a simple count with 95% confidence intervals from raw data provided the basis of decisions on changing pot design and protocols. The result from the raw data gave the insight that pot type B was most efficient and the floating pots A and C were less efficient. In cooperation with the fishers and their observations, a change in pot design was decided. All pots should have funnels and be bottom standing, resulting in the design of pot type D pot type E.

The results from the GAMM model supported this decision. The pot type C (the one without a funnel in the entrance, but with an extra chamber) caught noticeably and statistically significantly less than pot type A and B.

In trial 1 the "Location" predictor proved significant from the model. La Poma had significantly higher catch rates than both Alfonsinas and La Punta. It is possible that soak time is a factor here, as very little soak time (less than 2 hours) on the replicates from La Poma can be observed in the data, whereas longer soak times (more than 2 hours) were the norm in the Alfonsinas Bay. The shorter soak times at La Poma is because of the very strong currents in that exact area. The fishers had to adjust their fishing in La Poma with the tide as to fish when the tides were changing otherwise the pots would be tumbling over the seafloor (pers. comment: Javier, fisherman).

In trial 2, the predictor ”string” was significant. This tells us that most of the variance seen in the single pot was connected to the string, where it was attached. Either the specific string of pots fished well or bad, but the single catch of one pot in a string could be partly explained from the total catch of the string. This was expected.
Seen from the perspective of trial 1, it isn’t a surprise that the pot types in trial 2 fished equally from a statistical standpoint. Keeping in mind that the point of the pot trials was to test and facilitate a viable fishery more than testing novel pot types, hence changing the pot design to maximise catches was logical. While being cautious to draw conclusions based on model estimates with no significance, it is striking that pot type B, the only pot with two chambers, has the highest model estimates in both trial 1 and 2.
The area of fishing from the ”location” predictor proved significant in trial 1 but not in trial 2. One explanation could be that in trial 1, we wanted to have the pots in the water as much as we could to be able to gather as much information as possible. This meant going out fishing even though we couldn’t get out of the bay due to windy conditions. For this reason, the pots were often in the water during the night and days where the weather was bad, which is increasing the soak time which translates to fishing effort for Alfonsinas bay in the GAMM model but does not necessarily reflect catches. This was not the case in trial 2, where we weren’t there to influence the fishers to go out in unfavourable conditions or have the pots out for extended periods.
The positive model estimates of pot type B with two entrances in the pot is in line with similar pot trials where entrance effect was tested from Norway (D. M. Furevik & Løkkeborg, 1994) and in Sweden (Hedgärde et al., 2016). A single entrance is mostly used in floating pots, that swings with the current so that the entrance is in line with the odour plume of the bait (Jørgensen et al., 2017). If the extra entrance doesn’t increase the exit rate more than the rate of ingress, it makes sense that a better catch can be expected with more than one entrance (Meintzer et al., 2017). This could hold true in reefy areas such as ”La Poma” and ”La Punta” where an entrance could be partially blocked by a boulder or if the pot was set in between rocks.

A piece of advice for the final design of the pot, would from these trials be any of pot type B, D, and E as none of them proved statistically better or worse. However, adding an extra entrance in pots with one entrance, backed up by the model estimates, should be considered.

To compare the profitability of these trials, the INAPESCA pot trials from 2015 give some insight in how good catches for pot fishing should be, to make it a profitable fishery and a viable alternative to gillnets. Even though important data are missing in the 2015 trials, it can be used as a comparison for profitability if comparisons are made with caution.
As such, these trials didn't succeed in creating a profitable income when comparing the 2015 trials from INAPESCA. The positives are that trial 2 exceeded the catches from the 2015 trials of Santa Clara with at least 17.5 kg more fish per journey. In the San Felipe trials, the fishers caught 9,5kg of fish more per journey than trial 2.
Even the best results from the San Felipe trial showed only a tenuous profit according to the 2015 trials.
Based on the results from the bait and pot trials, the following suggestions should be considered in the fishing process to improve catches and profitability:

1. The expense of bait can at least be halved per pot if choosing flat-iron herring instead of Monterrey sardine and the catches could perhaps increase as the flat-iron herring proved more attractive than its more expensive counterpart.
2. If the fishers brought three strings of five pots instead of two, there would be 10 more pots hauled per day (As the fishers set and haul two times a day) which would increase the catches per journey with around 12 kg assuming a proportional 50% increase in catches.
3. The fishing time per journey could be increased. An average of 6,7 hours for a fishing journey in trial 2, was observed. When extrapolating from the WPUE/h (table 10) we can see that If the fishers worked with the pots for just one more hour each day on average, an additional catch of 8 kg could be made per journey assuming they are fishing with 15 pots.

If more pots are used and one more hour of fishing time is spent on average, a total catch per journey could be as high as 44.8 kg. On top of that, the bait expense per pot can be halved by

using flat-iron herring as bait, and the fuel expenses would go down per kg of fish caught, as it is the fuel expense from steaming that is usually the biggest expense.
Under these circumstances, it would likely be profitable in comparison with the 2015 trials, but it remains to be tested.

The species distribution is also a factor to count in when testing for novel gear. The cabrilla is supposedly less valuable than extranjera (pers. comment of the fishers) which is giving the fishers an incentive to steam to more exposed areas, such as La Poma and La Punta, to fish. The sizes of the fish were generally larger in La Poma and La Punta, which at least in Europe will raise prices. Unfortunately, no publicly available auctions from Mexico or scientific papers are available to give an estimate of the price difference between species and sizes and the prices we heard from the fishers varied a lot. If data were available it would be interesting to test the predictors for the pot trials with price as the response variable to test for most profitable fishing.

7.3 The management of the vaquita

The situation for the vaquita porpoise is desperate. There is literally no hope that the species will recover or be kept alive in captivity. All the effort that has been put in to save the vaquita has to a great extent been in vain. Only 18 individuals are left according to the IUCN. NGO's report only 12. When the vaquita is extinguished, the gillnet ban is likely to be abolished. If that happens the reports on the alternative gear development that has been going on since 2004 will have little impact on the fishery in the UGC as all the gillnetters will be back in full force. On top of that the enforcement combatting the illegal totoaba fishery is likely to decrease as a result.
On the other hand, valuable information has been gathered in the wake of the tragic faith of the vaquita porpoise, which can be utilised in other areas of the world if similar situations arise. Acoustic- and transect monitoring, new alternative gears, and hopefully improved management. The problem is that science and NGO activities are only separate parts of the solution to save an endangered species such as the vaquita porpoise. The ministries under the government in charge have the final say in laws that will drastically improve management.
It is easy to criticise the way management of the vaquita has been conducted in the UGC and the lack of governmental intervention. The biggest issue is that the recommendation from CIRVA, that

all gillnets should be banned in the range of the vaquita, wasn't dealt with or taken seriously and thereby not implemented in time. The PACE vaquita was too little and the gillnet ban in 2015 too late as it was in effect as the population of the vaquita porpoise was well under 100 individuals (CIRVA 5). The enforcement to keep illegal totoaba fishers at bay has been under heavy critique and if not for the NGO ”Sea Shepherd” who actively drags totoaba nets out of the water, the vaquita could already have gone extinct. Quite a few blame the fishery authorities of Mexico for the delaying of any real action towards saving the vaquita. The fishery authorities in Mexico have a history of manipulating datasets to avoid sanctions, openly be on the side of the fisherman and thus being suspects of politically sabotaging the saving of the vaquita by blaming the Colorado Rivers lack of discharge for the decline of the species. All done in order to not be interfered in fishing the annual expectancies (Cantú-guzmán et al., 2015). As mentioned before; science and NGO's can only do so much and if Mexican authorities had done their part, we wouldn't be in this situation.

7.4 Conclusions

The flat-iron herring can be a good and cheaper alternative to the expensive Monterrey sardine, which can instantly half the prices of baiting the pots. Calculations and extrapolation of total catches showed that the fishing process can be easily improved towards a more profitable fishery and thereby make the pot fishery a viable alternative to gillnets. The location had a clear effect on species composition, which is likely to affect profitability. For future pot fisheries in the UGC, it is indicated from these trials that bottom standing pots perform the best and two entrances per pot should be considered.

7.5 Potential improvements to the field work set-up.

In this project, we arrived in Mexico under the impression that the tripods for the bait trials and pots for the pot trials had already been manufactured. As this was not the case the research crew made suitable substitutes for the tripods expected, out of scrap building materials.

In hindsight, a stable and functioning tripod bait station would have given us more data, as it can not easily tilt over, as it was experienced with the bait stations constructed. In addition, an entire research day was spent in constructing the bait stations before commencing the bait trial.
Despite the unlucky offset the setup proved to be functional. Other sources of error such as bad visibility, fish shadowing each other, failing to determine species and fry or small fish shadowing fish of interest would have been similar with a normal tripod set-up.
More data could be obtained using stereo bait traps, not only to get a wider view around the bait bag, providing easier species recognition but also to determine the length of the fish so as to give an estimate of how the size distribution would be with different baits.
The first four days were spent to finalise the pots from the local pot-maker, who only had 5 pots out of 30 ready for our arrival. However impairing the magnitude of data from pot trial 1, it was a learning experience to construct entrances, floating systems, and funnels while discussing the different approaches and designs for a baited pot in practice.

8. Acknowledgments

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10. Appendice I

Fish list

Local name	English name	Scientific name	Family	Commercial Value
Sardina Monterrey	Monterrey Sardine	***Sardinops sagax caeruleais***	Clupeidae	-
Anchoveta	Flat-iron Herring	***Harengula thrissina***	Clupeidae	-
Sierra Mackerel	Sierra	***Scomberomorus sierra***	Scombridae	Yes
Cabrilla arenera	Spotted Sand Bass	***Paralabrax maculatofasciatus***	Serranidae	Yes
Extranjera	gold-spotted sandbass	***Paralabrax auroguttatus***	Serranidae	Yes
Extranjera	parrot sand bass	***Paralabrax loro***	Serranidae	Yes
Baqueta	Gulf Coney	***Hyporthodus acanthistius***	Serranidae	Yes
Corvina	Gulf Corvina	***Cynoscion othonopterus***	Sciaenidae	Yes
Cochito or Bota	Fine-scale triggerfish	***Balistes polylepis***	Balistidae	Yes
Bagres	Cominate Sea Catfish	**Occidentarius platypogon**	Ariidae	No
Mojarra	Mojarra	***Diapterus ?***		Yes
Totoaba	Totoaba	***Totoaba macnoldi***	Scianidae	No
Chano	Slender Croaker	***Micropogonias ectenes***.	Scianidae	Yes
Lenguado	Cortez flounder	**Paralichthys aestuarius**	Paralichthyidae	Yes
Cinto	Pacific Cutlassfish	**Trichiurus nitens**	Trichiuridae	No
Botete	Pufferfish	**-**	Tetraodontidae	No
-	King Angelfish	**Holacanthus passer**	Pomacanthidae	No
Pargo	Snapper	**Lutjanus ?**	Lutjanidae	Yes