An Analysis of Bioeconomic Tradeoffs in Vaquita Conservation Policies

Photo: Chris Johnson

A group project submitted in partial satisfaction of the degree requirements for the Master of Environmental Science & Management

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Group Project: An Analysis of Bioeconomic Tradeoffs in Vaquita (*Phocoena sinus*) Conservation Policies for the Upper Gulf of California, Mexico

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue.

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Abstract

Mexico's only endemic marine mammal, the vaquita (*Phocoena sinus),* is a porpoise widely cited as the most endangered cetacean in the world. With an estimated population of fewer than 200 individuals remaining in the Upper Gulf of California, entanglement in shrimp and fish gillnets threatens the vaquita with extinction within the decade; our analysis suggests that mortality from this ubiquitous fishing method is responsible for an annual population decline of 9.6%. However, cessation of fishing is not considered a realistic option since it is the principal economic activity for the region. To date, the Federal Government of Mexico has invested an estimated $30 million USD in an attempt to maintain fishing livelihoods while protecting the vaquita, yet current management strategies have failed to halt the continual population decline. We conducted a quantitative tradeoff analysis that assessed total fishery value and projected impact on vaquita growth rate for a spectrum of different policy scenarios. Using spatially explicit fisheries and vaquita data, we modeled the theoretical effects of spatial closures, fishery closures, buyout programs, and varying levels of compliance in 340 policy scenarios. A total of 46 policy combinations were identified that will achieve vaquita population growth at economic losses ranging from approximately 21-100% of current total fishery revenue. While our findings did not find a win-win scenario, they do provide a comparative evaluation that can optimize future management strategies.

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Executive Summary

Project Context

Mexico's one endemic marine mammal, the vaquita (*Phocoena sinus),* is a porpoise widely cited as the most endangered mammal in the world. Population surveys have estimated that fewer than 200 individuals remain[1]. Since early conservation efforts began in 1993, the Federal Government of Mexico has invested over $30 million USD in conservation initiatives for the vaquita, but the decline has continued. Thus, there is an urgent need to heighten conservation efforts, but such efforts must be sensitive to economic impacts on the local human population.

Currently, the vaquita is listed as Critically Endangered on the International Union for Conservation of Nature's (IUCN) Red List. The vaquita inhabits an area of just 2500 square kilometers between the Mexican states of Baja California Norte and Sonora, also known as the Upper Gulf of California (UGC). Incidental bycatch is recognized as the primary cause of vaquita mortality and population decline. Gillnets used by artisanal fishers to catch shrimp and finfish in the UGC unintentionally entangle the porpoise, which subsequently drown. Given the critically endangered status coupled with the clear threat posed by gillnets, it is commonly argued that the only way to completely eliminate incidental bycatch is to cease the use of gillnets in the UGC. However, this is a highly contentious option because regional fishers primarily rely on gillnetting for their livelihood.

Two fishing communities of the UGC, San Felipe and El Golfo de Santa Clara, would be economically impacted by expanded conservation policies which restrict fishing activities. Because there are few other alternative economic opportunities in these towns, fishing restrictions that eliminate vaquita bycatch but negatively impact fisheries revenue are undesirable. For this reason, it is useful to identify explicit tradeoffs for these competing values in order for stakeholders and managers to make informed decisions that optimize both vaquita conservation and fishing livelihoods.

WWF Mexico recognizes the importance of urgent conservation intervention in order to avert extinction of the vaquita. In moving forward with conservation advocacy, WWF Mexico seeks to evaluate projected biological and economic outcomes of potential policy solutions in order to best consider the contentious socio-economic realities of the region. For this reason, we developed a bioeconomic model that comparatively evaluates projected outcomes of conceivable policy combinations, and identifies explicit tradeoffs between competing conservation and economic interests.

[1] Report on the Fourth Meeting of the International Committee for the Recovery of the Vaquita (2012)

Project Objectives

The goal of this project is to assess the biological and economic tradeoffs of various vaquita conservation options for the Upper Gulf of California. This assessment is intended to help WWF Mexico, stakeholders, and managers as they look for policy solutions in the UGC. This goal was achieved through the following methods:

- Identify viable conservation policies in the Upper Gulf of California.
- Model impacts of policy combinations on vaquita population and regional fishing industry.
- Provide evaluation of bioeconomic tradeoffs in policies for a more explicit and transparent decision-making process.

Bioeconomic Model

We developed a bioeconomic model to evaluate a wide range of policies under varying levels of compliance, species or spatial closures that would affect gillnets, and the use of alternative gears. Data on the spatial distribution of both fishing effort and vaquita density were used to spatially represent the interactions between the fishers and vaquita in the UGC. Data collected included a spatial intensity of fishing effort, fisheries production, and biological parameters for *P. sinus.* Using these inputs, we projected outcomes for normalized annual net fisheries revenue and vaquita population growth rate, subject to the following policies:

1. **Spatial Closures:** considers five potential vaquita refuge configurations that include the current Vaquita Refuge, a swollen refuge, a full UGC closure, a refuge protecting 90% of the population, and a refuge protecting 95% of the population, the last two of which were derived using the program Marxan.

2. **Fisheries Closures:** considers gillnet restrictions for either finfish, shrimp, both, or none within any designated spatial closure.

3. **Gear Buyout Program:** considers the impact of fishers opting to retire fishing permits and gears to seek alternative employment for compensation, modeled at levels of 0%, 10%, 20% and 30%.

4. **Varied Levels of Compliance**: encompasses a realistic spectrum of compliance in the UGC for four different levels: 40%, 60%, 80%, and 100%.

5. **Alternative Trawl**: considers implementation of an artisanal shrimp fishing trawl prototype shown to have zero-impact on vaquita, but comparatively effective in capturing blue shrimp.

Tradeoff Analysis

To identify tradeoffs between fisheries revenue and vaquita growth rate, we plotted all outcomes of conceivable policy combinations resulting from fishing restrictions, compliance levels, and fisheries buyouts. The outer bound of outcomes, known as the *efficiency frontier*, represents those policy combinations that perform best for fisheries revenue, vaquita population, or both interests, relative to other outcomes. Inherent tradeoffs identified from this plot form the basis of our recommendations to WWF Mexico (see Figure 1).

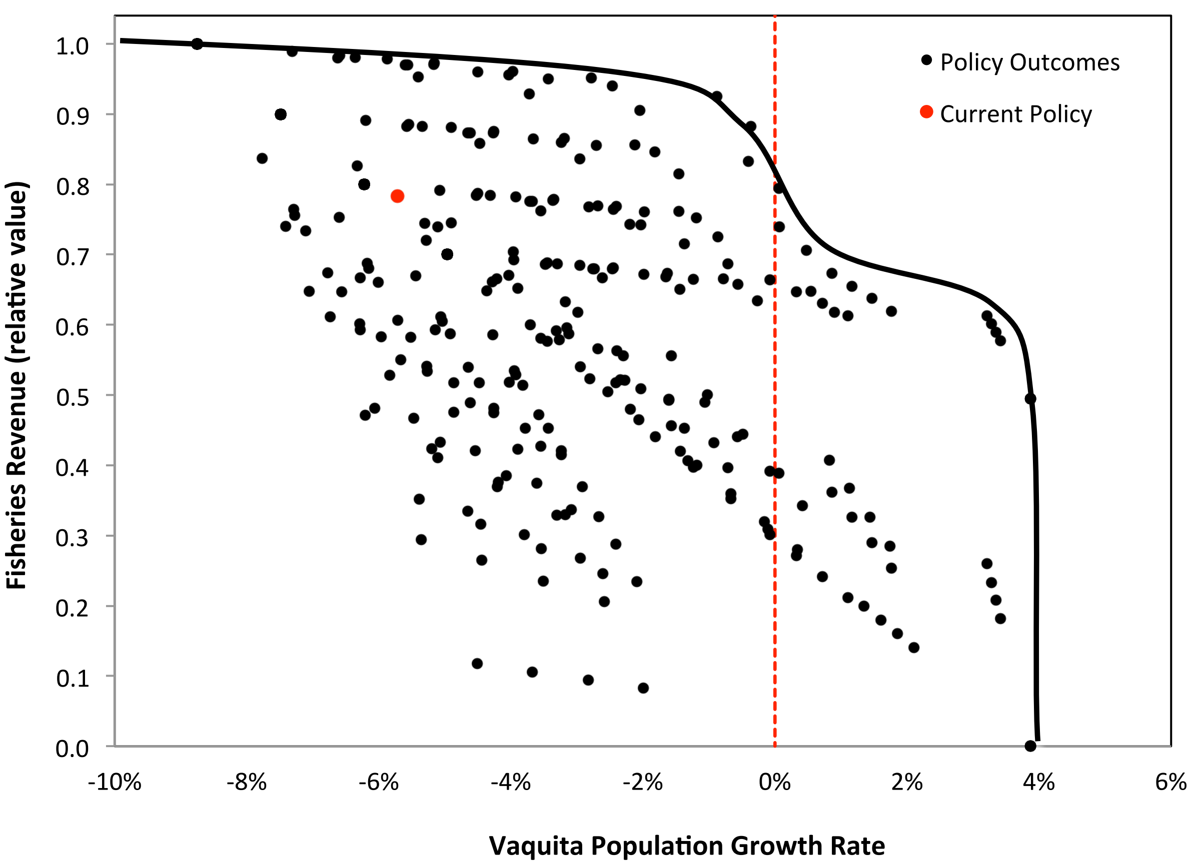

Figure 1: Outcomes for 340 different policy combinations: black points represent the projected outcome for a given policy scenario in terms of Fisheries Revenue and Population Growth Rate. The black line represents the efficiency frontier, extrapolated from those points that maximize the competing values. The red point represents the projected outcome of the current policy scenario, and the red dashed line represents the line where the population growth rate is equal to the bycatch rate and there is no growth or decline of the vaquita population.

Analytical Results

From the 340 policies modeled, only 39 projected outcomes had an increasing vaquita growth rate. There were no policy combinations with the current refuge closure projected to achieve population growth. However, the 90% protection refuge, 95% protection refuge, full closure, and swollen refuge scenarios would all achieve varying levels of population increase (with the exception of the swollen refuge under no buyout).

Results indicate that closing the gillnet shrimp fishery alone will never lead to an increase in vaquita abundance, but rather, a selection of finfish closure scenarios could allow for modest population growth at a comparatively lower cost to fisheries revenues. Furthermore, achieving a compliance level of at least 80% was identified to be a key element of any management scenario. Improvements to policies were identified that would allow modest fisheries revenue enhancement at no cost to vaquita growth, and vice versa, but none that achieve conservation goals of increased vaquita population.

Of the policies with positive outcomes for vaquita, the best fisheries revenue outcomes, by a substantial margin, allowed shrimp trawling in the gillnet closure area. However, only a select set of policies could consider fisheries revenue associated with trawling because full compliance of a gillnet ban for all species is a condition necessary for adequately implementing the trawl.

Project Recommendations

Increase in refuge size: we recommend increasing the size of the Vaquita Refuge in order to encompass a larger percentage of the population. Our results show that larger refuges are central to any policy with the outcome of vaquita population growth.

Restricting all gillnet fisheries: Policy outcomes do exist with projected outcomes of marginal vaquita population growth from a closure of the gillnet finfish fishery. Outcomes with significant population increase only result from combined shrimp and finfish closures. Closing shrimp gillnetting alone is not projected to lead to vaquita population growth.

Increase compliance to at least 80%: for any policy implemented, there should be priority in achieving higher levels of compliance. Our results indicate that when compliance for any policy combination is below 80%, vaquita population growth will not be achieved.

Implementation of a light trawl: the prototyped light trawl should be implemented to capture revenue forgone by gillnet closures. Our results indicate a bioeconomic optimum from closing a larger area to gillnetting, but allowing use of the zero-vaquita bycatch trawl where restrictions occur.

Additionally, we recommend further research into potential benefits to fisheries from spatial closures in order to enhance the economic assessment of policies. Further research into other zero-vaquita bycatch alternative gears should also be prioritized (e.g. long-lines, fish traps, diving, cultivation). Such additional insight can be used to enhance the projections of this model.

Project Conclusions

This project represents the discourse between conservation objectives focused on the vaquita and those intending to preserve fishing livelihoods. It is of utmost importance to design a policy that effectively works to benefit conservation while also valuing the livelihoods in fishing communities. Without this reconciliation of values, conservation policies are likely to underachieve their goals if they have little participation from communities in the Upper Gulf. Although a win-win scenario for fishers and vaquita was not identified, there were several policies that could likely lead to vaquita recovery. In the case that the Mexican government is willing to accept a decline in fishing revenues, this analysis can be used as a tool to identify and pursue policies that minimize economic impacts in the region.

Acronyms

CEDO	Intercultural Center for the Study of Deserts and Oceans
CICESE	Centro de Investigación Científica y de Educación Superior de Ensenada (Center for Scientific Research and Higher Education at Ensenada)
CICIMAR	Centro Interdisciplinario de Ciencias Marinas (Interdisciplinary Center of Marine Sciences)
CIRVA	Comite Internacional Para la Recuperacion de la Vaquita
CONABIO	Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. (National Commission for the Knowledge and Use of Biodiversity)
CONACYT	Comisión Nacional de Ciencia y Tecnología (National Commission of Science and Technology of Mexico)
CONANP	Comisión Nacional de Areas Naturales Protegidas (National Commission of Protected Areas and National Parks)
CONAPESCA	Comisión Nacional de Acuacultura y Pesca (National Commission of Aquaculture and Fisheries)
CPUE	Catch per unit effort
DPCIA	Dolphin Protection Consumer Information Act
EBM	Ecosystem Based Management
ETP	Eastern Tropical Pacific Ocean
GSC	Golfo de Santa Clara
INAPESCA	Instituto Nacional de la Pesca (National Fishery Institute)
INE	Instituto Nacional de Ecología (National Institute of Ecology)
LGEEPA	Ley General de Equilibrio Ecológico y la Protección al Ambiente (General Law of Environmental Protection and Ecological Balance)
LGEPAS	Ley General de Pesca y Acuacultura Sustentables (General Law of Sustainable Fisheries and Aquaculture)
MEBM	Marine Ecosystem Based Management
MIA	Manifestación de Impacto Ambiental (Environmental Impact Report)
MMPA	Marine Mammal Protection Act
MXN	Pesos
NOAA	National Oceanic and Atmospheric Administration
NOM	Normas Oficiales Mexicanas (Mexico's National Regulations)
NOS	Noroeste Sustentable A.C. (Sustainable Northwest)
NRDC	Natural Resources Defense Council
OGP	Ocean Garden Products, Inc.
PACE	Programa de Acción para la Protección de la Especie (Action Program for the Conservation of a Species)
PANGAS	Pesca Artesanal del Norte del Golfo de California – Ambiente y Sociedad" (Small-scale Fisheries in the Northern Gulf of California – Environment and Society)
PROCER	Programa de Conservación de Especies en Riesgo (Species at Risk Conservation Program)
PROFEPA	Procuraduria Federal de Proteccion al Ambiente (Federal Agency of Environmental Protection)
SAGARPA	Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (Secretariat of Agriculture, Livestock, Rural Development, Fisheries, and Food)
SEMARNAT	Secretaría del Medio Ambiente y Recursos Naturales (Secretariat of Environment and Natural Resources)
SFE	San Felipe
UGC	Upper Gulf of California
WTO	World Trade Organization
WWF	World Wildlife Fund

1. Project Significance

This project targets the complex challenge of how to balance conservation values with the needs of human communities. Although this conflict is centered on a high profile endangered species on the brink of extinction, an equally significant concern is how to protect the livelihoods entirely dependent on the marine resources of the Upper Gulf of California. As Mexico's only endemic marine mammal, the vaquita has increasingly gained recognition as a critically endangered species (IUCN 2011). Since the extinction of the Yangtze river dolphin in 2007, it is widely thought vaquita could be the next cetacean driven to extinction by anthropogenic causes (Gerrodette 2011). Explicitly assessing the bioeconomically favorable and unfavorable consequences of potential conservation options will assist stakeholders in transparently resolving this social-ecological conflict.

This analysis is of particular significance to Mexico's federal environmental and fisheries agencies, which have heavily invested in conservation of the vaquita, and also to international and national civil organizations, governments, and academic institutions interested in the survival of this marine mammal. Additionally, the lessons learned from conducting an analysis of bioeconomic tradeoffs in this case have potential to inform solutions to other relatable social-ecological conflicts around the world.

Our proposed tradeoff analysis will serve as an insightful tool in addressing such complicated issues, and holds direct significance towards the broader conservation goals of WWF Mexico. As the world's leading conservation organization, WWF strives to discover innovative solutions that sustain both society and nature while simultaneously strengthening the ability for communities to conserve the natural resources on which they depend. Our project deliverables will provide WWF Mexico with the evaluation needed to advocate for responsible vaquita conservation policy at both the federal level and at the local level with the two most impacted fishing communities.

2. Project Objectives

The goal of this project is to assess the biological and economic tradeoffs inherent in vaquita conservation options for the Upper Gulf of California. This assessment will serve as an illustrative tool for stakeholders and managers as they make decisions regarding regional management in the near future. This approach ultimately offers a comparative evaluation of policies and provides decision makers with information to better consider economic and conservation outcomes in designing policy. The project goal is achieved by the following objectives:

- Identify conceivable policy options for management in the Upper Gulf of California that allow the total number of vaquita to exhibit population growth over a 30 year time-horizon
- Identify an optimal spatial vaquita refuge with consideration to biological and economic attributes of the region
- Evaluate the current Vaquita Refuge using our bioeconomic model
- Evaluate and compare bioeconomic outcomes of plausible spatial management options (the current Vaquita Refuge, enlarged refuges that covers key vaquita habitat, no refuge area, and a full gillnet closure in the Upper Gulf)
- Illustrate bioeconomic outcomes of fisheries closures by species and by gear
- Illustrate how bioeconomic outcomes change with varying levels of enforcement in spatial scenarios
- Evaluate how bioeconomic outcomes change with varying levels of fishery buy-outs
- Identify the cost of a conservation solution for the best policy options
- Evaluate how much of the conservation cost can be made up through alternative fishing activities
- Provide recommendations for management scenarios using the efficiency frontier of tradeoffs developed by this model
- Offer recommendations for additional analysis to further assess marine spatial management in the Upper Gulf of California related to vaquita

3. Project Background

3.1 The Upper Gulf of California

The Gulf of California is considered one of the richest marine ecosystems in the world, with well over 5,000 species of macro-invertebrates (Aznar et al. 2012). The Gulf of California is a critical feeding, breeding, and nursery ground for some of the world's rarest marine animals, including 32 species of marine mammals, 170 species of sea birds, and 875 species of fish (Alles 2007).

This region is approximately five million years old and characterized by high levels of nutrients, winds, tidal action, and upwelling (Barlow et al. 2010). The UGC experiences extreme water temperature fluctuations, is hypersaline, and can experience large tides of up to 7 meters (CEDO 2008). The tidal mixing and upwelling bring essential nutrients to the surface for marine life in the region (Barlow et al. 2010). The damming of the Colorado River with the Hoover Dam, completed in 1936, destroyed a majority of the wetlands in the Colorado River Delta and the completion of the Glen Canyon Dam in 1963 cut off the Colorado River freshwater input to the UGC almost entirely (Brusca 2010). The scientific consensus is that the damming of the Colorado River over the last century, alongside introduction of invasive fish species, has led to an extensive decline in the numbers of native fish and wetland areas.

Scientists agree that the current habitat for the vaquita is far from ideal, with gillnet fishing being the main contributor to population decline (Marine Mammal Commission, 2007). According to the Intercultural Center for the Study of Deserts and Oceans (CEDO), "reduced freshwater, declining nutrient flow, and diminished water quality along with poorly-managed, non-selective fishing practices are the greatest perils to this once-rich ecosystem." Both bycatch in the gillnet fishery and the damming of the Colorado River were initially thought to be the prime contributors to the decline of the vaquita population. However, it is now believed that dam-related reduction in flow from the Colorado River does not have adverse effects on the vaquita (Rojas-Bracho and Taylor 1999).

Figure 2: A map of the Upper Gulf of California, Mexico with the three fishing towns of San Felipe, Puerto Peñasco, and El Golfo de Santa Clara.

3.2 Biology and Ecology of the Vaquita

The vaquita (*Phocoena sinus)* is a member of the porpoise family. It was initially discovered in 1950 when Ken Norris, a graduate student at UCLA, found a skull on the beaches near San Felipe, Mexico. The first live sighting occurred on April 8, 1955 and the first species description was published in 1958 (Norris and McFarland 1958). The vaquita has been identified as endemic and resident to the UGC.

The origins of the vaquita in the UGC are thought to be a result of a group of Burmeister's porpoises (*P. spinipinnis)* pursuing a food source through warm currents northward during the Pleistocene glacial period (Norris and McFarland 1958). Thereafter, the porpoise has adapted over time to the strong temperature fluctuations of the UGC (WWF 2011). Vaquita inhabit murky waters between 10 to 50 m deep and within 25 km of the shoreline. The vaquita is a generalist that feeds on over 21 species, including benthic fishes, squids and crustaceans (Rojas-Bracho et al. 2006).

The most distinguishing traits of the vaquita, aside from its small size, are the large black circles around its eyes and the black coloring around its mouth. This is in stark contrast to the dark grey skin on the top of the body that progressively lightens towards the abdominal surface of the porpoise (WWF 2011). The slender body shape also distinguishes the vaquita from most other members of the porpoise family. Some scientists believe these specific traits are adaptations the vaquita has undergone to better tolerate dramatic temperature fluctuations in the UGC (Würsiget et al. 2002). They average approximately 1.4 m in length and have an average weight of 45 kg (Würsiget et al. 2002).

Vaquita are known to occur only in the northern quarter of the Gulf of California, north of 30°45′N and west of 114°20′W (Gerrodette et al. 1995). There have been rare accounts of vaquita sightings below the region of Puertecitos, Mexico. The vaquita is known to be an extremely elusive cetacean, which accounts for the extremely low occurrence of sightings (Würsiget et al. 2002). When vaquita are encountered, the observations are usually brief, lasting only a few seconds. They do not jump or perform aerial acrobatics like other members of the porpoise family. In fact, the majority of vaquita encounters occur when they are caught in fishing nets.

The current population of the vaquita is estimated to be under 200 individuals (CIRVA 2012). The potential rate of population increase for the vaquita has been inferred to be about 4% per year, based on data from closely related species (D'Agrosa et al. 2000). Mature females give birth to one calf biennially, usually in spring (Würsiget et al. 2002) after an 11-month gestation period. Calves reach reproductive maturity in three to six years and live to a maximum age of 21 (D'Agrosa et al. 2000).

3.3 Fishing History in the Upper Gulf of California

The main fishing ports in the UGC are San Felipe, El Golfo de Santa Clara and Puerto Peñasco (see Figure 2). These towns are characterized by artisanal gillnet fisheries and developed concurrently with increasing fishing effort in the region. In the 1920s the totoaba fishery grew exponentially due to increased demand, which resulted in more gillnets in the water (Rodriguez 1997). Although the totoaba fishery has since been closed as a means to protect this endemic species, gillnets are still used for shrimp and finfish fisheries. According to the National Institute of Statistics and Geography of Mexico, in 2005 the three towns had a total population of 78,011. It is estimated that 55% of Golfo de Santa Clara residents are employed in fisheries, making it the largest contributor to fishing effort in the UGC. Puerto Peñasco and San Felipe both employ about 10 to 15% of their population in fisheries (Avila-Forcada et al. 2012).

Although the totoaba fishery was abundant in the 1900s, it crashed in 1945 due to bycatch and overfishing (Bobadilla et al. 2011). By 1975 a total ban on fishing for totoaba was placed on the UGC from the mouth of the Colorado River to Bahia Concepcion on the East Coast and the Fuerte River on the west coast (Bobadilla et al. 2011). In 1994 the Mexican government established measures for the protection of the totoaba under Mexican Official Norm 012-PESC-1993 (Bobadilla et al. 2011).

3.4 Fisheries in the Upper Gulf of California

The majority of fishers in San Felipe, Puerto Peñasco and El Golfo de Santa Clara belong to fishing cooperatives, with the remainder being independent fishers. The benefits of belonging to a cooperative include access to credit and lower transaction costs for member fishers. It is also difficult for individual fishers to obtain a permit outside of the cooperative (Avila-Forcada et al. 2012). Artisanal, small-scale fishers use small, fiberglass boats called *pangas*, which are 6 to 8 m long and typically operated by two or three men (Vidal et al. 1994; D'Agrosa et al. 2000). Fishing effort in the UGC is hard to represent in terms of fishing boats, as there are no consistent records of the numbers of pangas in each town. Rodriguez-Quiroz et al. (2012) claimed that there are 2100 artisanal fishing boats in the region while Gerrodette & Rojas-Bracho (2011) stated that there are 589 operating pangas between the two towns of San Felipe and Golfo de Santa Clara. CEDO's most recent environmental impact assessment (MIA) lists the number of pangas in Golfo de Santa Clara at 451 and 305 pangas in San Felipe (CEDO 2012). Due to the wide disparity in the number of actual pangas fishing from San Felipe and Golfo de Santa Clara, we chose to use the most recent numbers given in CEDO's 2012 MIA report. A variety of gear is used by artisanal fishers including drift nets, gillnets, suripera nets (modified cast nets used for trawling) and small trawls. Gillnets are the most widespread gear used by panga fishers to fish for targeted species including corvina (*Cynoscion othonopterus),* chano (*Micropogonias megalops*), blue shrimp (*Litopenaeus stylirostris),* sierra mackerel (*Scomberomorus sierra*), crab, scallop, sharks and rays (Vidal et al. 1994; Erisman et al. 2011).

The majority of fisheries revenue in the region is derived from the blue shrimp fishery. As of 2009, net revenue from the shrimp industry reached $10.1 million USD per season (Rodríguez-Quiroz et al. 2009). A significant portion of shrimp fishing occurs within the protected Vaquita Refuge (Rodríguez-Quiroz et al. 2009) where San Felipe and Santa Clara fishers accounted for all of the fishers illegally fishing in the refuge (Avila-Forcada et al. 2012).

The finfish fishery in the UGC also utilizes gillnets and is very profitable for local fishing communities, especially when the shrimp fishery is not in season. The six most targeted species are Spanish mackerel or sierra (*Scomberomorus sierra)*, sharks (*spp.)*, manta or rays (*spp*.), curvina or corvina golfina (*Cynoscion othonopterus)* and big eye croaker or chano (*Micropogonias megalops)*. The revenue from finfish is estimated to be $5.7 million USD per year, with nearly half resulting from illegal fishing (Barlow et al. 2009, Avila-Forcada 2012). Recently the demand for finfish, specifically chano and sierra mackerel, has grown due to an expanding market in China. The rising market value for these fish may affect the profitability of shrimp and is driving the regional fishers towards finfish. This trend is cause for concern because vaquita bycatch might be higher with finfish rather than shrimp gillnets (CIRVA 2012).

At 2007, Golfo de Santa Clara reported the highest volume of catch when accounting shrimp and finfish together. However, the breakdown of shrimp and finfish landings during the same year shows that San Felipe had the highest rate of shrimp landings with 342 metric tons (MT) followed by el Golfo de Santa Clara with 280 MT, whereas the highest rate of landings of finfish (3,946 MT) was obtained by Golfo de Santa Clara, with San Felipe finfish landings being 1,469 MT (see Appendix, Tables A and B) (Avila-Forcada et al. 2011). The town of Puerto Peñasco does not rely as heavily on gillnet fishing compared to El Golfo de Santa Clara and San Felipe. Puerto Peñasco has evolved into a resort town with a large amount of infrastructure and a larger population compared to the other two towns. Furthermore, fishing effort in Puerto Peñasco rarely encroaches on the vaquita habitat. However, San Felipe has gradually transitioned to tourism, with a 64% of population working in this sector in 2005 (Avila-Forcada et al. 2011).

3.5 Mexican Fisheries Institutions

In Mexico, the Secretary of Agriculture, Livestock, Rural Development, Fisheries, and Food (SAGARPA) is primarily responsible for food production and other primary-sector productive activity. Under SAGARPA, the National Commission of Aquaculture and Fisheries (CONAPESCA) regulates fisheries and aquaculture resources management. CONAPESCA administers design and implementation of policies, fisheries programs, and regulations to ensure legal compliance and sustainability for Mexico's living marine resources. Furthermore, CONAPESCA issues permits and concessions for access to fish, provision of subsidies, and inspection and surveillance of all bodies of water under federal jurisdiction, which includes marine, estuaries, lagoons, reservoirs, lakes, and rivers (SAGARPA 2001).

Within CONAPESCA, the National Fishery Institute (INAPESCA) provides technical advice to the government regarding fisheries management and aquaculture activities. This includes providing stock assessments, alternative fishing technologies testing, water body's biological carrying capacity research, and the preparation of specific regulations, also referred to as Normas Oficiales Mexicanas (NOM).

3.6 Permitting System

The cooperatives and free fishermen (*pescadores libres)* are required by law to operate under fishing permits issued by CONAPESCA, which are allocated for certain periods of time. Permit-holders may have one or more permits that allow them to fish a single target or multiple species. This method of management is convenient for fishers because species characteristics and seasons change spatially and temporally. By having several permits (for example, holding a permit for shrimp and one for finfish), fishers are enabled to fish year round (CONANP 2007).

3.7 Fishing Gear and Equipment

Artisanal, small-scale fishers use small, open-hulled fiberglass boats called *pangas*, which range from 6 to 8 meters in length equipped with outboard 48 to 200 horsepower motors. Pangas are usually operated by two or more fishers, but can be motored by a single captain (Vidal et al. 1994; D'Agrosa et al. 2000). A variety of fishing technologies are used by fishers from the three Upper Gulf towns, including gillnets, suripera nets, longlines, traps, and manual collection (diving). The following paragraphs provide a basic description of how and for what commercial species these fishing gears of the Upper Gulf are employed.

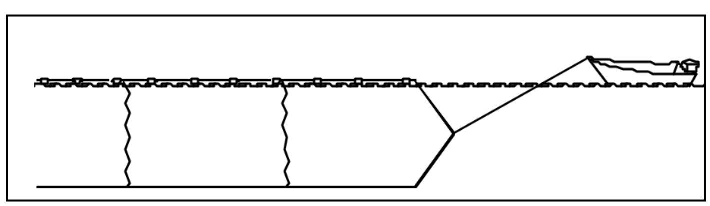

Figure 3: Shrimp gillnet operation. Source: INAPESCA, 2004

Locally named *chinchorro*, gillnets are the most popular fishing gear used by panga fishers. Gillnets are a fishing net used to target shrimp and finfish, as well as some crustacean species (Vidal et al. 1994; Erisman et al. 2011). Gillnets have a basic rectangular structure and are made with nylon mono-filament fibers. The also includes a buoyant line and a weighted line (lead weights) that allow the net to be positioned vertically in the water column (FAO n.d.). Gillnets vary in length (from 100 and up to 900 m length) and mesh size and can be positioned at any depth of the water column depending on the target species. For shrimp, gillnet mesh sizes range from two to four inches, but gillnets can have mesh sizes that exceed 15 inches for larger species such as sharks and rays (Pérez-Valencia et al. 2012). These nets are most commonly set out to drift in fishing grounds for several hours or even overnight to passively catch fish. In general, gillnets have low selectivity and cause significant non-targeted species bycatch or entanglement, putting many species such as marine turtles, birds and mammals at risk.

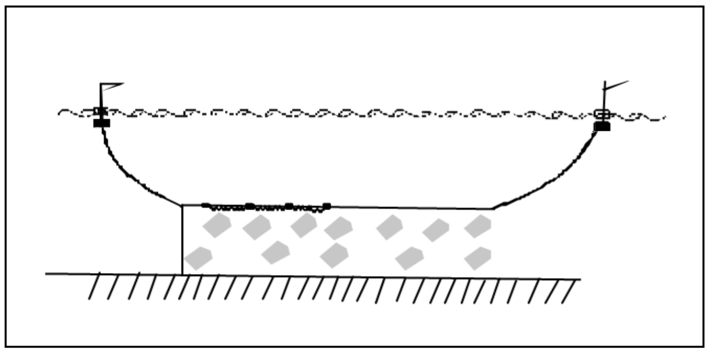

Figure 4: Finfish gillnet operation. Source: INAPESCA 2004

3.8 Fisheries Targeted in the Upper Gulf of California

Commercial fisheries include about 70 species in the Upper Gulf of California. This includes crustaceans, finfish, mollusks, sharks and rays, and other invertebrate groups (CONANP 2007; Cudney & Turk 1998) (see Appendix, Table C). The following paragraphs provide information for the specific targeted species associated with accidental vaquita mortality.

3.8.a Shrimp

The UGC has two primary shrimp species that are targeted: brown shrimp (*Farfantepeneus californiensis*) and blue shrimp (*Litopenaeus stylirostris*). However, the majority of fisheries revenue in the region is derived from the blue shrimp fishery since it is of higher value. As of 2009, net first-sale revenue from the shrimp industry reached an estimated $10.1 million USD per season (Barlow *et al.* 2010). Artisanal shrimp fishers employ gillnets and occasionally small trawl nets, *changos*, in order to fish. Gillnets used to catch shrimp are usually 200 m long but multiple gillnets may be tied together and effectively span over 900 m in length, with 50 to 100 mesh-height. Mesh sizes for shrimp are generally 2½ inches or 2¾ inches. The gear can be left adrift for periods for 0.5 to 1.5 hours, and multiple sets per outing are commonly deployed. In the Upper Gulf of California, blue and brown shrimp are exploited at its maximum sustainable yield level (INAPESCA 2010). The estimated MSY in 2009 was about 6,325 tons, and the suggested total allowable catch has been 2,400 tons (Pérez-Valencia et al. 2012).

As is the case for other coastal states in Mexico, both artisanal and industrial fleets target the blue shrimp fishery in the UGC. The UGC industrial trawl fleet reached 450 boats per season in 2002, with a majority of them based out of Puerto Peñasco (CONANP 2007). Due to the impacts of bottom trawling on benthic habitats and its high rate of bycatch, in 2003 industrial fleets were required to submit an Environmental Impact Report or *Manifestación de Impacto Ambiental* (MIA) to SEMARNAT in order to continue with their fishing activities. Although industrial trawling is permitted in the buffer zone of the biosphere reserve, vessels can only operate under certain restrictions, including the complete exclusion from the Vaquita Refuge, and must comply with bycatch reduction practices like the use of turtle excluder devices (Diario oficial de la Federación 2012). New restrictions push for bycatch ratios to not exceed a 1:1 target with the incidental biomass ratio (Pérez-Valencia et al. 2012)

Access to shrimp stock in Mexico is regulated under the federal regulation NOM-002-PESC-1993 and an amendment in 1997. Procedures for seasonal closures are established by NOM-009-PESC-1993 (INAPESCA 2010).

3.8.b Industrial vs. Artisanal Shrimp Fishery

Since the implementation of the Upper Gulf Biosphere Reserve, efforts have been made to reduce industrial trawling, which has been recognized to be over-capitalized. Buy-out programs for the industrial fleet have been successful in reducing the number of trawlers. Some fishers that participated in the buyout moved into the artisanal sector, leading to an increase in artisanal fishing effort (Vaquita Workshop 2012)**.**

3.8.c Finfish

The primary finfish fisheries in the UGC also employ gillnets, and are very profitable for local fishing communities. This is especially true when the shrimp fishery is closed. The primary target species include chano, corvina, sierra, manta/guitarra, and sharks. However, additional species of commercial value are also are targeted or incidentally caught. This includes flatfish *lenguado*, bass *cabrilla,* trigger fish *cochito*, snappers *parg*o, coney fish *baqueta*, skipjack *jurel*, mullet *lisa,* puffer fish *botete*, grouper *mero,* and coney *baqueta*. Revenue from finfish is estimated to be US$5.7 million per year, with nearly half of it resulting from illegal fishing (Barlow et al. 2009; Avila-Forcada 2012). For a more detailed description of the species considered in this analysis, see Appendix, Supplementary Information.

3.9 Profit Structure of Upper Gulf of California Fisheries

3.9.a International and Domestic Mexican Markets

The UGC shrimp and finfish fisheries contribute a large amount of revenue to the local economy. While fishers in the region fish for both shrimp and finfish, shrimp is more sought after due to its higher value.

The UGC is considered a *price acceptance* region where fishers have little to no bargaining power. Brokers and buyers of UGC seafood largely decide price dynamics in the international arena, and these set prices do not generally demonstrate dramatic fluctuations (Ardjosoediro & Bourns 2010). About 6 million MT of shrimp is produced globally, and 60% of this production is traded on the world market. Mexico represents about 8% of the value of shrimp exported to the U.S. and in 2008 it was recorded that total Mexico shrimp exports were estimated at $323 million USD, of which $308 million USD went to the U.S. (Ardjosoediro & Bourns 2010). Mexico's ability to supply large shrimp has been a comparative advantage for the country due to both the high quality of shrimp and its proximity to the U.S. (Melzter & Chang 2006).

The UGC's local seafood demand is dominated by local supermarkets (Ardjosoediro & Bourns 2010). Until recently, supermarkets represented only a small channel for seafood producers; however, growth in frozen seafood consumption has increased the quantity of seafood supplied (Ardjosoediro & Bourns 2010).

3.9.b Gulf of California Fishery Supply Chain

The shrimp fishery supply chain in the UGC is better documented than that of finfish. For this reason, information regarding the shrimp supply chain has been more accessible and informative. In comparison, the finfish supply chain is more regional compared to that of shrimp.

The majority of shrimp production from the upper gulf is exported in a shell-on frozen form to the U.S (Ardjosoediro & Bourns 2010). The three fishing towns San Felipe, Puerto Peñasco, and Golfo de Santa Clara have processing plants that include cleaning, on-ice processing, and transport to domestic wholesale markets (Ardjosoediro & Bourns 2010). The role of these processors ranges from serving as a buyer to providing processing services (Ardjosoediro & Bourns 2010).

Fishers in the UGC have relatively good access to the fish traders and brokers of the region. The three main exporters purchase over 80% of production from Golfo de Santa Clara, San Felipe, and Puerto Peñasco. These exporters include Ocean Garden Products, Inc., Ofi Markesa, Inc., and Eastern Fish. Large exporters have tremendous purchasing power over domestic suppliers and wholesalers, which has resulted in less favorable outcomes for shrimp fishers in the region. Fishers are pressured to sell product at lower prices than market value as a result of this export market power. Companies use local processors to package shrimp, then directly export products to the US through the nearby border crossings of Nogales, Tijuana, or Mexicali (Ardjosoediro & Bourns 2010). In an attempt to place purchased shrimp products in the highest-valued seafood channels, Ocean Garden Products, Ofi Markets, and Eastern Fish brand and market Mexican shrimp directly to chefs and restaurant buyers (Ardjosoediro & Bourns 2010).

Because US based companies are the dominant importers of shrimp from Mexico, they have a powerful influence over the shrimp value chain as well as trade credit conditions (Ardjosoediro & Bourns 2010). Trade credits accessible to local fishers are made through offers from both US and Mexican national brokers. Often these credits are interest-free in exchange for commitments to supply shrimp at set prices and quantities, leaving local producers with little to no bargaining power (Ardjosoediro & Bourns 2010).

3.10 Environmental Institutions

The Secretariat of Environment and Natural Resources (SEMARNAT) is responsible for the management of natural resources in protected areas, as well as the preservation of species and habitats. SEMARNAT takes actions to achieve environmental quality and ecological equilibrium under the General Law of Environmental Protection and Ecological Balance (LGEEPA 1988). Furthermore, the agency houses several institutions that play roles in the protection of the natural resources of Mexico. These include the National Commission of Protected Areas and National Parks (CONANP), the Federal Agency of Environmental Protection (PROFEPA), the National Commission for the Knowledge and use of Biodiversity (CONABIO), and the National Institute of Ecology (INE).

SEMARNAT administers several NOMs related to the conservation of endemic, threatened, and endangered species subject to protection. Habitat protection is one of the strategies used in accordance with the agency's mission to promote biodiversity conservation through the establishment of protected areas according to the statutes of the LGEEPA (SEMARNAT 1988). In addition, another regulation, the General Wildlife Law of Mexico decrees it the responsibility of SEMARNAT to preserve biodiversity, with particular attention to protect endangered species listed under NOM-059-ECOL-1994 (amended as NOM-059-SEMARNAT-2010).

Specific to marine mammals, Mexico has a legal framework for their protection and provides standards and tools useful for implementation of conservation programs. The official penalty for killing, causing harm, or commercializing marine mammals or protected fishery species under the NOM-059-SEMARNAT-2010 is up to nine years in prison with fines ranging between $2,000 and $22,000 USD according to Article 420 of the Federal Penal Code (Diario Oficial de la Federación 2013). Additionally, the country is a proactive participant in international treaties related to conservation and environmental issues.

3.11 History of Conservation

Just decades after its discovery as Mexico's only endemic marine mammal, the vaquita gained increasing national and international conservation attention, and has become the focus of many initiatives targeted at preventing marine mammal extinctions. After the Yangtze River dolphin of China was declared extinct in 2007, concern for the vaquita has only grown with recognition that it may very well be the next cetacean to face extinction (Gerrodette 2011). The following literature review provides summary descriptions of the major conservation efforts and strategies targeting the vaquita through 2012. The following figure (Table 1) is a representation of historic vaquita conservation implementations.

Vaquita Conservation Timeline	
1985	Vaquita added to US Endangered Species List
1986	Vaquita considered vulnearble by the World Conservation Union
1991	Vaquita considered endangered by the World Conservation Union
1993	President Salinas gives presidentail decree to establish the Alto Golfo Biosphere Reserve
1994	Vaquita gains legal status in Mexico as a species in danger of extinction under NOM-ECOL-1994
1995	Biosphere Reserve management plan published
1996	Vaquita considered critically endangered by the World Conservation Union
1996	CIRVA assembled to present recommendations to 48th meeting of IWC
2005	The Vaquita Refuge created
2005	Vaquita PACE Action Plan established
2006	Initial buyout program established
2007	CEC instructed to initiate collaborative actions to recover the vaquita
2008	PACE Action plan implemented, launching a new buyout, rentout, and switchout program for fishers

Table 1: A timeline of historic vaquita conservation implementations.

3.11.a International Attention

In 1985, the vaquita was added to the United States Endangered Species List under the Endangered Species Act (ESA). Since the species does not inhabit US waters, the government was not obligated to designate and protect critical habitat and create a Recovery Plan as required under the ESA. Instead, officials from the US Fish and Wildlife Service (FWS) and the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) have contributed to the Technical Committee for the Preservation of the Vaquita and the Totoaba (CTPVT) (PACE 2008). Additionally, the vaquita has been added as an Appendix 1 species under the Convention on International Trade of Endangered Species (CITES), despite not being a species of trade (IUCN 2011; CITES 2011).

Although the vaquita is only found in the Gulf of California, preventing extinction has become an international effort. Currently, there are three specific international agreements aiding vaquita conservation efforts. These include the North American Agreement for Environmental Cooperation (NAAEC), the International Committee for the Recovery of the Vaquita (CIRVA) and the International Union for Conservation of Nature (IUCN) Red list of Threatened Species.

International Union for the Conservation of Nature: Red List

The IUCN created a RED List of Threatened Species in 1994, whose aim is "to provide information and analyses on the status, trends and threats to species in order to inform and catalyze action for biodiversity" (IUCN 2011). The vaquita was considered vulnerable by the World Conservation Union in 1986, as endangered in 1991, and as critically endangered in 1996 (IUCN 2011).

International Committee for the Recovery of the Vaquita

The International Committee for the Recovery of the Vaquita (CIRVA) was assembled in 1996 in order to present conservation recommendations to the 48th meeting of the International

Whaling Commission (IWC). This international committee of scientists and officials was formed out of the request by the Mexican government to craft a recovery plan for the endangered porpoise (PACE 2008). CIRVA has since played a lead role in shaping government conservation actions, meeting before the IWC in 2004, 2007, and 2012 (CIRVA, 2012). Key recommendations focused on phasing out all gillnets in the vaquita range and the development of alternative income- generating activities. Many of the incremental recommendations of CIRVA have largely been included to the extent feasible by the most recent governmental conservation strategies (PACE 2008). CIRVA laid out the following recommendations in its latest report (CIRVA 2012):

- Gillnets and other entangling nets should be removed from the entire vaquita range
- Artisanal shrimp fishing vessels should be converted from using gillnets to small trawls
- Legal limit on length of gillnets and number of nets per vessel should be enforced
- Boundaries of the Vaquita Refuge should be extended

North American Conservation Action Plan

In 2007, under the North American Agreement on Environmental Cooperation (NAAEC), an environmental authority negotiated into the North American Free Trade Agreement (NAFTA), the Commission for Environmental Cooperation (CEC) was instructed to initiate collaborative actions to “recover the vaquita and promote sustainable local livelihoods” (NACAP 2008). The CEC’s council of ministers motivated this action with their consideration of the vaquita as a species of “common continental concern,” and the subsequent drafting of a North American Conservation Action Plan (NACAP) ensued. NACAP’s recommendations closely mirror those of CIRVA. The recommendations broadly emphasize meeting a zero-vaquita bycatch scenario using incentives, as well as the implementation of performance indicators (vaquita monitoring) for recovery of the species (NACAP 2008). Specific NACAP objectives are as follows:

1) Prevention, control, and mitigation of threats 2) Use of innovative approaches to developing sustainable livelihoods in the communities 3) Research, monitoring and evaluation of the state of the population 4) Increase awareness about the conservation of the vaquita.

In 1994 the vaquita gained legal status as a species in danger of extinction under the NOM-059-ECOL-1994 (similar to the US Endangered Species List). This listing, while initially providing little more than recognition and attention to the ecological status of the species, would eventually afford the vaquita the development of its own official recovery plan after the 2004 federal mandate to do so for NOM-059 species (PACE 2008). The vaquita recovery plan was developed under CONANP’s Endangered Species Conservation Program (PROCER). Additionally, under the fisheries secretariat of Mexico (CONAPESCA), two significant conservation measures were enacted to address the issue of vaquita bycatch within fishing activities: a regulation for the maximum mesh size permitted of 10 inches in gillnets used in the Northern Gulf (NOM-012-PESC-1993), which was further reduced to 6 inches in 2002; and a restriction on the length of shrimp gillnets permitted in 1997 (PACE 2008).

3.11.b Alto Golfo Biosphere Reserve

In June 1993 President Salinas gave a presidential decree, upon the recommendation of the CTPVT and under the auspices of the United Nation's Education, Science, and Culture Organization (UNESCO), establishing the Reserva de la Biosfera Alto Golfo y Delta del Rio Colorado (CONANP 2007). The Alto Golfo Biosphere Reserve was designed in accordance with UNESCO Man and the Biosphere program criteria for sustainable development and environmental conservation, featuring a zoned system for human activities within the reserve (Case et al. 2002). While the large Colorado River Delta ecosystem and commercially endangered totoaba were central to the biosphere designation, significant measures were also included to protect the vaquita and its habitat. Notably, commercial fishing was excluded from a core zone and industrial trawling was restricted in designated areas of the buffer zone, creating a vaquita conservation sub-zone (CONANP 2007). Regulations came into law with the designation of the biosphere; however, the reserve-specific management plan was not published until 1995 and was last updated in 2007. Currently, the Biosphere Reserve is managed by CONANP with restrictions enforced by PROFEPA.

The Biosphere Reserve was created with the intention of establishing a central "core" zone to prohibit any source of exploitation (Rojas-Bracho et al. 2006). President Salinas called for a halt on industrial shrimp trawling in the core and buffer zones of the Reserve, i.e. north of a line traversing the Upper Gulf from Puerto Peñasco to San Felipe (see appendix, Figure A) (Rojas-Bracho et al. 2006).

3.11.c Vaquita Refuge

Nearly a decade after the designation of the Alto Golfo Biosphere Reserve, researchers recognized that nearly 70% of all vaquita sightings were occurring outside the reserve boundary and as far as 45 miles south (D'Agrosa et al. 2000). This prompted the enactment of a supplemental spatial protection decree in 2005, called the Vaquita Refuge. Commercial gillnet and industrial trawl fishing were explicitly prohibited within the polygon-shaped refuge designation, as published within the new protection program (NACAP 2009). According to acoustic surveys and transects, roughly 50% of the population is encountered within the Vaquita Refuge polygon (Gerrodette & Rojas-Bracho 2011).

During CIRVA meetings in 1997 and 1999, participants identified a "core area" of vaquita density (Rojas-Brancho et al. 2006). This area comprises approximately 2235 km^2 and is considered high priority for conservation due to high vaquita density. With help from the Ministry of Agriculture and Fisheries and the Ministry of Environment, President Vicente Fox proceeded with creating the Vaquita Refuge in June of 2005, which occupies only 0.36% of the surface area of the Upper Gulf of California (Rojas-Brancho et al. 2006). The polygon covers 1263.77 km^2 and takes up about 900 km^2 inside the Biosphere Reserve (see Appendix, Figure A).

The Vaquita Refuge is an indication of progress, but by no means is a final solution to vaquita bycatch. The Refuge is not fully enforced and there is an immediate need for additional measures to reduce bycatch. The following are current shortcomings associated with the Vaquita Refuge:

- Design of the current polygon: the polygon was created by drawing lines to connect sighting positions; no consideration was given to creating a proper "buffer" area around the vaquita sightings (Rojas-Brancho et al. 2006).
- Difficulty of achieving compliance from fishermen: the Refuge's asymmetrical shape creates difficulties for fishermen to adequately identify Refuge boundaries (Rojas-Brancho et al. 2006).

3.11.d PACE Action Plan

Established soon after the Refuge, the Programme for the Protection of Vaquita (PACE-Vaquita) is considered a significant step in vaquita conservation. The program was established in the Mexican Federal Register on December 29th 2005 and called for a transfer of $ 1 million USD to the state governments of Baja California Norte and Sonora to help implement the Refuge (Rojas-Brancho et al. 2006). The Programme is the first noted measure taken by the Minister of Environment in an effort to protect vaquita from gillnets.

PACE was implemented in 2008 under CONANP to expedite governmental action to prevent the extinction of the vaquita. PACE set out to halt all incidental take of vaquita. At the core of PACE is a federal plan for a voluntary buyout program to remove gillnets in the vaquita habitat (Avila-Forcada 2012). Under PACE, fishermen who partake in the voluntary program are compensated through a rentout, switchout, or buyout.

Under the rentout option, fishermen are compensated if they agree to stop gillnet fishing within the Vaquita Refuge. Essentially this option is a payment-for-conservation, which provides incentives to fishermen to abandon gillnet fishing (Avila-Forcada 2012). In the case that a fisherman violates the agreement, officials have the appropriate authority to seize their vessels. Alternatively, the switchout program compensates fishermen for permanently adopting to vaquita-safe nets. The goal of the switchout program is to increase and promote new technological advancements with regards to artisanal fishing gear (Avila-Forcada 2012). The third option, the buyback program, compensates fishermen for permanently turning in fishing permits and all fishing equipment, which includes boats, engines, and other gear (Avila-Forcada 2012)

Two modifications were implemented to the PACE program in 2009 and 2010, with the intention of enhancing program results. In early 2010 the compensation structure was altered in such a way to make the rentout option more desirable than the buyout option. (Avila-Forcada 2012). The second modification came about due to low switchout participation in 2008. PACE-Vaquita restructured the switchout option in which fishers had the option to switch to vaquita-safe gear on an annual basis rather than a permanent one; however, compensation for a short-term switchout was lower than a permanent option – USD $17,000 vs. USD $30,000, respectively (Avila-Forcada 2012). The temporary switchout option was further broken down in 2010; fishers were given the option to choose between buying vaquita-safe nets and borrowing nets for a year. If fishers chose to borrow nets rather than investing in them, they would receive a compensation of USD $9,000 (Avila-Forcada 2012).

PACE has committed government resources to four primary actions (PACE 2008):

1) Increased enforcement of fishing regulations in the Upper Gulf (with CONAPESCA and PROFEPA)
2) Testing new fishing technology that reduces bycatch (with INAPESCA)
3) A voluntary buyout program of gillnet gears (with SEMARNAT and SAGARPA)
4) Strict enforcement of the established gillnet and industrial trawling ban within the designated Vaquita Refuge

3.11.e Buyout Programs

The government first attempted to launch a fisheries buyout program in 2006, which aimed to reduce incidental vaquita bycatch. The buyout program was entirely voluntary, and fishers looking to exit the fishery could petition the government to retire their permit. It is widely recognized that this initial buyout attempt had minimal impact in reducing the number of gillnets in vaquita habitat because fishers were only required to surrender their permits but not their gear (i.e. pangas, motors, or nets). Fishers who did opt for the buyout program were obligated to permanently leave the fishery and search for an alternative livelihood.

A restructuring of the 2006 buyout program came about in 2008 with the implementation of Pace-Vaquita. The restructuring of the buyout program resulted in 15% of fishers exiting the UGC fisheries market. Those who opted for the buyout now had to turn in their gear and permits to officials for an exchange of $40,000-60,000 USD, depending on the number of permits held (Avila-Forcada 2012). While the buyout effort reduced the legal fishing fleet by approximately one third (PACE 2008), a complicating dynamic emerged: as fishers left the fishery, individual catches increased for those who continued to fish, diminishing the incentive for remaining fishers to participate in the buyout program. In addition, illegal fishing has yet to be addressed within the buyout strategy (Avila-Forcada 2012) (see Table 2).

Buyout Participation (Avila-Forcada 2012)				
	San Felipe			
	2008	**2009**	**2010**	**Total**
Buyout	50	8	0	58
Switch Out	38	43	10	91
	Golfo de Santa Clara			
	2008	**2009**	**2010**	**Total**
Buyout	71	10	0	81
Switch Out	9	10	26	45
Total Buyout	**121**	**18**	**0**	**139**

Table 2: Table of buyout numbers realized since 2008. Switch outs consider those fishermen that were compensated for temporary switch of gillnets to a vaquita friendly gear.

3.11.f Funding

Since initial conservation efforts began, the Federal Government of Mexico and environmental organizations have invested an approximate $30 million USD in research and conservation. In 2005, the Mexican Ministry of Environment declared a decree to create, what is now known, the Vaquita Refuge. This decree granted $1 million USD to compensate affected fishermen and enforce the Vaquita Refuge.

Federal agencies such as CONANP, CONABIO, and the National Ecology Institute (INE) are funded through the Mexican government. There are instances where private donations are designated to these federal agencies for specific conservation programs, such as private donations from the Packard Foundation and local NGOs. Furthermore, these agencies receive financial support from cooperating agencies of several other governments (Ardojosoediro & Bourns 2010).

3.11.g Vaquita Research

Visual Surveys (1993, 1997, 2008)

Barlow et al. did the first formal vaquita abundance estimate in 1993 using observation data from four aerial and transect surveys conducted between 1986 and 1993. The rate of decline was estimated to be -17.7% per year (95% CI = -43.2% to +19.3%) and abundance was estimated to be 224 individuals (CV= 39%, 95% CI= 106 to 470 individuals) (Barlow et al. 1997).

In the summer of 1997, Jaramillo et al. performed a visual line-transect survey designed to estimate vaquita abundance over their entire range. The 1997 abundance estimate was nearly double the 1993 estimate at 567 individuals (CV= 50.72%, 95% CI= 177 to 1,073) (Jaramillo-Legorreta et al. 1999), but it is important to point out the areas surveyed were not the same and there was a large increase in survey effort.

In the fall of 2008, Gerrodette et al. combined acoustic and visual line-transect surveys, leading to a total abundance estimate of 245 individuals (CV= 73%, 95% CI= 68 to 884 individuals) (Gerrodette et al. 2008). The study area was divided into five strata that were surveyed visually, acoustically, or both with total abundance being the sum of these five strata. Approximately 50% of the vaquita population was found to be within the Vaquita Refuge, indicating that roughly half the population may be outside the refuge and receive no protection from gillnet fishing at any given time.

Acoustic Surveys

The National Marine Mammal Program at Mexico's National Institute of Ecology (Programa Nacional de Mamíferos Marinos) has applied passive acoustic monitoring programs in the UGC to locate vaquitas as part of a study to investigate habitat use and population distribution (Rojas-Bracho et al. 2006). A hydrophone is towed behind a sailboat in the main habitat areas and in waters too shallow for the larger vessels used in visual surveys. All abundance estimates based on acoustic data have had low precision, primarily due to a low number of acoustic detections on effort (only four acoustic detections from 449 km of transects in 2008) (Gerrodette et al. 2011), but the main results still confirm that vaquita are an extremely rare species.

Recent Research

Gerrodette and Rojas-Bracho (2011) conducted a more recent analysis and concluded that all gillnetting should be banned across vaquita habitat range to decrease extinction probability. A second recommendation was to develop effective alternative fishing gear (Gerrodette & Rojas-Bracho 2011). Ainsworth et al. (2011) developed an ecosystem-based model for the Upper Gulf known as an Atlantis model. This study demonstrated a great deal of uncertainty for probability of extinction due to limited information and necessary model parameters, yet concluded that the vaquita may become extinct within 10 years.

3.11.h Alternative Fishing Gear

In the search for alternatives for vaquita population recovery, the Mexican government, NGOs, and the international community have worked together in developing strategies focused on reducing bycatch for this species. Based on scientific evidence, various authors have suggested that zero vaquita bycatch scenarios, consisting of combinations of spatial gillnet bans and the use of technological improvements such as alternative gears can enable the vaquita population to increase (CIRVA 2012).

Given the commercial importance of blue shrimp for the Upper Gulf communities, a total ban of this fishery may cause significant economic loses and result in a set of complex social conflicts. For this reason, some of the recommendations from the last CIRVA meeting held in 2012 include technology-based strategies to address the vaquita extinction risk issue. The CIRVA Committee sees tremendous potential in light trawls as a replacement for gillnets. Trawling poses significantly less risk to vaquitas since they tend to avoid boats (Barlow *et al.* 2010). In addition, prototype trawl nets designed specifically for the artisanal fishery in the UGC are equipped with special devices to reduce bycatch (see Figure 5). Despite the existence of other alternative gears such as suripera nets which have zero bycatch effect on vaquita, performance trials have shown that trawling has substantially more catch than suriperas, making them more economically viable (CIRVA 2012).

The prototype trawl RS-INP has been designed by INAPESCA and NOAA scientists and has been proven during the 2009-2010 and 2010-2011 fishing seasons. The small lightweight trawl, also called a *red selectiva*, was tested in the UGC by cooperatives from San Felipe, Golfo de Santa Clara and Puerto Peñasco. Depending on the material of the net, this fishing trawl may cost from $1,000 to $5,000 USD (CIRVA 2012).

As a part of several programs related to test the light trawl effectiveness, fishermen were economically compensated and trained to develop field trials. The trawl performance data collected during the fishing trips was supported by observers onboard (INAPESCA 2010, 2011).

For the 2009-2010 season, the effectiveness of the light trawl was limited due to several factors including the timing of sampling: the trials were done only at night to avoid interfering with commercial fishing during daylight. Additionally, 4 individuals of the endangered fish totoaba were caught, causing concerned officers to inquire about the need for improving this gear (INAPESCA 2010).

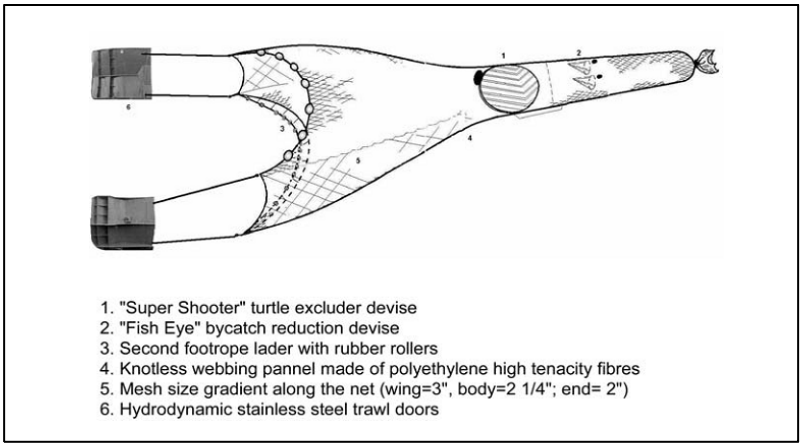

Figure 5: Basic configuration of the RS-INP prototype trawl net. Source: Aguilar-Ramirez (2010).

A new trial was developed for the 2010-2011 fishing season, prior to a new prototype design that incorporates improvements based on lessons learned from the 2010-2011 experiments. Daylight trips were developed during the closed season for commercial blue shrimp fishing, avoiding interference with gillnets. Under these conditions, it was possible to evaluate blue shrimp catch with the use of this prototype (Aguilar-Ramirez 2012). Improved light trawls were found to catch commercial quantities of brown shrimp at night and blue shrimp during the day. According to the last CIRVA report in 2012, in terms of blue shrimp "catch levels were comparable to that of gillnets with the trawls." We considered the most practical method to be a 1:1 ratio, given the uncertainty and variability registered in blue shrimp catches for both trawls and gillnets in our analysis.

Trawling for blue shrimp instead of using gillnets is estimated to increase costs by about 24% due to increased gasoline needs and variable costs of maintenance, payment to crew fishers, and keeping all other expenses equal (calculation does not include initial investment).

Despite these significant results, the implementation of the alternative gear resulted in complications with the current scenario. Even assuming full compliance with the 200 m length restriction on gillnets, it is possible that gillnet activities will spatially interfere with trawling operations (INAPESCA 2011). Additionally, there is no relationship between gillnet length and catch volume, which suggest a technical and economical failure in using nets of more than 200 m long (CIRVA 2012).

While trawls may serve as a viable alternative to gillnets, some potential drawbacks include the requirement of more operational skill and profitability. The newest light trawl prototype has a shrimp-bycatch ratio of 1:1 (Aguilar-Ramírez 2012). However, the potential effects on fish species and the environment have not been fully evaluated. Additional technological improvements in the design of vaquita-safe gears and fishing practices are encouraged by CIRVA.

3.12 Current Political Climate in Mexico

In Mexico, sexennial presidential transitions may generate uncertainty for the continuation of conservation programs. Domestic environmental policy can change with each administration. However, in the case of vaquita, conservation has national and international concern working in its favor to maintain support of the presidential administration. Mexico has made promises to solve this problem and has welcomed international coalitions. Additionally, it is worth mentioning that since the first months of the newly elected President Enrique Peña Nieto, he has prioritized emphasis on foreign affairs. This suggests that the possibility remains for a window of opportunity to continue working on cooperative agreements specifically conservation issues.

Future policies will need to be designed taking into account the historical development of fisheries management and conservation in the UGC. In the 1990s, social crises linked to the overexploitation of fishery resources, the extinction risk of marine mammals such as vaquita, and the need to integrate sustainability within the environmental agenda (Caddy and Cochrane, 2001) encouraged the government to design the Biosphere Reserve of the Upper Gulf of California. After the establishment of the Biosphere Reserve, a reconversion designed to slow down the growth of fishing activities and foster alternative economic activities such as tourism, sport fishing, and aquaculture was initiated. In addition, the implementation of the NAFTA in 1994 promoted modifications in commercial channels and the openness of international investment, particularly for the tourism sector (Valdéz-Gardea 2010).

Current and future policies and instruments will need to be evaluated and assessed in the context of current political realities in order to generate feasible alternatives in a long-term perspective rather than simply providing momentary solutions to the problematic situation of resources management in the UGC (Bobadilla et al 2011).

3.13 Case Study in Cetacean Extinction: Yangtze River Dolphin

The following case study serves as additional insight on mammal species similar to the vaquita. In the following case, the Yangtze River Dolphin faced critical endangerment due to local human activities. Conservation measures were adopted by the government to sustain the species, however, these adopted efforts proved unsuccessful due to various circumstances. In an attempt to learn from past conservation efforts, this case study provides valuable lessons that should be considered for the vaquita.

3.13.a Background

The Yangtze River Dolphin, or baiji (a freshwater dolphin), was once recognized as one of the world's rarest and most endangered mammal species. The baiji inhabited the middle and lower regions of the Yangtze River in China and it is now believed to be extinct. Threats from heavily populated areas along the Yangtze River are thought to be the leading cause of mortality. In attempts to conserve the baiji, the Chinese government categorized the species as a grade I national key protected animal (Bruford et al. 2006). Natural and seminatural reserves were put in place in the middle and lower regions of the river alongside a conservation plan for cetaceans of the Yangtze River, which was approved by the Chinese Ministry of Agriculture in 2001 (Bruford et al. 2006). It was estimated that fewer than 100 baiji individuals remained in the wild when these conservation management plans were adopted.

In 2006 an intensive 6-week study was conducted through November to December in an effort to discover any evidence of a remaining baiji population. Multi-vessel and acoustic surveys were carried out over the historic range of the baiji (Akamatsu 2007), but failed to discover a remaining population. While there have been a small number of unverified sightings in recent years, it has been concluded that the species is in fact extinct. Much of the baiji's endangerment is attributed to encountered threats from human impacts, such as overfishing of prey species, gillnet bycatch, and collisions with motorized vessels, among others. It is reported that more than half of all known baiji deaths occurred in the 1970s and 1980s. Prior to the 2006 study, a total of 17 baiji individuals were sighted during simultaneous multi-vessel surveys in 1997, 1998, and 1999 (Chen et al. 2003).

3.13.b Conservation Efforts

The combination of a staggering decrease in the baiji and an increase in awareness in the conservation community gave rise to two international workshops in 1993 and 2004. The 2004 workshop focused on attempts to rescue the species from extinction. These attempts included two options: (1) translocation of all remaining individuals to a 21-km oxbow lake, and (2) translocation of individuals to the Institute of Hydrobiology dolphinarium in Wuhan (Bruford et al. 2006). In a report conducted by the School of Biosciences, Cardiff University and Institute of Zoology, Chinese Academy of Sciences it was concluded that these options were not practical due to low prospects of capturing a viable group of baiji and a lack of probability that the species would survive in captivity (Bruford et al. 2006).

The two options explored in the 2004 workshop for the baiji are not applicable in the case of the vaquita, as current evidence suggests the species cannot survive in captivity. However, there are still two main points that can be learned from this case study. First, the probability of saving a species from extinction drastically decreases as the population becomes small and isolated, exemplifying the need to be proactive with conservation actions. Second, the causes of decline for the baiji were extensive and nearly impossible to manage. In the case of the vaquita, the cause of the decline is clear (gillnets) and the area is small and manageable, giving much more hope to conservationists than they had for the baiji.

3.14 Market Based and Alternative Approaches to Conservation

3.14.a Develop and Market Eco-label for "Vaquita-free" Shrimp

In the 1990 the United States passed the Dolphin Protection Consumer Act, which created eco-labeling standards for tuna caught with zero dolphin bycatch. Since then, certification standards have been initiated for various fish and seafood products. Eco-labeling targets industry and consumer stakeholders in an effort to increase corporate social responsibility and awareness. The Mexican government has the opportunity to introduce a similar law for "vaquita-free" shrimp. In essence, “vaquita-free” shrimp would mimic standards implemented for dolphin-safe tuna. In order for suppliers to receive certification for “vaquita-free” shrimp, they would have to ensure that no vaquita were harmed in the process of catching shrimp. Eco-labeling has the potential to establish a simple way for consumers to support vaquita safe measures through simply altering consumer behavior. This certification process would enable consumers to make a difference without having to do anything other then purchase a good with a label. Additionally, the creation of “vaquita-free” shrimp will further spread international awareness regarding vaquita bycatch.

3.14.b Alternatives to the Shrimp Fishery

The government has the potential to incentivize alternatives to shrimp by further assisting fishers who participate in gear switch-out program (Ardjosoediro & Bourns 2009). In order to commercialize alternative fisheries, there needs to be a proper application of proven technologies and market connections (Ardjosoediro & Bourns, 2009). Potential alternative fisheries include the geoduck clam (*panopea abrupta)*, crab fishery, pescado extranjero, and an increase in the curvina golfina fishing effort.

3.15 Tradeoff Analysis

3.15.a Utility of Approach

Tradeoff analyses have been used to illustrate relationships between two or more competing values in various decision scenarios. The approach has long been used in financial planning, where returns on assets are compared against each other (Lester et al. 2012). Through the development of an efficiency frontier along a set of axes that represent competing values or interests, management options can be identified with potential to increase benefits to one, some, or all of the values (see Figure 6). Case studies have shown that this approach can also reveal inferior management options, demonstrate the benefits of comprehensive planning for interacting ecosystem services, and identify win–win management options (Lester et al. 2012).

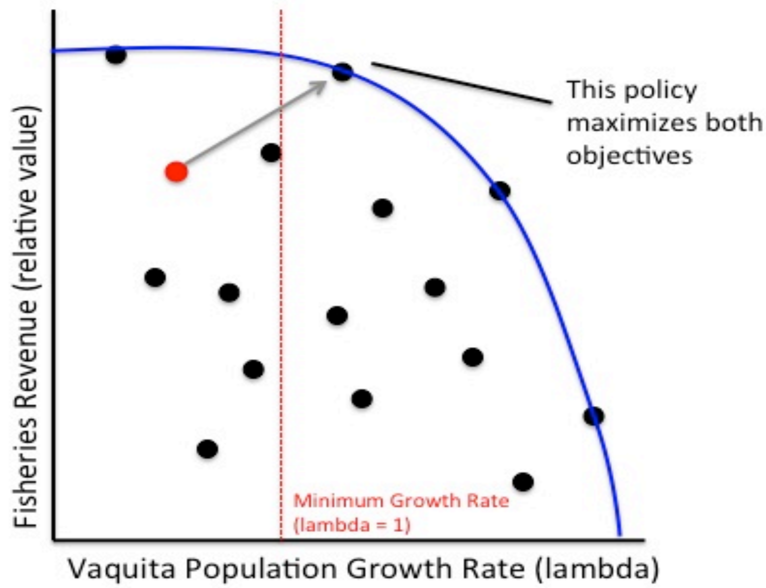

Figure 6: The above figure illustrates the generic tradeoff analysis diagram, where an efficiency frontier is identified and Pareto improvement options can be clearly observed.

Points that fall below an efficiency frontier can be improved at no cost to either sector in what is referred to as *Pareto improvement* or *Pareto-efficiency option* (White et al. 2012; Lester et al. 2012). Points that exceed the efficiency frontier are unattainable, given that the outermost possible points comprise the efficiency frontier. Points closer to or along the frontier represent the optimal solutions in the given decision-making scenario (White et al. 2012).

Tradeoff analyses have been increasingly recognized for their utility in environmental problem solving. A prime example of the principal applications to a conservation scenario was used to assess development and habitat protection in the Willamette Valley of Oregon. Polaski et al. (2008) evaluated spatial plans for biodiversity protection and land development with consideration to their merits respective to economic and conservation value. The evaluated land use plans were plotted on tradeoff axes along with a modeled efficiency frontier, which was created by plotting the outcomes of any possible land use plan. From this tradeoff analysis, it became clear that more efficient land use planning was achievable from recognizing potential Pareto improvements from the proposed land use plans (Polaski et al. 2008).

3.15.b Application of a Tradeoff Analysis to Marine Spatial Planning

In another example of the application of tradeoff analyses in environmental management, White et al. (2012) modeled tradeoffs in marine spatial planning for the contentious Cape Wind Project in the Nantucket Sound off the coast of Cape Cod in Massachusetts. This example of applying a tradeoff analysis to a marine environmental issue used spatial evaluation of economic benefits for multi-sectorial interests, including fishing sectors and whale watching tourism, in addition to the economic interests of the offshore wind industry. As with the Willamette Valley case, the results of these analyses were presented as illustrative and not necessarily prescriptive (White et al. 2012). This approach revealed an explicit conflict of values, identified viable options to minimize conflicts, showed gains of alternative options, and served to facilitate rational decision-making (White et al. 2012). The benefits of a tradeoff analysis come from comparing policy options compared to an efficiency frontier, which transparently show likely outcomes of decisions made for all interests.

3.15.c Application of a Tradeoff Analysis to the Vaquita Issue

Success with the prior applications of a tradeoff analysis to spatial planning in the Willamette Valley of Oregon and wind farms off the coast of Massachusetts suggest a similar approach can be beneficial in evaluating conservation-oriented management for the vaquita in the UGC. For this case, the tradeoffs inherent in management options are evaluated for their merit in terms of economic and conservation outcomes. More specifically, the outcomes of a given policy are measured by their efficacy in reducing vaquita bycatch incidents, and minimizing impact to local fishing economies that could result from restrictions to fishing activity. This approach provides a useful tool to managers and stakeholders in the UGC, particularly because livelihoods are closely linked with fishing activities that have proven detrimental to the vaquita population. Applying a tradeoff analysis to this case allows for explicit illustration of where and which fishing activities should be targeted by policies to yield the greatest cost-effectiveness, and inform of potential management improvements that are most beneficial—or the least negatively impactful—to both vaquita abundance and economic interests in the region.

3.15.d Framing Losses of Revenue as the Cost of a Policy

Our analytical approach perceived the differences in net revenue associated with a given management option to equate to the cost of a conservation solution. This is to say the amount of revenue loss[2] resulting from any policy scenario, measured in the present value on an annual basis, is the cost associated to the local fishing economy of that policy. We consider this to be a proxy for the minimum amount impacted fishing livelihoods should be compensated, or enabled to generate with alternative revenue. By framing revenue losses, instead, as the cost associated with a given management scenario, a measureable benchmark is set for efforts to recuperate revenue (Vaquita Workshop 2012). Moreover, a very contentious political and ethical debate is inherent in the question of who should pay this cost.

[2] Revenue losses as calculated in this analysis do not account for the potential income accrued to fishers that elect to participate in the gillnet buyout program (See Section 3.11.e).

4. Data Used in Analysis

4.1 Vaquita Density

The best estimates for vaquita abundances have come from visual surveys conducted in the years 1986, 1993 (Barlow et al. 1997), 1997 (Jaramillo-Legorreta et al. 1999) and 2008 (Gerrodette et al. 2011). Each of these surveys performed visual transects and recorded locations of observed vaquita individuals and groups. An estimate of abundance was extrapolated from these surveys in the region.

Gerrodette et al. (2011) performed the 2008 surveys by splitting the transect area into five strata: North, East, West, Central and Calibration (Figure 7). For each stratum, a vaquita density per km^2 was estimated (see Table 3). Using these strata, we overlaid the location coordinates onto a project map in ArcGIS. For each cell that fully overlapped a stratum, the vaquita density was calculated by multiplying the published densities by 25 to account for the cell size, effectively giving the cell a vaquita density per 25 km^2. In cells that overlapped more than one stratum, or only partly overlapped a stratum, the cell's vaquita density was calculated by averaging the multiple densities by the area of overlap in the cell.

The 2008 visual survey covered less than one-third of the project study area. To account for this gap in data, assumptions based on discussion from the Vaquita Workshop (2012) were used to estimate vaquita densities for cells outside of the survey area. The surveys conducted between 1986 and 2008 reported very low or no observations of vaquita in the region east of the 2008 transect study, and therefore all cells to the east of the transect area were given a vaquita density of zero. A new vaquita density was also applied to the West stratum (Figure 7). Gerrodette et al. (2011) did not observe a single vaquita during transects in the West stratum, but while in transit the vessel did detect vaquita acoustically. Using this evidence as well as anecdotal evidence from experts in the field, the cells overlapping the West stratum were given a vaquita density of 0.008 vaquita per km^2, half the density of the neighboring Central stratum. A new stratum, "Southwest," was created for the purposes of this project in order to account for the small gap between the East stratum and the shore (Figure 7). The cells overlapping the Southwest stratum were given the same density as the West stratum, 0.008 vaquita per km^2. The densities for all strata were the same as those published in Gerrodette et al. (2011) and can be seen in Table 3.

After calculating the estimated densities of vaquita per 25 km^2 cell, the densities were recalculated to represent the 2013 vaquita population rather than the 2008 population. This was calculated by converting the densities per cell into proportions of the total vaquita abundance. Once the proportion of total abundance per cell was calculated, the updated 2013 vaquita densities were found by multiplying current abundance (N_0) by this proportion. The spatial distribution of vaquita can be seen in Figure 8.

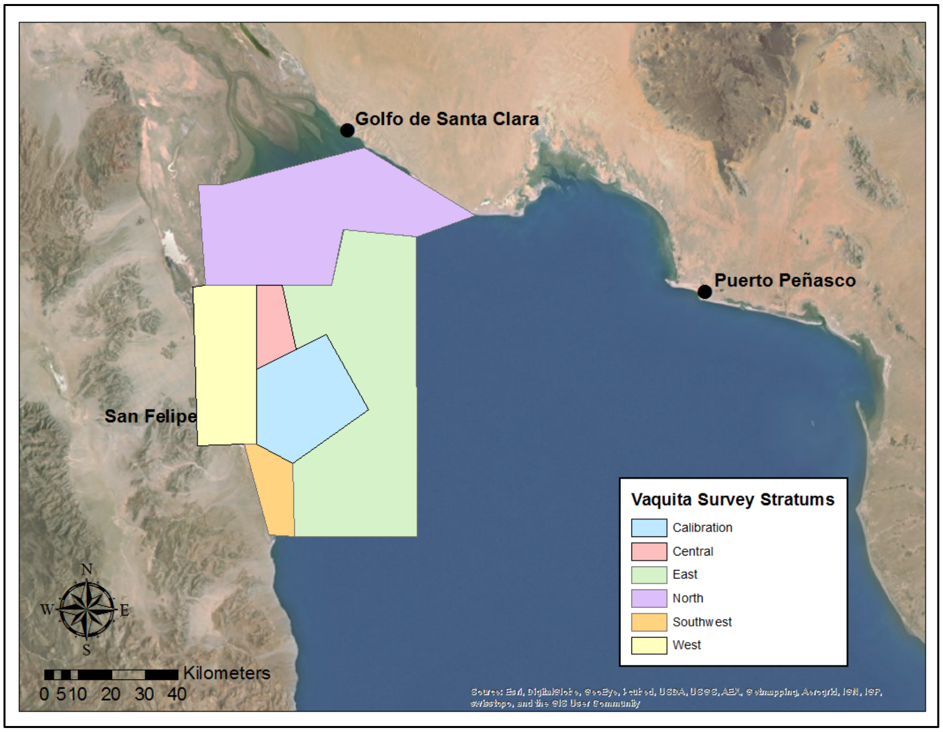

Figure 7: Map of Upper Gulf of Mexico with 2008 vaquita survey stratums.

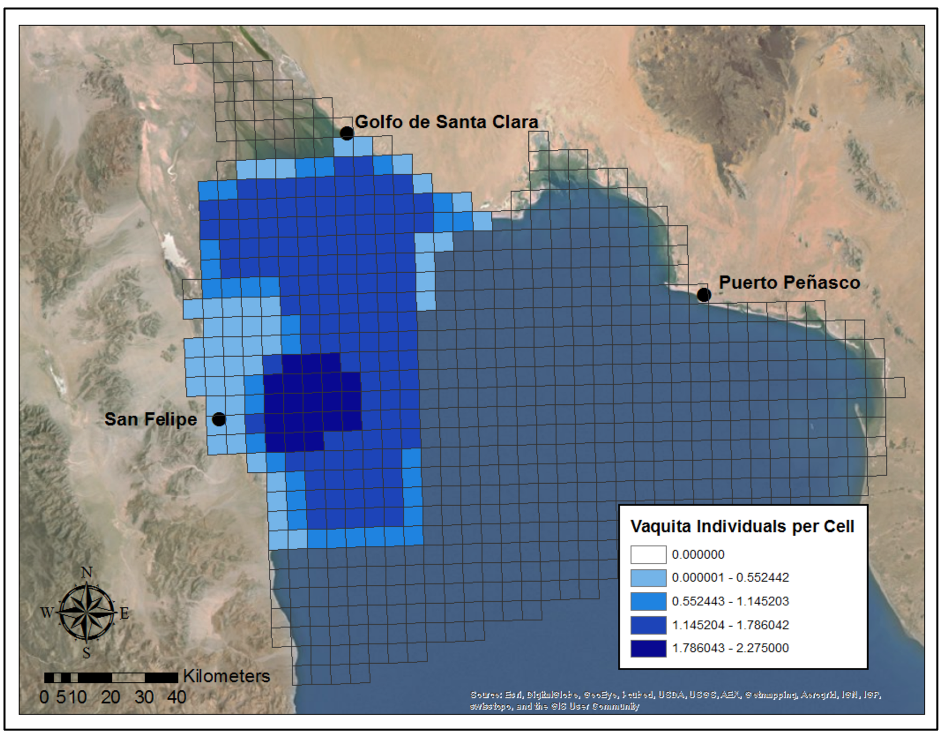

Figure 8: Vaquita density in the UGC. Density per 25 km^2 cell was calculated from estimated densities in Gerrodette et al. (2011).

Stratum	Estimated Density	CV(%)	L95	U95
Calibration	0.091	52.3	0.035	0.238
East	0.058	45.6	0.025	0.137
Central	0.016	138.1	0.002	0.12
West*	0	-	-	-
North	0.051	141.8	0.006	0.397
Southwest**	0.008	-	-	-

Table 3: Estimated vaquita density per km^2 for each stratum in the 2008 survey (Gerrodette et al. 2011). *Our analysis used a density of 0.008 instead of 0 due to high likelihood of vaquita presence in the West stratum. **The Southwest stratum was created for the purposes of this project and was not a 2008 transect survey stratum.

4.2 Spatial Fishing Effort

Fishing effort for each town and targeted species was spatially represented in ArcGIS 10.1. The data came from a project conducted in 2005 and 2006 led by the University of Arizona research initiative, PANGAS (see NGOs and Research Institutions section). Their project aimed to collect information on local knowledge from fishing communities throughout the UGC through detailed interviews with panga captains (Moreno-Baez et al. 2012). For a detailed description of the fishers' local knowledge project see Moreno-Baez et al. 2012.

In order to collect information on where fishermen were fishing, each interviewed captain was given a map of the region and asked to outline their primary and secondary fishing grounds for each species they targeted (for an example, see Appendix, Figure C). This led to a collection of over 1000 individually identified fishing grounds for the five species groups pertinent to this project. Information on each fishing ground included what species was caught there, which town the captain came from, and whether it was considered a primary or secondary fishing ground. The data lacked information for how often these fishing grounds were visited and the average amount of time spent fishing in the grounds. Furthermore, there is no reference to how much harvest is associated with each fishing ground. In the absence of quantitative information, we assumed that each fisherman's primary areas represented equivalent effort, and that secondary areas represented half that effort. Based on these assumptions, we developed a relative fishing effort index for each grid cell (Figure 9).

There is anecdotal evidence that fishing effort has changed since 2008 in response to increased enforcement and fishermen generally becoming more aware of the boundaries of the Vaquita Refuge, albeit legally established in 2005. Since the fishing effort data was collected in 2006 it is likely that current fishing effort is not accurately represented in the data. Therefore, we consider this data to be representative of a baseline fishing effort distribution, indicative of where fishing would occur if there were no vaquita refuge or buyouts.

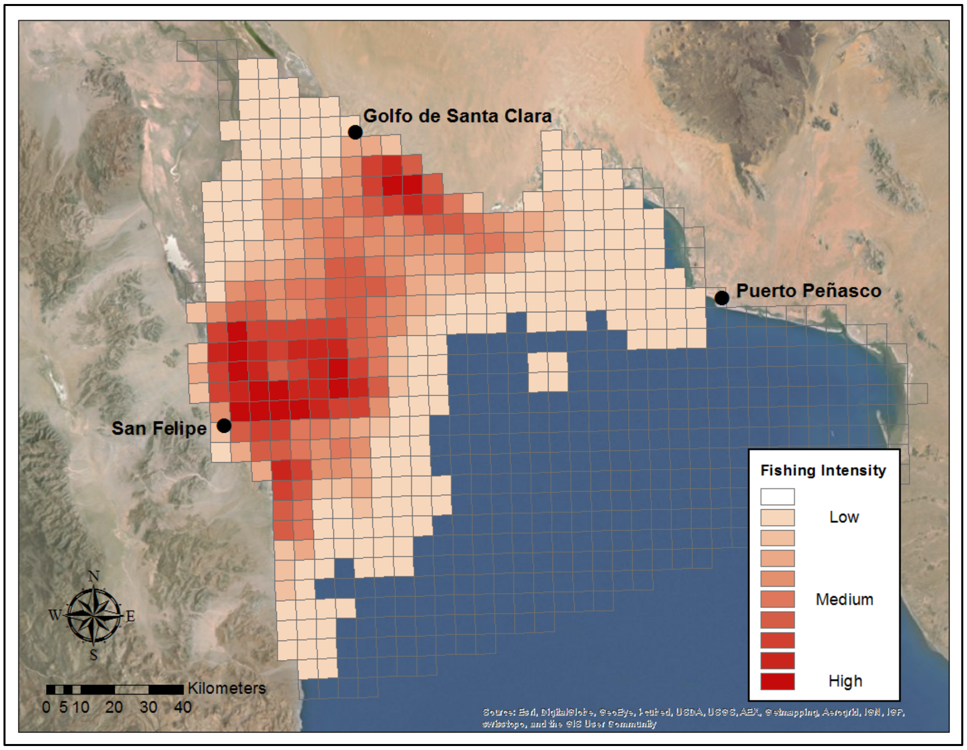

Figure 9: Spatial distribution of fishing effort in the UGC. Darker cells indicate areas of highest fishing effort. Data comes from a PANGAS-led project in 2005 and 2006.

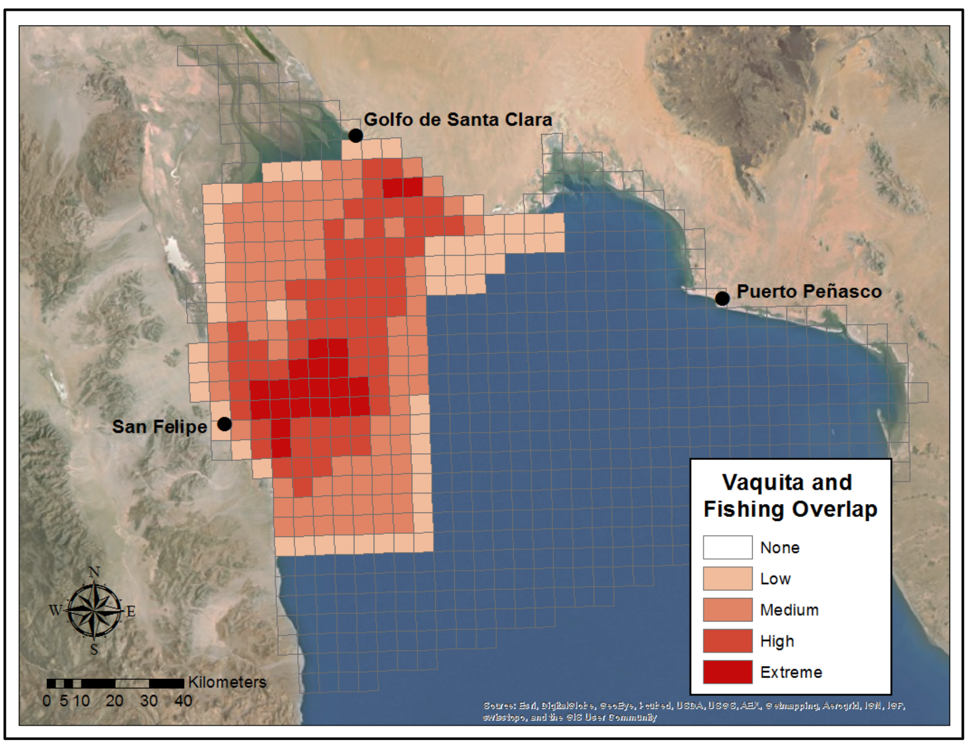

Figure 9.1: Areas of overlap between vaquita density and fishing effort.

4.3 Economic data

Modeling changes in revenue under different management options for the UGC is dependent on fish landings data reported regionally. For this analysis, we used CONAPESCA data collected at the local branches of the federal fisheries commission, from San Felipe and Golfo de Santa Clara separately. We used the average landings per species for each of the primary species targeted by artisanal gillnet fishers, respective to each town. We did not use data that included landings from industrial fleets. With this data, average yearly landings were calculated for the years spanning 2000 to 2007 (see Table 4 & 5) to generate a pre-Refuge baseline level of landings. We excluded landings data more recent than 2007 in our analysis due to a significant increase in enforcement of the Vaquita Refuge starting in 2008 (Gerrodette & Rojas-Bracho 2011), which altered where fishing activity occurred thereafter. By using the data collected prior to 2008, our analysis more accurately captured fisher's activities in a baseline scenario of no management, which allowed us to observe how landings will be impacted from implementation of modeled restrictions. Finally, we used landings data starting in the year 2000 because of the fact that landings were highly variable and fishing effort experienced rapid expansion in the decade prior (Rodriguez-Quiroz 2010). It is important to note that landings have remained relatively constant on an annual basis from 2000-2007.

GSC Landings Value						
Species	**Average Landings (kg)**	**Landings Error (kg)**	**Average price ($MXN)**	**Price Error ($MXN)**	**Cost of landings ($MXN)**	**Net Revenue ($MXN)**
Shrimp	294,214.00	37,542.39	$124.20	$5.66	$25,075,933.17	$11,465,923.60
Sierra	668,503.00	94,096.37	$9.78	$0.37	$5,532,838.41	$1,007,696.30
Shark	8,984.63	2,392.39	$12.70	$0.79	$87,655.00	$26,449.74
Manta & Guitarra	36,517.00	10,412.19	$9.11	$0.32	$353,635.24	-$20,817.65
Chano	614,336.00	90,956.37	$6.89	$0.74	$2,778,621.45	$158,546.95
TOTAL					**$33,828,683.27**	**$12,637,798.94**

Table 4: Landings values calculated from previously described data sources for Golfo Santa Clara. Values from these tables were used as inputs in our model to form the basis of economic valuation of policy scenarios represented in our tradeoff analysis.

SFE Landings Value						
Species	**Average Landings (kg)**	**Landings Error (kg)**	**Average price ($MXN)**	**Price Error ($MXN)**	**Cost of landings ($MXN)**	**Net Revenue ($MXN)**
Shrimp	313,019	41,374.28	$120.94	$4.95	$20,408,429.03	$17,448,835.28
Sierra	144,532	52,095.86	$9.89	$0.70	$1,062,117.68	$367,460.85
Shark	77,638	18,633.41	$9.70	$1.07	$87,654.99	$665,221.81
Manta & Guitarra	213,934	11,917.93	$9.13	$0.70	$1,755,074.40	$197,882.98
Chano	571,208	65,886.87	$6.26	$0.77	$2,884,494.29	$689,808.01
TOTAL					**$26,197,770.39**	**$19,369,208.93**

Table 5: Landings values calculated from previously described data sources for San Felipe. Values from these tables were used as inputs in our model to form the basis of economic valuation of policy scenarios represented in our tradeoff analysis.

4.3.a Official Landings

Data collected and compiled at the local offices are aggregated at the state and national level to be published each year. Landings information is available through an online database that provides the officially reported landings for all managed species, categorized by the local office it was registered with. This online database provides data starting in 2006 through the present year. For landings data prior to 2006, we relied on published data collected from the same fisheries offices for the same species by Rodriguez-Quiroz (2010) for 2000-2005. CONAPESCA collects and compiles reported landings data with an *Official Notice of Arrival* from local offices of the federal fisheries commission in every coastal town in the country. The Official Notices of Arrival acts as a certificate of production and sale to local fish wholesalers and must accompany the fish product to market as certification of its legality.

4.3.b Fishing Costs

Cost data used in our economic model came from a study conducted by CONAPESCA in 2004 (see CONAPESCA 2005), which analyzed information gathered from fisher interviews conducted in two towns of the UGC. While it would be ideal to use the most recent available cost information relevant to our landings data (i.e. 2007) since fishing costs tend to evolve (increasing or decreasing over time with changes in technology, efficiency, and operational costs), no studies more recent than 2004 were available to us from CONAPESCA. Nevertheless, because the reported landings in 2004 closely fit the average annual landings between 2000-2007, we made the assumption that a cost of landings ratio based on the 2004 costs/landings could be scaled to the average yearly landings calculated for 2000-2007. To do this, we calculated a proportional difference between 2004 landings and the 2000-2007 average, then multiplied this difference by the 2004 reported costs for each species in each town. This same extrapolation was also used to fill in holes where cost data lacked for a given species[3]. The equation below describes how costs were extrapolated from the 2004 report, and all resulting cost-multiplier values are listed in Appendix, Table D:

$$Cost\ of\ Landings = \frac{Landings_{2004}}{Average\ Landings_{2000-2007}} \times Costs_{2004}$$

While the cost data we used was provided by the 2004 CONAPESCA study on fishing costs, calculating such costs of fishing more generally is complex. Calculations must consider both fixed and operational costs across the fishing fleet. For example, fixed costs in the UGC include the initial capital investment costs associated with the panga, motor, and auxiliary equipment (i.e. trailer, GPS, radio, etc.); seasonal investments are also generally considered in fixed costs, including the expenses of replacing nets and other gear as needed, in addition to any fees associated with permit renewal. Additionally, the value of gear is subject to depreciation with use and time, and should be calculated into estimates of fishing costs since the investment of gear

[3] The 2004 cost study did not report Golfo de Santa Clara manta landings; therefore costs were extrapolated using reported costs for the same fishery in San Felipe.

tends to be spread across the total seasons of use. Fixed costs vary widely in the UGC as many fishers are able to economize by investing in previously used gears. Our 2004 cost data provided by CONAPESCA does not explicitly state how fixed costs were treated in their calculations.

Furthermore, operational costs will vary for each panga captain depending on their fishing practices. Costs will inherently increase with distance to fishing grounds, increases in net length, additional crew, etc. while fishing costs will decrease with efficiency of extractive activity. In the case of the UGC, costs of fishing vary significantly for fishers in the three towns due to different proximities to their preferred fishing grounds, vary widely depending on gears employed (i.e. gas used in trawling or gillnet), and vary widely by the species targeted since some species demand more time or crew to capture (CONAPESCA 2005). For UGC fishing activity, the principle operational costs are comprised of gasoline, motor oil, bait, and daily food expenses for fishing crew during outings. However, from our data it is not clear how operational costs were calculated, limiting our economic analysis to a generic application of cost as a 'cost per landings per species per town.'

4.3.c Fish Prices

Fish prices used in our model are the average prices calculated from the CONAPESCA landings figures available through the National Fishery Commission's database. Price data is reported along with landings to the local fisheries offices, which reflects the first-sale value the fisher receives when offloading his catch. We use the average prices reported for each species from 2000-2007[4] in order to capture local seasonal fluctuations and inter-annual variability associated with UGC fisheries resources. These averages were calculated (see Tables 4 & 5) in proportion to the quantity landed at a given price each month over the 7 years.

While fish prices are said to have remained relatively constant over the past decade on the international market (Vaquita Workshop 2012), prices do tend to fluctuate at the local level. Price fluctuations are seen to vary seasonally and annually depending on the species but the long-term trend is relatively stable for most species in the UGC (see example of blue shrimp in Figure 10). It is important to note that significant price increases could be the result of expanding export fish markets to Asia in the near future, as has been seen with the both the chano and curvina swim bladder fishery (CapLog 2012). Yet while it is recognized that Chinese and other Asian markets are increasingly showing interest in Mexico's finfish market (Vaquita Workshop 2012), we do not model expected increases in prices associated with this market demand into the future due to the highly volatile and uncertain nature of these market influences. Appendix Figure B provides the average annual prices and price trend for each of the principal species by town between 2000 and 2007.

[4] A 5-year price average starting in 2006 was used in the case of chano, recognizing the value has dramatically increased from the earlier part of the decade due to influence of recent Asian market demand.

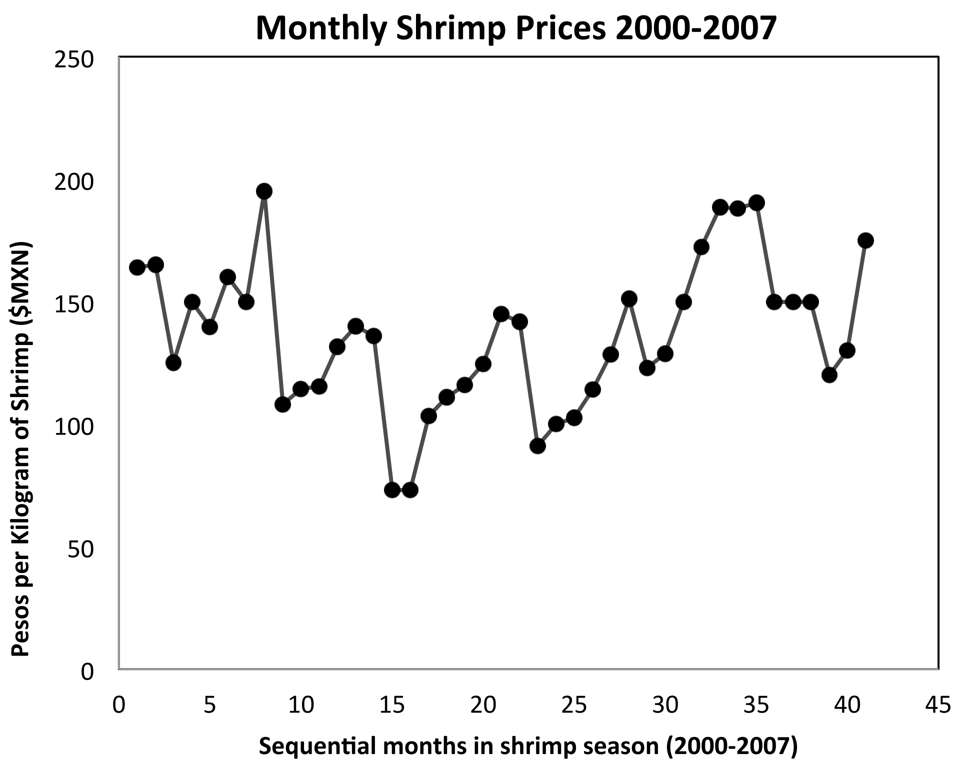

Figure 10: The above figure illustrates the intra and inter-seasonal variation in first-sale prices of blue shrimp in the UGC. Months of the shrimp seasons over 7 years are represented sequentially.

5. Methods

5.1 Policies Evaluated

As previously stated, the current policy options have failed to successfully protect vaquita. In an effort to reduce vaquita bycatch while taking economic impact into consideration, the following policy alternatives were evaluated:

1. Spatial closures
2. Species closures
3. Fisheries buyout programs
4. Varied levels of compliance
5. Implementation of an alternative fishing trawl

5.1.a Spatial Closures

Implementing spatial closures in high vaquita density areas has the potential to mitigate incidental vaquita bycatch in the UGC. Low levels of enforcement have led to common incidents of illegal gillnet fishing in the refuge. Since the current refuge has not effectively reduced vaquita bycatch we chose to evaluate four additional refuge designs.

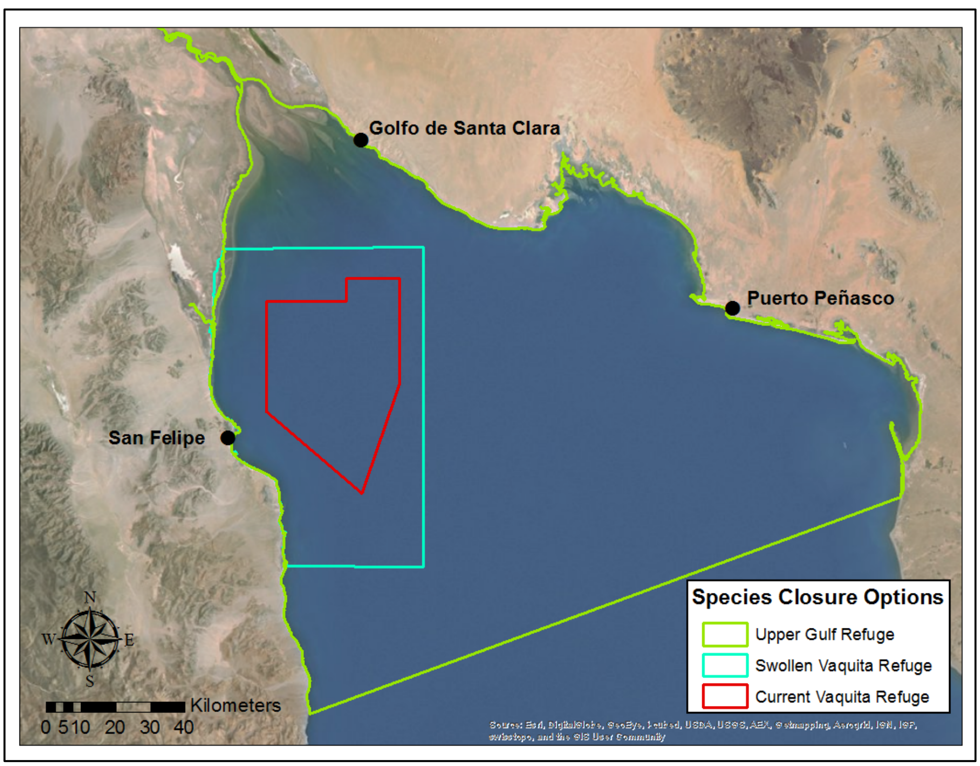

Figure 11: Current vaquita refuge outlined in red and two proposed expanded refuges – Swollen Refuge and Upper Gulf Refuge

Current Vaquita Refuge

The current Vaquita Refuge was implemented in 2005 and designated as a gillnet no-take zone (Figure 11). Gerrodette & Rojas-Bracho (2011) estimated that the Vaquita Refuge efficiently protects just 49% of the vaquita population when the refuge is perfectly enforced.

Swollen Refuge

Gerrodette & Rojas-Bracho (2011) evaluated a larger vaquita refuge listed as "Option 2" in their study, renamed as a "swollen refuge" for the purposes of this project. The swollen refuge is estimated to protect 80% of the vaquita population (Figure 11).

Upper Gulf of California Refuge

This project chose to evaluate the option of closing the entire UGC region to gillnet fishing. Even though this is the most unrealistic option it was important to include in our model for purposes of comparison between all vaquita refuge options. Gerrodette & Rojas-Bracho (2011) also evaluate this closure, listed as "Option 3" in their study.

Marxan 90% and 95% Refuges

We felt it was important to evaluate new vaquita refuge designs apart from those that have already been proposed. We used the conservation planning software MARXAN (Ball et al. 2009) to design two new vaquita refuges. MARXAN creates efficiently designed protected areas based on set conservation targets. When setting the target to protect at least 90% and 95% of the vaquita population, MARXAN designed two refuges that are larger than the proposed swollen refuge but much smaller than a region-wide vaquita refuge (Figures 12 & 13).

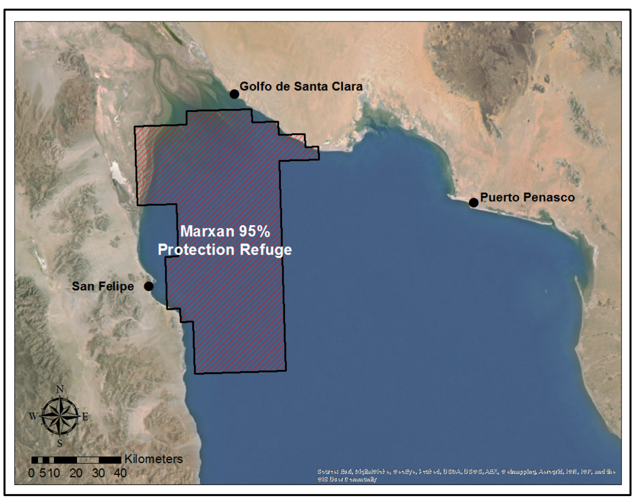

Figure 12: Vaquita refuge derived using Marxan protect 95% of the current vaquita population.

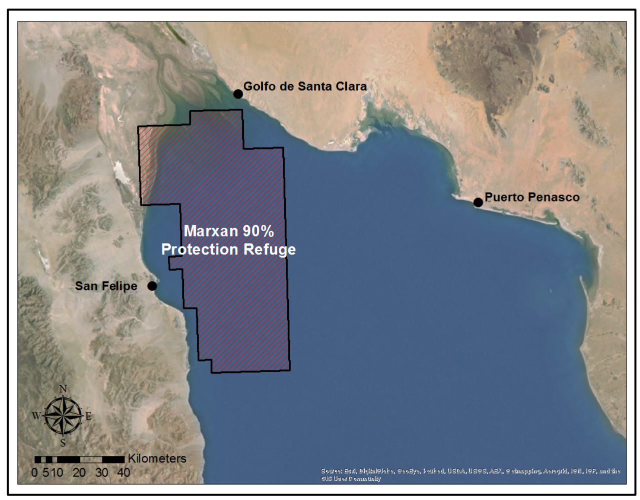

Figure 13: Vaquita refuge derived using Marxan protect 90% of the current vaquita population.

5.1.b Species Closures

High fishing intensity in the UGC contributes to an increased probability of incidental vaquita bycatch. In an effort to analyze current fisheries in the UGC, we considered five different fishing policy options as shown in Table 6. The five fishing policies may restrict complete forms of fishing or in some cases may prohibit fishing of certain species.

	Fishing Policy
1	No Fishing
2	Finfish fishing permitted
3	Shrimp fishing permitted
4	All species can be fished
5	Trawling for shrimp permitted

Table 6: Description of fishing policy options

To capture the impacts of new policy implementation, we first considered policy option 1 and policy option 4. Policy option 1 prohibits all fishing in each of the refuges, while policy option 4 enables all fishing in every refuge. By examining these two policies we evaluated extreme outcomes. For instance, policy option 1 represents a scenario where no economic revenue is generated. However, vaquita bycatch rate is drastically reduced. Policy option 4 represents a scenario where maximum fisheries revenue is generated, but consequently produces high levels of vaquita bycatch.

Policy option 2 and 3 also represent critical outcomes with specific implications for fisheries revenue and vaquita bycatch. Policy 2 permits fishers to only fish for finfish in the UGC, while policy option 3 only permits fishers to fish shrimp in the UGC. Shrimp landings generate high revenue and, for this reason, a majority of local fishers primarily direct fishing efforts towards shrimp. It is imperative to model the shrimp fishery in order to further access impacts on revenue and vaquita bycatch.

The last policy option we considered was option 5, which permits the use of light shrimp trawls for artisanal use in the spatial closures. The introduction of a light trawl is only possible when all gillnetting activities are restricted.

5.1.c Fisheries Buyout Programs

In 2008 a restructured buyout program was launched in the UGC that reduced fishing effort by 15%. For the purpose of our analysis, we chose to incorporate a 10%, 20% and 30% reduction in total fishing effort through a buyout program. The three buyout levels modeled were based on past historic trends and thought to be the most realistic to implement (Vaquita Workshop 2012). We did not consider any buyout level above 30% due to financial restrictions. However if more funding is allocated toward a buyout program, higher buyout levels may become feasible.

5.1.d Varied Levels of Compliance

Increased levels of compliance in the UGC are a direct result of increased levels of enforcement. To encompass a realistic spectrum of compliance in the UGC, we modeled compliance at 20% intervals from 40% to 100%.

5.1.e Implementation of Alternative Shrimp Trawl

One potential method to retrieve lost revenue from spatial closures is to allow former gillnet fishers to utilize specially designed shrimp trawls inside a proposed vaquita refuge. Trials have confirmed that vaquita are extremely unlikely to be caught by trawls due to their notable avoidance of boats, thus this method would have no vaquita bycatch. We modeled trawl effects on revenue for policies with perfect compliance and no gillnet fishing allowed within refuges, as described in 5.6.b.

5.2 Fishing Effort Index

In order to understand the interactions between the vaquita population and fishing effort in the UGC, it is important to model the interactions at a much smaller resolution than the entire region. We gridded the UGC study area with 698 cells, each with an area of 25km^2 as seen in Figure 14.

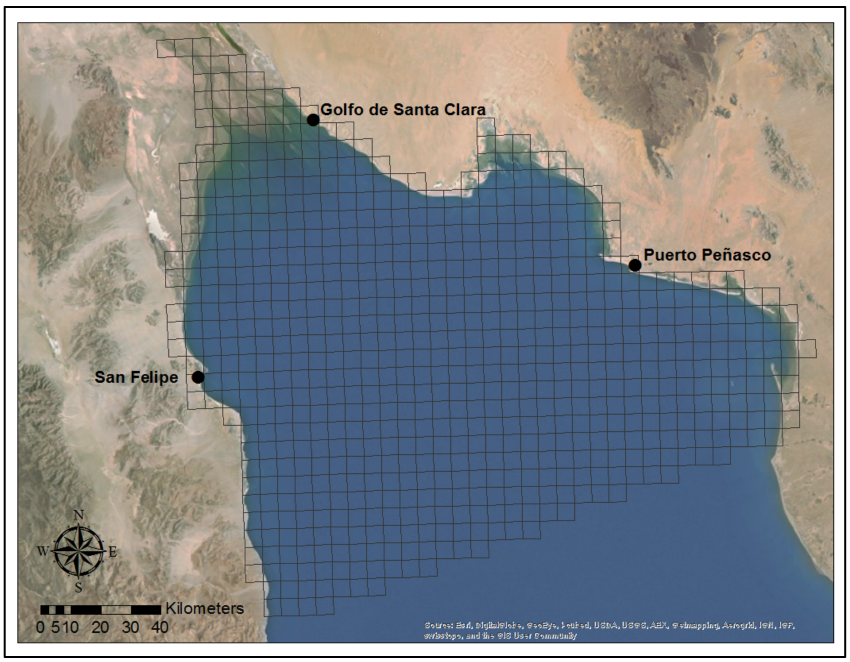

Figure 14: A map of the grid cells covering the project study area in the Upper Gulf of California. The grid consists of 698 individual cells that are each 25 km^2.

Since the fishing effort data lacked information on the quantity of fish caught and time spent fishing, an accurate metric of fishing effort per cell was not possible to calculate. Instead, spatial fishing effort was calculated for all cells based on the number of fishing grounds overlapping each cell (see Appendix, Figure C). This calculation resulted in a baseline fishing effort index with values of fishing effort (E_b) for each cell (i) for each species (x). To arrive at a fishing effort value per cell for each species, the spatial fishing ground data was separated by town, species, and priority (primary or secondary fishing grounds). If a cell was used as a secondary fishing ground, it was given half the weight of a primary fishing ground (Vaquita Workshop 2012) through the following calculation;

$$F_t = F_1 + (F_2 * 0.5)$$

where F_1 is the number of primary fishing grounds, F_2 is the number of secondary fishing grounds and F_t is the weighted total number of fishing grounds per cell in the study area.

Total Fishing Effort (San Felipe)				
Species	Primary	Secondary	Total	Total Weighted
Sierra	104	81	185	144.5
Shrimp	832	389	1221	1026.5
Chano	222	96	318	270
Manta & Guitarra	331	129	460	395.5
Shark	14	17	31	22.5
All Species	1503	712	2215	1859

Table 7: Fishing grounds per cell for Golfo de Santa Clara

Total Fishing Effort (Golfo de Santa Clara)				
Species	Primary	Secondary	Total	Total Weighted
Sierra	1032	367	1399	1215.5
Shrimp	1847	929	2776	2311.5
Chano	194	92	286	240
Manta & Guitarra	380	99	479	429.5
Shark	155	164	319	237
All Species	3608	1651	5259	4433.5

Table 8: Fishing grounds per cell for San Felipe

The total number of primary and secondary fishing grounds that overlapped with each cell was calculated using the Spatial Join Tool in ArcGIS 10.1 for each species. For each cell *i,* the baseline fishing effort value (E_b) was calculated per species *x* separately for both Golfo de Santa Clara and San Felipe:

$$E_{b_{i_x}} = \frac{F_{t_{i_x}}}{F_{t_x}} * w_x$$

where $F_{t_{i_x}}$ is the weighted number of fishing grounds per species x in cell i, F_{t_x} is the sum over all cells of $F_{t_{i_x}}$, and w_x is the seasonal weight applied.

The seasonal weight, w_x, was calculated by determining how many months each species was fished out of a year. The seasonal fishing information came from the PANGAS fishing database, which contained information from all panga captains interviewed, including what specific months they fished for each species. Since there was no species-specific effort information included in the fishing effort data it was important to differentiate between fisheries that are more and less intensive. The only information available was the seasonal differences between all fisheries. The proportion of months per year that were fished for each species per town were calculated, and then normalized to 1 to account for overlapping fisheries. Table 9 lists all species weights per town.

	San Felipe	Golfo de Santa Clara
Sierra	0.1538	0.1290
Shrimp	0.2692	0.2581
Manta & Guitarra	0.2308	0.2903
Chano	0.1538	0.1935
Shark	0.1923	0.1290

Table 9: Seasonal weights (w_x) per species *x* for both San Felipe and Golfo de Santa Clara. These weights were calculated from reported species fishing seasons included in the fishing data supplied by Marcia Moreno-Baez. All weights were normalized to sum to 1.

In order to model how a given policy affected fishing effort, a new variable, the resulting fishing effort (E_r), was calculated per cell i. Since each policy combination included a spatial closure component, only the fishing efforts of cells included in the spatial closure were subject to all variables of the policy; the species-specific fishery closures and the buyout and compliance levels. Those cells that lie outside the spatial closure were only subject to the buyout policy.

If cell *i* was included in the spatial closure;

$$E_{r_{i_x}} = E_{b_{i_x}}(1 - C)(1 - U)$$

and if cell *i* was not included in the spatial closure;

$$E_{r_{i_x}} = E_{b_{i_x}}(1 - U)$$

where $E_{b_{i_x}}$ is the baseline fishing effort, *C* is the level of compliance ranging from 0.4 to 1, and *U* is the level of buyout ranging from 0 to 0.3. The resulting fishing effort per cell was the sum of each effort per species;

$$E_{r_i} = \Sigma\, E_{r_{i_x}}$$

Without data on how fishing effort would be displaced under each policy, we assumed that all fishing effort affected by the spatial closures would exit the fishery rather than be displaced to open areas.

5.3 Calculating Vaquita Bycatch

When a cell had both fishing and vaquita, the interaction between these two was calculated in order to determine the amount bycatch in the given cell. The following equations were used to calculate the vaquita bycatch per cell (B_i) under each modeled policy for each town;

$$B_i = N_i * E_{r_i} * q_i * P$$

where in cell *i, N* is the vaquita density, E_r is the fishing effort, q_i is catchability per panga in the cell, and P is the number of pangas in the fishery. A full table of the variable and parameter descriptions and values are located in Tables 3.6 and 3.7.

5.3.a Catchability

The catchability parameter, q, was estimated by Gerrodette & Rojas-Bracho (2011) to be 0.00017. Catchability can be considered a constant vaquita bycatch rate calculated from "the given number of pangas, fraction of pangas that are active annually, the fraction of active pangas that fished on a given day and the probability that a vaquita was caught given that a panga was fishing…" (Gerrodette & Rojas-Bracho 2011). The estimated q value of 0.00017 is based on a nonlinear average of joint distribution of fishing effort and vaquita, which means it is not scale independent. In order to use q in our model it had to be rescaled from the entire gulf to our particular cell size of 25km^2 by performing the following calculations:

The total annual vaquita bycatch in Gerrodette & Rojas-Bracho (2011) was calculated as

$$B = P * E_{UGC} * q_{UGC} * N_{UGC}$$

where B is the total number of vaquita caught as bycatch, P is the number of pangas, E_G is the total fishing effort in the entire Upper Gulf of California (UGC), q_{UGC} is the catchability for the entire UGC (0.00017), and N_{UGC} is the total number of vaquita in the UGC (177).

In this project the total vaquita bycatch needs to be calculated at a much smaller scale, at the level of each 25 km^2 grid cell:

$$B = \sum_i (P E_r q_{25} N_i)$$

$$B = P q_{25} \sum_i (E_r N_i)$$

where B is the total number of vaquita caught as bycatch, P is the number of pangas, E_r is the fishing effort per cell, q_{25} is the catchability per 25 km^2 cell (always constant) and N_i is the vaquita density per cell.

To find the appropriate q_{25}, we set these two bycatch (B) equations equal to each other,

$$P * E_{UGC} * q_{UGC} * N_{UGC} = Pq_{25} \sum_{i} (E_r N_i)$$

where q_{25} can be estimated as

$$q_{25} = \frac{q_{UGC} N_{UGC}}{\sum_i (E_r N)}$$

$$q_{25} = \frac{(0.00017)(177)}{\sum_i (E_r N)}$$

Given these equations the adjusted q_{25} was calculated to be 0.04351. A key assumption of this correction of q is that the spatial distribution of both vaquita and fishing effort was consistent across the time period used to estimate the q used in Gerrodette & Rojas-Bracho (2011).

The annual bycatch rate (b) is calculated as the proportion of the number of vaquita caught in year one (B_t) out of the entire population (N_t);

$$B_t = \sum B_i$$

$$b = \frac{B_t}{N_t}$$

5.4 Estimating the Vaquita Population in 2042

The most recent published estimate of vaquita population abundance is 248 individuals in 2008 (Gerrodette & Rojas-Bracho 2011). Due to uncertainty in the vaquita population size, we chose to evaluate the impact each policy would have on the population growth rate since it is not dependent on the number of individual vaquita there may be in the Upper Gulf of California. While the growth rate was our main concern we were able to produce an estimated vaquita population for the year 2042 for all policies as well. In order to estimate the 2042 vaquita abundance under any given policy, it was important to begin with a current 2013 estimate of the vaquita population. The model described in Gerrodette & Rojas-Bracho (2011) was used to project forward from 2008 to 2013. This analysis was performed by Tim Gerrodette at the NOAA Southwest Fisheries Science Center in La Jolla, CA in January of 2013. The model was run with the assumption that the Vaquita Refuge has been operating under a 50% compliance level since 2008. The number of pangas has also changed through the years, decreasing from 837 in 2007 to 819 in 2008, then to 589 since 2009 (Gerrodette & Rojas-Bracho 2011). Using these panga estimates and the assumed 50% compliance with respect to the Vaquita Refuge, the 2013 vaquita population (N_0) was estimated to be 177 (95% CI 98 – 295).

The current estimated vaquita population is less than 10% of historical levels mainly due to incidental bycatch (Jaramillo-Legorreta 2008) and therefore is assumed to not be limited by carrying capacity. For this reason the vaquita population (N_t) was modeled using the exponential growth equation:

$$N_t = N_0(e^r - b)^t$$

where N_0 is the estimated vaquita population in 2013 (177), r is the intrinsic growth rate (0.038), b is the annual bycatch rate calculated for each policy scenario and t is the number of years the vaquita population is modeled forward – in this model t is set to 30 to represent the year 2042.

Variable	Description
F_1	No. of primary fishing grounds
F_2	No. of secondary fishing grounds
F_t	Total no. of fishing grounds (weighted)
E_b	Baseline Fishing Effort
E_r	Resulting fishing effort
b	Bycatch rate
B	Vaquita bycatch (no. individuals)
w_x	Seasonal weights per species x
N_t	Vaquita population in year t

Table 10: List of model variables

Parameter	Description	Estimate (95%)	Reference
N_0	Vaquita population in 2013	177 (98-295)	Pers. Comm. with T. Gerrodette (2013)
r	Vaquita population intrinsic growth rate	0.038 (0.015, 0.078)	Gerrodette & Rojas-Bracho (2011)
$q25$	Catchability for each 25km^2 cell	0.04351 (0.0344 - 0.0859)	Estimated
q_{UGC}	Catchability for entire UGC region	0.00017	Gerrodette & Rojas-Bracho (2011)
P_{SFE}	Number of pangas in San Felipe	305	CEDO MIA (2012)
P_{GSC}	Number of pangas in Golfo de Santa Clara	451	CEDO MIA (2012)

Table 11: Parameters of the vaquita bioeconomic model

5.5 Calculating Vaquita Population Growth Rate (Lambda)

The vaquita population growth rate is represented as the geometric population growth rate, lambda;

$$\lambda = e^{r} - b$$

where $\boldsymbol{\lambda}$ is the geometric population growth rate, *r* is the intrinsic growth rate (0.038) and *b* is the incidental bycatch rate. Lambda was also represented as a percent of annual population increase or decline on the x-axis of figures in this analysis to be more easily understood by a wider audience. This was calculated by the following equation:

$$annual\ population\ growth\ rate = (\lambda - 1) * 100$$

5.6 Calculating Economic Values

5.6.a Calculating Net Revenue

Revenues per cell were calculated using the weighted index of fishing intensity described in the previous section under "Fishing Effort Index." This weighted index E_1 identified which cells within our ArcGIS grid are considered to be primary and secondary fishing grounds, and by how many fishermen there are for each species. By multiplying this weighting by the total landings in the UGC for each species in each town, the seasonal weighting *w* as described in section 5.2 (Fishing Effort Index), and price per species P_x, we assigned a value per cell for the fraction of the gross revenue it represents. We then subtracted the fishing costs per species C_x to get the total net revenue for each species $\boldsymbol{\pi}_{Tx}$:

$$\pi_{T_x} = \sum(E_{1_{i_x}} * H_x * w_x * P_x) - C_x$$

where E_1 is the fishing effort and H_x is the harvest of each species. As seen in the equation above, the sum of all cells will total to the net revenue provided by the economic data from CONAPESCA. With this weighted economic value now assigned to each cell, across the grid, our analysis considered the economic importance of each cell to fishers in tandem with the biological importance for vaquita. As management options were considered, and spatial closures assigned, net revenue was affected as potentially valuable cells were closed to fishing. Summing all cells for a particular management option and comparing this resulting net revenue E_2 to the no-management baseline E_1 provided the loss of fisheries revenue.

5.6.b Revenue from Alternative Shrimp Trawl

Recent experimental trials with light trawls capable of being pulled by modified pangas have shown that the shrimp catch rates can equal 1:1 with gillnet rates, but overall annual costs are approximately 24% higher primarily due to increased gasoline expenses. We assumed that fishers would be unlikely to use these trawls outside of a refuge due to the increased costs and interference caused by gillnets, but would be willing to use this method inside a proposed refuge with a gillnetting ban rather than being displaced.

During the shrimp trawling analysis, only policies with perfect compliance and no allowed gillnet fishing inside refuges were considered due to the interference with trawling this would cause. Since we assume that trawl and gillnet catch rates are 1:1, our model assumes landings unaccounted for outside of the refuges could be accounted for inside the refuges with trawls. We modeled the additional net revenue for the current refuge, swollen refuge, full Upper Gulf closure, 90% protection refuge, and 95% protection refuge, then combined with total gillnetting net revenue using the following equations:

Trawl shrimp landings inside proposed refuges:

$$GSC_{TL} = GSC_{SUG} - GSC_{GL}$$
$$SFE_{TL} = SFE_{SUG} - SFE_{GL}$$

Trawl net revenues:

$$SFE_{TNR} = SFE_{SP} \times SFE_{TL} - 1.24\,(SFE_{TL} \div SFE_{SUG} \times SFE_{SC})$$
$$GSC_{TNR} = GSC_{SP} \times GSC_{TL} - 1.24\,(GSC_{TL} \div GSC_{SUG} \times GSC_{SC})$$

Total Net Revenue (normalized):

$$TNR = \left(G_{TNR} + (SFE_{TNR} + GSC_{TNR})\right) \div NR_{baseline}$$

GSC_{TL} = total Golfo de Santa Clara trawl shrimp landings (kg)
SFE_{TL} = total San Felipe trawl shrimp landings (kg)
GSC_{GL}= total Golfo de Santa Clara gillnet landings (kg)
SFE_{GL}= total San Felipe gillnet landings (kg)
GSC_{SUG}= total average shrimp landings in UGC by Golfo de Santa Clara fishers (no spatial closures) (kg)
SFE_{SUG}= total average shrimp landings in UGC by San Felipe fishers (no spatial closures) (kg)
GSC_{SC}= total annual costs to shrimp fishery in Golfo de Santa Clara (pesos)
SFE_{SC}=total annual costs to shrimp fishery in San Felipe (pesos)
GSC_{TNR}= trawl net revenue in Golfo de Santa Clara (pesos)
SFE_{TNR}= trawl net revenue in San Felipe (pesos)
GSC_{SP}= market price of shrimp received by fishers in Golfo de Santa Clara (pesos)
SFE_{SP}= market price of shrimp received by fishers in San Felipe (pesos)
G_{TNR}= total gillnetting net revenue (pesos)
$NR_{baseline}$= net revenue in UGC with no fishing restrictions
TNR= normalized total net revenue

5.6.c Normalized net revenue

Evaluation of economic performance for each management option was normalized to the calculated net revenue achieved under a no management scenario. By normalizing this baseline to *1.0*, which would be the maximum amount of revenue possible without fishing restrictions, we quantified relative decreases associated with any given management option. Normalized economic values were plotted on the bioeconomic tradeoff axes as discussed in the previous section under tradeoff approach. We normalized each net revenue values as follows for $\boldsymbol{\pi}_{\text{norm}}$, where $\boldsymbol{\pi}_T$ is the resulting net revenue calculated for any one of the 340 policy combinations evaluated in our analysis per species x, and $\boldsymbol{\pi}_1$ is the baseline fisheries net revenue for all species:

$$\pi_{norm} = \frac{\pi_{T_x}}{\pi_1}$$

5.6.d Cost of Compensating Lost Fishery Revenue

While we used normalized fisheries revenue to model tradeoffs in the outcomes of conservation policies, allowing decision makers or stakeholders to consider impacts in relative terms for their operations, we also reported the actual value of annual changes in 2013 pesos ($MXN). By also presenting predicted revenue changes in a pesos amount, these values can then be incorporated into calculations of how much money would be needed in order to sufficiently compensate for losses—assuming this would be the preferred strategy for mitigating losses in economic revenue associated with vaquita conservation. Here we consider one method for estimating the actual cost of compensation for the annual losses in fisheries revenue if we know the loss[5] to the fisheries in each year.

Because we made the assumption that landings will be constant over time, in accordance to the weighted fishing index (described in Section 5.2 'Fishing Effort Index'), we also made the assumption that each policy will have the same effect on landings each year throughout the time horizon. This signifies that any change in fisheries revenue associated with a policy will also be constant each year in perpetuity. Therefore, compensation for losses would also need to occur every year. The true cost of this amount can be reflected by the minimum peso amount needed for a trust fund to generate interest on capital each year, equivalent to the amount in losses associated with a given vaquita recovery policy (see Appendix, Table E). We calculate the compensation costs associated for a given policy using Mexico's 2013 inflation adjusted interest rate *r* of 4.5% for a 10-year Mexican securities bond (Banco de Mexico 2013), whereby $\boldsymbol{\pi}_1$ is the baseline net fisheries revenue, and $\boldsymbol{\pi}_T$ is net revenue for any policy outcome:

$$C_{compensation} = \frac{(\pi_1 - \pi_T)}{r}$$

5.7 MARXAN

Marxan is open-source conservation planning software developed at the University of Queensland, Australia (Ball et al. 2009). This analysis utilized Marxan as a decision support tool to evaluate the efficiency of the existing Vaquita Refuge (see Figure 11) and to investigate new reserve designs under varying conservation objectives. Marxan uses heuristic, simulated annealing algorithms to provide good, near-optimal solutions in a timely manner, as opposed to exact algorithms that are often times impossible to use for complicated spatial planning (Ball et al. 2009). A score is assigned to each simulation based on the cost of the reserve, boundary

[5] Lacking other info, we assume that the losses are the same every year.

length of the reserve, and penalties for unmet conservation goals. The simulation with the lowest score is the optimal choice, meaning the reserve with the lowest economic cost that achieves a specified conservation goal.

For our analysis, we used our data on fishing revenue per cell and vaquita abundance per cell in our Marxan input files. The proportion of vaquita being conserved (90% and 95% of the population) was manipulated in the Conservation Feature File to investigate how to minimize fisheries closures while still meeting conservation goals. In the case of the 90% refuge, a boundary length modifier of 30 was required to create a contiguous refuge, which would most likely be necessary since vaquita are capable of traveling throughout their entire range in a single day. The 95% refuge required a boundary length modifier of 1 to create a contiguous refuge. For each refuge, we did 100 runs in Marxan. It is also important to note that refuges protecting 50% and 80% of the population were also analyzed, but not considered in our final analysis (see Appendix, Figures E & F and subsequent description).

Our analysis utilized three different Marxan output files to gather information on the two theoretical refuge sizes needed to achieve varying levels of vaquita protection:

- Best Solution from All Runs File (output_best.txt): displayed planning unit ID numbers for the most efficient refuge and if they should be opened or closed to fishing.
- Summed Solution File (output_ssoln.txt): showed the selection frequency of each planning unit. This file was used to confirm that the planning units selected in the Best Solution from All Runs file were consistently selected over the 100 Marxan runs we similated, which they were.
- Missing Values File (output_mvbest.txt): showed the vaquita abundance goal, actual abundance achieved by the reserve, and stated yes/no if the goal was met. Refuges were only considered if the conservation goal was met; in our two cases, the refuges had to effectively protect 90% and 95% of vaquita range.

For a map of the Marxan 90% and 95% protection refuges, see Section 5.1, Figures 12 and13.

5.8 Using R to Find Model Outputs

After first creating a basic model in Microsoft Excel we developed a more robust model in the computer software R. Since the bioeconomic model calculated the outcomes of over 300 different policy combinations it was important to use R rather than Excel to facilitate multiple runs of the model.

5.9 Structure of Tradeoff

The final deliverable for this project is a tradeoff analysis to serve as a tool to guide the selection of policy options that will lead to increased vaquita abundance at the least economic expense. Although win-win solutions are always highly sought out with conflicting conservation and economic interests, gains for biodiversity and human well-being are often difficult to attain

(McShane et al. 2011). Rather than only seeking management strategies that achieve increases in both vaquita abundance and net revenue, our analysis aimed to identify policies with the best economic outcome for each of a range of vaquita outcomes.

5.9.a Tradeoff Axes

Our tradeoff analysis has two primary axes: projected vaquita growth rate on the x-axis and normalized revenue on the y-axis. The baseline net revenue value was based on total fishery revenue with no fishing restrictions, which was then normalized to 1.0 on the y-axis. Each policy's economic effects were measured by the relative decrease from the baseline value and were considered constant for each policy over the 30-year period of our model.

5.9.b Efficiency Frontier Curve

By plotting all policy options, a downward curve along the upper bound of plotted points was created, also called the efficiency frontier. Points that fell below the efficiency frontier could be improved at no cost to either interest, and no points exceeded the efficiency frontier since, by definition, this is unattainable in a tradeoff analysis (White et al. 2012).

Concavely shaped tradeoffs indicate that even small increases for one interest come at a large cost to the other interest (Lester et al. 2013), which appears to be the case with the vaquita when considering policies that lead to an increasing growth rate. In these cases societal preferences for one interest play a major role in choosing policy options. Convexly shaped tradeoffs indicate that improvements to one interest are possible without a large cost to the other interest (Lester et al. 2013), which may be the case if displacement and spillover effects are considered.

5.9.c Policy Evaluation

We evaluated our five different management options (spatial closures, buy-outs, compliance levels, alternative trawling, and species closures) with a statistically robust analysis using the program R. For each individual policy a projected vaquita growth rate (x-coordinate) was calculated as described in Section 5.5 and the resulting net revenue from fishing under the same policy (y-coordinate) was calculated as described in Section 5.6. These coordinates, vaquita growth rate and normalized fisheries revenue, were plotted to create the final tradeoff output.

5.10 Calculating Uncertainty

Uncertainty around the results was calculated as a probability of the vaquita population growth rate (lambda) being greater than 1 for each policy output. Estimated parameters (q, N and r) were drawn from their bivariate distributions as provided by Tim Gerrodette for his vaquita population model (see Appendix). Appendix Figure D displays the probability that a policy outcome may result in an increasing population growth rate.

6. Results

6.1 Tradeoff Plot

The final output tradeoff plot displays all 340 separate policy outcomes in terms of annual net fisheries revenue (normalized to baseline of no management) and the projected population growth rate (Figure 15). The growth rate along the x-axis (lambda) is displayed as a percent where a value of 0% represents neither population growth nor decline. Values greater than 0% indicate population growth and values less than 0% represent population decline. 294 policy scenarios are projected to hold the population growth rate below 0%, indicating continued vaquita decline and likely extinction. 46 policy outcomes are projected to reduce bycatch to where the vaquita population will increase, as seen by all points to the right of the line in Figure 15. This final output shows a broad spectrum of policy outcomes achievable through different policy combinations; these include numerous policies that meet conservation goals as well as minimize forgone fisheries revenues. Figure 16 displays the same results but in terms of expected vaquita population in 2042. The following section presents the principal observations that emerged in this tradeoff analysis.

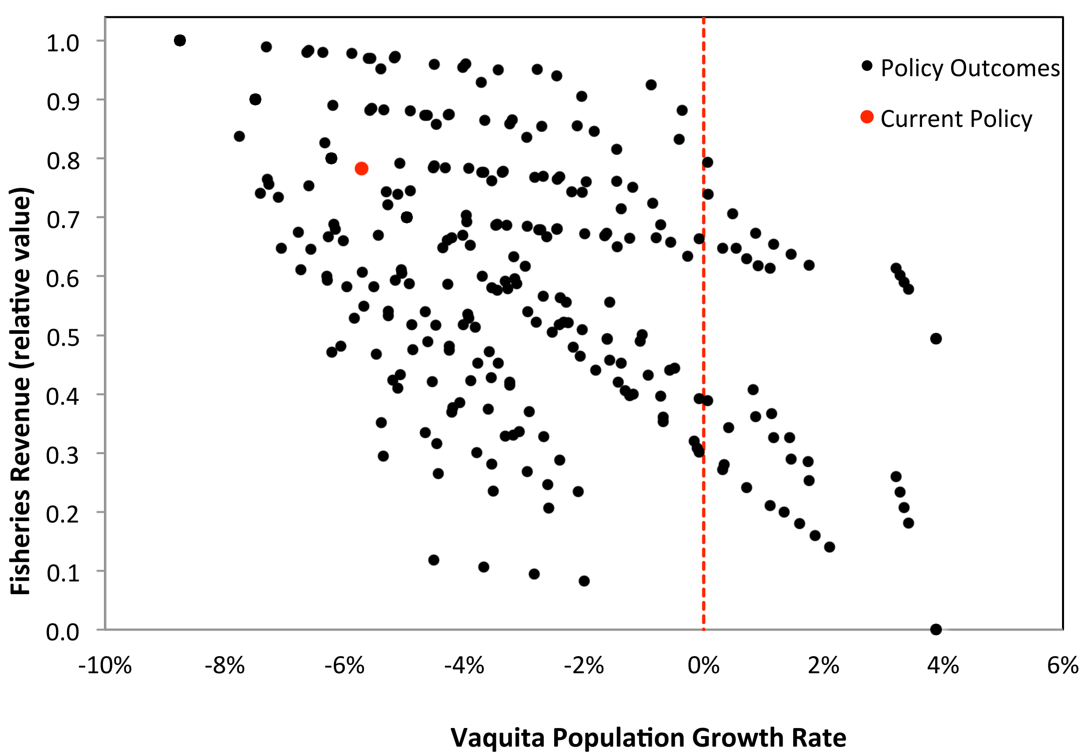

Figure 15: Tradeoff plot of all 340 different policy combinations. Black points represent the modeled outcome of a single policy scenario in terms of fisheries revenue and the vaquita population growth rate. The vertical red dashed line at 0% represents the point in which population growth rate is neither growing nor declining. All policies that lie to the right of the dashed line indicate a growing vaquita population.

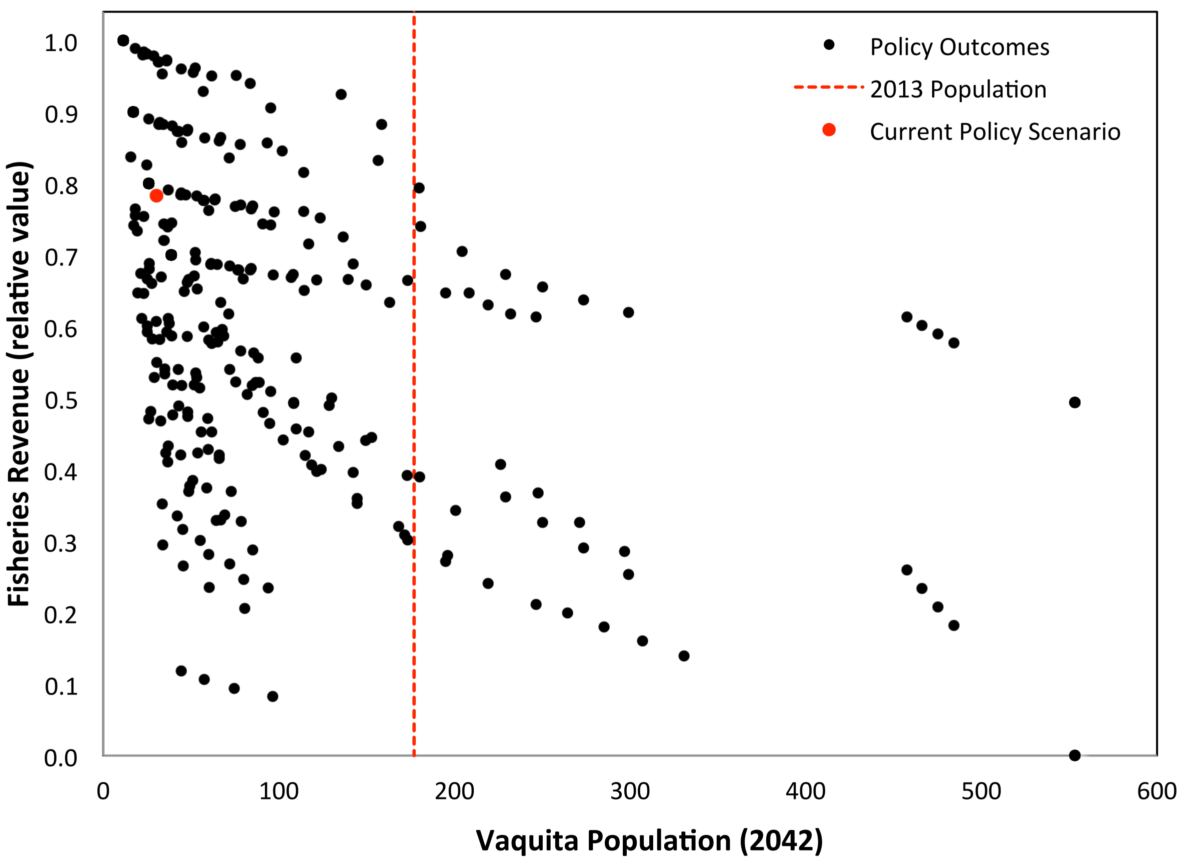

Figure 16: Tradeoff plot of all 340 different policy combinations. Black points represent the modeled outcome of a single policy scenario in terms of fisheries revenue and the estimated vaquita population. The vertical red dashed line at 177 represents the current estimated vaquita population for 2013. All policies that lie to the right of the dashed line indicate a growing vaquita population after 30 years.

6.2 Efficiency Frontier

From plotting the results of our modeled policy combinations, a clear efficiency frontier can be observed along the outermost points (seen as the black line in Figure 17). The efficiency frontier identifies all points with efficient policy outcomes, either optimizing for the vaquita population, fisheries revenue, or both. Under policies where the vaquita population growth is maximized, all fisheries revenue is forgone; conversely, policies that maximize fisheries revenue cause the vaquita population to decline by 9% each year. The general shape of this curve, neither completely convex nor concave, is a result of the alternative trawl being only implementable under certain policy combinations. Any point below the frontier can be considered sub-efficient, meaning that policy modifications could allow a better performance if pushed out to the frontier.

From identifying this efficiency frontier, our results also indicate that the current policy scenario is not efficient. The red point in Figure 17 represents the bioeconomic outcome of the current Vaquita Refuge, complied with at a 50% level and no buyout. This policy yields only 78.2% of baseline fisheries revenue while achieving vaquita population growth rate lambda of 0.94 – a 6%

decrease in population annually - which is far below the 1.0 required for population increase over the time horizon. There are clear improvements to the current policy that will move the outcome closer to the efficiency frontier, which are detailed in section 7.2.a.

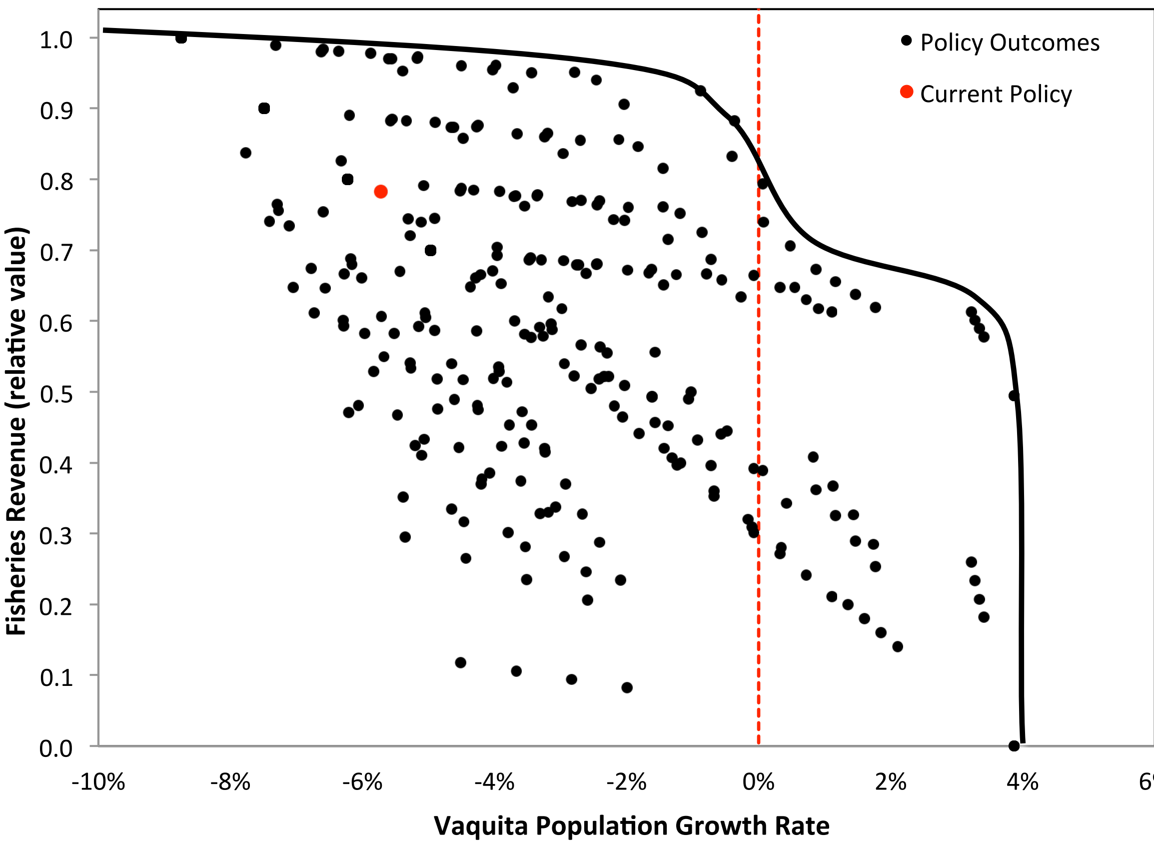

Figure 17: Tradeoff plot of all 340 different policy combinations. Black points represent the modeled outcome of a single policy scenario in terms of fisheries revenue and the vaquita population growth rate. The vertical red dashed line at 0% represents the point in which population growth rate is neither increasing nor decreasing. All policies that lie to the right of the dashed line indicate a growing vaquita population. The red point represents the current policy – the vaquita refuge operating at a 50% compliance rate. The black line marks the efficiency frontier, which is outlined by the most optimal policy points.

6.3 Varying Outcomes for Gillnet Restrictions

An important aspect of this analysis is to evaluate the effect of closing the small scale gillnet shrimping fishery as it is widely believed to be one of the most threatening fisheries to vaquita in the UGC. Much of the contentious management debate centers on shrimp gillnetting; therefore explicitly modeling the outcome of policies that would close this fishery provides valuable insight for stakeholders.

Our results indicate that only prohibiting shrimp gillnet fishing within any of the five spatial refuge designs will never result in vaquita population growth. This policy option was modeled with the assumption that all other finfish gillnet-fisheries operated without restriction. For this case, the best outcome for the vaquita population would be an estimated lambda growth rate of 0.98, which translates into a 2% decline annually. This is significantly below the goal of achieving a growth rate (lambda) greater than 1 (Figure 18). Furthermore, there is a comparatively high loss in fisheries revenue associated with the shrimp closure policy that performs best for the vaquita (seen in terms of the y-axis in Figure 18). In this best-case scenario for the vaquita population, the cost would be equivalent to over 90% of baseline fisheries net revenue. Because the alternative trawl cannot operate when gillnet fishing occurs in the same area, this policy option was not modeled with the option to implement the shrimp trawl.

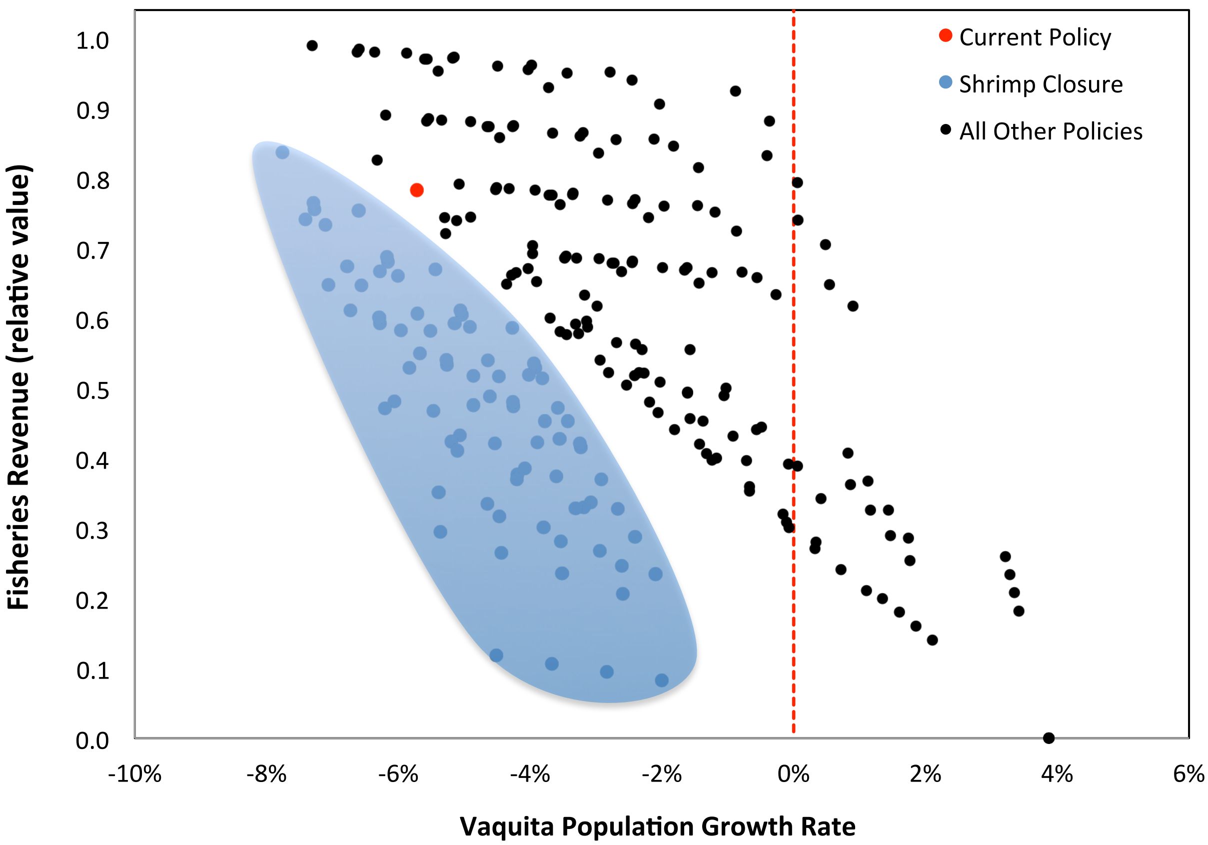

Figure 18: The above chart shows the resulting vaquita population growth rate for all policies (blue points) that ban only shrimp gillnet fishing; black circles represent all other policy scenarios that do not ban shrimp gillnetting. The red point represents the current policy. Policies are plotted according to their economic (y-axis) and biological performance (x-axis). The dashed red line at 0% marks a stable growth rate where the vaquita population is neither growing nor declining. The policies that will promote vaquita population growth lie to the right of this line. None of the shrimp ban policies met or increased vaquita population.

We plotted fisheries closures in order to identify if any scenarios that close finfish gillnetting, while leaving shrimp gillnetting open, lead to vaquita population growth. Five policies were identified that allow increases beyond the minimum target of a growth rate at or above a lambda of 1, or 0% growth (see Figure 19**)**, in which only finfish gillnetting is banned. The best performing policy from these shows that with full compliance of a finfish gillnet ban in the full spatial closure, vaquita population will grow by 0.9%. This is the case when the fishing effort is reduced by 30% through a buyout program, leading to a 39% loss in fisheries revenue. A slight increase in population growth rate to 0.1% can be achieved if the buyout level is 10%, with fisheries revenue expected at 79.4% of the current estimated fisheries revenue. The other three population increasing finfish bans have intermediary outcomes (see Table 12 for values).

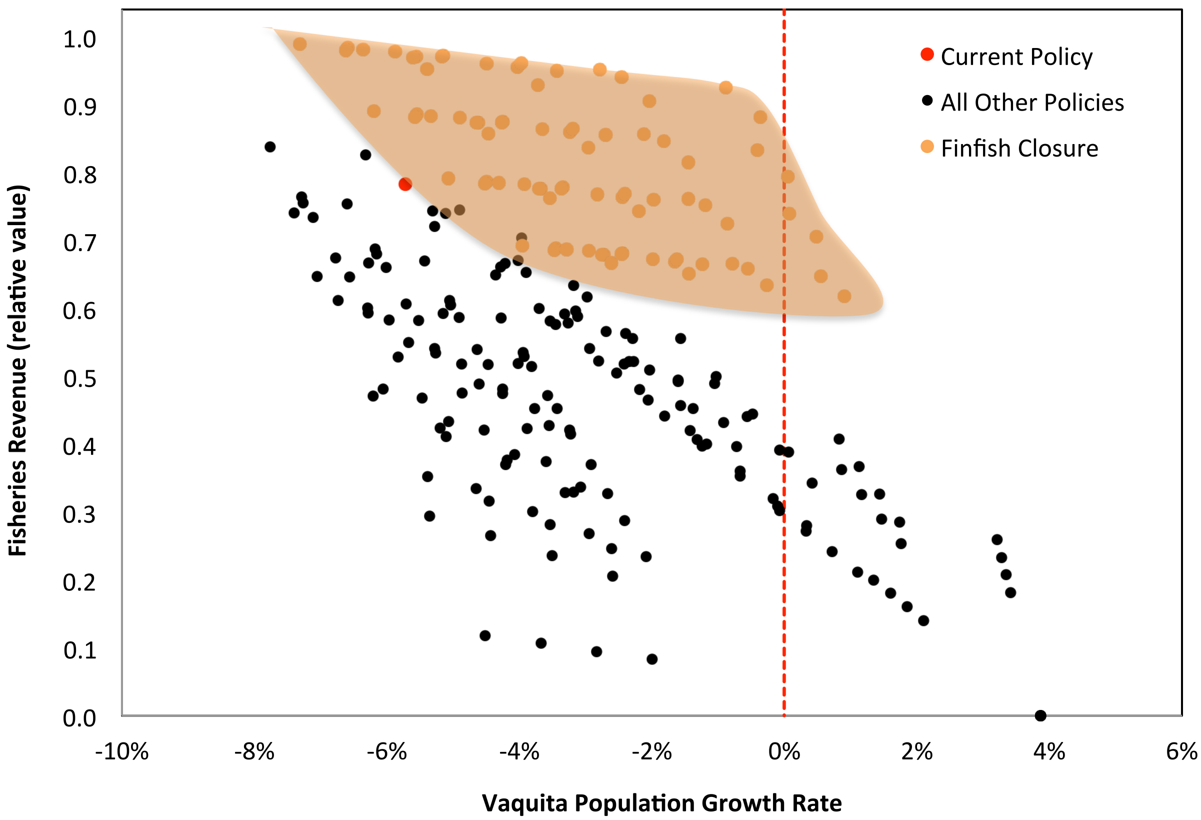

Figure 19: The above figure shows all possible finfish-only closures represented by the orange points; black points represent all other policy scenarios. The red point represents the current policy. The vertical line at a growth rate of 0% indicates a stable population growth rate, therefore the point from which population increase would be observed (to the right of the line).

Shrimp Gillnet Closures that Allow Vaquita Population Growth					
Spatial Closure	**Buyout Level**	**Fisheries Closure**	**Compliance Level**	**Normalized Revenue**	**Vaquita Population Growth Rate**
All Closed	0.3	3	1	0.617	1.009
Marxan 95	0.3	3	1	0.647	1.005
All Closed	0.2	3	1	0.706	1.005
Marxan 95	0.2	3	1	0.740	1.001
All Closed	0.1	3	1	0.794	1.001

Table 12: The above table provides a description of specific policies and associated numerical values for all policies that only ban gillnetting for finfish (Fishery Closure "3"), but that can have an outcome of increased vaquita abundance. These policies are ordered from greatest vaquita population growth rate, as seen from furthest to the right in Figure 19.

Fishery policies that do allow for substantial vaquita population increases are those that include restrictions on both finfish and shrimp. Figure 20 shows that numerous policies lie to the right of our target for a vaquita population growth rate at or above 0%. The policies of highest benefit to the vaquita are observed at the far right of the plot, where the population growth rate reaches a lambda of 1.04 – indicating an annual growth of 4% each year. This policy scenario includes full compliance with a complete closure of the study area (being the 'Full Closure' policy); under this scenario, all fisheries revenue is lost. Significant population growth can be seen in the incremental polices to the left of the vaquita maximizing point, representing the Marxan 95% refuge, which would allow for an annual population increase of 3.2% and a 74% loss of current fisheries revenue (without any level of buyout). Values representing all policies that lead to population growth under the combined shrimp and gillnet closure are presented in Appendix, Table F.

Figure 20: The above figure depicts all policies that include a combination of shrimp and finfish closures, represented by the dark green points; black circles represent all other policy scenarios that are not a shrimp-finfish combined closures. The red point represents the current policy. Policies are plotted according to their economic (y-axis) and biological performance (x-axis). The vertical line at a growth rate of 0% indicates a stable population growth rate, therefore the point from which population increase would be observed (to the right of the line). Policy descriptions and values for all policies with outcomes of an growing vaquita population are listed in Appendix, Table F.

6.4 Current Vaquita Refuge Does Not Achieve Population Increase

Our results indicate that the current policy scenario does not achieve population increase, which is comprised of the Vaquita Refuge designated in 2005. Furthermore, in examining all possible outcomes from policy combinations that include the Vaquita Refuge, our results show that there are no possible policy combinations that achieve a reduction in bycatch sufficient enough to allow for an increase in population. All Vaquita Refuge policy combinations are highlighted in Figure 21. The vaquita maximizing combination for these policies achieves a lambda growth rate of 0.99 (decline of 1% annually) and fisheries revenue is reduced to 68.7% of the current baseline revenue. This large loss to fisheries revenue can be decreased to a 39.5% loss by implementing the alternative trawl.

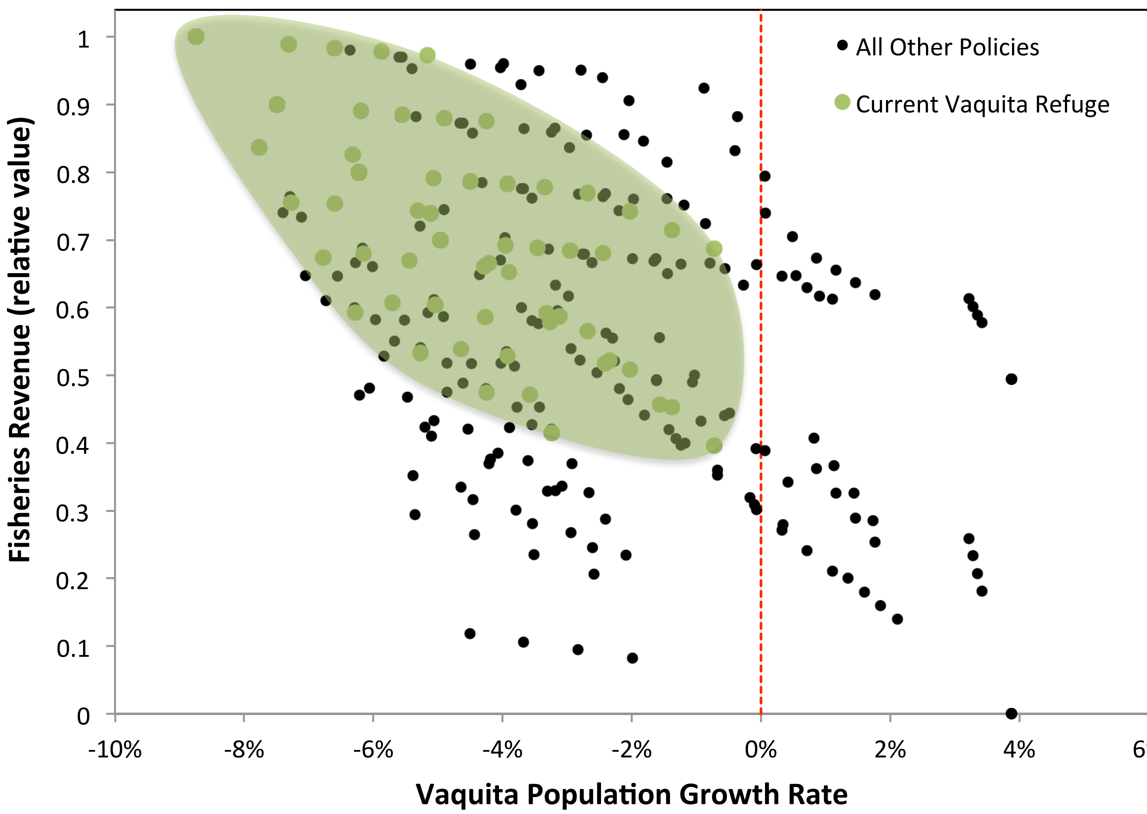

Figure 21: The above plot illustrates all policy combinations for the current Vaquita Refuge, represented by the green points. The vertical line at a growth rate of 0% indicates a stable population growth rate, therefore the point from which population increase would be observed (to the right of the line). The shaded green area is considered the policy space associated with the current refuge.

6.5 Alternative Trawl Enhances Economic Performance of Policies

Our model identified 20 policies that met the compliance and species closure criteria for implementation of the alternative trawl. Fifteen of these achieved vaquita population growth (see Table 13). None of the current Vaquita Refuge closure and buyout scenarios are projected to achieve population growth, while the 90% protection refuge, 95% protection refuge, full closure, and swollen refuge scenarios all achieve this goal, with one exception for the swollen refuge in the case of no buyout. There is a general trend of decreasing economic value as fishing restrictions favor vaquita, but it is important to point out that this trend is less pronounced when alternative trawling is considered. The model results indicate economic declines from successful conservation policies may be as little as 33-51% with trawling introduced, compared to declines of 64-100% without trawling (Figure 22). Regardless, trawling would lead to a substantial reduction in the economic impact of successful conservation policies.

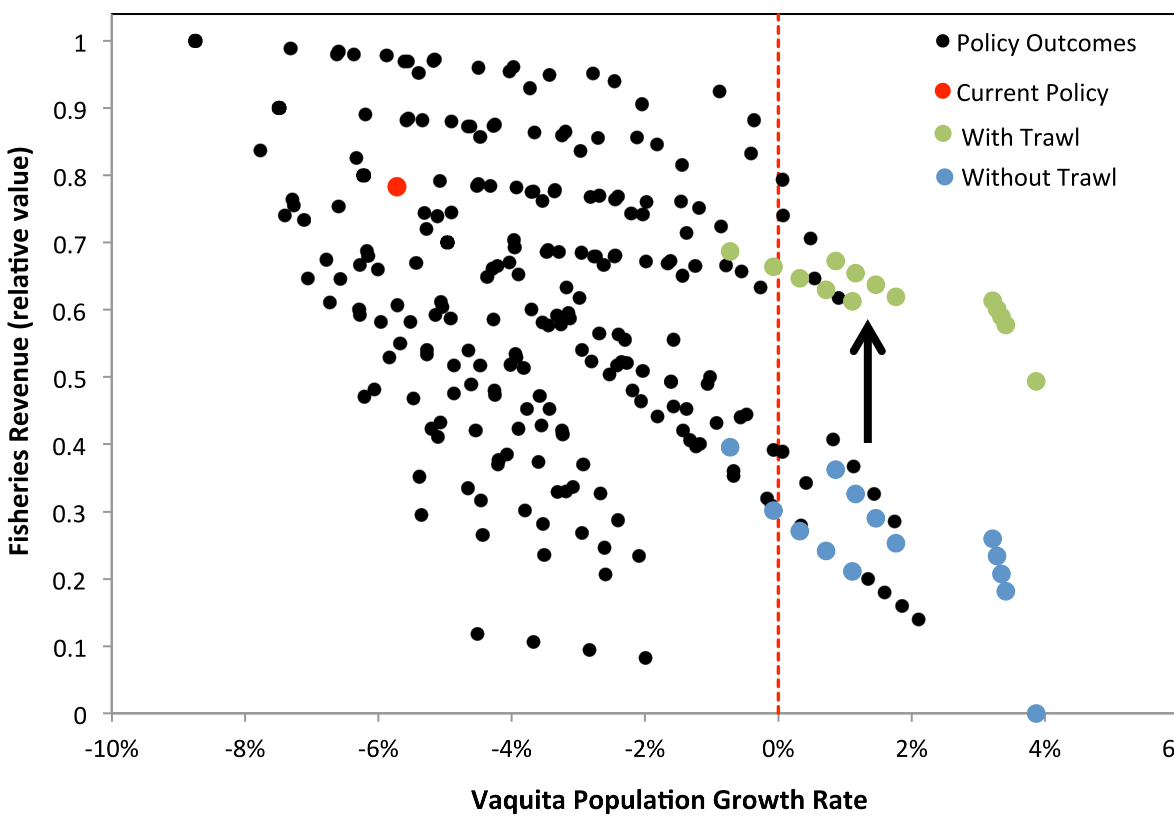

Figure 22: Expected outcomes for vaquita population growth rate and fisheries revenue under each policy scenario. Blue points mark policies that are viable for alternative trawl implementation due to a perfect compliance level and no gillnetting allowed within trawl areas (refuges). Green points mark the reduced losses to fisheries revenue after the alternative trawl is implemented.

Evaluation of Alternative Trawl Policies				
Spatial Closure	Buyout Level	Normalized Revenue (Trawl)	Normalized Revenue (No Trawl)	Vaquita Growth Rate
Refuge	0	0.77	0.57	0.97
Refuge	0.1	0.74	0.51	0.98
Refuge	0.2	0.71	0.45	0.99
Refuge	0.3	0.69	0.40	0.99
Swollen Refuge	0	0.66	0.30	1.00
Swollen Refuge	0.1	0.65	0.27	1.00
Swollen Refuge	0.2	0.63	0.24	1.01
Swollen Refuge	0.3	0.61	0.21	1.01
Marxan 95%	0	0.61	0.26	1.03
Marxan 95%	0.1	0.60	0.23	1.03
Marxan 95%	0.2	0.59	0.21	1.03
Marxan 95%	0.3	0.58	0.18	1.03
All Closed	0	0.49	0.00	1.04
All Closed	0.1	0.49	0.00	1.04
All Closed	0.2	0.49	0.00	1.04
All Closed	0.3	0.49	0.00	1.04
Marxan 90%	0	0.67	0.36	1.01
Marxan 90%	0.1	0.66	0.33	1.01
Marxan 90%	0.2	0.64	0.29	1.01
Marxan 90%	0.3	0.62	0.25	1.02

Table 13: Alternative trawl policy scenarios and respective impacts on revenue. Policies in red indicate failure to achieve increasing vaquita growth rate. Any growth rate (lambda) greater than 1 indicates a growing population.

6.6 Marxan 90% Refuge Performance

Of the 68 policy options considered for the 90% protection refuge designed with Marxan, 9 (13.2% of all policy options) achieved population growth above the current estimate (see Figure 23). These policies constitute 19.5% of the total that had growth rates high enough for the population to either remain stable or increase. In total, there were only three successful policies with revenues higher than the 95% protection refuge, although the abundances were only minimally greater than the current estimate in those instances. The maximum growth rate for this spatial closure was projected to be at 2% when combining this refuge with a 30% buyout, although fisheries revenue would be reduced to 25.3-61.9% of the current level, depending if the shrimp trawl was implemented within the refuge. To be successful and have any population increase, this refuge would require either perfect compliance, or a minimum of 80% compliance coupled with a 30% buyout and no gillnet fishing allowed within its borders (see Table 14).

Evaluation of Marxan 90 Refuges that Project Increasing Vaquita Population					
Spatial Closure	**Buyout Level**	**Fisheries Closure**	**compliance Level**	**Fisheries Revenue**	**Vaquita Population Growth Rate**
Marxan 90	0.3	5	1	0.619	1.018
Marxan 90	0.3	1	1	0.253	1.018
Marxan 90	0.2	5	1	0.637	1.015
Marxan 90	0.2	1	1	0.290	1.015
Marxan 90	0.1	5	1	0.655	1.012
Marxan 90	0.1	1	1	0.326	1.012
Marxan 90	0	5	1	0.673	1.009
Marxan 90	0	1	1	0.362	1.009
Marxan 90	0.3	1	0.8	0.343	1.004

Table 14: All Marxan 90 refuge options that achieve increasing vaquita population growth rates. Any growth rate (lambda) greater than 1 indicates a growing population.

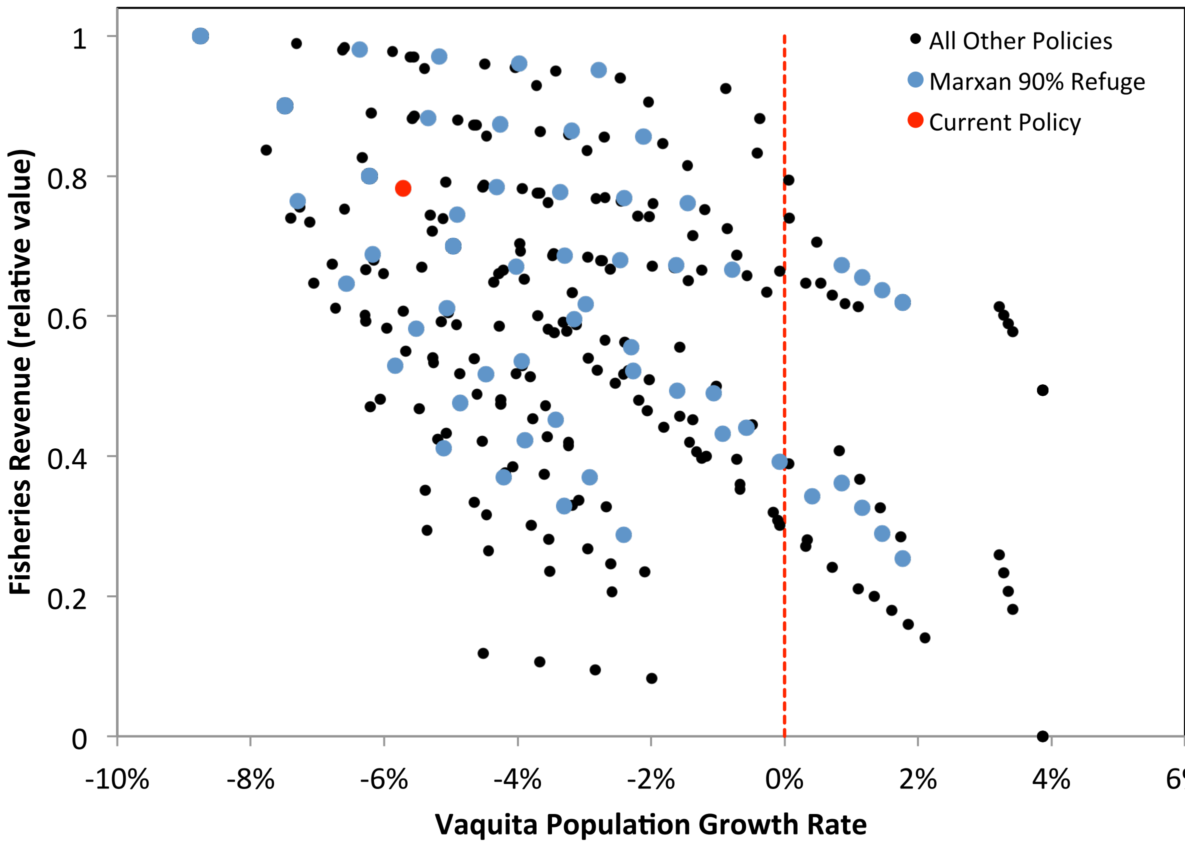

Figure 23: Comparison of projected vaquita growth rate and corresponding changes in fisheries revenue when implementing 90% protection refuge. Policies with near-perfect compliance and no gillnetting within the refuge achieve population growth rate greater than 0% (marked by the dashed red line).

6.7 Marxan 95% Protection Refuge Performance

Of the 68 policies considered for the Marxan 95% protection refuge, 15 achieved an increasing growth rate above the current estimate (Figure 24). With the exception of the full closure scenario, this spatial closure had the most policy options that met our conservation goal. The maximum growth rate for this spatial closure was projected to be a lambda of 1.03 (approximately 3.5%) when combining this refuge with a 30% buyout, although fisheries revenue would be reduced by 42.3% from the current value. Under the best scenario for revenue that also met the conservation goal, there was a reduction of 26.1% and growth rate equal to 0%. To be successful and have any growth rate increase, this refuge would require either perfect compliance, or a minimum of 60% compliance coupled with a 30% buyout and no gillnet fishing allowed within its borders (Table 15).

Successful Policy Combinations for 95% Protection Refuge

Buyout Level	Fishery Closure	Compliance Level	Normalized Revenue	Vaquita Abundance	Bycatch Rate	Growth Rate
0.3	1	1	0.1816	484	0.00	1.03
0.3	5	1	0.5775	484	0.00	1.03
0.2	1	1	0.2075	475	0.01	1.03
0.2	5	1	0.5895	475	0.01	1.03
0.1	1	1	0.2334	466	0.01	1.03
0.1	5	1	0.6014	466	0.01	1.03
0	1	1	0.2594	458	0.01	1.03
0	5	1	0.6133	458	0.01	1.03
0.3	1	0.8	0.2852	297	0.02	1.02
0.2	1	0.8	0.3260	271	0.02	1.01
0.1	1	0.8	0.3667	248	0.03	1.01
0	1	0.8	0.4075	226	0.03	1.01
0.3	3	1	0.6473	208	0.03	1.01
0.2	3	1	0.7398	181	0.04	1.00
0.3	1	0.6	0.3889	180	0.04	1.00

Table 15: All policy options that achieve vaquita abundance and growth rates above the current estimate.

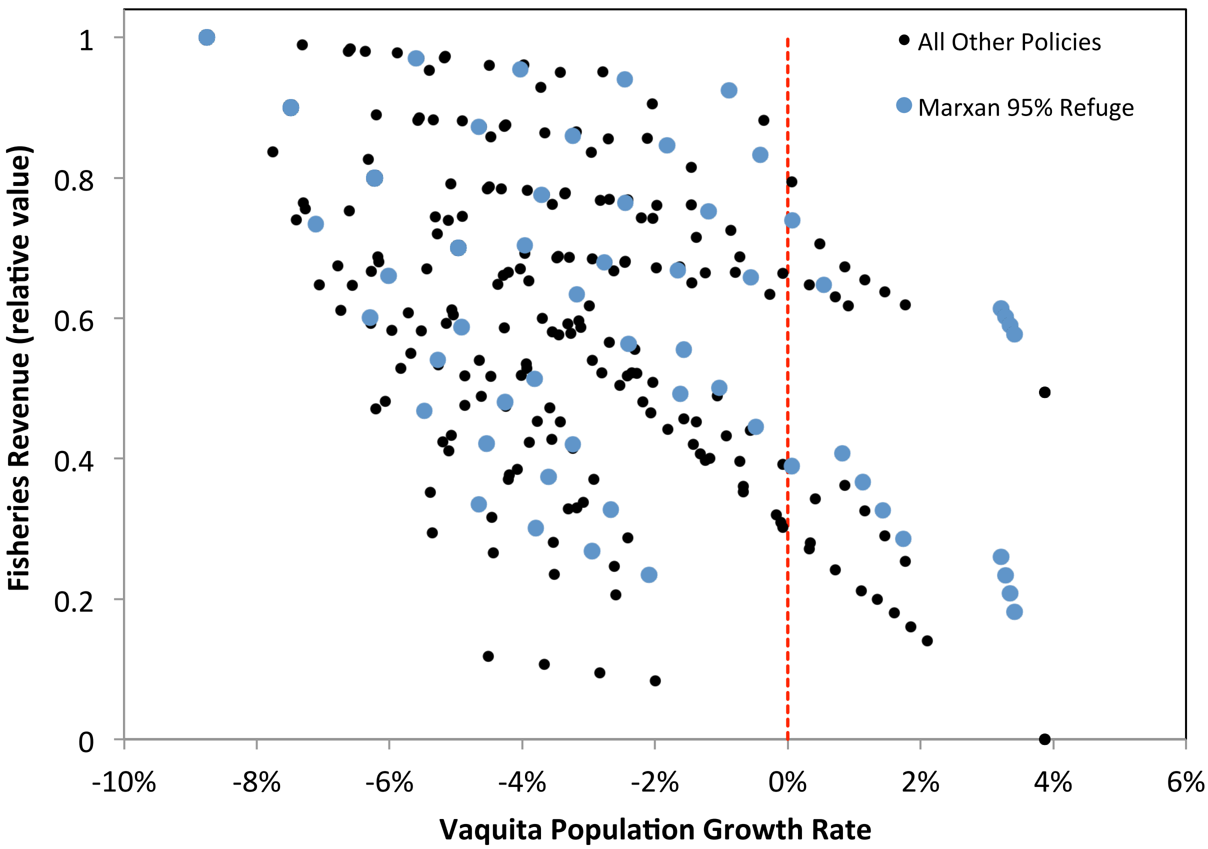

Figure 24: The above plot show all 64 possible 95% protection Marxan generated closures represented by the blue points; black points represent the full-closure policy scenario. Policies are plotted according to their economic (y-axis) and biological performance (x-axis). The vertical line at a growth rate of 0% indicates a stable population growth rate, therefore the point from which population increase would be observed (to the right of the line).

6.8 80% Compliance Threshold

In order to understand the effect of compliance over the set of policies generated, all options that indicated population growth were analyzed in relation to the level of associated compliance. Results showed that all policies that allow vaquita population to increase have compliance levels at or above 80%, with the exception of two policies that had 60% compliance level (see Appendix, Table G). However, these two policies result in a 0% and 3% increase in population annually. Figure 25 shows how a majority of options with less than 80% compliance project outcomes under the threshold line that indicates the current population of vaquita, while numerous policies with higher than 80% compliance exceed the population recovery line.

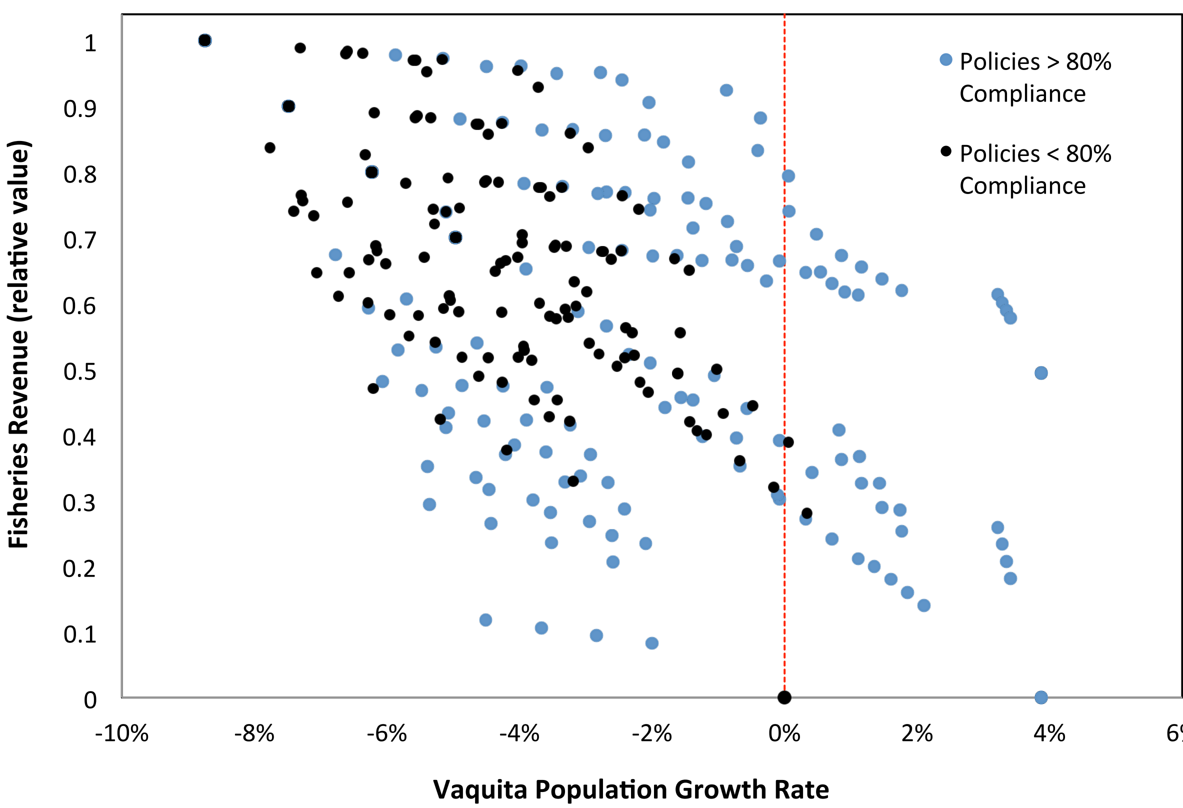

Figure 25: Comparison between policies that have greater than 80% compliance (blue points) and those that have a compliance level less than 80% (black points). The vertical line at a growth rate of 0% indicates a stable population growth rate, therefore the point from which population increase would be observed (to the right of the line).

6.9 Comparative Effect of Compliance and Buyout Levels

Our results indicate that buyout and compliance have different effects on policy outcomes for revenue and vaquita population growth rate. Because the impact will vary with the particular combination of a policy, comparing the average effect is helpful to understand the relative impact achieving incremental levels of these two factors has on vaquita population growth rate and fisheries revenue from landings. Table 16 provides values for the mean and median difference in outcomes from a 10% incremental change in buyout or compliance. Achieving an increase in buyout would have an average effect of increasing the vaquita population growth rate by 0.0081, while resulting in a decrease of normalized net revenue from landings of 0.0669. For compliance, achieving a 10% increase would have the effect of increasing 0.0042 for vaquita population growth rate, and a decrease in normalized revenue of 0.0292. These results indicate that incremental changes in buyouts have a greater impact in the outcomes of conservation policy than do those of compliance, on average.

Average change in outcome from 10% change in buyout or compliance level				
	Normalized Revenue		Vaquita Population Growth Rate	
	Mean	Median	Mean	Median
Buyout	0.0669	0.0674	0.0081	0.0088
Compliance	0.0298	0.0202	0.0042	0.0037

Table 16: Average change in the outcome of a policy from a 10% change in buyout or compliance level.

6.10 Accounting for Uncertainty

With the high amount of uncertainty involved inherent in the vaquita model, it is important to look at the range of uncertainty that lies around each policy option. Understanding this uncertainty will help select policies that meet the conservation goal with the lowest amount of uncertainty. As described in section 5.1, bivariate distributions of the estimated parameters, *q, N* and *r,* were used to calculate the probability that each modeled policy output could have a vaquita population growth rate greater than 1, indicating a growing population. The range in probabilities around the output can be seen in Figure 26.

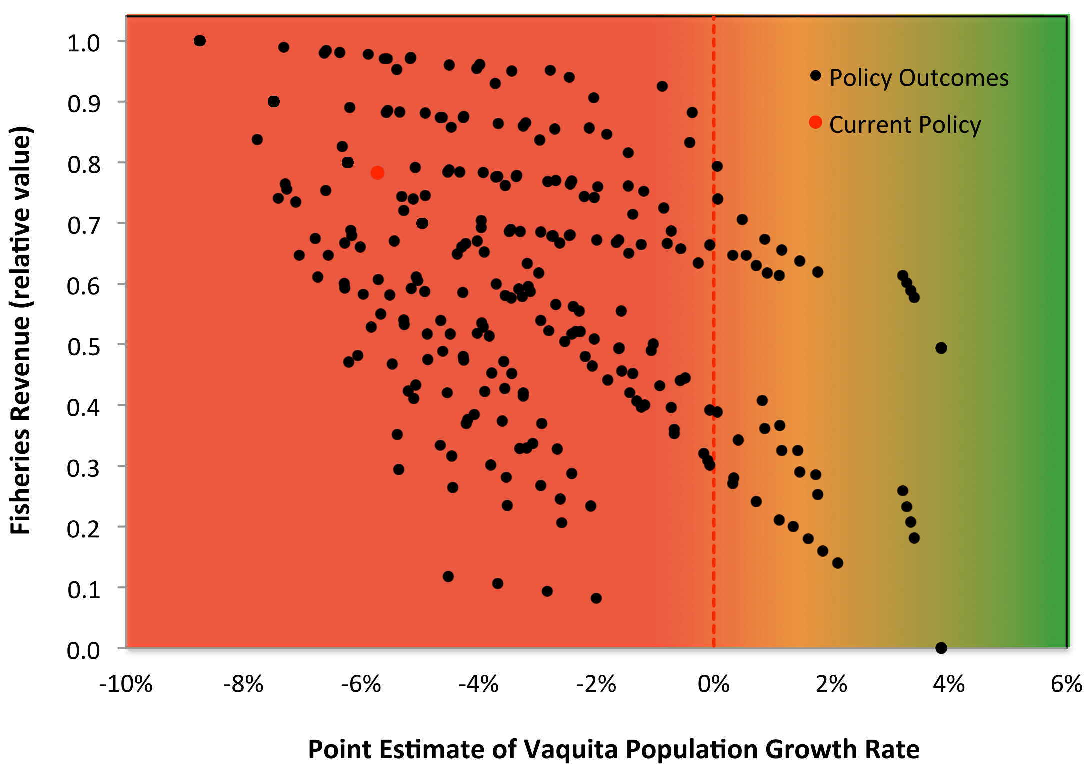

Figure 26: All policy options displayed against a gradient of uncertainty. Outcomes that fall within the red and orange space are less likely to result in an increasing vaquita population while those policies that lie within the green space are almost certain to lead to vaquita population growth. Full table of probabilities for each possible lambda value are given in Appendix Table H.

7. Discussion

Explicitly modeling the outcomes of 340 conceivable policy combinations for the Upper Gulf of California shows how tradeoffs between goals for vaquita conservation and fisheries revenue can vary widely. Drawing on the results of this analysis we offer the following discussion to provide context for our core findings.

7.1.a Pareto Improvements

Pareto improvement policies, defined whereby one competing value cannot be further increased without cost to the other (Lester et al. 2012), have tremendous value in illustrating the policy space where a contention-free dialogue should occur. Such win-win policies are often sought in environmental conflict resolution, yet our results illustrated nearly all Pareto improvement policies do not result in vaquita population growth. The outcomes of 39 policies performed better then the current status quo policy scenario (see Appendix, Table I). These Pareto improvement policies are seen in Figure 27, represented by all points above and to the right of the status quo Fisheries Revenue and Vaquita Population Growth Rate. All other non-Pareto policies, despite performing comparatively better for either vaquita abundance or fisheries revenue, do not result in increases to one value without cost to the other.

It should be noted that one Pareto improvement policy exists that marginally results in vaquita population to increase—specified as a combination of 100% compliance for a gillnet ban for finfish fishing throughout the "All Closed" spatial policy, along with a 10% buyout of the fleet. However, while technically considered a win-win policy, much better policies exist when considering both uncertainty and incremental increases (or decreases) in fisheries revenue with vaquita population growth rate of non-Pareto policy options.

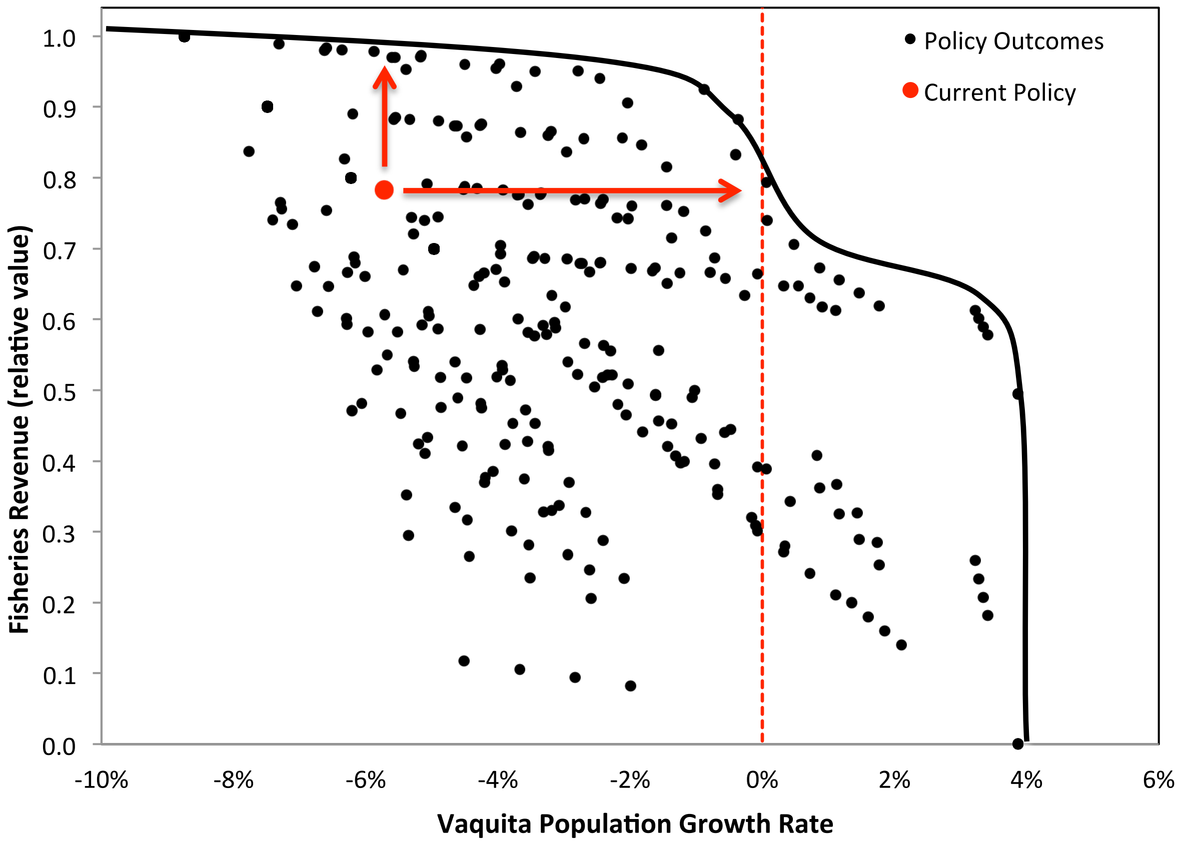

Figure 27: The above plot indicates all Pareto improvement policies, relative to the current policy scenario (red point). Pareto improvements are identified as those policies that would be an improvement, *either* economically *or* biologically or for both, compared to the status quo outcome. All Pareto improvements are indicated by points above and left of the red lines extending from the current policy represented by the red point. Values for all Pareto improvement policies can be seen in Appendix, Table I.

7.1.b Fisheries-Specific Closures

Firstly, projected outcomes from policies that close gillnetting for shrimp, finfish, or both combined clearly showed that not all gillnet closures are equivalent for fisheries revenue or associated vaquita bycatch. In fact, we determined that closing the gillnet shrimp fishery alone will never lead to an increase in vaquita abundance, but that a selection of finfish closure scenarios can allow for modest population growth for a comparatively lower cost to fisheries revenues. Because the shrimp fishery is of much higher value than finfish, these two findings are important to consider together. From these results it becomes apparent that a gillnetting closure for finfish will need to be central to any policy scenario if an increase in vaquita abundance is the target; however, a few policy scenarios allow shrimp gillnetting to remain open and still achieve this goal—albeit only marginally. Despite these findings, which may be favorable to many fishers in San Felipe and Golfo de Santa Clara, more strategic policies that better achieve vaquita population growth with fisheries revenues in mind will be found in the policy space that combines shrimp and finfish gillnet closures. Policy options for each of these three fisheries closure options are comparatively highlighted Figure 28.

Figure 28: Policy space for closures to gillnet fisheries, either alone or in combination. The blue region represents possible outcomes of policies that just ban gillnetting for shrimp; orange region indicates policy outcomes for closures to finfish gillnetting; the green region represents policy outcomes for combined shrimp and finfish gillnet closures. The vertical line at a growth rate of 0% indicates a stable population growth rate, therefore the point from which population increase would be observed (to the right of the line).

7.1.c Alternative Trawl

Trawling would lead to a substantial reduction in the economic impact of successful conservation policies. For instance, the full UGC closure scenario would cease all fishery revenue without trawling. However, revenue approaches 50% of a scenario with no fishing restrictions once trawling is incorporated into the model (see Section 6.5, Table 13). In a less extreme and more realistic closure scenario, such as the Marxan 90% or 95% refuges, economic losses ranged from 33-42% with trawling, compared to losses of 64-82% without. In addition, the trawl fishers themselves would have an incentive to enforce refuge boundaries since illegally placed gillnets within refuges would be an interference that would compromise their own fishing efficiency. Such an incentive could decrease enforcement costs for the Mexican government while also increasing compliance amongst fishers. Despite these benefits, it is also important to point out fishers would have to buy or be provided with these trawls, trained for appropriate use, and most importantly be persuaded to swap out their gillnets and accept using the trawls, all of which were not taken into account in this analysis.

7.1.d Compliance

It is clear that a compliance level of greater than 80% is necessary, but achieving this level will not necessarily guarantee a successful conservation outcome (see Figure 25). This outcome stresses the need to ensure other conservation measures are taken and combined with enforcement levels to have a successful management policy. If the current refuge size were to expand in the future, as we recommend, fishermen willingness to comply with fishing restrictions may decrease as a response to limited legal fishing grounds and the difficulty for the government to enforce such a large area. This may require more funds to provide fishermen with economic alternatives to fishing or for more enforcement personnel.

7.1.e Spatial Closures

Our model shows that increasing the refuge size is the most effective policy for vaquita conservation, especially when coupled with high fishermen compliance. Vaquita showed no signs of recovery under any circumstances when analyzing the current refuge. The previously proposed swollen refuge did have 6 policy combinations that produced an increasing growth rate, but this was minimal. Substantial increases in vaquita growth only came as a result of much larger closures, such as the 90% and 95% protection refuges or a full UGC closure to gillnetting (Figure 29). Since any of these closure scenarios would lead to the closure of prime fishing grounds, simply expanding the size of the current refuge would be an insufficient solution for vaquita recovery. Fishers would certainly be resistant to such changes without being provided adequate compensation or alternatives, so any policies that increased refuge size would also require other considerations, such as allowing fishing gear other than gillnets within a refuge.

These finding indicate that our Marxan designs are viable economic solutions, not just ecological ones, as projected from our model. The 95% Marxan Refuge policy with combined implementation of the alternative trawl is seen to be an economically and ecologically advantageous policy when compared to all other policy combinations in our research, regardless of the level of buyout achieved.

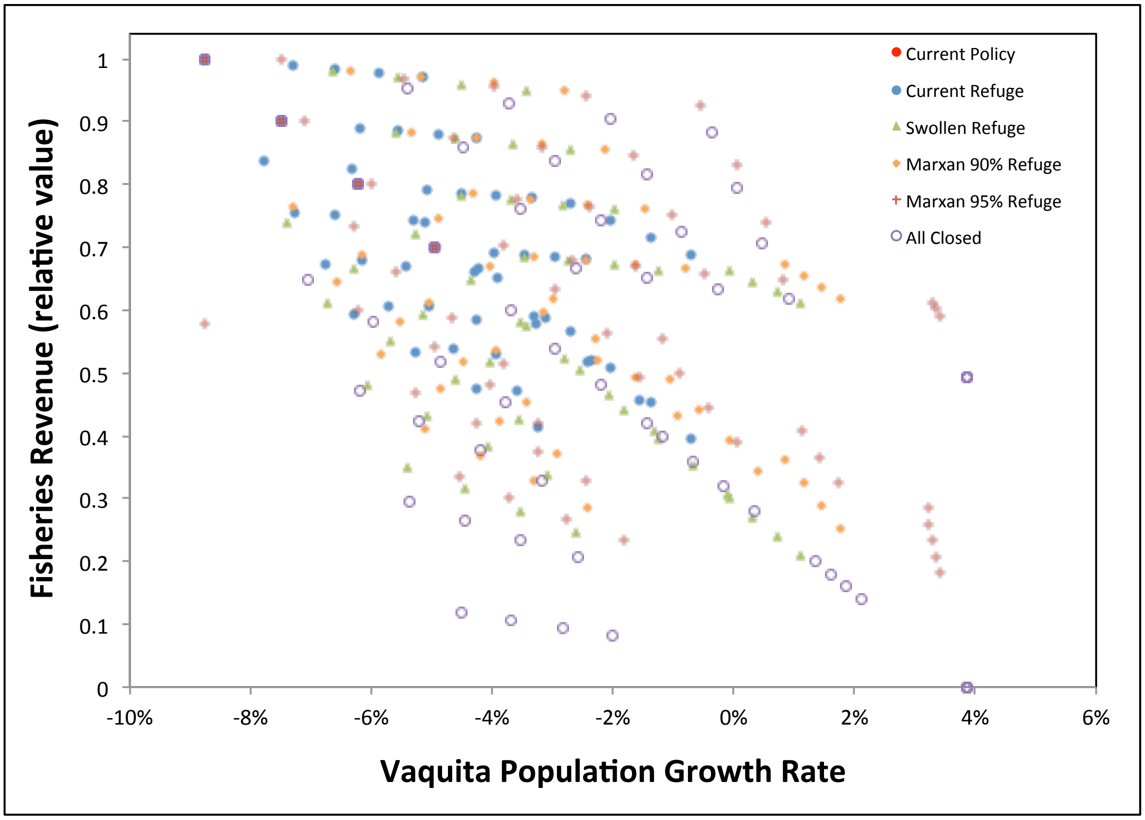

Figure 29: All policy scenarios, represented by spatial closures.

7.1.f Buyout Programs

Modeling the impact of a fishing effort buyout program shows a clear effect on the biological outcomes for any given policy combination. The effect that a buyout program has on the fisheries revenue is not as clear. Insofar as there would be reduced revenues from the actual sale of landings with implementation of buyout programs (see Table 16, section 6.9), the money compensated to fishers who opt for retirement should also be calculated into revenue (albeit coming at a cost to government or other funders).

The previous buyout program was not well received by fishers, in that the buyout funds came with conditions of investing the compensation money into specified 'alternative activities'. And while this condition was intended to help sustain long-term economic income, adequate capacity building for business management and market demand (e.g. tourism) for new businesses was lacking. Unsurprisingly, few of the new businesses endured. Further, the fishermen who opted to buyout were those who operated less efficiently, were close to retirement, or had several other permits to continue fishing; therefore they elected to do so at a lower buyout price. Any effort to be bought out beyond what left with the initial programs will come at a higher price.

Ultimately, in order to best-strategize conservation policy in the UGC, these higher buyout costs (to government) must be considered when comparing the bioeconomic cost-effectiveness of a buyout program to that of increasing compliance. However, data for cost to government of enforcement[6] by Mexico's Environmental Protection Agency (PROFEPA) and the Mexican Navy is not available for this analysis. Therefore, cost data for compliance-increasing enforcement activities is still needed to further identify the cost-effectiveness of strategizing to achieve greater levels of compliance or buyout.

7.1.g Assumptions

The model developed for this project can be used as a tool in the decision-making process for managers in the UGC. However, there are important assumptions that pertain to its use and implementation. While specific caveats and assumptions in our sub-models are discussed in their respective sections, those that are more general to our model include the following:

Fishing Effort Index

Due to the lack of quantitative fishing effort information in our fishing data, the assumption was made that current fishing effort is operating at the optimal level. Thus under an open-access regime with no restrictions on fishing effort, the spatial distribution of fishing activity would be that of our model (Figure 9). It is more realistic that certain fisheries are not performing optimally, which would require a different weighting scheme besides the seasonal weighting, but the data needed to capture the different fishing efforts between species was not made available for this model. If this assumption was an overestimate, and current fishing effort is actually operating at a less than optimal level; the possible increase in fishing activity would have a greater negative effect on the vaquita population growth rate than currently predicted. If this assumption is an underestimate and the current fishing activity is above the optimal level, it is expected that the fishing activity modeled in this project will scale back over time as a response to overexploitation of stocks. If a reduced effort is accounted for in the future – as a response to overfishing – the model would predict a higher vaquita population growth rate.

Another key caveat of our model was assigning secondary fishing grounds half the weight of primary fishing grounds. The subjective nature of collecting the information on both types of fishing grounds from fishers necessitates an assumption of what a secondary fishing ground really is in comparison to a primary fishing ground. This was discussed at the Vaquita Workshop and a weighting of 0.5 was agreed upon for secondary fishing grounds. This treatment is rather arbitrary but it was important to use any level of data that describes the distribution of fishing effort. The model can be improved if a more robust analysis of fishers CPUE is calculated for each fishing ground, which would eliminate the need to differentiate between primary and secondary fishing areas.

Exclusion of Puerto Peñasco in Model

Initially Puerto Peñasco was included in the model but after much discussion with experts at the Vaquita Workshop, it was decided to exclude the town from the analysis. While Puerto Peñasco is the largest town in the region, it has far fewer fishers than San Felipe and Golfo de Santa Clara and the fishing grounds used by those fishers do not overlap with the modeled vaquita range. If Puerto Peñasco was included in the analysis the outcome of each policy would have been nearly the same in terms of vaquita population growth rate, but the relative change in fisheries revenue

[2] Cost of compliance is not comparable due to lack of data for costs of government law enforcement.

would be less. This would have resulted in a misrepresentation of the economic impacts of each policy to each town. Both San Felipe and Golfo de Santa Clara would experience much greater losses than the model would predict and Puerto Peñasco would expect almost none since the modeled policies affected fishing activity that overlapped with the vaquita range. Since our model is built to look at all towns separately it is possible to include Puerto Peñasco in the model for future analyses.

7.1.h Uncertainty

Vaquita conservation inherently has multiple sources of uncertainty. Information on the abundance and distribution of the vaquita is limited to only a few surveys and anecdotal evidence of observations. Any estimate of current vaquita abundance has a large confidence interval, which has posed problems in gaining acceptance of the vaquita's plight. Additionally, information on the artisanal fishing effort of the region is usually inconsistent and difficult to track down. Multiple sources have cited different numbers of pangas for the same time period (Rodriguez-Quiroz 2012; CEDO 2012; Gerrodette & Rojas-Bracho 2011; Barlow et al. 2009) and information on the amount of fish caught per town is equally as disparate between governmental reports and independent studies (CONAPESCA 2010; Rodriguez-Quiroz 2009; Barlow et al. 2009). This analysis attempted to capture the uncertainty in estimating a vaquita population growth rate under each of the 340 policies. Without more accurate data on the number of individuals it is difficult to model an estimated vaquita population size without incurring a wide range of uncertainty around each estimate. Since a population growth rate is not dependent on the number of vaquita in the wild it is a better estimate of how any conservation policy may affect the current population.

Uncertainty in the spatial distribution fishing effort was not fully accounted for in this analysis. Rather than estimating fishing effort in terms of annual landings or catch per unit effort (CPUE), the data provided only allowed for measurement of fishing effort in terms of a relative index over the entire UGC region. Since the fishing effort index was based upon fishers' responses to interviews, uncertainty in the distribution of fishing effort could not be calculated. The model can be improved upon in this aspect if data became available that indicated the average amount of time each fisher spent fishing for all species as well as the harvested amount from each fishing ground.

Information on the regional fish landings from CONAPESCA were used to calculate the current baseline fisheries revenue for San Felipe and Golfo de Santa Clara, as well as the expected loss of fisheries revenue under each modeled policy. Tables 4 and 5 list the standard errors in both prices and landings reported in the CONAPESCA data. By including these errors in the uncertainty analysis it is possible to see how each outcome could shift along the fisheries revenue axis, but the relative comparison between policy outcome would not change and therefore would not affect a manager's decision to pick one over the other. The data is included in the report to allow for a more detailed analysis in the future.

7.2 Data Limitations

7.2.a Fisheries Data

Our economic analysis of the artisanal fisheries of the UGC used data collected by CONAPESCA, which is available in technical reports (CONAPESACA 2005, CEDO 2012) and commonly considered in scientific literature. We justified using official CONAPESCA data instead of other unofficial sources (which are argued by some to be more accurate) for our landings data in order to gain wider reception of our results within the regional management community. However, we made this decision aware that official data lacks adequate representation of illegal landings, which have been approximated to be as high as 40% of total landings in other reports (Barlow et al. 2010). The discrepancy in official and unofficial reporting stems from pervasive under-reporting of unpermitted landings to CONPESCA offices, being that CONAPESCA officials are also responsible for enforcing against illegal fishing activities. CEDO data aims to better capture illegal extraction of fisheries resources in the UGC (CEDO 2011). However, this data is not directly comparable to that of CONAPESCA due to differing methods in data collection.

7.2.b First-Sale Value of Landings

Our model uses net revenue calculated using the *first-sale* value of fish, which is the price a fisher receives from a permitted buyer—called a *permisionario*—for his or her landings at the beach. Using first-sale prices allows for direct accounting of fishing costs associated with landings in calculating net revenue. The first-sale value data is also less ambiguous for direct comparisons across fisheries products, and is a commonly used point of reference across technical reports and relevant literature. For broader understanding of the full value of UGC fisheries, one should consider all the value added to that first-sale reference point from processing, preparation and resale of seafood products, as well as reliant industries such as fishing and marine supply stores, boat manufacturing, and motor mechanics. We did not estimate this regional impact to the economy in our analysis.

7.2.c Compensation for Lost Fisheries Revenue

The above approach provides the most costly (worst-case) compensation scenario being that payout would occur for as long as the policy is implemented, considered here to be in perpetuity. However, with further analysis of fishery demographics in the UGC, data for the average timespan a fisher remains in the fishery, calculations of opportunity costs associated with local employment, and even extrapolated values from the prices other fishers were *willing* to buyout of the fishery for could lead to conceivably less costly estimates of the cost of compensation.

7.2.d Fishing Effort Displacement

When modeling the effects of fishing policies it is important to consider the resulting behavior of affected fishers. Under any spatial closure it is likely that a proportion of fishers who used to fish in a now protected area will be displaced into a non-restricted area. Although this may result in a decreased catch per unit effort due to competition for limited fish stocks, the overall economic impact may be less severe than if the displaced fishers had completely departed from the fishery. This would depend on the revenue exceeding the costs, which is not guaranteed. It is also conceivable that the costs would be too high to justify displaced fishers continuing to fish, in which case they would indeed leave the fishery.

We did not consider possible biomass spillover effects from different reserve scenarios due to extremely limited biological parameter data needed for dynamic modeling, such as accurate growth rates, stock sizes, and stock locations on a temporal scale. If this information were available, it would be possible to predict how many displaced fishers could be sustained along refuge borders and not negatively affect catch rates or stock levels. In addition, this information would also allow for predicting areas with the largest and most reliable fish stocks, which is where fishers would likely go if displaced.

Since data required to predict fisher behavior is scarce, we assumed that all fishers displaced from spatial closures would partake in buyouts or leave the fishery, with the exception of times when non-perfect compliance was modeled and some remained within spatial closures. Our model predictions should be viewed as slightly pessimistic since a proportion of fishers would most likely be displaced and continue to fish rather than leave the industry altogether. For policies with perfect compliance and no gillnetting allowed within spatial closures, we also considered giving fishers the option to use a light trawl to fish for shrimp within a proposed vaquita refuge. This would reduce the pressure on fishing grounds outside of spatial closures due to less displacement and have the same result on the vaquita population since bycatch with the light trawl is estimated to be zero.

8. Recommendations

Four core recommendations emerged from the quantitative analysis of the model outcomes. These recommendations are most likely to enhance likelihood of increased vaquita population growth and should serve as principles to guide future conservation and fishery management policies. While these recommendations embrace the goal of increased abundance, they also strive to consider relative costs of a given solution to local fishing livelihoods. Our recommendations for future management decisions and policies are described as follows:

8.1 Increase Refuge Size

A new spatial closure policy must consider an expanded design that is larger than the current Vaquita Refuge dimensions in order to allow population recovery. According to our results, any policy combination that includes the current spatial closure does not guarantee growth in vaquita abundance in the future, and that the swollen refuge should be considered the minimum refuge design to achieve this goal. The other three proposed spatial closures (swollen refuge, Marxan 90 and Marxan 95) were found to considerably increase projection of vaquita recovery. In addition, these larger refuges allow for policies with a broader spectrum of alternatives with respect to buyout, compliance, fisheries closures, and the use of the alternative trawl.

8.2 Restrict Gillnet Fisheries

Results of this analysis reinforce a common recommendation to reduce or eliminate the use of gillnets for fishing in the areas of the UGC inhabited by vaquita. This conclusion is frequently cited throughout the vaquita conservation literature (Gerrodette & Rojas-Bracho 2011; Morzaria-Luna 2012; CIRVA 2012; Jaramillo-Legorreta 2007). Gillnet restrictions will significantly decrease the vaquita bycatch rate (from 9.6% annual bycatch under no restriction, to 0% under full) and therefore can achieve an objective of vaquita recovery. While a full ban on gillnet fishing would be economically costly and locally unpopular, a closure to gillnet fisheries should be enforced for a vaquita refuge. Furthermore, given the high dependence of the UGC communities on fisheries resources harvested with gillnets, an adequate strategy to facilitate the adoption of alternative fishing technologies should complement a well-enforced restriction of gillnets in a vaquita refuge.

8.3 Implement an Artisanal Trawl

The second recommendation is to move forward with the implementation of the light trawl inside of any spatial closure configuration, providing an alternative fishing activity to regain revenue lost due to gillnet restrictions. Our analysis showed the best performing management scenarios for both vaquita and fisheries revenues were achieved when implementing the light trawl with expanded refuge scenarios. The use of the trawl for blue shrimp fishing will reduce the loss in revenue from expanded spatial closures for a vaquita refuge. Therefore, this alternative gear alleviates the potential economic impact that would arise from a policy that includes an expanded refuge. In addition, the use of the light trawl has the added benefit of incentivizing fishermen to comply with gillnet closures because the trawls cannot be effectively operated when gillnets are set in fishing grounds. It is important to note that the light trawl has been considered to fish blue shrimp within our analysis, so its use within spatial refuge options shall correspond with this use only.

While we do recommend the trawl for use in the near future, our model relies on some very big assumptions (1:1 catch ratio with gillnetting, 100% compliance) and ignores some others (learning curve, upfront cost of the trawl gear). And so while we do recommend its use we also strongly recommend a fast push to gather accurate data to better represent the effects of the trawl in our model. Particular effort should concentrate on confirming experimental trawl conclusions that there is in fact zero vaquita bycatch associated with this method.

8.4 Increase Compliance to at Least 80%

Achieving higher levels of compliance should be a central priority in order to meet the goal of vaquita recovery over our 30-year time-horizon. Under the assumption that the current policy scenario operates with only 50% compliance, it is clear how this would be insufficient when applied to any other policy to achieve vaquita recovery. Our analysis shows the best-performing policy combinations were those that include compliance values at or above 80%, which allow (but don’t guarantee) an increase in vaquita population under expanded refuge configurations.

Moreover, this policy recommendation also identifies the urgent need to identify effective mechanisms for enforcement and appropriate incentives for fishers to comply with policy scenarios.

8.5 Additional Research Recommendations

In addition to our recommendations for conservation management in the UGC, several additional research recommendations have emerged from this project. Four particular areas of future analysis will serve not only to address some of the uncertainty within our analysis, but will also augment our understanding of UGC bioeconomic dynamics and better guide stakeholders towards more informed decisions.

8.5.a Spillover dynamics

One of the objectives of this project was to analyze the effectiveness of management scenarios within a refuge for recovery of the vaquita, which all focus on restricting fishing activities. All of these scenarios are projected to come at a cost to fisheries revenues because we do not capture the potential benefits to fisheries from closing off productive habitat. Spillover effects of fish biomass are a demonstrated result of marine protected areas (McClanahan et al. 2000; Russ et al. 2004), and increasing protected biomass inside a vaquita refuge could lead to increased stocks outside the refuge. Therefore, if a vaquita refuge is complied with, it is likely that it will increase both vaquita abundance and that of commercially targeted fish stocks, potentially enhancing harvests for displaced fishermen. Reframing a vaquita refuge as a 'fisheries refuge' or fisheries replenishment zone could potentially gain support from the fisheries sector. However, if this framing is to be considered in future debate, a more rigorous scientific analysis of potential fisheries spillover is necessary. If there is spillover, fishers will likely "fish the line" just around the refuge which could result in higher bycatch of those vaquita that move outside of the refuge boundaries. A larger refuge should be designed in order to account for the high probability of catching vaquita along the refuge boundary. Dynamic modeling of this could have further influence on effective and politically feasible reserve design. Capturing these dynamics will inherently change the shape of the bioeconomic efficiency frontier, with potential to establish a more convex shape that identifies win-win policy policies.

8.5.b Buyout Restructuring

As identified in our analysis, the level of buyout has an important role to play in decreasing incidental bycatch of vaquita, yet the program is unlikely to achieve additional reductions in effort as it is structured today. We recommend additional analysis of the buyout program that has been in place since 2008. To date, roughly 15% of the gillnet effort in GSC and SF has been retired through the program, yet there has been no additional effort retired since 2010. Modifications to the level of payout for effort retirement should be reevaluated, particularly if policy makers are attracted to management policies that rely on additional buyouts to meet vaquita abundance goals. Additionally, our analysis does not capture the bioeconomic effect of the current "switch-out" program where fishers can temporarily exchange their gillnets for alternative vaquita safe gear (light trawls), yet understanding these dynamics would also be important to guide future buyout program implementation. Ultimately, a buyout program can help achieve vaquita recovery goals, and should be continued if it is a) restructured and b) combined with other policies.

8.5.c Alternative Gear and Value-added Seafood Products

Our analysis took a conservative approach in quantifying the amount of fisheries revenue lost under a given policy. Due to the wide range of reported landings, costs, and prices, we felt it was more effective to look at an overall loss, normalized to the current annual fisheries revenue. This method largely ignores the very real possibility of fishermen using alternative gear, capturing alternative fisheries product values, or moving into other forms of employment to make up the loss from a given fisheries policy. Identifying alternative sources of revenue generation can more accurately project the true cost of a given policy. Research into alternative fishing activities that have no incidental catch of vaquita (in addition to the light trawl), such as broader utilization of long lines, fish traps, or dive harvesting, has potential to relieve the economic impact of any restriction to gillnet fisheries. Market research into fisheries value chains and identifying potential areas for value added processing or markets has further potential to generate distinct revenue from UGC fisheries, as is currently the case with highly valued curvina swimbladder *buche* (Caplog 2012), sea cucumber (*pepino)*, and the geoduck clam (*almeja generosa)*. Success has been seen in value added production through certification programs, which conceivably serve as the basis for marketing *vaquita-safe* seafood.

8.5.d Assessment of Cost-effectiveness for Buyouts Compared to Enforcement

Results of our analysis identified that buyout levels and compliance levels have disproportionate influence on the bioeconomic outcomes of a given policy scenario. To reconcile this difference, further assessment of the comparative cost-effectiveness of both buyout and enforcement programs should be prioritized. By developing a better understanding of their relative impact, managers can more strategically select a policy that will have a greater gain in bioeconomic outcomes for a given investment. This research should consider the actual costs to government of getting to a desired level of compliance (including enforcement costs) and a restructured buyout program, in order to fully capture costs associated with their respective bioeconomic influence on a given policy scenario.

9. Project Conclusions

Modeling bioeconomic tradeoffs between outcomes of conservation policies in the UGC informs our understanding of key policy tools, including gear restrictions and spatial closures. The relative impacts of buyout programs, alternative trawl implementation, and level of regulatory compliance are also considered in their effectiveness as combined policies. The principal results of this analysis indicate that in order to achieve the goal of reducing the bycatch rate below the current level, UGC environmental policy should encompass the following policy principles: that a closure of gillnet fisheries is central to preventing vaquita extinction; that a shift to artisanal light-trawling is fundamental to generate revenue when gillnets fisheries are closed; that a significantly larger protected area is needed than the Vaquita Refuge designated in 2005; and that achieving a compliance level of at least 80% for any policy will be essential.

Additionally, because of the large degree of uncertainty within some of the data we used as inputs to this model, managers and policy makers should recognize how desired outcomes of a policy are not guaranteed. Due to the large range in uncertainty, it is very important for those involved in policy making in the UGC to employ a precautionary approach and aim for policies that favor lower vaquita bycatch given the confidence intervals discussed. Managing this uncertainty in policy will likely come at a cost to fisheries revenue, yet is a necessary consideration to safeguard conservation values.

Most importantly this project represents the discourse between conservation objectives focused on the vaquita and those intending to preserve fishing livelihoods. It is of utmost importance to design an appropriate conservation policy that also values the livelihoods in fishing communities. Without this reconciliation, conservation policies are likely to underachieve their goals if there is little participation from Upper Gulf of California communities. Any successful vaquita conservation policy must result in realized economic benefits to local stakeholders, either through incentivizing alternative fishing methods or by providing new employment opportunities.

Tradeoff analyses have a valuable application to forming a comprehensive management plan. While this project focused on evaluating tradeoffs between just two competing values—conservation of the world’s most critically endangered marine mammal against fisheries livelihoods—such analysis can be expanded to include other values beyond those captured in our model. For inclusion of additional values in this model, such as the tourism sector, other productive sectors can be identified that both safeguard biodiversity and the communities that depend on it.

Our hope for this preliminary tradeoff analysis is that it serves as one more step towards identifying solutions for vaquita recovery that are viable in the social-ecological context of the UGC. If we are not successful in preventing the extinction of the vaquita, the tradeoff analysis will be transparent in showing where society has placed values. However, if successful, we will see the value from such decision-making tools and surely take lessons from this case on social-ecological conflict resolution to other 21st century environmental challenges.

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Appendix

Vaquita Workshop - November 2, 2012

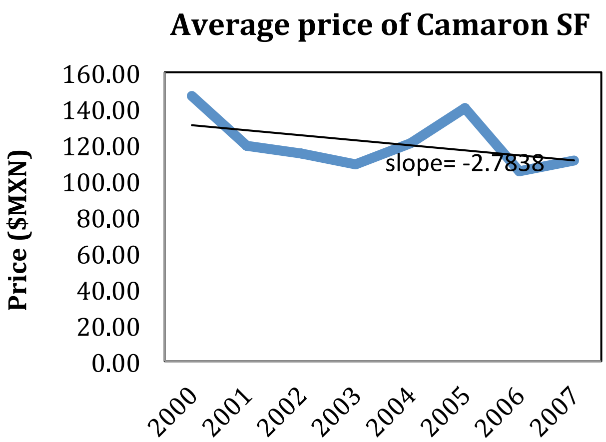
On November 2nd we presented our bio-economic model to professionals from NOAA, Scripps Institution of Oceanography, CEDO, WWF, and INE with the intention of gaining input regarding key considerations such as granularity of cell sizes, population density layers, and net length trends. In addition, objectives of the workshop included gaining better understanding of realistic options for policies in the Upper Gulf of California, determining an appropriate analytical relationship between vaquita bycatch and fishing effort, and enhancing elements of our spatial analysis with respect to uncertainty in the available data. Our group presented a range of projected fishery revenues under example policy scenarios in order to demonstrate the functioning of the model. After receiving feedback during the workshop, we have decided to evaluate various spatial closures, fisheries buy-outs, and the sensitivity of these policies to levels of compliance.

Workshop attendees provided additional recommendations to enhance our analytical approach. Key suggestions were to change vaquita *enforcement* to a measure of *compliance*, perform sensitivity analyses for vaquita abundance and catchability, frame the revenue losses associated with spatial closures as the *cost* associated with that particular solution, use larger grain in our grid of cells, and evaluate policies that are potentially attainable (focusing on species closures, simple area closure, and low-cost policies for the respective fishing towns).

Participants included Enrique Sanjurjo (WWF Mexico), Alejandro Rodriguez (WWF Mexico), Marcia Moreno-Baez (Scripps Institute of Oceanography), Tim Gerrodette (NOAA Southwest Fisheries Science Center), Armando Jaramillo (National Institute of Ecology, Ensenada), Jay Barlow (NOAA Southwest Fisheries Science Center), Barbara Taylor (NOAA Southwest Fisheries Science Center), Brad Erisman (Scripps Institute of Oceanography), Lorenzo Rojas-Bracho (National Institute of Ecology, Ensenada), Octavio Aburto (Scripps Institute of Oceanography), Peggy Turk Boyer (CEDO), and Sarah Mesnick (NOAA Southwest Fisheries Science Center).

Figures

Appendix, Figure A: A map of the Upper Gulf of California, Mexico with boundaries of the two current conservation areas. The Upper Gulf of California and Colorado River Delta Biosphere (highlighted in green) was put in place in 1993. The current Vaquita refuge (highlighted in red) was implemented in 2005.


Average price of Camaron SF
Price ($MXN)
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
slope= -2.7838
2000
2001
2002
2003
2004
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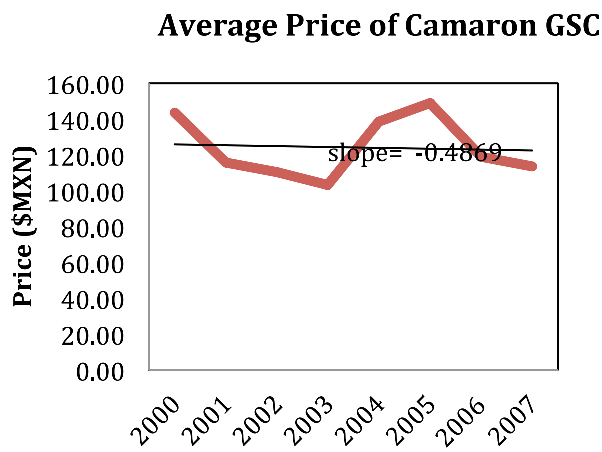
2006
2007


Average Price of Camaron GSC
Price ($MXN)
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140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
slope= -0.4869
2000
2001
2002
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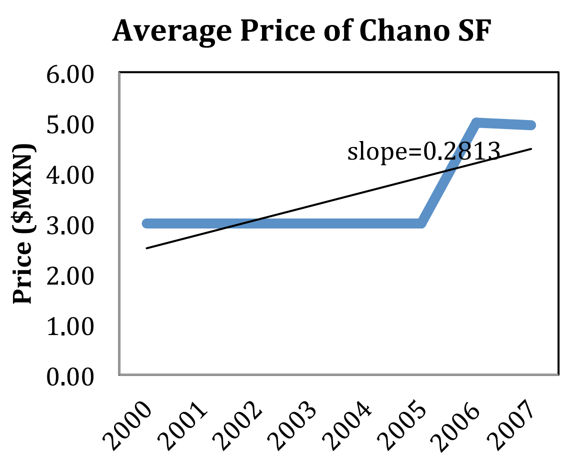
Average Price of Chano SF
Price ($MXN)
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5.00
4.00
3.00
2.00
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0.00
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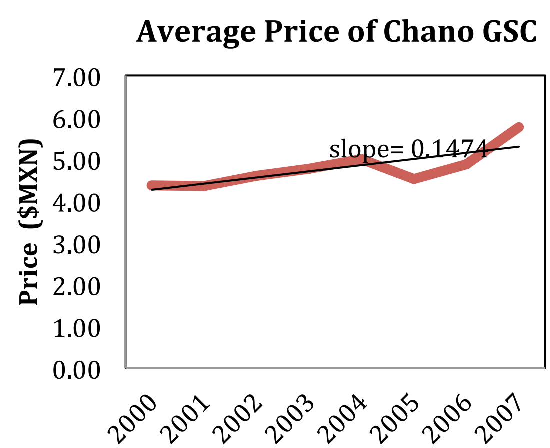
2003
2004
2005
2006
2007


Average Price of Chano GSC
Price ($MXN)
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6.00
5.00
4.00
3.00
2.00
1.00
0.00
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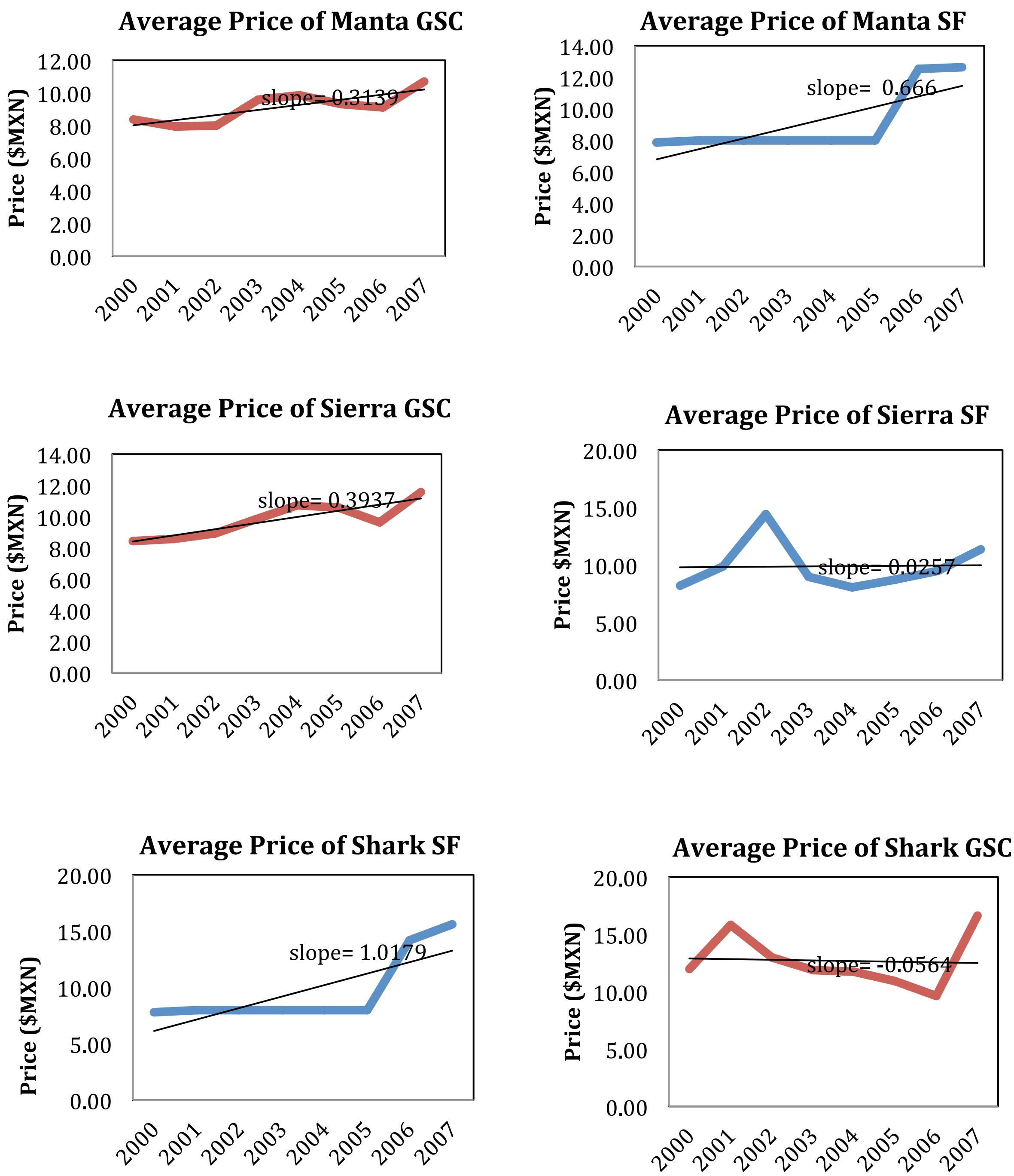
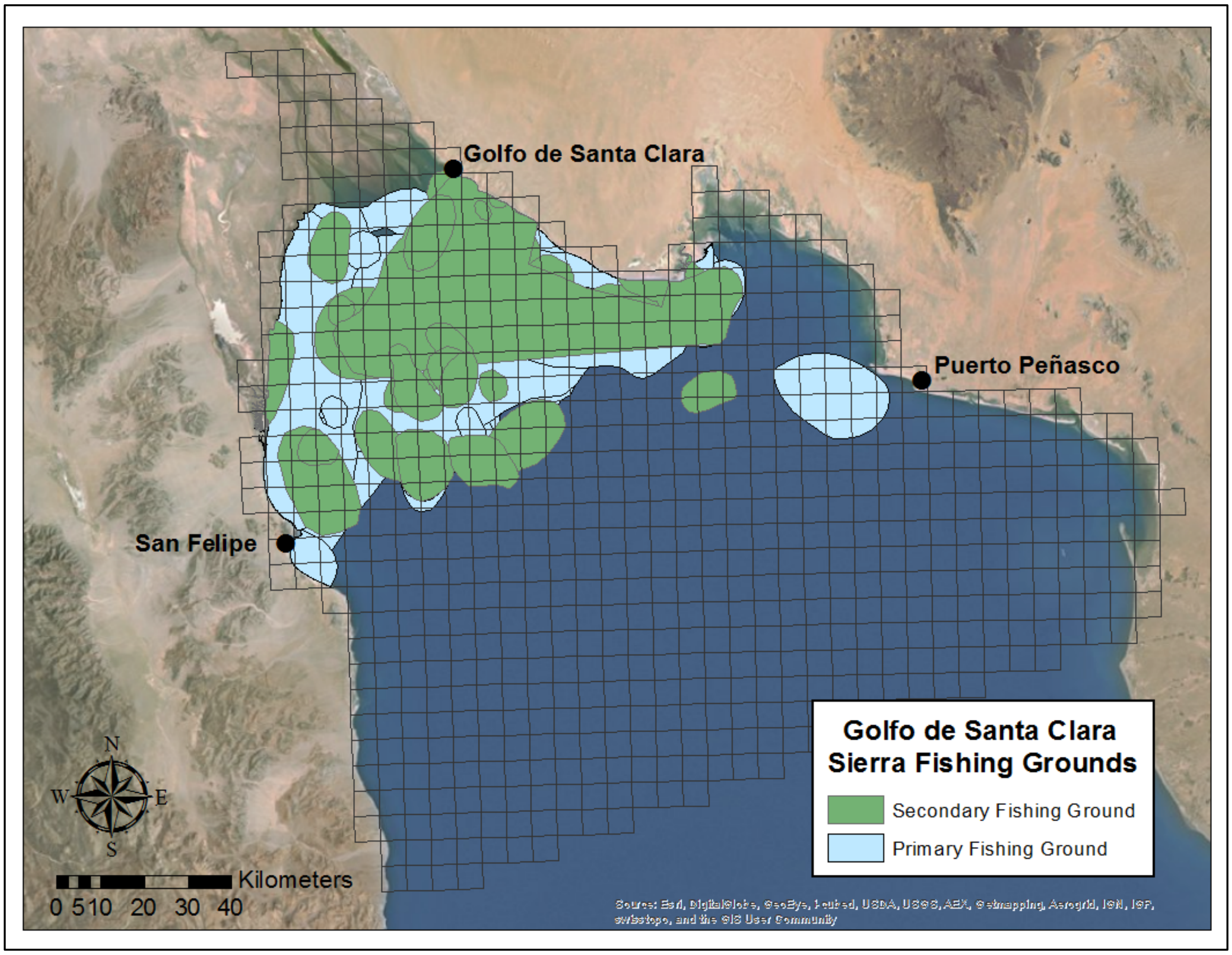
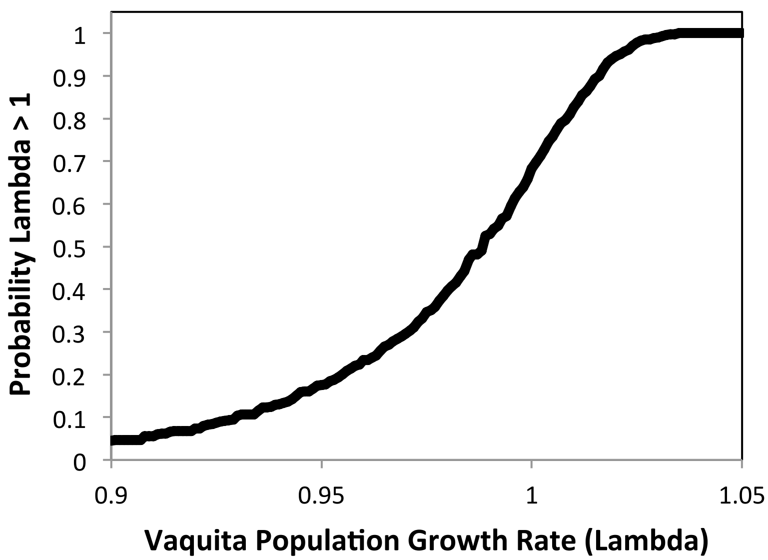


Appendix, Figure B: Plots of the average yearly first-sale price for each species in San Felipe and Golfo de Santa Clara respectively, from 2000-2007.



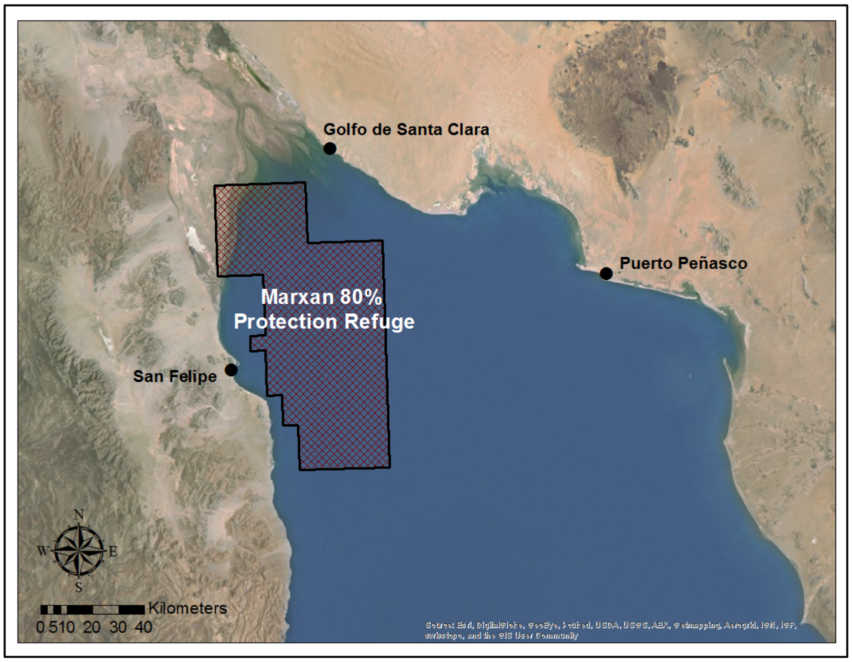
Appendix, Figure C: A map generated in ArcGIS representing the overlapping sierra fishing grounds for all fishing captains interviewed in Golfo de Santa Clara.



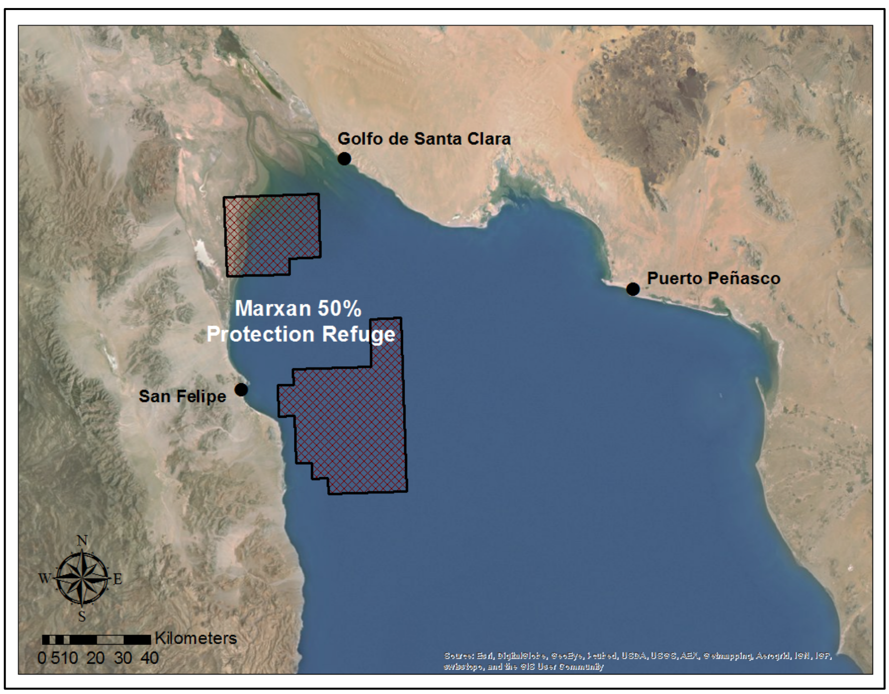
Appendix, Figure D: Calculating Uncertainty – The probability (y-axis) that a policy's resulting lambda (x-axis) could be greater

	percentiles							
	mode	0.025	0.05	0.25	0.5	0.75	0.95	0.975
r	0.0387	0.014	0.017	0.028	0.038	0.050	0.071	0.079
q	0.1685	0.105	0.113	0.144	0.167	0.193	0.236	0.252
N2012	180.98	105.279	116.13	154.11	185.12	218.83	277.01	302
N2013	172.59	98.310	108.92	146.01	177.05	210.84	270.01	295

Appendix, Figure D.1: Summaries of the marginal posterior distributions, based on 6 million samples. Source: Tim Gerrodette (NOAA SWFSC)



Appendix, Figure E ArcGIS map of Marxan designed refuge configuration targeting the protection of 80% of the vaquita population. This refuge did not perform better than the swollen refuge and was not considered in the our final analysis.



Appendix, Figure F: ArcGIS map of Marxan designed refuge configuration targeting the protection of 50% of the vaquita population. This refuge did not perform better than the current Vaquita Refuge and was not considered in the our final analysis.

Supplementary Information and Figures

Bioeconomic Outcomes of Marxan 50% and 80% Vaquita Refuge Designs

The conservation planning software Marxan was used to evaluate the efficiencies of the current Vaquita Refuge (see Appendix, Figure A) and the swollen refuge (see Appendix, Figure A) - proposed as "Option 2" in Gerrodette & Rojas-Bracho (2011) – at protecting a given proportion of the vaquita population. Gerrodette & Rojas-Bracho (2011) estimate the current vaquita refuge protects 49% of the vaquita population and that the swollen refuge would protect 79% of the vaquita population. The methods for the Marxan model used to design both refuges can be found in the Analytical Approach section of this report.

Marxan created the most cost-efficient vaquita refuge designs that protect 50% and 80% of the vaquita population with minimal impacts to the local fisheries revenue, compared to the current and proposed refuges. Each of the Marxan refuges was evaluated against the current and swollen refuges to compare respective impacts on vaquita population growth rate and annual fisheries revenue. Appendix Figure E displays the Marxan 80% and Appendix Figure F displays the Marxan 50% Vaquita Refuge. Neither of these refuges was considered in the final analysis since there was essentially no difference in economic and conservation outcomes when compared to the swollen refuge and current Vaquita Refuge. Furthermore, we considered the swollen refuge and Vaquita Refuge to be more spatially, politically, and biologically realistic.

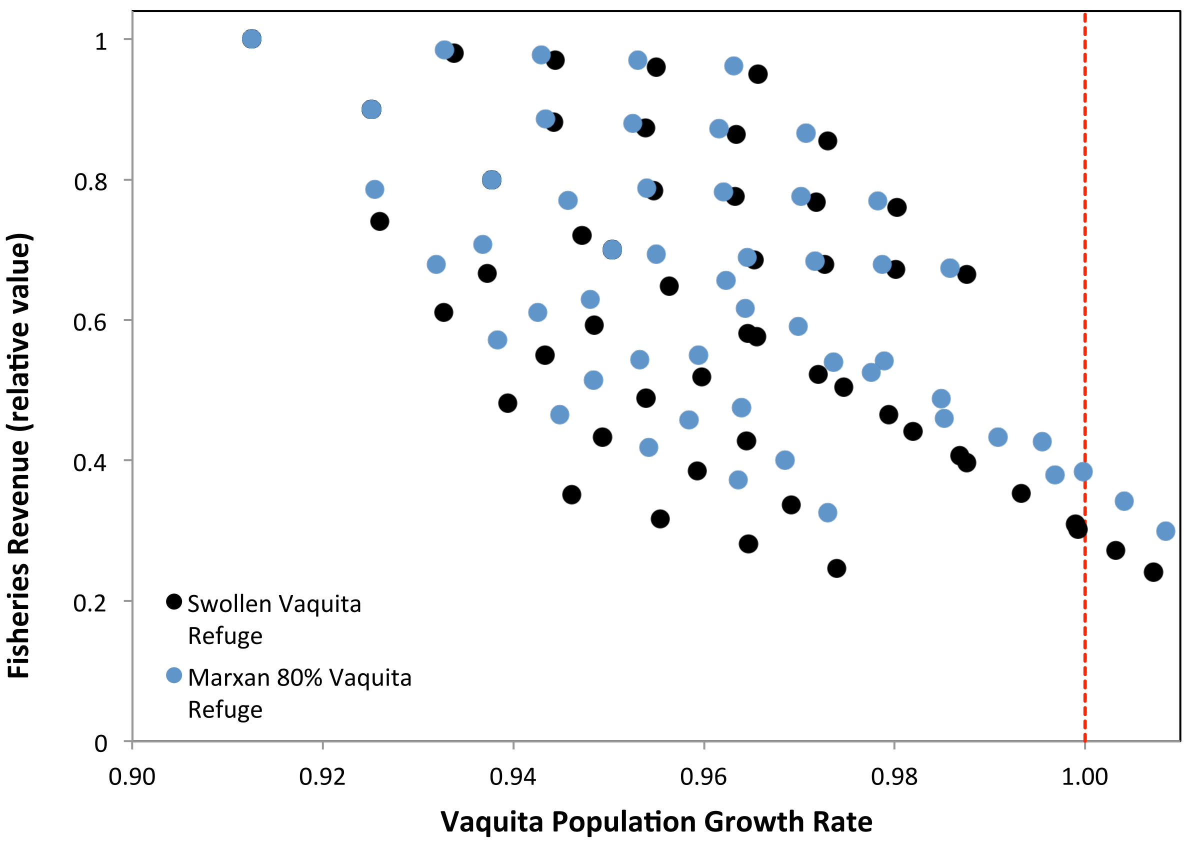


Figure G: Vaquita population growth rate and corresponding change in annual fisheries revenue under two spatial closure scenarios: (1) the swollen vaquita refuge proposed as "Option 2" in Gerrodette & Rojas-Bracho (2011), and (2) the refuge which protects 80% of the current estimated vaquita population as designed by Marxan. Red dashed line represents a lambda of 1, where there is neither growth nor decline and to the right of which indicates growth.

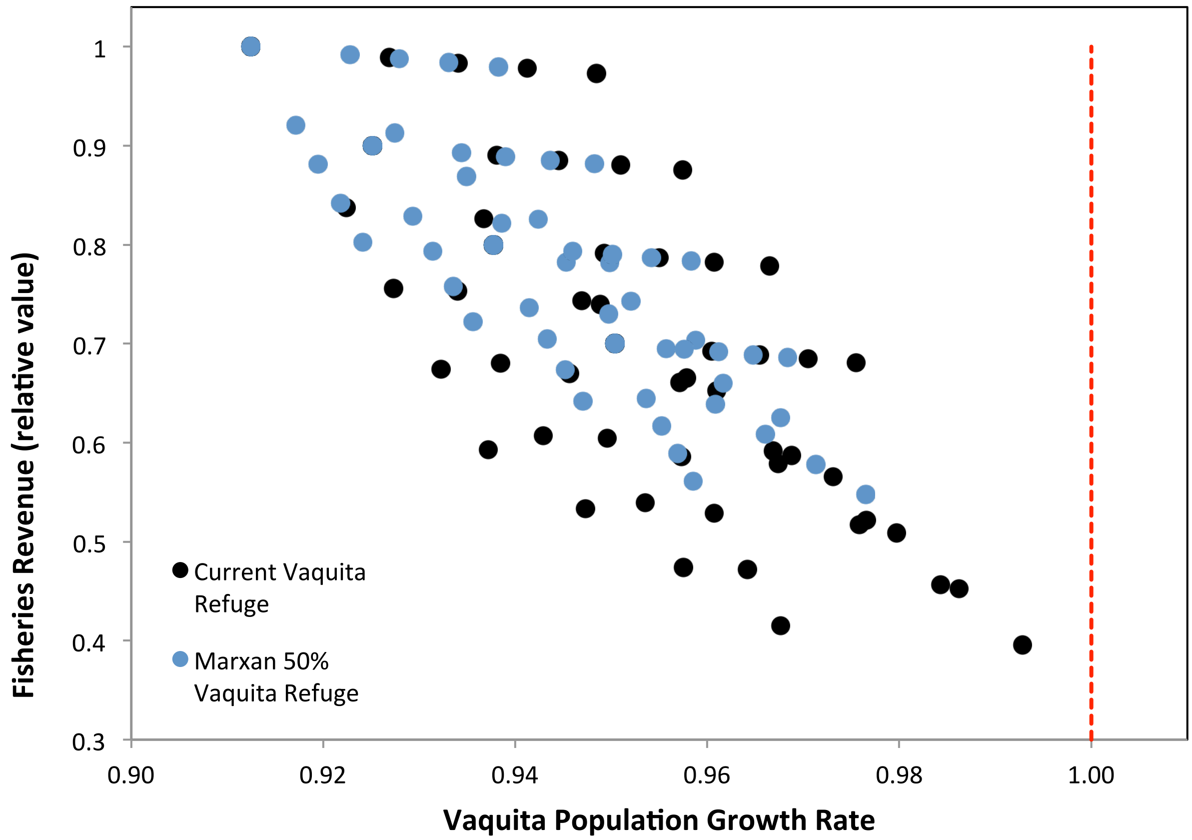


Figure H: Estimated vaquita population growth rate and corresponding change in annual fisheries revenue under two spatial closure scenarios; (1) the current vaquita refuge which Gerrodette & Rojas-Bracho (2011) found to contain 50% of the current vaquita population and (2) the refuge which protects 50% of the current estimated vaquita population as determined with Marxan. Red dashed line represents a lambda of 1, where there is neither growth nor decline and to the right of which indicates growth.

There is very little difference between these two spatial closures as can be seen in Appendix Figures G and H. Under any given combination of buyout, compliance level and species closure policy, the Marxan 80% and 50% Vaquita Refuges have less impact on fisheries revenue than the proposed swollen refuge and the current refuge respectively. This is a result of Marxan's cost minimizing objective, which tries to avoid including areas of high value. The swollen refuge (Gerrodette & Rojas-Bracho 2011) was not designed with consideration for areas of fisheries importance, but rather for distribution of the vaquita population. While the Marxan 80% Vaquita Refuge is better for UGC fisheries, it performs worse for the vaquita population. Since the swollen reserve borders the Western coastline, all fishing activities must be eliminated in the area. The Marxan designed refuge allows for a small amount of fishing in this area since the predicted density of vaquita is very low. By permitting fishing along the coastline between the Marxan 80% refuge boundary, there is a higher rate of bycatch compared to the swollen reserve. In each scenario the vaquita population growth rate is lower with Marxan-derived vaquita refuges when compared to the swollen and current refuges.

The differences between these two published refuges and our comparative Marxan refuges were not significant enough to warrant consideration as a realistic spatial closure in our larger analysis, and therefore are not included as policy options in the final tradeoff analysis.

Chano

Endemic to the Gulf of California, the big eye croaker, or *chano,* is principally targeted using gillnets with mesh size of 4¼ inches, between 200 to 600 m in net length, and 1.5 to 3 m in height. Chano is caught from March to August. From 1995 to 2007, the chano fishery generated average gross revenue of $388,000 USD annually, with an average annual catch of 1.37 metric tons (Aragón-Noriega *et al*. 2009). This species is thought to be an alternative finfish target for fishermen displaced from the shrimp industry (Cudney & Turk 1998). Despite the lack of official information about this species, some studies indicate this fishery is currently exploited under MSY levels, which has been estimated in 2169.5 tones according to Schaefer models (Pérez-Valencia et al. 2012).

Sierra

The Spanish mackerel, or *sierra,* is caught with gillnets having a 2¾ inch to 3½ inch mesh size. These nets most commonly range from 200 to 500 m long in length, with a height of 1.5 to 3 m. The sierra season extends from November to June, and fishing occurs primarily during the night or early morning. Several techniques are used to fish sierra, one of which is leaving the net out all night long and gathering the catch in the morning. Another alternative is to find the sierra shoals and encircle them until they are caught in the net. Sierra are also caught incidentally in gillnets used for chano and shrimp (Pérez-Valencia *et al*. 2012). This species is exploited at its MSY levels. The suggested total catch calculated for the species *S. concolor* (located in the North Sonoran Region) is 1,400 tons, while suggested total catch for *S. sierra* is 1,000 tons and 100 tons for the North Sonoran Region and Northern Baja California, respectively.

Manta (rays) and Guitarra

This elasmobranch fishery generates an important source of revenue, particularly when other fisheries are scarce (Cudney & Turk 1998). Gillnets with 5 ½ to 9 inch mesh size are used to target ray species (including *Dasyatis brevis* and *Gymnura marmorata*) and guitarra (*Rhinobatus productus*) (Cudney & Turk 1998). Many species are targeted together in a functional group. Two techniques are used: gillnets being deployed to the bottom and anchored there for 1 to 4 days, or nets being used to enclose rays in groups. Rays and guitarra are exploited at their MSY levels, and it has been recommended to not increase current effort for these species (Pérez-Valencia *et al*. 2012).

Shark

The shark fishery in the UGC includes the bironcha (*Rhizoprionodon longurio*), lobero (*Carcharhinus leucas*), mako (*Isurus oxyrinchus*), mamón (*Mustelus lunulatus*), tiburón volador

(*Carcharhinus limbatus*) and others (CONANP, 2007). In the 1960s, this fishery was considered extremely important, but in the 1980s overexploitation caused decline in abundance (Cudney and Turk 1998). The main method to fish for sharks is to leave gillnets anchored at the bottom of the sea for multiple hours, if not overnight. In some cases, fishers surface gillnets to fish for shark. Both shark and ray fisheries are regulated under the *Norma Oficial Mexicana* NOM-029-PESC-2006. The shark fishery is closed from May 1st to June 30th (Pérez-Valencia *et al*. 2012).

Other Significant Fisheries

Corvina Golfina

The *corvina golfina,* or corvina *(Cynoscion othonopterus),* is a large endemic species that has supported an important Upper Gulf artisanal fishery since the late 1980s (Scripps 2009). The fishery is characterized by four short periods of intense fishing, amounting to about 4 weeks annually – this is correlated with highest tides of the lunar cycles. The majority of the fishing effort is located within the Colorado River Delta near the core zone of the Biosphere Reserve (Erisman *et al.* 2012). Corvina is caught through the use of a gillnet, but in a way that differs from fishing procedures for another finfish species. In a very fast-pasted *rodeo* net deployment, fishers take advantage of the ocean currents produced by the tides and reproductive aggregations to encircle corvina shoals with gillnets. For this reason, the corvina fishery results in a relative high selectivity for the target species. Multiple sets can be done in a single day. It is considered very active fishing because the gear never floats adrift in the water. Fishing specifications for this species are authorized under the regulation NOM-063-PESC-2005 (Carta Nacional Pesquera 2010). This species is exploited to its maximum sustainable yield levels (Pérez-Valencia et al. 2012)

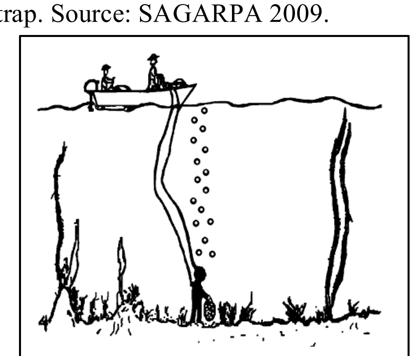
Jaiba (Callinectes bellicosus)

The blue swimming crab, or *jaiba,* is most commonly caught through metallic Chesapeake style traps. These traps measure 60 x 60 x 40 cm and are tied to a main line or rope (see Appendix, Figure I). Baited traps are left in the water and then collected in 24 hours (Pérez-Valencia *et al*. 2012). Permits under the Ley de Pesca allow for 80 traps deployed per permit. In addition, blue swimming crab can be harvested in gillnets set at the bottom of shallow waters. The blue crab is exploited to MSY levels in the region of the Gulf of California (Pérez-Valencia *et al*. 2012).

Appendix, Figure I: Jaiba crab Chesapeake trap. Source: SAGARPA 2009.

Caracol Chino (Hexaplex spp.)

This marine murex snail, also known as *caracol chino,* is easily collected by a single or pair of divers while hookah diving (surface supplied air through hoses). The catch is deposited in a special snail bag. Usually a knife or other instrument is needed to extract the snail from the bottom. Fishermen seek caracol chino clusters or banks located in sandy bottoms, and thus usually get big amounts of snails



Appendix, Figure J: Hookah diving for snail and scallop Source: Carta Nacional Presquera, 2004 per catch (Pérez-Valencia *et al*. 2012). In other regions of the Gulf of California, this resource is currently overexploited. Suggested MSY levels are 271 tons according to Schaefer model estimations (Pérez-Valencia *et al*. 2012).

Almeja Catarina (Argopecten circularis)

The almeja catarina is a scallop collected by hookah divers. The catch is deposited in a bag while doing the collection, much like the marine snails (see Appendix, Figure J). In other regions of the Gulf of California, this scallop is exploited to MSY levels. However, there are no specific estimations for the Upper Gulf region. Nevertheless, the NOM-004-PESC-1993 regulation indicates a minimum size of 60 mm and exploitation rates of 60% of biomass (Pérez-Valencia *et al*. 2012).

Cannonball Jellyfish (Stomolophus meleagris)

The cannonball jellyfish, known locally as *aguamala,* is an emerging fishery, with the first fishery development permits being granted over this past decade. This product is exported to Asian markets, where consumption spans use in cosmetics to vitamins to culinary uses.

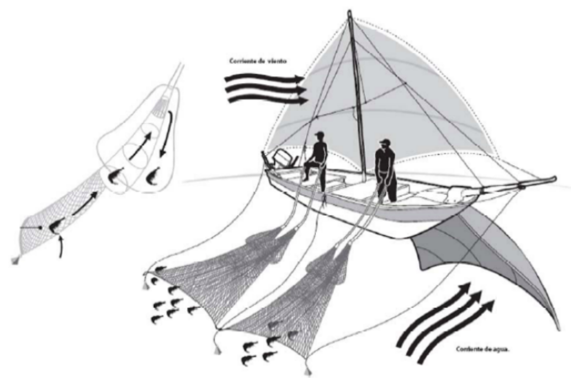
Appendix, Figure K: Cannonball jellyfish fishing Source: **López**-Martinez 2011

Landings have reached more than 3000 annual tons (López–Martínez & Álvarez–Tello 2008). Currently, jellyfish is an important resource primarily for Golfo de Santa Clara and the communities in the state of Sonora. The commercial-sized jellyfish are usually encountered drifting on the surface layer, and are easily collected manually with “spoon nets” used by fishermen aboard pangas (see Appendix, Figure K). This fishery occurs in the late spring and early summer months as warmer water temperatures are favorable to the notable increase in jellyfish populations.

Alternative Fishing Gears

Suripera Net

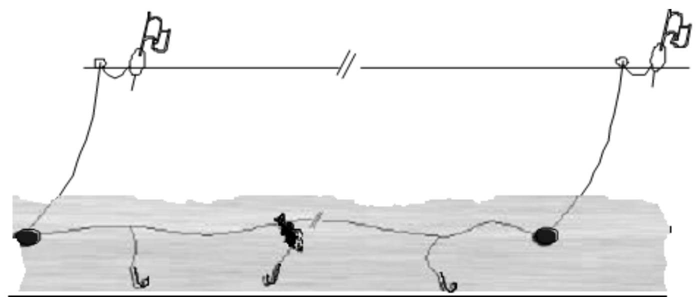
A suripera net is a very selective net for shrimp. Given its operation and small surface, vaquita are unlikely to get entangled or caught by this kind of gear (Barlow *et al.* 2010). The net consists of a cone-shaped trapezoidal section where a footrope is fitted. Two sections on top of the trapezoidal section are fitted with 40-cm bags that act as traps to encourage shrimp to move upwards (see Appendix, Figure L). These nets were not considered in our analysis due to the low catch rates making them economically unfeasible.



Appendix, Figure L: Suripera net operations Source: INAPESCA-WWF 2010

Longlines

Longlines, also referred to as *palangre* or *cimbra*, are set with baited hooks located at intervals along a mainline. These gears can have 250 hooks and can be deployed to sit along the seafloor or at any depth in the water column. In the Upper Gulf, longlines are used to target finfish and most commonly used for baqueta, chano and sharks. Longlines may catch significant rates of non-targeted species; however, vaquita are not caught as incidental bycatch through this fishing gear (Pérez-Valencia et al. 2012) (see Appendix, Figure M).



Appendix, Figure M: Cimbra operation. Source: Carta Nacional Presquera, 2010

Research, conservation, and industry institutions

WWF Mexico

World Wildlife Fund (WWF) is a leading global non-governmental conservation organization. WWF strategies are focused on prioritizing social-economic opportunities as an important component of the global environmental agenda. Specifically in Mexico, the WWF has promoted the conservation of the country's biodiversity and the sustainable use of natural resources and the communities depending on them.

Since 1968, WWF Mexico has protected charismatic species and established priority regions in terms of biodiversity, including vaquita in the Upper Gulf of California. WWF Mexico has supported government and other institutions to generate management plans for vaquita recovery as well as promoted an increase in public awareness about the issue. Currently WWF Mexico is continuing efforts to involve stakeholders and governments in the development and implementation of adequate management strategies such as facilitation and training for better fishing practices and market prospects for eco-certified products (WWF Mexico 2012)

NOAA

The National Oceanic and Atmospheric Administration (NOAA) is the primary federal government agency in the US in charge of science and stewardship of marine resources. It plays an active role in data collection, science, and management of regionally and globally important fisheries as well as marine mammals and endangered species. NOAA's Protected Resources Division (PRD) of the Southwest Fisheries Science Center has collaborated with the PACE recovery plan to prevent extinction of the vaquita, and extends technical advisement to the Mexican government and other institutions in coordinating surveys and laboratory research for population abundance assessments. It also provides technical support through advanced science in choosing better strategies for population recovery of the vaquita (NOAA n.d.).

SCRIPPS

The Scripps Institution of Oceanography (SCRIPPS) is recognized worldwide for ocean and earth science research, education, and related public service. Within this institution, the Center for Marine Biodiversity and Conservation brings together faculty and researches of various institutions such as UCSD, NOAA and Mexican universities as well as research institutes. The center has published key articles related to the Gulf of California fisheries resources and the vaquita issue. SCRIPPS also provides its scientific support in the development of proposals for vaquita recovery (SCRIPPS n.d.)

CICIMAR

The *Centro Interdisciplinario de Ciencias Marinas,* also known as the Interdisciplinary Center of Marine Science, is located in La Paz, Baja California Sur, Mexico, this research institution has an important role in supplying science and technology-based solutions for the sustainable use of the country's marine resources, mostly for the marine areas of Northwestern Mexico including the Upper Gulf of California. CICIMAR produces research on assessment and management of fisheries, aquaculture and fish products technologies, oceanography, and marine biology. This research institution is a dependent of the National Institution of Technology, and offers Masters and PhD programs with autonomous funding for fellowships to grad students (CICIMAR n.d.)

CICESE

The *Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California* or the Center for Scientific Research and Higher Education at Ensenada, was created by the Federal government in 1973 under the institutional system of the National Commission of Science and Technology of Mexico (CONACYT). Since then, CICESE has produced applied scientific research in the fields of biology, physics, ocean and Earth processes, health, computer and communication technologies, as well as in topics such as water, food, environment, alternative energies and the study of nature-based disasters. CICESE is also committed to forming future researchers through offering PhD and Masters Degrees (CICESE n.d.).

Both, CICIMAR and CICESE have made important contributions to the knowledge of the biology and conservation of the vaquita in the Upper Gulf of California. Past and ongoing research conducted on these institutions through projects, Masters and PhD thesis support the knowledge and synergies for science-based conservation for the Mexican porpoise in future (CICIMAR; CICESE n.d.).

PANGAS

PANGAS, being an acronym for Pesca Artesanal del Norte del Golfo de California—Ambiente y Sociedad or Artisanal Fisheries of the Northern Gulf of Califonia—Environment and Society, is a multi-institutional collaborative project sponsored by the David and Lucile Packard Foundation. Its principal goal is to promote sustainable fisheries in the Upper Gulf of California through conducting research in both social and biophysical sciences, ultimately supporting the design of management plans. PANGAS recognizes the importance of the social component to the success of management plans, and for that reason incorporates traditional knowledge provided by fishermen. The group provides training on data collection and monitoring, and empowers local resource users to monitor and contribute to the understanding of regional fisheries resources. The PANGAS project is composed of six institutions from Mexico and the US: CEDO, COBI, ProNatura Noroeste, the University of Arizona, CICESE, and the University of California-Santa Cruz (PANGAS 2008).

CEDO Intercultural A.C.

The *Centro de Estudios de Desiertos y Océanos* (CEDO), or Center for the Study of Deserts and Oceans, is an NGO founded in 1980 in Puerto Peñasco, Sonora, Mexico. CEDO's main mission is to preserve and promote the natural and cultural resources of the Northern Gulf of California and the closely connected Sonoran Desert ecosystems. CEDO works with local communities, governments, and visitors on increasing awareness about the importance of species and environmental conservation. Since its foundation, CEDO seeks livelihood improvement for fishing communities through straightforward collaboration, and has served as a catalyzer for appropriate solutions on environmental issues affecting them. In this, CEDO has been involved with the conservation of the vaquita by making efforts in education, research, incentives design, and the promotion of responsible fishing practices in the three surrounding communities on the Upper Gulf where vaquita are distributed (CEDO n.d.)

NOS, A.C.

Noroeste Sustentable, or Sustainable Northwest (NOS), is an environmental NGO established in 2007. NOS effectively works in the three main areas interacting in regional systems, being social, environmental and economics systems by involving the private sector, market organizations, fishing cooperatives and other partners to work together and generate healthy ecosystems. Achieving management of fisheries resources and trade through the creation of management agreements based on citizen commitments and income optimization for the communities of the Mexican Northwest is their working strategy (NOS n.d.).

OCEAN GARDEN PRODUCTS, Inc. (OGP)

Initially created as a public-private co-venture for fishing and aquaculture cooperatives in the 1960s to develop markets for Mexican seafood, this enterprise grew to become recognized as the largest marketer of seafood products from Mexico. Today OGP is a fully privately incorporated enterprise (Meltzer & Chang 2006). OGP imports, exports, sells and develops markets for seafood through its US based headquarters in San Diego, California. OGP is primarily focused on importing wild and farm raised shrimp from Mexico, but also commercializes other seafood products such as salmon, abalone and calamari from different regions of the world. Shrimp from the Upper Gulf of California are largely marketed through OGP. The Ocean Garden brand is recognized for its high quality of products, and supplies many high-end restaurant chains and retailers mainly throughout the US (Ocean Garden Inc. n.d.).

NRDC

The Natural Resources Defense Council is an action group dedicated to the protection of the environment. It is composed of activist members, lawyers, scientist and professionals. Protection of endangered species and oceans as well as the promotion of sustainable communities are specific agenda areas of the NRDC. In 2005, this organization started a campaign to protect vaquita and its habitat, negotiating between fishermen and corporations such as Ocean Garden, Inc. to reach agreements for trading more responsible seafood products. Additionally, NRDC collaborates on international plans such as CIRVA in the development of economic alternatives for fishermen to facilitate their transition to sustainable fishing (NRDC 2007).

Tables

El Golfo de Santa Clara	Source	Units	Result
Finfish (total landings)	Avila-Forcada, et al. 2011	Metric tons	3,946
Average finfish gross income per season per panga	Barlow et al. 2010	US $	1.7
Net income[1] per panga per season	Barlow et al. 2010	US $	1,935
Sum of net profits from legal and illegal finfish fishing per season in the area	Barlow et al. 2010	US $	1,089
Shrimp (total landings)	Avila-Forcada, et al. 2011	Metric tons	280
Average shrimp gross income per Season per Panga	Barlow et al. 2010	Thousands US $	8.9
Labor Costs per Season per Panga	Barlow et al. 2010	Thousands US $	2.1
Sum of net profits from legal and illegal shrimp fishing per season in the area	Barlow et al. 2010	Thousands US $	973

Appendix, Table A: Net income is the gross income minus the operational costs. Operational costs include fuel, nets, depreciation, repairs, etc in the UGC as published in the literature.

San Felipe	Source	Units	Result
Finfish (total landings)	Avila-Forcada, et al. 2011	Metric tons	1,469
Average finfish gross income per season per panga	Barlow et al. 2010	Thousands US $	0.7
Net income per panga per season	Barlow et al. 2010	Thousands US $	857
Sum of net profits from legal and illegal finfish fishing per season in the area	Barlow et al. 2010	Thousands US $	442
Shrimp (total landings)	Avila-Forcada, et al. 2011	Metric tons	342
Average shrimp gross income per Season per Panga	Barlow et al. 2010	Thousands US $	9.6
Labor Costs per Season per Panga	Barlow et al. 2010	Thousands US $	2.3
Sum of net profits from legal and illegal shrimp fishing per season in the area	Barlow et al. 2010	Thousands US $	1,335

Appendix, Table B: Table of relative earnings associated with fishing livelihoods in the UGC as published in the literature.

Commercial Targeted Species in the Upper Gulf of California

Cientific Name	Common Name Spanish	Common Name English
Laevicardium elatum	Almeja sol	Giant Pacific egg cockle
Dosinia sp	Almeja blanca gigante	Dosinia clam
Argopecten circularis	Almeja voladora, almeja catarina	Scallop
Pecten vogdesi	Almeja voladora, almeja catarina	Vogde's scallop
Pteria sterna	Concha nácar	Western wing oyster
Spondylus calcifer	Almeja burra, callo de escarlopa	Donkey thorny oyster
Pinna rugosa	Pinna rugosa	Rugose pen shell
Atrina tuberculosa	Atrina tuberculosa	Tuberculate pen shell
Spondylus princeps	Callo mechudo	Pacific thorny oyster
Pinctada mazatlanica	Madreperla	Mazatlan pearl oyster
Strombus galeatus	Caracol burro	Giant Eastern Pacific conch
Melongena patula	Caracol de uña	Pacific melongena
Phyllonotus erithrostoma	Caracol chino rosa	Pink-mouthed murex
Hexaplex (Muricanthus) nigritus	Caracol chino negro	Black murex
Octopus bimaculatus	Pulpo	Octopus
Isostichopus fuscus	Pepino de mar	Sea cucumber
Litopenaeus stylirostris	Camarón azul	Blue shrimp
Litopenaeus californiensis	Camarón café	Brown shrimp
Callinectes bellicosus	Jaiba	Warrior swimcrab
Negaprion brevirostris	Tiburón amarillo	Lemon shark
Rhizoprionodon longurio	Tiburón bironcha	Pacific sharpnose shark
Carcharodon carcharias	Tiburón blanco	White shark
Alopias superciliosus	Tiburón coludo, zorro	Bigeye thresher
Alopias vulpinus	Tiburón chango, zorro	Thresher
Sphyrna lewini	Tiburón cornuda, martillo	Scalloped hammerhead
Sphyrna mokarran	Tiburón cornuda, martillo	Great hammerhead
Carcharhinus leucas	Tiburón lobero	Bull shark
Isurus oxyrinchus	Tiburón perro	Shortfin mako
Galeocerco cuvier	Tiburón tigre	Tiger shark
Carcharhirus obscurus	Tiburón barroso	Dusky shark
Mustelus lunulatus	Tiburón tripa, mamón, cazón	Sicklefin smooth-hound
Mustelus henlei	Tiburón tripa, mamón, cazón	Brown smooth-hound
Carcharhinus lumbatus	Tiburón volador	Blacktip shark
Squatina californica	Angelito	Pacific angelshark
Rhinobatus productus	Guitarra	Shovelnose guitarfish

Appendix, Table C: List of commercially targeted species in the Upper Gulf of California.

Commercial Targeted Species in the Upper Gulf of California

Cientific Name	Common Name Spanish	Common Name English
Dasyatis brevis	Manta arenera	Whiptail stingray
Gymnura marmorata	Manta mariposa	California butterfly ray
Myliobatis longirostris	Manta gavilán	Snouted eagle ray
Myliobatis californica	Manta ratón	Bat eagle ray
Epinephelus niphobles	Baqueta ploma	Grouper
Epinephelus acanthistius	Baqueta roja	Rooster hind
Micteroperca jordani	Baya	Gulf grouper
Ephinephelus analogus	Cabrilla pinta	Spotted grouper
Mycteroperca rosacea	Cabrilla sardinera	Leopard grouper
Paralabrax auroguttatus	Extranjero	Seabass sp
Stereolepsis gigas	Pascara	Giant seabass
Paralichthys aestuarius	Lenguado	Speckled flounder
Oligoplites altus	Bichi	Longjaw leatherjacket
Trachinotus paitensis	Palometa	Paloma pompano
Trachinotus rhodopus	Pámpano	Gafftopsail pompano
Eucinostomus sp	Mojarra	Mojarra
Menticirrhus nasus	Bocadulce	Highfin king croaker
Micropogonias megalops	Chano	Slender croaker, bigeye croaker
Atractoscion nobilis	Cabaicucho	White weakfish
Cynoscion xanthulus	Curvina aleta amarilla	Orangemouth weakfish
Cynoscion parvipinnis	Curvina blanca	Shortfin weakfish
Cynoscion othonopterus	Curvina golfina	Gulf weakfish
Cynoscion reticulatus	Curvina rayada	Weakfish
Totoaba macdonaldi	Totoaba	Totoaba
Mugil cephalus	Lisa	Flathead grey mullet
Mugil curema	Lisa, liseta	White mullet
Scomberomorus sierra	Sierra	Pacific sierra
Scomberomorus concolor	Sierra	Monterey Spanish mackerel
Coryphaena hippurus	Dorado	Common dolphinfish
Nematistius pectoralis	Gallo	Roosterfish
Balistes polylepsis	Cochito	Finescale triggerfish
Caulolatilus affinis	Conejo	Bighead tilefish
Merluccius sp	Merluza	Hake
Lobotes pacificus	Juancho	Pacific tripletail
Hoplopagrus guntheri	Pargo coconaco	Mexican barred snapper
Stomolophus meleagris	Medusa bola de cañón	Cannonball jellyfish

Appendix, Table C cont. Main commercial targeted species in the Upper of Gulf of California

Proportional Costs to Landings ratio (2004 Baseline to 2000-2007 Average)			
SF		GSC	
Species	Cost-multiplier	Species	Cost-multiplier
Shrimp	0.636703442	**Shrimp**	1.002671559
Sierra	0.231782226	**Sierra**	0.774417158
Shark	0.44694491	**Shark**	0.646882869
Ray	0.232314368	**Ray**	146.1070424
Chano	0.622890122	**Chano**	76.42369755

Appendix, Table D: The above table provides the values calculated as cost multipliers for each fishery in San Felipe and Golfo de Santa Clara. The cost multiplier is identified taking the scaled difference between 2004 landings and the average annual landings, which is then the value multiplied by the 2004 fishing costs for each species published by CONAPESCA (2005) to estimate fishing costs that would be associated with the average landings (see calculated costs used in bioeconomic model).

Compensation in Perpetuity						
Spatial Closure	**Buyout Level**	**Fisheries Closure**	**compliance Level**	**Annual Net Revenue Loss ($MXN)**	**Vaquita Population Growth Rate**	**Compensation Trust ($MXN)**
All Closed	0	1	1	36,422,200	1.0387	**809,382,212**
All Closed	0.1	1	1	36,422,200	1.0387	**809,382,212**
All Closed	0.2	1	1	36,422,200	1.0387	**809,382,212**
All Closed	0.3	1	1	36,422,200	1.0387	**809,382,212**
All Closed	0.3	1	0.8	31,323,092	1.0211	**696,068,702**
All Closed	0.2	1	0.8	30,594,648	1.0185	**679,881,058**
All Closed	0.1	1	0.8	29,866,204	1.0160	**663,693,414**
Marxan 95	0.3	1	1	29,809,636	1.0341	**662,436,366**
All Closed	0	1	0.8	29,137,760	1.0135	**647,505,769**
Marxan 95	0.2	1	1	28,864,985	1.0335	**641,444,102**
Swollen Refuge	0.3	1	1	28,737,050	1.0111	**638,601,107**
Marxan 95	0.1	1	1	27,920,333	1.0328	**620,451,839**
Swollen Refuge	0.2	1	1	27,639,171	1.0072	**614,203,807**
Marxan 90	0.3	1	1	27,194,013	1.0176	**604,311,394**
Marxan 95	0	1	1	26,975,681	1.0322	**599,459,575**
Swollen Refuge	0.1	1	1	26,541,293	1.0032	**589,806,506**
All Closed	0.3	1	0.6	26,223,984	1.0034	**582,755,192**
Marxan 95	0.3	1	0.8	26,033,041	1.0174	**578,512,026**
Marxan 90	0.2	1	1	25,875,700	1.0146	**575,015,563**
Marxan 90	0.1	1	1	24,557,388	1.0116	**545,719,732**
Marxan 95	0.2	1	0.8	24,548,876	1.0143	**545,530,570**
Marxan 90	0.3	1	0.8	23,940,542	1.0042	**532,012,048**
Marxan 90	0	1	1	23,239,076	1.0086	**516,423,901**
Marxan 95	0.1	1	0.8	23,064,710	1.0113	**512,549,115**
Marxan 95	0.3	1	0.6	22,256,446	1.0006	**494,587,685**
Marxan 95	0	1	0.8	21,580,545	1.0082	**479,567,660**
All Closed	0	5	1	18,424,912	1.0387	**409,442,489**
All Closed	0.1	5	1	18,424,912	1.0387	**409,442,489**
All Closed	0.2	5	1	18,424,912	1.0387	**409,442,489**
All Closed	0.3	5	1	18,424,912	1.0387	**409,442,489**
Marxan 95	0.3	5	1	15,387,038	1.0341	**341,934,174**
Marxan 95	0.2	5	1	14,953,056	1.0335	**332,290,129**
Marxan 95	0.1	5	1	14,519,074	1.0328	**322,646,084**
Swollen Refuge	0.3	5	1	14,094,887	1.0111	**313,219,706**
Marxan 95	0	5	1	14,085,092	1.0322	**313,002,039**
All Closed	0.3	3	1	13,935,271	1.0091	**309,672,681**
Marxan 90	0.3	5	1	13,867,287	1.0176	**308,161,926**
Swollen Refuge	0.2	5	1	13,476,312	1.0072	**299,473,594**
Marxan 90	0.2	5	1	13,216,197	1.0146	**293,693,275**
Swollen Refuge	0.1	5	1	12,857,737	1.0032	**285,727,482**
Marxan 95	0.3	3	1	12,844,620	1.0054	**285,436,003**
Marxan 90	0.1	5	1	12,565,108	1.0116	**279,224,623**
Marxan 90	0	5	1	11,914,019	1.0086	**264,755,971**
All Closed	0.2	3	1	10,722,852	1.0048	**238,285,605**
Marxan 95	0.2	3	1	9,476,395	1.0007	**210,586,545**
All Closed	0.1	3	1	7,510,434	1.0006	**166,898,529**

Appendix, Table E: The above table provides the values for all policy scenarios with vaquita population increase expected. Given a 4.5 percent interest rate, the Compensation Trust column indicates the amount of money (#MXN) that would need to be set aside in order to generate enough interest on an annual basis to compensate the losses in fisheries revenue (values in red) associated with the defined policy. Interest from a compensation trust of this size will provide compensation in perpetuity for losses in fisheries revenue projected for each policy.

Evaluation of Policies that Project Increasing Vaquita Population

Spatial Closure	Buyout Level	Fisheries Closure	compliance Level	Fisheries Revenue	Vaquita Population Growth Rate
All Closed	0	5	1	0.494	1.039
All Closed	0.1	5	1	0.494	1.039
All Closed	0.2	5	1	0.494	1.039
All Closed	0.3	5	1	0.494	1.039
All Closed	0	1	1	0.000	1.039
All Closed	0.1	1	1	0.000	1.039
All Closed	0.2	1	1	0.000	1.039
All Closed	0.3	1	1	0.000	1.039
Marxan 95	0.3	5	1	0.578	1.034
Marxan 95	0.3	1	1	0.182	1.034
Marxan 95	0.2	5	1	0.589	1.033
Marxan 95	0.2	1	1	0.207	1.033
Marxan 95	0.1	5	1	0.601	1.033
Marxan 95	0.1	1	1	0.233	1.033
Marxan 95	0	5	1	0.613	1.032
Marxan 95	0	1	1	0.259	1.032
All Closed	0.3	1	0.8	0.140	1.021
All Closed	0.2	1	0.8	0.160	1.019
Marxan 90	0.3	5	1	0.619	1.018
Marxan 90	0.3	1	1	0.253	1.018
Marxan 95	0.3	1	0.8	0.285	1.017
All Closed	0.1	1	0.8	0.180	1.016
Marxan 90	0.2	5	1	0.637	1.015
Marxan 90	0.2	1	1	0.290	1.015
Marxan 95	0.2	1	0.8	0.326	1.014
All Closed	0	1	0.8	0.200	1.013
Marxan 90	0.1	5	1	0.655	1.012
Marxan 90	0.1	1	1	0.326	1.012
Marxan 95	0.1	1	0.8	0.367	1.011
Swollen Refuge	0.3	5	1	0.613	1.011
Swollen Refuge	0.3	1	1	0.211	1.011
All Closed	0.3	3	1	0.617	1.009
Marxan 90	0	5	1	0.673	1.009
Marxan 90	0	1	1	0.362	1.009
Marxan 95	0	1	0.8	0.407	1.008
Swollen Refuge	0.2	5	1	0.630	1.007
Swollen Refuge	0.2	1	1	0.241	1.007
Marxan 95	0.3	3	1	0.647	1.005
All Closed	0.2	3	1	0.706	1.005
Marxan 90	0.3	1	0.8	0.343	1.004
All Closed	0.3	1	0.6	0.280	1.003
Swollen Refuge	0.1	5	1	0.647	1.003
Swollen Refuge	0.1	1	1	0.271	1.003
Marxan 95	0.2	3	1	0.740	1.001
Marxan 95	0.3	1	0.6	0.389	1.001
All Closed	0.1	3	1	0.794	1.001

Appendix, Table F The above table provides each bioeconomic outcome for all policy scenarios that project increasing vaquita abundance (in order of greatest vaquita population growth rate). Policies are characterized by a fishery closure code, a spatial closure, buyout level, and compliance level. Estimated change in fisheries revenue is provided. Growth rate is provided in terms of lambda.

Compliance levels in Alternative Policies

Spatiall Closure	Buyout Level	Fisheries Closure	Compliance	Vaquita Population Growth Rate	Normalized Revenue
All Closed	0.1	3	1	1.00	0.79
All Closed	0.3	1	0.6	1.00	0.28
All Closed	0.2	3	1	1.00	0.71
All Closed	0.3	3	1	1.01	0.62
All Closed	0.0	1	0.8	1.01	0.20
All Closed	0.1	1	0.8	1.02	0.18
All Closed	0.2	1	0.8	1.02	0.16
All Closed	0.3	1	0.8	1.02	0.14
All Closed	0.0	1	1	1.04	0.00
All Closed	0.1	1	1	1.04	0.00
All Closed	0.2	1	1	1.04	0.00
All Closed	0.3	1	1	1.04	0.00
All Closed	0.0	5	1	1.04	0.49
All Closed	0.1	5	1	1.04	0.49
All Closed	0.2	5	1	1.04	0.49
All Closed	0.3	5	1	1.04	0.49
Marxan 90	0.3	1	0.8	1.00	0.34
Marxan 90	0.0	1	1	1.01	0.36
Marxan 90	0.1	1	1	1.01	0.33
Marxan 90	0.2	1	1	1.01	0.29
Marxan 90	0.3	1	1	1.02	0.25
Marxan 90	0.0	5	1	1.01	0.67
Marxan 90	0.1	5	1	1.01	0.66
Marxan 90	0.2	5	1	1.01	0.64
Marxan 90	0.3	5	1	1.02	0.62
Marxan 95	0.3	1	0.6	1.00	0.39
Marxan 95	0.2	3	1	1.00	0.74
Marxan 95	0.3	3	1	1.01	0.65
Marxan 95	0.0	1	0.8	1.01	0.41
Marxan 95	0.1	1	0.8	1.01	0.37
Marxan 95	0.2	1	0.8	1.01	0.33
Marxan 95	0.3	1	0.8	1.02	0.29
Marxan 95	0.0	1	1	1.03	0.26
Marxan 95	0.0	5	1	1.03	0.61
Marxan 95	0.1	1	1	1.03	0.23
Marxan 95	0.1	5	1	1.03	0.60
Marxan 95	0.2	1	1	1.03	0.21
Marxan 95	0.2	5	1	1.03	0.59
Marxan 95	0.3	1	1	1.03	0.18
Marxan 95	0.3	5	1	1.03	0.58
Swollen Refuge	0.1	1	1	1.00	0.27
Swollen Refuge	0.2	1	1	1.01	0.24
Swollen Refuge	0.3	1	1	1.01	0.21
Swollen Refuge	0.1	5	1	1.00	0.65
Swollen Refuge	0.2	5	1	1.01	0.63
Swollen Refuge	0.3	5	1	1.01	0.61

Table G: The above table shows the numerical values associated with the selected policies that allow vaquita population recovery. The asterisks in some options in the Spatial Closure column indicate policies that make use of the light trawl. As indicated in the Compliance column (red), all policy options that enable vaquita to recover are at or above a compliance level of 0.8 (80%), with exception of two policies with 0.6 of compliance (blue).

Lambda of Policy Outcome	Probability >1	Lambda of Policy Outcome	Probability >1	Lambda of Policy Outcome	Probability >1	Lambda of Policy Outcome	Probability >1
0.9	0.045	0.94	0.13	0.98	0.397	1.02	0.947
0.901	0.046	0.941	0.133	0.981	0.406	1.021	0.951
0.902	0.047	0.942	0.136	0.982	0.416	1.022	0.957
0.903	0.047	0.943	0.142	0.983	0.431	1.023	0.962
0.904	0.047	0.944	0.15	0.984	0.442	1.024	0.971
0.905	0.047	0.945	0.159	0.985	0.47	1.025	0.978
0.906	0.047	0.946	0.161	0.986	0.481	1.026	0.982
0.907	0.047	0.947	0.161	0.987	0.481	1.027	0.985
0.908	0.055	0.948	0.167	0.988	0.49	1.028	0.986
0.909	0.055	0.949	0.174	0.989	0.525	1.029	0.989
0.91	0.056	0.95	0.176	0.99	0.53	1.03	0.99
0.911	0.06	0.951	0.177	0.991	0.541	1.031	0.993
0.912	0.062	0.952	0.184	0.992	0.549	1.032	0.996
0.913	0.062	0.953	0.187	0.993	0.565	1.033	0.997
0.914	0.066	0.954	0.193	0.994	0.572	1.034	0.998
0.915	0.068	0.955	0.201	0.995	0.595	1.035	1
0.916	0.068	0.956	0.208	0.996	0.614	1.036	1
0.917	0.068	0.957	0.214	0.997	0.629	1.037	1
0.918	0.068	0.958	0.221	0.998	0.639	1.038	1
0.919	0.068	0.959	0.223	0.999	0.658	1.039	1
0.92	0.073	0.96	0.234	1	0.683	1.04	1
0.921	0.074	0.961	0.234	1.001	0.697	1.041	1
0.922	0.08	0.962	0.24	1.002	0.712	1.042	1
0.923	0.083	0.963	0.245	1.003	0.728	1.043	1
0.924	0.084	0.964	0.257	1.004	0.747	1.044	1
0.925	0.087	0.965	0.265	1.005	0.758	1.045	1
0.926	0.09	0.966	0.27	1.006	0.776	1.046	1
0.927	0.092	0.967	0.277	1.007	0.789	1.047	1
0.928	0.093	0.968	0.284	1.008	0.797	1.048	1
0.929	0.094	0.969	0.29	1.009	0.81	1.049	1
0.93	0.103	0.97	0.296	1.01	0.826	1.05	1
0.931	0.106	0.971	0.303	1.011	0.84		
0.932	0.106	0.972	0.311	1.012	0.855		
0.933	0.106	0.973	0.324	1.013	0.864		
0.934	0.106	0.974	0.331	1.014	0.876		
0.935	0.115	0.975	0.346	1.015	0.893		
0.936	0.123	0.976	0.351	1.016	0.9		
0.937	0.123	0.977	0.359	1.017	0.916		
0.938	0.124	0.978	0.373	1.018	0.931		
0.939	0.129	0.979	0.384	1.019	0.939		

Table H: List of all possible lambda values under given modeled policies and the associated probability of being greater than 1.

Evaluation of Pareto Improvement Policies						
Spatial Closure	**Buyout Level**	**Fisheries Closure**	**compliance Level**	**Annual Net Revenue ($MXN)**	**Normalized Revenue**	**Vaquita Population Growth Rate**
All Closed	0.1	3	1	28,911,766	0.794	1.001
All Closed	0	3	1	32,124,184	0.882	0.996
Marxan 95	0.1	3	1	30,314,031	0.832	0.996
Marxan 95	0	3	1	33,682,256	0.925	0.991
All Closed	0.1	3	0.8	29,685,408	0.815	0.985
Marxan 95	0.1	3	0.8	30,807,220	0.846	0.982
All Closed	0	3	0.8	32,983,787	0.906	0.980
Marxan 90	0.1	3	1	31,180,631	0.856	0.979
Marxan 95	0	3	0.8	34,230,245	0.940	0.975
Swollen Refuge	0.1	3	1	31,139,539	0.855	0.973
Marxan 90	0	3	1	34,645,146	0.951	0.972
All Closed	0.1	3	0.6	30,459,051	0.836	0.970
Marxan 90	0.1	3	0.8	31,500,501	0.865	0.968
Marxan 95	0.1	3	0.6	31,300,410	0.859	0.968
Swollen Refuge	0	3	1	34,599,488	0.950	0.966
Swollen Refuge	0.1	3	0.8	31,467,627	0.864	0.963
All Closed	0	3	0.6	33,843,390	0.929	0.963
Marxan 90	0	3	0.8	35,000,557	0.961	0.960
Marxan 95	0	3	0.6	34,778,234	0.955	0.960
Refuge	0.1	3	1	31,886,983	0.875	0.957
Marxan 90	0.1	3	0.6	31,820,371	0.874	0.957
Marxan 90	0.2	3	0.4	28,569,102	0.784	0.957
All Closed	0.1	3	0.4	31,232,694	0.858	0.955
Swollen Refuge	0	3	0.8	34,964,031	0.960	0.955
Refuge	0.2	3	0.6	28,661,495	0.787	0.955
Swollen Refuge	0.2	3	0.4	28,554,492	0.784	0.955
Swollen Refuge	0.1	3	0.6	31,795,715	0.873	0.954
Marxan 95	0.1	3	0.4	31,793,600	0.873	0.953
Refuge	0.1	3	0.8	32,065,582	0.880	0.951
Refuge	0.2	3	0.4	28,820,250	0.791	0.949
Refuge	0	3	1	35,429,981	0.973	0.948
Marxan 90	0	3	0.6	35,355,967	0.971	0.948
Marxan 90	0.1	3	0.4	32,140,240	0.882	0.947
All Closed	0	3	0.4	34,702,993	0.953	0.946
Refuge	0.1	3	0.6	32,244,182	0.885	0.945
Swollen Refuge	0	3	0.6	35,328,573	0.970	0.944
Swollen Refuge	0.1	3	0.4	32,123,804	0.882	0.944
Marxan 95	0	3	0.4	35,326,222	0.970	0.944
Refuge	0	1	0.5	28,509,885	0.783	0.943

Appendix, Table I: The above table provides all policy configurations and bioeconomic outcomes for any Pareto improvement policies**.** Pareto improvements are those policies that have a better outcomes, for both revenue and vaquita abundance, than the current policy scenario. Values are ordered by policies that have the greatest benefit for vaquita abundance, descending in performance to the current policy listed at the bottom of the table (in red). The top policy represents the one Pareto improvement policy that is projected to have a vaquita population growth rate above a lambda of 1.0, indicating population growth.