Status Review of the Gulf Grouper (*Mycteroperca jordani*)

Sala et al. 2003

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EXECUTIVE SUMMARY

Background

On July 15, 2013, the National Marine Fisheries Service (NMFS) received a petition from the WildEarth Guardians to list 81 marine species under the Endangered Species Act (ESA) and to designate critical habitat under the ESA. On February 24, 2014, NMFS published a 90-day petition finding and request for information in the Federal Register (79 FR 10104) for 10 species of skates and rays and 15 species of bony fishes, including the gulf grouper (*Mycteroperca jordani*). Upon review of the petition, NMFS determined that it provided substantial scientific/commercial information indicating that the petitioned action may be warranted for the gulf grouper. This document reports the results of a comprehensive ESA status review of the gulf grouper.

Approach of the Status Review

NMFS acknowledges that there is considerable uncertainty surrounding aspects of the gulf grouper's biology, abundance, trends in abundance, and threats. The petitioner asserted that all five ESA section 4(a)(1) factors threaten the survival of the gulf grouper: (A) the present or threatened destruction, modification, or curtailment of its habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) the inadequacy of existing regulatory mechanisms; and (E) other natural or manmade factors affecting its continued existence. Each of these factors will be discussed in detail with current known information for this species.

Conclusion

The gulf grouper has undergone a dramatic decrease from its historical abundance. The gulf grouper resides in the subtropical eastern Pacific Ocean and Gulf of California from 32.84° N (La Jolla, California; United States) to 23.22° N (Mazatlán, Sinaloa; Mexico), typically in reefs in waters up to 30-45 m deep. In the early 20th century, the gulf grouper was an abundant fish. Since that time, gulf grouper have been subject to fisheries which have reduced their abundance to less than 1% of their historical levels. Due to their biology, gulf groupers are maladapted to fishery pressures. First, they are a long lived (48 years), late maturing fish (six years as a female). Second, they are protogynous hermaphroditic, so they mature as females and later transition into males. Since males are older and, thus, larger, they are selected for at harvest, which skews their sex ratios. Third, gulf grouper spawn at aggregation sites. Once a year, they aggregate for reproduction at a known time (full moon in May), at known locations (reefs and seamounts), at higher than normal densities, and at an adult size rendering them highly susceptible to direct harvest. Due to poor regulations and enforcement, harvest activities will continue to severely impact gulf grouper. Direct harvest has been the major factor in the decline of the gulf grouper and will continue to be a major threat to their persistence. Indirect harvest as bycatch in the shrimp trawler fishery, due to a lack of bycatch reduction devices (BRDs), is also a major threat. Other threats for gulf grouper include loss and degradation of reef habitats and climate change impacts upon coral ecosystems. Minor impacts upon gulf grouper persistence include decreased freshwater inputs, coastal city growth, tidal power, shrimp farms, and increasing ocean temperature and acidification as a result of climate change. Due to the aforementioned threats and demographic risk factors associated with this species, I conclude that the gulf grouper is at a high risk of extinction throughout all of its range. Overall, these threats place the current viability of the species at risk and likely influenced by stochastic and/or depensatory processes.

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1.0 INTRODUCTION

This status review of the gulf grouper (*Mycteroperca jordani*) will be presented in six sections. Section one (Introduction) will discuss the purpose and layout of the status review. Section two (Taxonomy and biology of the gulf grouper) will discuss grouper family characteristics and a general description of the gulf grouper. Section three (Natural history of the gulf grouper) discusses the population structure, distribution, habitat, abundance, diet, reproduction, and mortality of the gulf grouper. Section four (Threats to the gulf grouper) discusses the environmental and human threats to gulf grouper. Section five (Existing regulatory mechanisms) discusses the local and federal laws and regulations that protect and/or degrade gulf grouper survival. Section six (Extinction risk analysis for the gulf grouper) synthesizes the biology, threats, and regulations to determine extinction risk to the gulf grouper.

2.0 TAXONOMY AND BIOLOGY OF THE GULF GROUPER

2.1 Taxonomy

Groupers are bottom-associated fishes found in tropical and subtropical oceanic waters and are commonly associated with coral reefs, estuaries, and rocky reefs (Heemstra and Randall 1993). Most grouper species inhabit depths of less than 100 m with juveniles often found in tidepools (Heemstra and Randall 1993). Groupers are mostly solitary fish, except for spawning aggregations, and can be resident on particular reefs for long periods of time (Heemstra and Randall 1993). Groupers are considered a valuable but vulnerable fishery resource due to their longevity, late sexual maturation, and aggregation spawning (Sadovy de Mitcheson et al. 2012).

Gulf grouper (*Mycteroperca jordani*) is a member of the *Serranidae* family, the grouper family.[1]

Phylum:	*Chordata*
Class:	*Actinopterygii* (ray-finned fish)
Order:	*Perciformes* (“perch-like”)
Family:	*Serranidae* (3 subfamilies)
Subfamily:	*Epinephelinae* (5 tribes)
Tribe:	*Epinephelini* (20 genera)
Genus:	*Mycteroperca* (15 species)
	jordani (Gulf grouper)

Fifteen species reside within the *Mycteroperca* genus (Table 1). Five species are distributed in the Pacific Ocean, and 10 species are distributed in the Atlantic Ocean. Many groupers are aggregate hermaphroditic breeders that mature as females and transition into males (protogynous hermaphrodite). Two of these 15 species are considered endangered by the IUCN (www.iucnredlist.org), and they were both included in the WildEarth Guardians ESA listing petition. Gulf grouper are most closely related genetically to *M.*

[1] Sources – http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=167765 and Craig and Hastings (2007).

bonaci (black grouper) and *M. venenosa* (yellowfin grouper), both Atlantic Ocean basin species (Craig and Hastings 2007).

Table 1. *Mycteroperca* species distribution, sex structure, IUCN status, and population trend.

Species	Ocean Basin	Sex structure [1]	IUCN Status [2]	Population Trend [2]
Black grouper (*Mycteroperca bonaci*)	Atlantic	PH	Near threatened	Decreasing
Broomtail grouper (*M. xenarcha*)	Pacific	Unk.	Least Concern	Unknown
Colorado grouper (*M. olfax*)	Pacific	Unk.	Vulnerable	Unknown
Comb grouper (*M. acutirostris*)	Atlantic	Unk.	Least Concern	Stable
Gag grouper (*M. microlepis*)	Atlantic	PH	Least Concern	Decreasing
Gulf grouper (*M. jordani*)	Pacific	PH	Endangered	Decreasing
Island grouper (*M. fusca*)	Atlantic	Unk.	Endangered	Decreasing
Leopard grouper (*M. rosacea*)	Pacific	G	Vulnerable	Decreasing
Mottled grouper (*M. rubra*)	Atlantic	PH	Least Concern	Unknown
Sawtail grouper (*M. prionura*)	Pacific	Unk.	Near threatened	Decreasing
Scamp grouper (*M. phenax*)	Atlantic	PH	Least Concern	Stable
Tiger grouper (*M. tigris*)	Atlantic	PH	Least Concern	Unknown
Venezuela grouper (*M. cidi*)	Atlantic	Unk.	Data deficient	Unknown
Yellowfin grouper (*M. venenosa*)	Atlantic	PH	Near threatened	Decreasing
Yellowmouth grouper (*M. interstitialis*)	Atlantic	PH	Vulnerable	Decreasing

[1] G - gonochoric (single sex); PH - protogynous hermaphrodite; Unk. – Unknown

[2] Based upon IUCN Red List of Threatened Species analyses (www.iucnredlist.org).

2.2 Species Description

The gulf grouper was first described by O. P. Jenkins and B. W. Evermann (1889) after a scientific trip to the town of Guaymas along the east coast of the Gulf of California (GOC). At the time, the species was described as common in the Bahía de Guaymas and having great flavor (Jenkins and Evermann 1889). In Mexico, gulf grouper are known predominantly as *baya*, but are also known as *cabrilla de astillero*, *garlopa*, *garropa*, *mero baya*, and *mérou golfe*[2]. The gulf grouper can grow up to 150 cm (in length), 91 kg (in weight), and 48 years (Heemstra and Randall 1993, Aburto-Oropeza et al. 2008).

The gulf grouper is a large, heavy-bodied grouper with rounded preopercle and moderate sized scales (Smith 1971). They have a comparatively elongated and compressed body shape with body depth much less than their head length (Jenkins and Evermann 1889, Heemstra and Randall 1993). The dorsal fin has XI spines (fourth or fifth spine longest) and 16 to 17 rays with the posterior margin rounded (Heemstra and Randall 1993). The anal fin has III spines and 10 to 11 rays; and the gill rakers range from 21 to 26, not counting rudiments (Heemstra and Randall 1993). Gulf groupers can be confused with broomtail groupers, which share the same range. Broomtail groupers, however, are anatomically different in that: (1) the anal fin is pointed with the middle spines near twice the length of the adjacent spines (the anal fin is squared off in gulf grouper), (2) the caudal fin is truncate with exserted rays (exserted rays are absent in

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[2] Source – http://www.iucnredlist.org/details/14049/0

gulf grouper), and (3) the color is of a blotchy pattern (gulf groupers are more uniform in color) (Heemstra and Randall 1993).

Juvenile gulf grouper are greyish-brown with large, dark grey oblong blotches on the dorsal part of the body and fins (Heemstra and Randall 1993). Female adults are generally dark brown to grey, but they can assume a juvenile pattern when disturbed or excited. Larger adult males develop a white margin along the pectoral fin with the medial fin developing a narrow white edge (Heemstra and Randall 1993). In spawning aggregations, breeding individuals exhibit conspicuous dark lines radiating from the eye (Sala et al. 2003).

Sex ratios, in protogynous hermaphroditic reproduction systems, trend towards a higher percentage of females (Allsop and West 2004). An analysis of six grouper reproduction studies observed sex ratios ranging from one male for every 3.5 females to one male for every 17.3 females (Table 2). Since protogynous groupers transition from females to males as they age, males of these species are larger and more targeted by fisheries. Thus, fisheries can further skew sex ratios by removing males from the population (McGovern et al. 1998).

Table 2. Sex ratios of various hermaphroditic grouper species.

Species	Sex ratio (M:F)	Reference
Half-moon grouper (*Epinephelus rivulatus*)	1:6.5	Mackie 2003
Hawaiian grouper (*Hyporthodus quernus*)	1:6.1	DeMartini et al. 2011
Red hind (*E. guttatus*)	1:8.7	Shapiro et al. 1993
Gag grouper (*Mycteroperca microlepis*)	1:4.0 to 1:17.3	McGovern et al. 1998
Dusky grouper (*E. marginatus*)	1:3.5	Marino et al. 2001
Red grouper (*E. morio*)	1:5.05	Brule et al. 1999

3.0 NATURAL HISTORY OF THE GULF GROUPER

3.1 Population Structure, Distribution, Habitat, and Abundance

3.1.1 Historical and Current Distribution

The gulf grouper resides in the subtropical eastern Pacific Ocean and GOC from 32.84° N (La Jolla, California; United States) to 23.22° N (Mazatlán, Sinaloa; Mexico) (Figure 1) (Heemstra and Randall 1993). Gulf grouper typically reside in reefs and seamounts in waters up to 30 - 45 m deep (Heemstra and Randall 1993, Sala et al. 2003, Moreno-Baéz 2010).

Starting at the northern part of the range, the coastline begins as urban (La Jolla / San Diego / Tijuana / Ensenada) but quickly becomes mostly unpopulated. The largest towns on the Pacific coast of the Baja Peninsula (775 miles long) are Guerrero Negro (13,054 population – 2010), midway down the peninsula, and Cabo San Lucas (68,463 population – 2010), on the southern tip of the peninsula. The eastern shoreline of the peninsula has the largest city bordering the GOC – La Paz (215,178 population – 2010) – which is only 90 miles north of Cabo San Lucas. Going clockwise around the GOC from La Paz, all of the remaining cities are less than 50,000 people, except for Guaymas (113,082 population – 2010).

Current gulf grouper distribution appears to be much more limited than their historical range (Sáenz-Arroyo et al. 2005a). In the 1930s, some irruptions of gulf groupers occurred along the San Diego coastline (Hubbs 1948); but there are no records of any occurring since then. Gulf grouper fisheries peaked for California ports in the early 1950s (the harvest occurred in Mexican waters) and disappeared by 1970[3]. Recent gulf grouper observations outside of the GOC, in areas of the historic California fishery, are limited to some observations in Bahía Magdalena during recent marine surveys (Octavio Aburto-Oropeza, Scripps Institution of Oceanography, Aug 29, 2014, pers. comm.). Meanwhile, gulf grouper observations in the GOC are more common, but they are still only found in a few, scattered locations and are still generally rare. Overall, the historic and current range distribution for gulf grouper is considered restricted, less than 800,000 km^2, making them more vulnerable to local stochastic events (Morris et al. 2000).

3.1.2 Population Structure and Genetics

The ESA defines a species to include any subspecies and any distinct population segment of a vertebrate species that interbreeds when mature, and NMFS and the U.S. Fish and Wildlife Service published a policy to interpret the phrase “distinct population segment” in 1996 (61 FR 4722). Not enough information is known about the gulf grouper to determine if it can be broken down into distinct population segments (DPS). Although its current distribution appears to be fragmented, this may be more of an artifact of past exploitation rather than a natural distribution pattern. Second, the distance a gulf grouper will travel for reproduction is unknown, though in some grouper species movements of over 100 km have been documented (see Section 3.1.5). Third, there are no known genetic analyses among gulf grouper specimens to determine if any differentiation at the population level exists. Due to these factors, the gulf grouper species will not be broken into DPSs and will, therefore, be analyzed at the species level.

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[3] Source: California Department of Fish and Wildlife (http://libraries.ucsd.edu/apps/ceo/fishbull/)

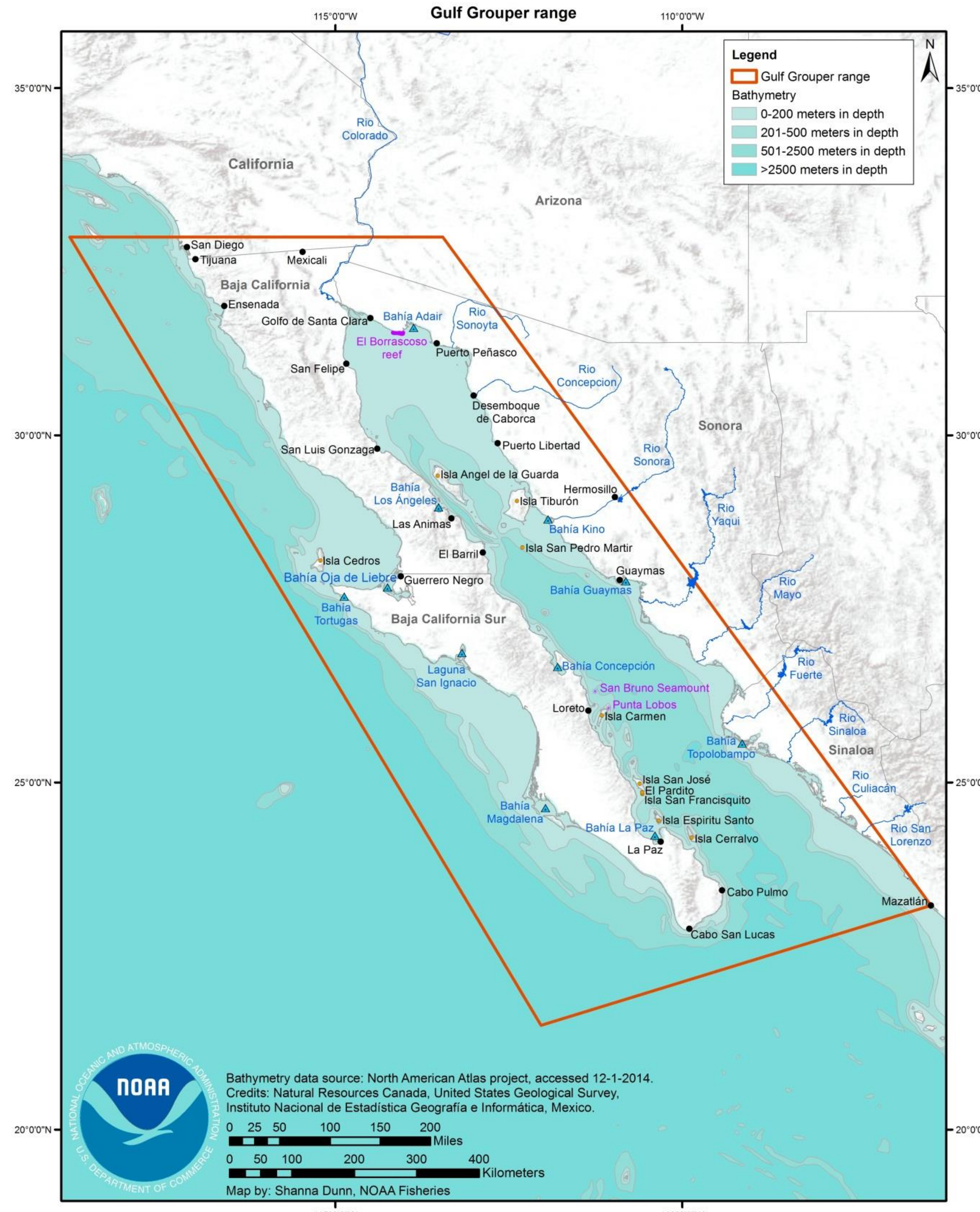

Figure 1. Map of gulf grouper range.

3.1.3 Habitat

Gulf grouper habitat requirements vary throughout life. All groupers pass through a pelagic larvae phase (20-50 days) during which they settle into rocky, coastal reefs (Aburto-Oropeza et al. 2008). After this phase, they acquire juvenile characteristics while they settle into shallow, coastal habitats (e.g. sargassum beds, seagrass areas, mangroves, and estuaries); this nursery stage can last up to two years. After the nursery stage, juvenile gulf groupers move to adult gulf grouper habitat (Aburto-Oropeza et al. 2008). Adult gulf grouper predominately use rocky reefs, seamounts, and kelp beds of depths from five to 30 meters (Heemstra and Randall 1993, Sala et al. 2003) and deeper (30 to 45 m) during the summer months (Moreno-Baéz 2010). During the spawning season, gulf groupers will aggregate in rocky reefs and seamounts in depths from 20 to 35 m (Sala et al. 2003). GOC reefs are predominantly rocky with a coral component, in the south, that shifts to kelp (brown algae), in the north (Squires 1959). Coral reefs are thermally constrained to the southern part of the GOC due to winter temperatures below the optimal 25-29° C range (Squires 1959) but are still impacted by warmer ocean temperatures during "El Niño" events (Bonilla 1993, Bonilla 2001). Rhodolith beds (red algae) are extensive throughout the GOC and support high species richness, including free-living hermatypic corals, to depths of 100m (Reyes-Bonilla et al. 1997, Steller et al. 2003, Hinojosa-Arango and Riosmena-Rodríguez 2004).

3.1.4 Abundance

Due to a lack of research, most gulf grouper knowledge comes from anecdotal information and fisheries data. Historical and current gulf grouper population numbers are unknown. Only through anecdotal information (Section 3.1.4.1), marine surveys (Section 3.1.4.2), and fishing reports and statistics (Section 3.1.4.3 and 3.1.4.4) can a picture of gulf grouper abundance be approximated. Based upon old grey literature, naturalist's observations, and fisher's anecdotes, Sáenz-Arroyo et al. (2005a) theorized that (1) gulf grouper stocks collapsed in the early 1970s which was well before fishing statistics were being collected, (2) gulf grouper were once abundant and probably dominated the rocky-reef fish community in terms of biomass, and (3) gulf grouper abundance has dropped by over 99% since the 1940s based upon numbers aggregating to spawn.

3.1.4.1 Early Observations and Anecdotal Information

With a lack of fisheries data until recently, anecdotal information is one of the few ways to determine gulf grouper abundance and range. A species that is rare now, may not have been until recent times due to a shifting baseline. Pauly (1995) described shifting baseline syndrome as "each generation of fisheries scientists accepts as a baseline the stock size and species composition that occurred at the beginning of their careers, and uses this to evaluate changes. When the next generation starts its career, the stocks have further declined, but it is the stocks at that time that serve as a new baseline. The result obviously is a gradual shift of the baseline, a gradual accommodation of the creeping disappearance of resource species, and inappropriate reference points for evaluating economic losses resulting from overfishing, or for identifying targets for rehabilitation measures." For example, Lozano-Montes et al. (2008) interviewed fishers from northern GOC fishing communities and found that the older fishers could recall capturing five times as many fish species and up to 25 times more gulf grouper than the younger fishers could.

Early European explorers during the 16th and 18th centuries described both coasts of the Baja California peninsula as abundant with species believed to be goliath and gulf groupers (Sáenz-Arroyo et al. 2006). When Jenkins and Evermann (1889) described gulf groupers, they noted them as abundant in the Bahía de Guaymas. In the 1930s, Californian fishermen would sail south of the border to fish between Bahía Tortugas and Bahía Magdalena where groupers were described as so common that "(s)port fishermen who angle in Mexican waters encounter no difficulty in catching their fill of the abundant *cabrilla* and grouper. In fact they find it virtually impossible to catch anything else along the rocky shores inhabited by these voracious and unwary fish that will strike at any moving object smaller than themselves (Croaker 1937)." Though several different *Mycteroperca* species would be caught, gulf grouper were the most important grouper for that commercial fishery (Croaker 1937, Fitch 1949). In the GOC, a good day fishing during the 1940s and 1950s was harvesting 25 or more gulf grouper, all more than 80 cm long. In 1960, the gulf grouper still represented 45% of the artisanal fishery in the southern GOC (Aburto-Oropeza et al. 2008).

El Club de Vuelos was one of the first sport fishing resorts in Baja California (Sáenz-Arroyo et al. 2005a). Based out of Loreto, the resort operated from 1951 through 1963. On a daily basis, up to six boats fished the Punta Lobos and San Bruno seamounts (both were probable spawning aggregation sites), averaging 10 to 12 gulf grouper weighing between 50 and 100 kg. In 1962, the club owner began flying harvested gulf grouper to San Diego, CA, two to three times per week for two months. One of the retired fishermen estimated that 35 to 40 gulf grouper (six to seven per boat) averaging 70 kg were being harvested daily for shipment. During these two months, an estimated 63 metric tons of gulf grouper were harvested (Sáenz-Arroyo et al. 2005a). For comparison, only 58 metric tons of gulf grouper were harvested from 2006 through 2012 throughout its entire range (Section 3.1.4.3). From 2001 through 2004, Sáenz-Arroyo et al. (2005a) conducted over 30 dives during the gulf grouper spawning season at sites that were recommended by the original fishers' from the resort. During these dives, only three gulf groupers were observed; and they were all observed at the Punta Lobos seamount.

Dynamite is a very indiscriminate and destructive method of fishing (Sáenz-Arroyo et al. 2005a). In 1918, a speaker at the Mexican Society of Geography and Statistics complained that "some fishers fish with dynamite, a terrible means that destroys all animals." One fisher, from the 1940s and 1950s, described using dynamite to fish for gulf and leopard grouper; and he would harvest, on average, from 40 to 100 grouper (a mix of both species) per explosion. At the San Bruno seamount (a spawning aggregation site), one fisher recalled observing a boat using dynamite to harvest gulf grouper during the 1950s. He described the fishers as filling their boat to capacity with gulf grouper (70 metric tons, approximately 1,000 gulf groupers) and leaving the rest behind. In 2002 and 2003, a biologist from nearby Loreto Bay National Park fished the San Bruno seamount during the spawning aggregation season; and he was only able to capture one gulf grouper (Sáenz-Arroyo et al. 2005a).

Along the Pacific coast of the Baja California peninsula, gulf grouper abundance is even more of a mystery. With the dearth of towns and ports along the Mexican Pacific coast, not much is known about gulf grouper. Californian fishers frequented these waters for gulf grouper harvest throughout the mid-20th century; but by 1970, the gulf grouper harvest dropped to nearly zero and has not since reappeared in the commercial fisheries (despite fisheries still being present through this part of its range) (Section 3.1.4.4). Recently, some gulf grouper observations have occurred in Bahía Magdalena during marine surveys (Octavio Aburto-Oropeza, Scripps Institution of Oceanography, Aug 29, 2014, pers. comm.).

3.1.4.2 Marine Surveys

In Mexico, marine surveys examining fish abundance and diversity have been conducted throughout the gulf grouper's range. In an analysis of 38 scientific papers and theses conducted since 1970, gulf groupers were found in only eight of these documents – four literature reviews and four field studies (Appendix; Table 9).

Using literature searches and museum collections from the 20th century, four scientific papers documented gulf grouper presence. Martínez-Guevara (2008) studied five coastal systems along the Baja California peninsula (Laguna Ojo de Liebre, Laguna de San Ignacio, Bahía Magdalena, Bahía Concepción, and Bahía de La Paz). From these locations, museum collections and peer-reviewed articles were analyzed; and 446 species were identified. Gulf grouper were found in two of these locations (Laguna de San Ignacio and Bahía Magdalena). Del Moral-Flores et al. (2013), in an annotated checklist of GOC fish fauna, described 615 fish species found amongst 67 GOC islands. Gulf grouper were observed adjacent to seven islands (Ángel de la Guarda, Carmen, Las Ánimas, Espíritu Santo, Cerralvo, Tiburón, and Conjunto Mazatlán). Two other localized literature searches found gulf grouper presence at Cabo Pulmo (Villarreal-Cavazos et al. 2000) and Isla Cerralvo (Galván-Magaña et al. 1996), both in the GOC.

The remaining four documents observed gulf grouper presence through original research. From 1978 through 1982, Balart et al. (1995) conducted net sampling, local fisheries observation, and fish otolith identification from California sea lion (*Zalophus californianus*) scat in Bahía de la Paz. The research added an additional 132 fish species (including gulf grouper) to the systematic list of fish species for Bahía de la Paz.

From 1987 through 2008, Saldívar-Lucio (2010) conducted 340 visual censuses during 19 surveys at Cabo Pulmo National Park near the southern tip of the Baja California peninsula. The marine habitat is mostly reef, and a total of 109 fish species were observed. Gulf grouper were only observed once during these surveys (six individuals, June 1998).

From 2000 through 2002, Palacios-Salgado et al. (2012) conducted gill and charalera net surveys and visual censuses near San Jose, San Francisquito, and El Pardito islands in the GOC. Visual censuses were conducted during 10 monthly trips to 13 locations in habitats dominated by rocky reefs. During the field sampling, 160 species were recorded with 130 species observed during the visual censuses. Gulf groupers were only observed during the visual censuses.

In 2001 and 2002, Barjau-González et al. (2012) conducted 48 visual transects at eight locations around Isla San José in the GOC. Surveys were conducted bimonthly (from March to the following February) in mostly rocky reef habitat (~90%). A total of 112 species were observed, including gulf grouper. Using a Fisher alpha index, the relative abundance for gulf grouper was calculated at 0.162 (38 of 112 species).

3.1.4.3 Mexico Fisheries

Until the past decade, federal fishery harvest statistics have been unreliable in Mexico for tracking most species. In 1988, federal authorities began tracking artisanal fishery harvests. From 1989 to 2001, disaggregated harvest records from three GOC ports (La Paz, Loreto, and San Felipe) showed gulf grouper harvest dropping from 57 to 12 metric tons (Sáenz-Arroyo et al. 2005a). By 2000, the capture of one to two gulf groupers less than 60 cm was considered a successful fishing trip (Aburto-Oropeza et al. 2008). Up until 2006, official federal fish harvest statistics had gulf grouper lumped in with 200 other species as 'peces marinos de escama' (Cinti et al. 2010). Beginning in 2006, harvest data began to be broken out to the species level; and annual gulf grouper harvest throughout its range varied from 1.5 (2011) to 17.4 metric tons (2007) (Figure 2). While analyzing harvest data from 2001 through 2005, Aburto-Oropeza et al. (2008) estimated that 29% of the groupers harvested in the GOC were gulf grouper. In a study of fishing records from Bahía de Los Angeles, 321 gulf grouper were harvested during April, May, and June in 2002 and 2003 (the time of the year when gulf grouper are harvested in this area). Of those gulf grouper harvested, approximately 99% of them were immature (Octavio Aburto-Oropeza, Scripps Institution of Oceanography, Aug 26, 2014, pers. comm.). Gulf grouper are mainly harvested by hook and line or spearfishing, but are also caught as bycatch in gill nets. In the official Mexican fishery statistics, gulf grouper are, currently, a minor part of the fish harvest constituting less than 1% of total annual commercial fishery catch. Since most of the decline in gulf grouper abundance occurred in the mid-20th century, the official harvest statistics fail to encapsulate most of the changes to gulf grouper abundance (Aburto-Oropeza et al. 2008).

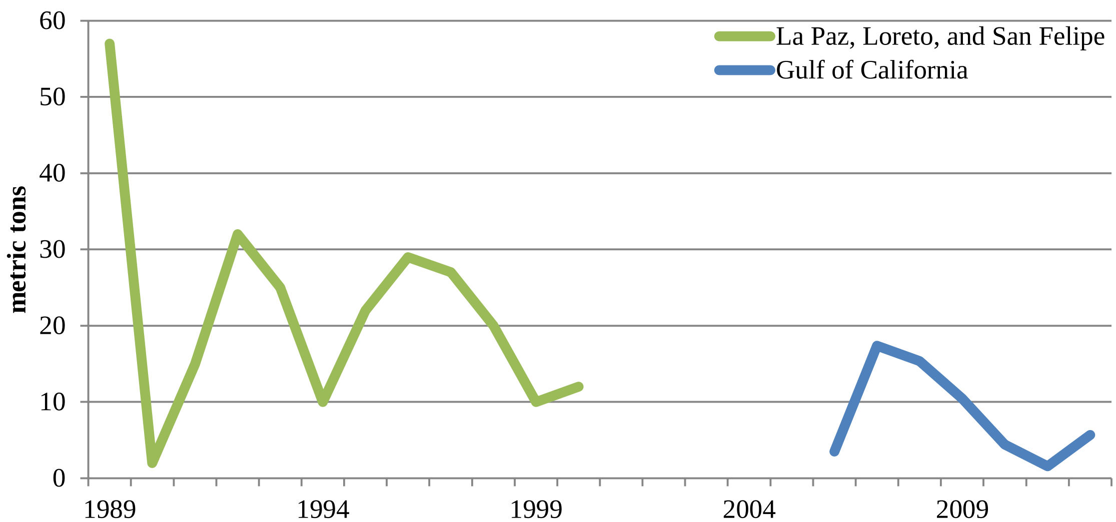

Figure 2. Gulf grouper harvested (metric tons) at three ports in the Gulf of California (1989 – 2000; Sáenz-Arroyo et al. 2005a) and all Gulf of California ports (2006 – 2012; http://www.sepescabc.gob.mx/).

Tournaments – At least 18 sport fishing tournaments occur throughout the GOC annually. Most of these tournaments are for billfish, dorado, and wahoo; however, two of these tournaments currently include gulf grouper as prize categories. The Rocky Point Deep Sea Fishing Tournament started in 2008 (Puerto Peñasco, Sonora, Mexico). The 2012 *Baya* category winner was an 80-pound gulf grouper that garnered a $4,000 prize[4]. Starting in 2011, the Great Loreto Yellowtail Tournament (Loreto, Baja California Sur, Mexico) offers prizes for two categories – yellowtail and cabrilla/pargo (which includes the *Mycteroperca*

[4] Source - http://rockypoint360.com/5th-deep-sea-fishing-tournament-day-2/

genus)[5]. Trophy fishing selectively targets and removes the largest individuals in a population (and most important reproductively) resulting in a larger negative impact upon the species while exacerbating population declines (Shiffman et al. 2014).

3.1.4.4 California Fisheries

In California, the grouper commercial fishery is composed of broomtail and gulf groupers. Beginning in 1927, the gulf grouper fishery became popular in southern California ports (Croaker 1937). Originally marketed as "golden bass," gulf groupers became one of the leading fisheries; especially since they were harvested during the winter, when local species were scarce. Both San Diego fisher boats and halibut fisher vessels from Seattle, after the halibut season closed, would fish the Pacific coast of the Baja peninsula between Bahía Tortugas and Bahía Magdalena and return to Los Angeles or San Diego to sell their catch (Croaker 1937). Grouper harvest peaked in the early 1950s at 376 metric tons, dropped down to the 100-150 metric ton range from the late 1950s until the late 1960s, after which the grouper fishery completely crashed (Figure 3). California Department of Fish and Game adopted no-take prohibitions for broomtail and gulf grouper in 1976 that are still in effect today (Chuck Valle, California Fish and Wildlife, April 14, 2014, pers. comm.).

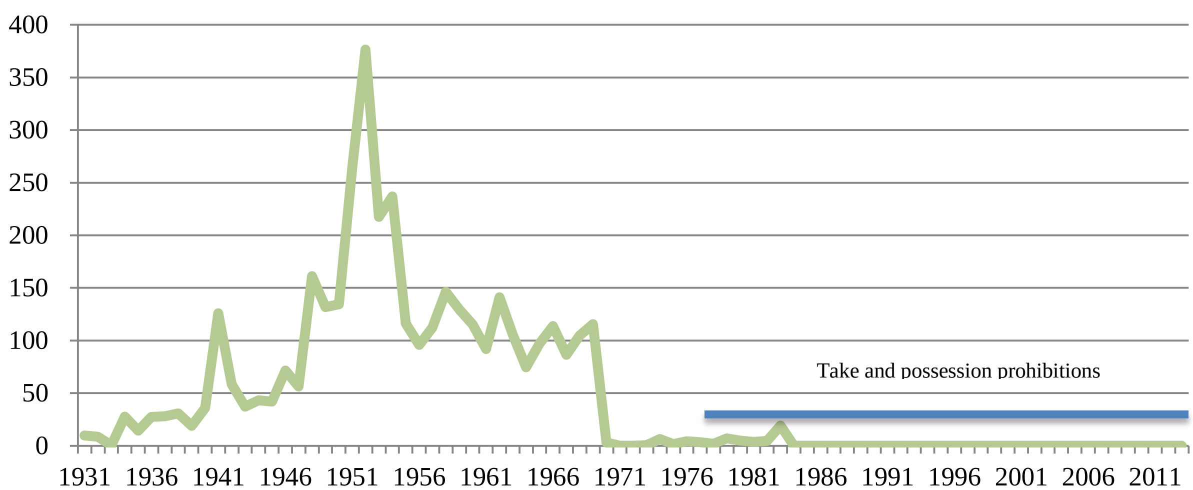

Figure 3. Commercial catch (metric tons) for grouper (broomtail and gulf grouper) in the California commercial fishery (1931-2013) (Source: California Department of Fish and Wildlife Bulletin #74, 80, 86, 89, 95, 102, 105, 108, 111, 117, 121, 125, 132, 135, 138, 144, 149, 153, 154, 159, 161, 163, 166, 168, 168, 170, and 173 - http://libraries.ucsd.edu/apps/ceo/fishbull/).

3.1.5 Movement

No specific studies for gulf grouper movements have been found. Juvenile gulf groupers are found in shallower, coastal habitats while adults are found in deeper environments. Sexually mature gulf grouper move to spawning aggregations from unknown distances. Other groupers, such as Nassau grouper (*Epinephelus striatus*), are known to travel more than 100 km from their resident reefs to spawning

[5] Source - http://loretotournaments.com/

aggregation sites (Sadovy de Mitcheson et al. 2008). Gulf grouper are considered to be solitary predators that aggregate at higher densities during spawning season. After spawning, successful gulf grouper eggs and larvae drift from the spawning aggregation sites to settlement habitats (Aburto-Oropeza et al. 2008).

3.2 Diet

Gulf grouper are considered voracious, solitary predators though little is known about their diets. In a Nassau grouper study, juvenile groupers (< 20 cm) consumed mostly small crustaceans and shifted to fish as they grew larger (> 30 cm) (Eggleston et al. 1998). Sadovy and Eklund (1999) also found that with increasing age and size, there is a shift away from crustaceans to fish, larger bivalves, lobster, gastropods, and even some prey larger than themselves. In a dusky grouper study, young grouper (3-7 cm) diet was dominated by crustaceans (i.e., amphipods, isopods, cumaceans, shrimp, and crab). As larger juveniles (13-25 cm), they shifted primarily to crab and fish as their dominant prey (Harmelin and Harmelin-Vivien 1999). As adults, gulf grouper diet is varied and known to include such prey as large fish, slipper lobster, and juvenile hammerhead shark (Aburto-Oropeza et al. 2008).

3.3 Reproduction

3.3.1 Hermaphroditic sexual lifecycle

Gulf grouper are a protogynous hermaphroditic fish that mature as females and, later in life, transition into males (Sáenz-Arroyo et al. 2005a). Gulf groupers are believed to transition from female to male based upon their size (size-advantage model) (Bhandari et al. 2006, Zhou and Gui 2010). The size-advantage model theorizes that if it is advantageous for one sex to reproduce at a small size and the other sex to reproduce at a larger size, than the individual should change sex at some point in life (Ghiselin 1969, Bhandari et al. 2006). At an estimated six to seven years of age, gulf grouper mature as females (Aburto-Oropeza et al. 2008).

Larger females produce more quality eggs. In Nassau grouper, a mean relative fecundity of three to five eggs per mg of ripe ovary has been estimated (Sadovy and Eklund 1999). With gag grouper, Collins et al. (1998) found a significant positive correlation between fecundity and total length, body weight, and age (Figure 4). On average, an eight-year-old female *Mycteroperca* produces 60 times the number of eggs that a five-year-old female would (Aburto-Oropeza et al. 2008).

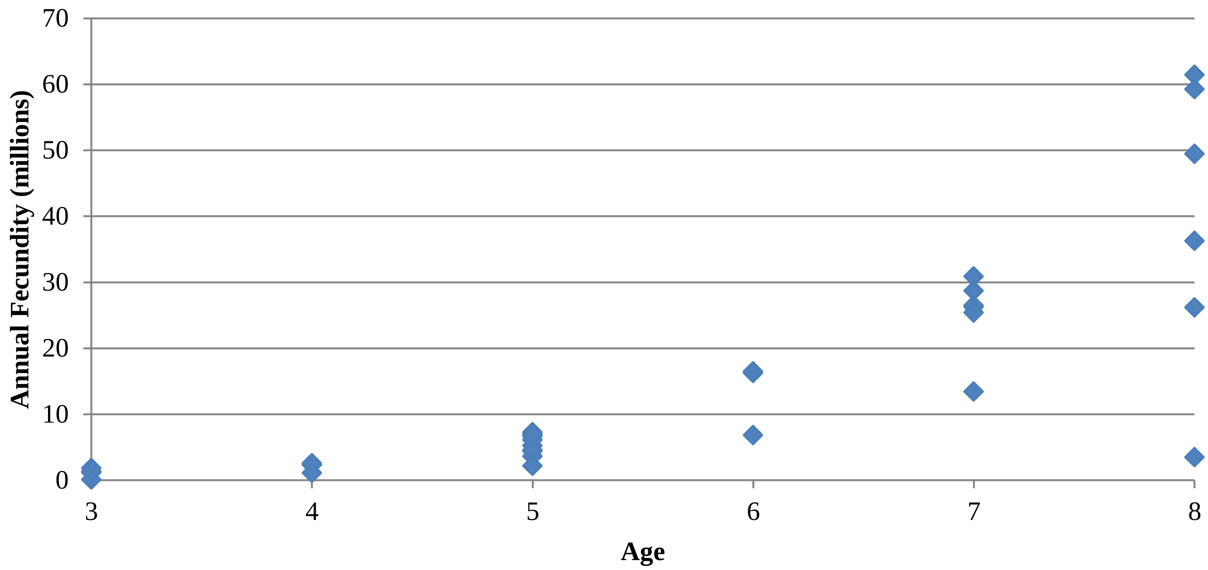

Figure 4. Annual fecundity of female gag groupers by age (Collins et al. 1998).

3.3.2 Aggregate spawners

Gulf groupers are transient aggregate spawners. Domeier and Colin (1997) defined spawning aggregations as "a group of conspecific fish gathered for the purpose of spawning with fish densities or numbers significantly higher than those found in the area of aggregation during the non-reproductive periods." Spawning aggregations are further categorized as either "resident" or "transient" depending upon aggregation criteria. Transient spawning aggregations tend to (1) draw individuals from a relatively large area (individuals travel days to weeks to gather), (2) occur during a very specific time of year (one or two months of the year), (3) persist for only a few day period, and (4) do not occur year-round (Domeier and Colin 1997). Transient aggregate species are often large sized, predators that are not known to spawn outside of aggregations (Domeier and Colin 1997).

Spawning aggregation sites may be located so that the planktonic eggs will be carried to locations favorable for offspring survival (Domeier and Colin 1997). One theory on spawning aggregation site location and timing is that it can depend upon tidal influences for egg/larvae distribution (Domeier and Colin 1997, Cherubin et al. 2011). The GOC, with its length and combinations of basins, islands, and sills, has large tides (up to 4 m) and fast tidal currents (up to 1.5 m/sec) which peak during the full moon (Filonov and Lavín 2003) when gulf grouper spawn. In a genetic parentage analysis study, Almany et al. (2013) found that half of the squaretail coral grouper (*Plectropomus areolatus*) larvae settled within 14 km of the spawning aggregation site.

Spawning aggregation sites can persist for multiple generations. For example, some Nassau grouper spawning aggregation sites have persisted for over 80 years (Aguilar-Perera and Aguilar-Dávila 1994). Other spawning aggregation sites can be short lived and may disappear after a minimum number of individuals fail to aggregate (Colin 1996). Spawning aggregation sites may be learned from older individuals leading new recruits; thus, the loss of these individuals may result in the loss of these sites (Bolden 2000, Aguilar-Perera 2006).

Adult gulf grouper form spawning aggregations of 40 or more individuals near the full moon in late spring (May), in areas larger than 1,000 m^2 (Aburto-Oropeza et al. 2008). Their spawning aggregation sites consist of rocky reef (gorgonians and black coral) seamounts with abrupt relief habitat at 20 to 35 m depth. Based upon three observed spawning aggregations, gulf grouper spawning aggregation density was estimated at 220 fish/ha with grouper length ranging from 100 to 150 cm. Though spawning was not observed at these sites, spawning colorations were (Sala et al. 2003). Moreno-Baez (2010) delineated six spawning aggregation sites (of which only four were validated) in the northern GOC (from the Midriff Islands north) based upon local fisher knowledge.

3.3.3 Settlement, Recruitment, and Growth

Not much is known about gulf grouper settlement, recruitment, or growth; but groupers, as a whole, exhibit many similarities during this life phase (Aburto-Oropeza et al. 2008). As their eggs develop into larvae, they drift from the spawning aggregation sites to their settlement habitats. Glamuzina et al. (1998), in a laboratory experiment, reared dusky grouper from egg to larvae. At 23° C, the dusky grouper hatched from fertilized eggs to larvae within 33 hours [from 1983-2000, average May sea surface temperatures in the GOC ranged from 20° C to 25° C (Aragón-Noriega 2007)]. Growth rates were fastest during the first 24 hours with pigmentation beginning to appear and the mouth opening after 72 hours and fully functional by 96 hours (Glamuzina et al. 1998). Groupers stay as pelagic larvae from 20 to 50 days, can actively swim, and settle into coastal habitats (coastal reefs, estuaries, and mangrove) where they develop into juveniles during this nursery stage (Aburto-Oropeza et al. 2008).

3.4 Mortality

3.4.1 Larvae and juvenile

Gulf groupers are believed to undergo episodic mass-settlements, which feature infrequent recruitment events when favorable conditions occur (Aburto-Oropeza et al. 2008). The predominant, environmental factor that controls gulf grouper recruitment is the El Niño-Southern Oscillation (ENSO) oceanic pattern. During the warm phase of the ENSO (“El Niño”), the marine waters become nutrient poor with lower plankton densities (Lavaniegos et al. 2002). Brown algae beds (*Sargassum* spp.), recruitment habitat for groupers, decrease in size and coverage during these “El Niño” events. Good recruitment years, as has been observed with leopard grouper, are believed to occur during the cool phase of the ENSO (“La Niña”) when habitat and nutrients are more available (Aburto-Oropeza et al. 2007 and 2008). Other factors that can impact recruitment events are large waves and strong currents that are generated by storms, hurricanes, and large tides (Domeier and Colin 1997, Aburto-Oropeza et al. 2008, Cherubin et al. 2011).

Though no specific research has been completed on gulf grouper development, life stage development has been found to be very similar among various grouper species. Despite producing a large number of eggs annually, most offspring suffer an extremely high mortality rate that decreases with size and age (Aburto-Oropeza et al. 2008). First, groupers pass through a pelagic larval state that lasts from 20 to 50 days and then settle into coastal habitats where they develop into juveniles. This life stage, the nursery stage, can last up to two years before they move to adult habitat (Aburto-Oropeza et al. 2008).

3.4.2 Adult

Gulf groupers are a long-lived fish that are believed to live up to 48 years (Aburto-Oropeza et al. 2008). However, recent studies of another long-lived grouper may indicate that gulf grouper longevity may be even greater. Until recently, speckled hind (*Epinephelus drummondhayi*) were believed to live up to 35 years based upon otolith age-reading of growth zones, but a study that utilized atomic bomb radiocarbon dating validated ages exceeding 43 years, with evidence for longevity of up to 60-80 years (Andrews et al. 2013). Gulf grouper otoliths are also difficult to interpret for estimation of age; but based on the findings for speckled hind, it is likely that the 48-year estimate for gulf grouper may be an underestimate of their lifespan.

Due to their size, gulf grouper predation risk decreases with age. For larger juveniles and adult gulf groupers, fisheries are a major cause of mortality via direct capture (Sections 4.3.1 and 4.3.2) or bycatch (Section 4.3.3).

4.0 THREATS TO THE GULF GROUPER

4.1 Introduction

This section summarizes the threats to gulf grouper persistence, either in relation to information presented earlier or based upon scientific findings of similar species (when that information is not available for the gulf grouper). Four major threats will be discussed in this section – habitat loss and degradation, harvest, shrimp aquaculture, and climate change. Since the beginning of the 20th century, human population growth and development has resulted in the loss and degradation of habitat throughout the gulf grouper's range. Growth and development has exacted impacts throughout the GOC by reducing fresh water inputs, increasing pollution, and degrading or destroying habitats (Section 4.2). Harvest has greatly reduced gulf grouper abundance throughout their range, especially at spawning aggregation sites, and as bycatch in the commercial shrimp industry (Section 4.3). Shrimp aquaculture has substantially increased since the mid-1980s and has turned Mexico into the second largest shrimp producer in the western hemisphere. The majority of Mexico's shrimp production occurs in the GOC where tens of thousands of hectares of coastal habitat have been converted into shrimp farms (Section 4.4). Lastly, climate change will have an increasing impact upon gulf grouper and its coral habitat due to increasing ocean temperatures and acidity (Section 4.5).

4.2 Habitat Loss and Degradation

Gulf groupers are dependent upon rocky reefs and coastal habitats, and the further loss or degradation of these habitats would be detrimental to the species. The terrestrial habitat surrounding the GOC is mostly arid to semi-arid with rivers feeding the estuaries and marine waters with its limited supplies of fresh water and sediments. Human population growth and its associated development and infrastructure have, and will continue to, impact the GOC and its surrounding environments (Section 4.2.1). Further, the need for electricity and water has resulted in proposed tidal power and desalination plant projects that may impact prime gulf grouper habitat (Sections 4.2.1.1 and 4.2.1.2). Consequently, the rivers are dammed, exploited for agricultural water, polluted from agricultural waste and cities, and developed for shrimp farms. The coastal habitats bordering the GOC, important as gulf grouper settlement habitat, have been reduced and degraded while nearshore salinities, upon which ecosystems have evolved for, have changed (Section 4.2.2). The reef habitats, essential for gulf grouper juveniles and adults, are further threatened by fisheries and developmental activities (i.e., dredging, pollution) (Section 4.2.3).

4.2.1 Human Population Growth

Population growth in the GOC region is expected to continue at a high rate with approximately 150,000 new residents per year due to expanded infrastructure and an increased emphasis on trade and tourism (Table 4). The terrestrial landscape surrounding the GOC is mostly arid to semi-arid with rainfall averaging less than 10 inches rain annually except for southern Sinaloa state which averages up to 30 inches annually. Due to this dry climate (low precipitation and high temperatures), most cities are dependent upon rivers and groundwater for urban and agricultural uses. Directly, gulf grouper may be impacted through fisheries (both legal and illegal) and as bycatch. Further, gulf grouper habitat will be impacted by habitat changes and degradation from shrimp aquaculture, river and stream manipulation (i.e., dams, water diversions, pollution), and dredging activities (i.e., marina and port development).

Table 4. Human population for Mexican states bordering the Gulf of California (1930 – 2030).

State	1930 [a]	1950 [a]	1970 [a]	1990 [b]	2010 [b]	2030 [bc]
Baja California Norte	48,000	227,000	870,000	1,732,550	3,224,844	4,169,240
Baja California Sur	47,000	61,000	128,000	339,387	649,616	1,106,468
Sinaloa	396,000	636,000	1,267,000	2,215,227	2,851,334	3,302,931
Sonora	316,000	511,000	1,099,000	1,858,664	2,727,032	3,476,930
Total	**807,000**	**1,435,000**	**3,364,000**	**6,145,828**	**9,452,826**	**12,055,569**
% change	**-**	**+77.8%**	**+134.4%**	**+82.7%**	**+53.8%**	**+27.5%**

[a] INEGI 1973
[b] Source: http://www.conapo.gob.mx/es/CONAPO/Proyecciones_Datos
[c] Projected population

The current mission statement for Mexico's Secretary of Tourism is to boost the development of supply, support, and operation of tourism and become the world leader by 2030.[6] In the current world rankings, Mexico ranks first for cruise boat destinations, third for tourism employment, and seventh in number of tourists.[7] In response to these goals, the Mexican federal government has placed a major emphasis on tourism and trade development throughout the GOC. Beginning in 2008, the first paved highway along the Sonoran GOC coast was constructed from Puerto Peñasco to Mexicali (population 689,775) (Wilder et al. 2012b). This highway, *Carretera Costera*, has been finished north of Puerto Peñasco and is currently under construction towards the south terminating in the town of Guaymas. This highway provides a direct path from the urban centers in Arizona and California and greatly improves accessibility by replacing the gravel roads that previously provided access from inland highways. Another project, the *Escalera Náutica del Mar de Cortés y Riviera Maya*, will construct 29 new marinas within one-day travel distance (120 nautical miles) of each other with facilities to accommodate 60,000 cruise ships and boats annually throughout the GOC (Wilder et al. 2012b). In Puerto Peñasco, the construction of a new marina with associated breakwaters and facilities for cruise liners has started and is expected to be completed by summer 2015 at a cost of 600 million pesos.[8] Another purpose of the improved ports is to increase trade. Guaymas is located 260 miles south of Arizona and accessible to the U.S. via railroad. After dredging its harbor in 2013, the Port of Guaymas became the second largest port in Mexico and is capable of handling vessels up to 130,000 tons while increasing its port capacity from 8 to 30 million tons of cargo and creating 20,000 to 30,000 jobs.[9] South of Guaymas, the Port of Topolobampo is currently undergoing a 200 million peso upgrade that will increase the port's capacity by 10%.[10]

With the upgraded infrastructure of the coastal GOC towns, residential and resort developments are being planned and built. With improved accessibility by land and sea, Puerto Peñasco is currently undergoing a

[6] Source – http://www.sectur.gob.mx/conoce-la-sectur/vision-y-mision/
[7] Source – http://embamex.sre.gob.mx/singapur/index.php/home
[8] Source – http://www.sonoraturismo.gob.mx/descarticulos.php?id=23 and http://puntodevista.mx/2014/11/licitan-muelle-de-homeport/
[9] Source – http://tucson.com/business/local/port-of-guaymas-set-to-double-its-capacity-seeks-arizona/article_16947664-811b-56eb-b67a-abf186bac8c7.html
[10] Source – http://www.sct.gob.mx/despliega-noticias/article/inaugura-sct-terminal-maritima-de-topolobampo-1/

construction boom with two major resorts – The Mayan Palace and Sandy Beach – adding over 100,000 rooms via hotels and condominiums along with golf courses and 22 small-scale desalination plants (Wilder et al. 2012b). Along with the construction of the *Carretera Costera*, the rapid development of the Puerto Peñasco region may impact nearby *El Borrascoso*'s unique reef formations through coastal development (i.e., dredging, shrimp farming) and increased fishing pressure (Zamora-Arroyo et al. 2005). Two hundred kilometers south in Puerto Libertad, the Liberty Cove resort has been approved for 60,000 dwellings, golf courses, race track, and marina.[11] Large developments such as these can impact the shoreline and coastal habitats due to its corresponding septic tanks, roads, golf courses, dredging activities, and marinas which degrade and destroy coastal habitat and marine waters (Glenn et al. 2006).

4.2.1.1. Tidal Power

With the increased development and infrastructure across the region (Mexico and southwestern U.S.) come increased energy (i.e., tidal power) and water needs (i.e., desalination plants). For tidal power locations, the GOC is considered one of the best locations in the world due to its large tides and proximity to urban areas in both countries. The northern and central GOC provides a significant energy potential due to its potential impoundment area of 2,590 km^2 which could garner up to 23 TWh annually.[12] Currently, two tidal power site locations have been identified and are in the early stages of planning:

1. Bahía de Adair (Capacity 1,380 MW / Annual output 5 TWh) – This site is proposed to supplement the power lost from the closure of the San Onofre nuclear power plant.[13] This site is located within the "Alto Golfo de California y delta del Río Colorado" biological reserve near *El Borrascoso*. The estuary is an extensive halophyte marsh system with salt flats and, currently, has no significant human impacts (Glenn et al. 2006).
2. Canal del Infiernillo (1,500 to 4,800 MW / Annual output 5-17 TWh) – This site is considered to be an excellent location due to it being a narrow, shallow strait running between Isla Tiburon and the mainland; possessing large tides; and having a large basin north of the strait. Tiburon Basin takes approximately seven hours to fill and five hours to drain, thus creating a large energy potential. Tiburon Agua y Electridad's plan is to anchor turbines to the 12 m seabed at the northernmost and southernmost chokepoints of the strait to exploit the variation in water levels caused by the tides.[14]

Tidal power does come with environmental impacts. Construction of the tidal power facility (i.e., turbines, electric cables, anchors, hard-fixed structures) will disturb the seabed by removing sediments along with suspending sediments into the water resulting in increased turbidity and mobilization of contaminants (Gill 2005). If pile driving is necessary, then very-high intensity noises would be generated (Boehlert and Gill 2010). Depending upon the seabed substrate, the tidal power facility structures may change the distribution of mobile sediments from local and afar sources (Neill et al. 2009). Eventual changes in the morphodynamics of the seabed may be evident up to 50 km from the tidal power facility (Neill et al. 2009). The facility layout may create and/or modify the existing pelagic habitat creating an

[11] Source – http://www.libertycove.com/home.asp
[12] Source – http://theearthsfund.com/energias-renovables/energia-mareomotriz/?lang=en
[13] Source – http://www.halcyontidalpower.com/projects/
[14] Sources – http://social.tidaltoday.com/technology-engineering/coolest-tidal-project-world and http://www.tiburonaguayelectricidad.com/Desalination_and_Tidal_Electric_Generation_Project.pdf

artificial reef that may negatively impact some species while positively impacting others (Boehlert and Gill 2010). Further, estuaries that provide nurseries for breeding fish may no longer provide the necessary conditions (Wolf et al. 2009). The high-voltage electric cables create electromagnetic fields that may serve as an attractant or deterrent to electrosensitive fish species such as elasmobranchs (Gill 2005).

4.2.1.2. Desalination Plants

In both the southwestern U.S. and northwestern Mexico, water demands increasingly outstrip water resources resulting in the search for additional water supplies. By 2016, global water production by desalination is expected to exceed 38 billion cubic meters of water annually, double the rate of 2008 (Elimelech and Phillip 2011). Currently, three binational desalination projects (Ensenada and Rosarito, Baja California Norte and Puerto Peñasco, Sonora) are planned that would desalinate seawater in Mexico and pipe it to the U.S. (McEvoy 2014). One of the primary benefits of placing these planned binational desalination plants in Mexico are the reduced regulatory hurdles and fewer environmental laws (McEvoy and Wilder 2012). Within Mexico, multiple locations are using desalinated water for water supply. Cabo San Lucas became Mexico's first municipal desalination plant in 2006 which supplements the overdrawn aquifers and 22 small-scale private desalination plants (McEvoy 2014). Desalination plants are often part of the plans in the currently planned tourist resorts (Wilder et al. 2012b). Desalination plants impact the environment by both their very substantial power requirements and the wastewater discharges which include brine plumes (at twice the salinity of marine waters), antiscalents, coagulants, heavy metals (especially copper), and membrane preservatives that get released into the marine environment (Roberts et al. 2010). Further, marine organisms can get trapped in intake systems, and brine wastewater, at twice the salinity of seawater, is released (Wilder et al. 2012a).

4.2.2 Rivers and Coastal Habitats

The GOC has a delicate balance of marine and terrestrial inputs with the southern portion opening up to the Pacific Ocean and the GOC extending over 700 miles to the north where it ends at the Río Colorado delta. As a function of its shape, climate, and geography, the GOC attains large tides, strong currents, and waters of varying salinity. Much of its shoreline is either rocky or sandy and indented at frequent intervals with esteros – negative estuaries that have greater salinity at their heads due to evaporation than at the mouth or opening to the sea (Glenn et al. 2006). With large tidal fluctuations and flat topography, the esteros and associated salt flats are maintained by tidal water intrusions and evaporation from the hot and arid climate.

The GOC has ten major watersheds providing freshwater, sediment, and nutrient inputs (Table 3). In the coastal habitats, the freshwater inputs mix with the marine waters and esteros to create rich estuaries, mangrove swamps, and other habitats. Though the mangrove marshes are federally protected, the remaining wetlands are not protected and are subject to development (Glenn et al. 2006). Due to human population growth, river water is either consumed directly or used indirectly (i.e., agriculture, shrimp farms) and replaced by lower quantity and quality (i.e., effluence, agriculture runoff) water sources which modify and degrade the coastal habitats. For example, upstream dams and water diversions have resulted in a cessation of freshwater inputs from the Río Yaqui to its corresponding esteros. Instead, agricultural runoff and municipal sewage flows into its esteros resulting in eutrophication and pollution (Glenn et al. 2006).

Table 3. Ten largest river watersheds that flow into the Gulf of California.

River	Watershed (km^2)	% of freshwater watershed	Threats				
			Dams	Agriculture	Urban (>500,000)	Water Diversion	Shrimp Farms
Río Colorado	466,939	68.0%	X	X		X	
Río Concepcíon	25,808	3.8%		X			
Río Culiacán	15,731	2.3%	X	X	X		X
Río Fuerte	33,590	4.9%	X	X			X
Río Mayo	15,113	2.2%	X	X			X
Río San Lorenzo	8,919	1.3%	X	X			X
Río Sinaloa	12,260	1.8%	X	X			X
Río Sonora	27,740	4.0%	X	X	X		X
Río Sonoyta	7,653	1.1%		X			
Río Yaqui	72,540	10.6%	X	X		X	

The Río Colorado is the largest watershed flowing into the GOC representing over two-thirds of the GOC's watershed acreage. Historically, 16.4 million acre-feet of water flowed annually into the GOC; unfortunately, the river now rarely flows to the GOC (Goodfriend and Flessa 1997, Bureau of Reclamation 2012). In 1901, the first diversions along the Río Colorado began in the Imperial Valley and, from 1905 to 1907, increased with the accidental creation of the Salton Sea (Goodfriend and Flessa 1997). In 1935, the Hoover Dam was built farther upstream, forming Lake Mead, and further decreased river flows (Goodfriend and Flessa 1997). In a 1944 treaty between Mexico and the United States, 1.5 million acre-feet of the Río Colorado flows, less than 10% of historical levels, were allotted to Mexico (United States of America and Mexico 1944). In 1963, Glen Canyon Dam was completed upstream of Hoover Dam, creating Lake Powell, and further reducing flows until the reservoir filled in 1980 (Glenn et al. 1996). Not only did these dams decrease Río Colorado freshwater inputs, they decreased nutrient and sediment delivery to its delta environment (Glenn et al. 1996, Rodriquez et al. 2001, Glenn et al. 2006). As a result, the Río Colorado delta has lost approximately 90% of its wetlands (Rodriquez et al. 2001). To help alleviate wetland loss and other estuary problems, the U.S. and Mexico agreed in 2012 to increase river flows into the GOC through a series of "pulse flows" to help regenerate native habitats and begin to alleviate salinity issues; these flows began in March 2014 (International Boundary and Water Commission 2012). However, the reduction in river flows has decreased nutrient availability and has mostly eliminated 4,000 km^2 of brackish water environment from the northern GOC. And this has impacted some species that reside in the northern GOC such as the totoaba (*Totoaba macdonaldi*) by delaying maturation and reducing lifetime fecundity (Rowell et al. 2008). In a survey of fishing villages in the northern GOC, the majority of fishers cited that the physical and biological conditions in the northern GOC had declined due to decades of intense fishing, wetland habitat loss, and changes in salinity (Lozano-Montes et al. 2008).

Juvenile gulf groupers reside in the coastal habitats (e.g., brown algae and seagrass beds, mangroves) during the first few years of life and are susceptible to these environmental hazards (Aburto-Oropeza et al. 2008). Pollution and nutrient overload from cities, agriculture, and shrimp farms has degraded water quality threatening coastal habitats. Increased anthropogenic nitrogen from sewage, agricultural, and shrimp farming sources are directly utilized by macroalgae, creating more frequent blooms and corresponding anoxia throughout coastal habitats in the GOC (Piñón-Gimate et al. 2009). Besides the direct impacts of pollution, marine waters can become susceptible to disease outbreaks. For example, a 2008 mortality event, resulting from Mycobacteriosis, afflicted dusky grouper resulting in hundreds of dead grouper along the water surface and between coastal rocks in lagoons along the Mediterranean coast of Egypt (Eissa et al. 2011). This disease outbreak was believed to be triggered by environmental pollution and elevated temperatures and magnified by the grouper's behavior of predating upon other diseased fish (Eissa et al. 2011). In 1997, a similar Mycobacteriosis outbreak in Chesapeake Bay involving striped bass was believed to be triggered by eutrophic waters, elevated temperatures, and hypoxic waters (Jacobs et al. 2009).

4.2.3 Reef Habitats

Reefs support a wide diversity and high density of marine life, including gulf grouper, and are sensitive to anthropogenic threats. Due to the productivity of reefs, harvest activities are the most common threat (see Section 4.3.1); but there are other threats to consider. Both direct (i.e., fishing with dynamite, dredging) and indirect actions (i.e., anthropogenic nutrients, climate change) can have a detrimental impact on reefs. In the past, dynamite was often used for fishing on reefs, which has resulted in permanent damage to gulf grouper spawning habitat (Lozano-Montes et al. 2008). Also, housing and related development causes an increase in dredging activities and various forms of pollution (Zamora-Arroyo et al. 2005). These activities can further increase anthropogenic nutrients to the marine ecosystem, resulting in algal growth and hypoxic waters that can degrade and kill corals (Kline et al. 2006). The effects of climate change can lead to coral degradation through bleaching and mortality events, from elevated ocean temperatures, and loss of structural integrity, from ocean acidification (see Section 4.5.2).

In the northern GOC, the "Alto Golfo de California y delta del Río Colorado" is a 934,756 ha biosphere reserve that is one-third terrestrial and two-thirds marine. Within this reserve is *El Borrascoso*, a 5,813 ha beachrock-coquina limestone reef built from 125,000 year old fossiliferous sediments (Zamora-Arroyo et al. 2005). This reef type is restricted to the northern GOC, is found at only three other locations, and has disproportionately high species diversity, including gulf grouper (Zamora-Arroyo et al. 2005). This reef is currently threatened by coastal development (see Section 4.2.3), shrimp aquaculture (see Section 4.4), and commercial and sport fisheries (see Section 4.3.1) from Puerto Peñasco and El Golfo de Santa Clara (Zamora-Arroyo et al. 2005).

On the southern tip of the Baja California peninsula, the Cabo Pulmo reef is unique in being the only true coral reef in the GOC (Brusca and Thomson 1975). Cabo Pulmo is a National Park with a no-take marine zone (see Section 5.1.2.2). Further, this is the only protected marine zone in the GOC that has seen improved marine fish life diversity and density over the past decade (Aburto-Oropeza et al. 2011).

Unfortunately, the land surrounding Cabo Pulmo has been under continual threat of development from the tourist industry. In 2012, the Cabo Cortés resort (over 30,000 hotel rooms with a desalination plant and marina) was proposed, but the project was rejected by the Mexican government. In September 2012, the IUCN requested the Mexican government to "guarantee the protection of Cabo Pulmo from projects that may constitute a risk for its conservation, including large-scale tourism and real-estate developments, as it is a priority conservation site...."[15] In 2014, another resort, the Cabo Dorado, was proposed for development near Cabo Pulmo. Financed by former Mexican president Vicente Fox and a Chinese real estate consortium, the resort would develop 3,770 ha into over 20,000 hotel rooms, two golf courses, and three beach clubs, and would use nearly 5 million cubic meters of water from the aquifer annually.[16] On May 30, 2014, the developers withdrew their *manifestación de impacto ambiental* (MIA)[17] on the proposed 3.6 billion dollar project, but state on their website to "restart the procedure with a new project and a new MIA."[18]

4.3 Harvest

Gulf grouper are a highly prized fish species. At the time the species was identified and named, it was described as having great flavor (Jenkins and Evermann 1889). In the early 20th century, gulf grouper were harvested by artisanal fishers in pangas but as more effective harvesting tools (i.e., dynamite, nylon nets) became available along with greater access (i.e., more advanced boats, coastal town development, improved transportation), gulf grouper harvest increased. In the 1950s, the fishing industry further developed with fishing camps and tournaments targeting gulf grouper while bringing in fishers from outside the region. Currently, commercial fisheries still directly harvest gulf grouper, though at much lower numbers (Section 4.3.1). Even though gulf grouper numbers are low, they have the additional vulnerability to harvest by being an aggregate spawner whose spawning grounds place them at well-known locations and times as they congregate at high densities (Section 4.3.2). Lastly, gulf groupers are susceptible as bycatch from the large commercial shrimp fishery (Section 4.3.3).

4.3.1 Directed Fisheries

GOC fisheries have increased and changed through time due to species abundance, fishing regulations, market demands/abilities, and fishing advancements. Over the past several decades, fisheries composition has changed with species, such as grouper and sharks, going from common to infrequent targets as their abundances decrease. As a result, regional fisheries shift to the next most abundant species in succession, leading to serial declines (Sala et al. 2004). Because fishing regulations for species like gulf grouper have never relied upon catch quotas or the stock status of the species, there is an inherent susceptibility to overfishing. While the 2007 fishery changes were an improvement (i.e., marine protection zones), a lack of quotas and proper enforcement still remain a significant issue (Cinti et al.

[15] WCC-2012-RES-054-EN Guaranteeing the protection of the Cabo Pulmo National Park; Source – https://portals.iucn.org/docs/iucnpolicy/2012-resolutions/en/WCC-2012-Res-054-EN%20Guaranteeing%20the%20protection%20of%20the%20Cabo%20Pulmo%20National%20Park.pdf
[16] Source – http://www.aida-americas.org/en/cabo_pulmo
[17] An MIA is equivalent to an Environmental Impact Statement (EIS) in Mexico.
[18] Sources – http://www.cabodorado.com.mx/ and http://www.geo-mexico.com/?p=11584.

2010). Development of the GOC region (i.e., increased population, improved infrastructure – highways, electricity) has increased demand on resources and the ability to extract them. Lastly, technological advances for fishers (i.e., monofilament nets, outboard motors, GPSs, depth finders) have increased their harvest yields and improved their ability to find rare fish and aggregation sites (Sadovy 1994, Sadovy and Eklund 1999, Erisman et al. 2012, Sadovy de Mitcheson et al. 2012).

Gulf grouper abundance numbers, past and present, are data poor. No direct studies of gulf grouper abundance have been completed, so this assessment relies upon local fishers' knowledge (LFK), federally compiled fisheries data, and presence/absence survey data (see Section 3.1.4.2). LFK indicates that gulf groupers were once abundant and represented 45% of the artisanal fishery in 1960, 10% by the 1970s, and is now less than 1% of the fishery (Figure 5; Sáenz-Arroyo et al. 2005a). Unfortunately, artisanal fisheries data were not collected until 1988, so these data were never included in the federal fisheries database (only commercial landings were recorded prior to that date). To further complicate matters, the federal fisheries database has been broken down to the species level only since 2007. Since gulf grouper were already in a depleted state by 2007, recent gulf grouper landings statistics can be misinterpreted, leading one to incorrectly conclude that the gulf grouper is a naturally rare species. It is unfortunate that decades of harvests have greatly reduced gulf grouper abundance, but LFK indicates that they were once a common and abundant fish (Sáenz-Arroyo et al. 2005a).

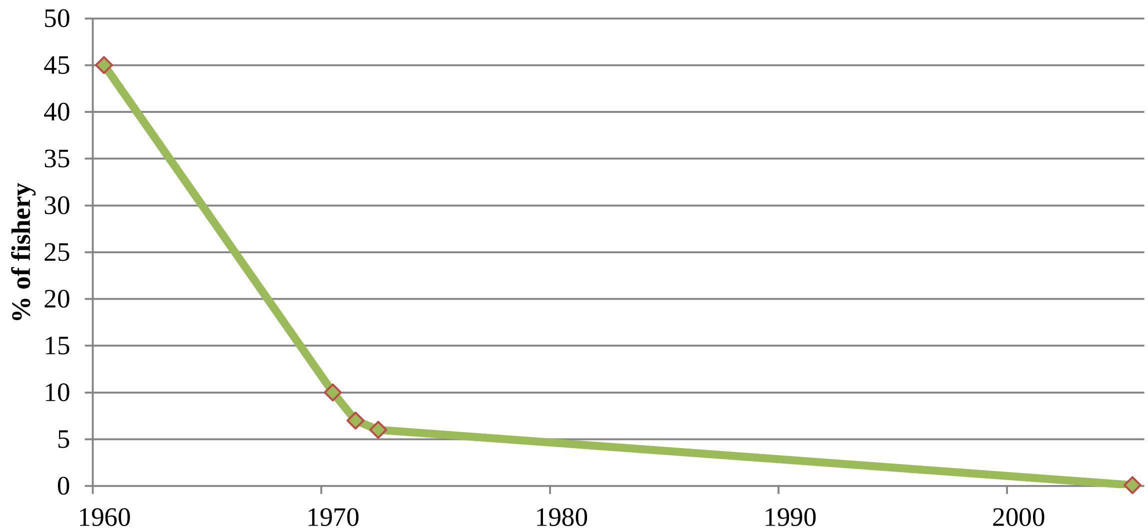

Figure 5. Gulf grouper percentage of artisanal, finfish fishery in Baja California, Mexico (Sáenz-Arroyo et al. 2005a).

Gulf grouper are highly vulnerable to harvest due to their biology and ecology. They currently show signs of population decline marked by (1) reductions in their capture volumes, (2) modifications in their sex ratios, (3) reductions in their average and maximum sizes, and (4) extirpations or reductions of their spawning aggregations (Aburto-Oropeza et al. 2008). The following four studies examined and documented fishery changes over the preceding decades from the fishers who worked the waters from the northern (Lozano-Montes et al. 2008 and Moreno-Báez et al. 2010 and 2012) to southern GOC (Sáenz-Arroyo et al. 2005a and 2005b and Sala et al. 2004) (Appendix; Table 10). All four of these studies examine whether or not a shifting baseline syndrome exists for GOC fisheries as each subsequent generation of fishers start with a new baseline of fish diversity and abundance based upon when their observations begin (Pauly 1995).

Lozano-Montes et al. (2008) interviewed 49 active fishers from industrial and small-scale fleets originating from three main fishing ports along the northern edge of the GOC (San Felipe, Puerto Peñasco, and Golfo de Santa Clara). The fishers were organized into three age groups (15-30, 31-55, >55) and asked about fishing gear, species abundance trends (1950 -2000), and preferred fishing sites to determine LFK. Past abundances were only estimated for six taxonomic groups [sharks, totoaba, corvinas, sea lions, whales, and vaquita (*Phocoena sinus*)]; none of which, unfortunately, included gulf grouper. From the surveys, LFK perceived that overall fishery resources declined by 60% from 1950 to 2000. Most fishers reported a depletion of fishing sites along the east coast of the northern GOC (and major declines in *El Borrascoso*) with older fishers reporting that they used to be able to fish within 10 km of their fishing camps. Among age groups, older fishers reported more depleted fishing sites (5.6 of 11 main fishing sites) than the middle-aged (4.1) and young fishers (2.7). Overall, the majority of fishers reported that the physical and biological conditions in the northern GOC were degraded due to (1) decades of intensive fishing and (2) wetland loss and salinity changes from hydrological changes with the Río Colorado (Lozano-Montes et al. 2008).

Moreno-Báez et al. (2010 and 2012) interviewed 376 fishers from 17 fishing communities across the northern GOC from El Barril clockwise around the GOC to Bahía de Kino. Information gathered from the fishers included species, harvest location, month, and gear type. Seventy-three species were commonly captured with 52 species specified as the most important by the fishers. Overall, fishing communities would travel on average 40 km to harvest locations with five communities capable of traveling up to 200 km for harvest activities. Gulf grouper was one of the harvested species and was harvested by four methods [diving, gillnets (as bycatch), longline, and hand fishing line] at 15 of the 17 fishing communities in the northern GOC. At six of these communities, gulf grouper were specifically targeted with the four primary fishing locations being identified as *El Borrascoso* (Reserva de las Biosfera Alto Golfo de California y delta del Río Colorado), La Choya-Los Tanques (Puerto Peñasco Marine Network), Bahía Tepoca (between Desemboque de Caborca and Puerto Libertad), and Punta Tepopa (north of Isla Tiburón) (Moreno-Báez et al. 2010 and 2012).

Sáenz-Arroyo et al. (2005a and 2005b) interviewed 108 fishers from 11 fishing communities in the central GOC. The fishers were organized into three age groups [young (15-30), middle-aged (31-54), and oldest (≥55)] and asked about overall GOC and gulf grouper fisheries. For GOC fisheries, fishers were asked about species harvested and fishing sites that they consider depleted by fishing. For species harvested, older fishers considered 11 species depleted compared to seven for middle aged and two for young fishers ($p<0.001$). For fishing sites, older fishers were able to identify 95 sites as depleted while middle-aged fishers identified 72 and young fishers identified 40 sites. For gulf grouper fisheries, fishers were asked about best day's catch, heaviest fish caught, and years of these catches. For best day's catch, catches decreased significantly ($p<0.001$) from 25 fish daily (1940s and 1950s) to 10 - 12 (1960s) to 1 - 2 (1990s). For heaviest gulf grouper caught, weight per fish decreased significantly ($p<0.0001$) from ≥ 80 kg (1940s through 1960s) to 60 kg (2000). Among age groups, 96% of the oldest and 90% of the middle-aged fishers had captured gulf grouper while only 45% of the young fishers had. When asked whether or not they considered the gulf grouper depleted, 85% of the oldest considered them depleted as opposed to 56% of the middle-aged and 10% of the young fishers (Sáenz-Arroyo et al. 2005a and 2005b).

Sala et al. (2004) interviewed 63 fishers from four fishing villages along the southern GOC from 25 to 67 years old. Fishers were asked about the relative importance of each species caught during the 1970s, 1980s, 1990s, and 2000. Harvested species were assigned to one of five trophic levels (from primary producer (1) to top predators (5)), and mean trophic level was calculated based upon the fisher's catches. Further, fishing importance was assigned to the harvested species ranging from 0 to 5, with 0 representing species absent from the catch to 5 for the species representing most of the catch by weight. Analysis of the data showed that larger predatory fish [i.e., gulf grouper, sharks, goliath grouper (*Epinephelus itajara*)] were among the most important fisheries in the 1970s, but they were rare thirty years later (Table 5). Despite decades of declining harvests, gulf grouper were still one of the top five important fish species harvested in the southern GOC during the 1970s and 1980s. However, by the 1990s, species that were not sought in the 1970s (i.e., parrotfish, tilefish) had become the most important fish. Meanwhile, gulf grouper had declined in its fishing importance as the mean trophic level of the fish harvest further declined from 4.22 to 3.78. Further, maximum fish size decreased by 46 cm from the 1970s to 2000. For fishers from El Pardito, fishing site locations moved from within 10 km of the fishing camp in the 1970s, to mostly 50 km away in 2000 (Sala et al. 2004).

Table 5. Temporal changes in mean trophic level, maximum fish size, and top five fish species/groupings of fishing importance in the coastal fisheries of the southern Gulf of California (Sala et al. 2004).

	1970s	**1980s**	**1990s**	**2000**
Trophic level (mean)	4.22	4.18	3.80	3.78
Max. fish size (cm)	144	138	106	98
#1 fish of importance	Sharks	Gulf coney	Triggerfish	Parrotfish
#2 fish of importance	Leopard grouper	Leopard grouper	Parrotfish	Triggerfish
#3 fish of importance	**Gulf grouper**	Sharks	Red snapper	Red snapper
#4 fish of importance	Jacks	**Gulf grouper**	Barred pargo	Jacks
#5 fish of importance	Gulf coney	Jacks	Jacks	Leopard grouper

Further, gulf grouper are highly vulnerable to fishing due to their biology and ecology. First, groupers share some life history characteristics that make them susceptible to overfishing such as being carnivorous, long lived, large in size at sexual maturation, slow growing, and easy to harvest (Sadovy 1994). In a study of aggregating fish in the GOC, Erisman et al. (2010) compared fish landings from 1956 through 1961 (Mexican Navy records) and from 2000 through 2005 (CONAPESCA). Landings records were broken down into 24 fish groups with gulf groupers included in the large grouper and seabass group. From 1956-1961 to 2000-2005, landings in the large grouper and seabass group declined by 76% with their overall annual harvest amounts decreasing from 198 to 47 tons while the overall aggregating fish harvests increased from 3,994 to 14,178 tons (Erisman et al. 2010). Further, it is important to note that artisanal fisheries data were not included in the 1956-1961 data, so that data is an underestimate of the actual harvest (Sáenz-Arroyo et al. 2005a). In two studies, Aburto-Oropeza studied gulf grouper harvest. From April through June of 2002 and 2003, 321 gulf grouper were harvested by local fishers in Bahía de Los Angeles of which 99% were immature fish (Aburto-Oropeza et al. 2008). In an analysis of official fishing records from 2001 through 2005, gulf grouper still composed 29% of all grouper landings throughout the GOC (Octavio Aburto-Oropeza, Scripps Institution of Oceanography, Aug 26, 2014, pers. comm.).

Two other fish species from the GOC share a similar background to gulf grouper and can serve as proxies. The totoaba has a limited distribution, was extensively harvested, and has been listed as Endangered in the United States since 1979[19]. The totoaba fishery was closed by the Mexican government in 1975, but they are still harvested illegally for their swim bladder and are frequently captured as bycatch in the shrimping industry. The gulf corvina (*Cynoscion othonopterus*) also has a limited distribution, aggregate spawns in the northern GOC, is currently heavily harvested (especially at their spawning aggregation sites within the "Alto Golfo de California y delta del Río Colorado" biosphere reserve), and its population is showing signs of decline.

The totoaba is a large fish (up to 2 m, 100 kg) that is limited to the central and northern GOC. Totoaba commercial fisheries began in the 1920s; peaked at 2,300 metric tons in 1942; decreased to 280 metric tons by 1958; and by 1975, the fishery was closed (Lercari and Chávez 2007). The totoaba declined despite the Mexican government closing their fishing season during their spawning season (March through May), in the 1950s, and eventually completely closing their fishery, in 1975 (Cisneros-Mata et al. 1995). So despite over three decades of take prohibitions on totoaba, why have they not recovered? First, the marine habitat has not recovered, with only 10% of the Río Colorado flows making it to Mexico and even less to the GOC due to natural processes and agricultural diversions (see Section 4.2.1). Increased water salinity and temperature is believed to decrease carrying capacity at their spawning grounds. Second, due to a lack of law enforcement, direct totoaba take has never stopped. During the 1980s, adult totoaba poaching was occurring at a rate of 160 metric tons per year (Cisneros-Mata et al. 1995). In the Chinese market, the totoaba swim bladder sells as *buche* at $8,500 per kg and is served as a medicinal soup. Totoaba are currently harvested by using large, anchored gill nets that are set for several days. This illegal harvest is a threat to gulf grouper, believed to be increasing, and is considered a major threat to vaquita survival (CIRVA 2014). Finally, the commercial shrimp industry is considered to have a large impact upon the totoaba as bycatch with an estimated 120,000 juvenile totoaba captured annually (see Section 4.3.3) (Cisneros-Mata et al. 1995). Despite the collapse in their population, however, the totoaba still possess adequate genetic diversity to recover (Valenzuela-Quiñonez et al. 2014).

The gulf corvina has a small distribution in the northern GOC. They reproduce in spawning aggregations from five to two days before the new and full moons in late February through May during the large spring tides (Erisman et al. 2012). Currently, the gulf corvina is the second most important fishery in the northern GOC with 1.5 to 1.8 million fish harvested annually (concentrated at their spawning aggregation sites) with most of the take occurring in the no-take zone of the "Alto Golfo de California y delta del Río Colorado" biosphere reserve (Erisman et al. 2012). So despite the regulations in place, the no-take zone is not sufficiently enforced due to its large size, difficult topography, and large number of fishing vessels. From 1995 to 2007, Rodríguez-Quiroz et al. (2010) found that 55% of the biosphere reserve and 94% of the Vaquita Refuge was fished for gulf corvina. Currently, the IUCN has categorized the gulf corvina as vulnerable (facing a high risk of extinction in the wild) due to its very restricted area of occupancy and being prone to the effects of human activities (IUCN 2012).

[19] National Marine Fisheries Service listed the totoaba as endangered in 1979 (44 FR 29478) due to overfishing [historical, direct, and indirect (shrimp fisheries)] and the diversion of the Colorado River (loss of spawning habitat).

4.3.2 Susceptibility to Fishing – Reproductive Strategy

Gulf groupers are susceptible to overfishing for two reasons: (1) they are a protogynous hermaphroditic fish and (2) they aggregate spawn. Protogynous hermaphroditic fish mature as females and later transition into males as a larger fish. Since fishing activities tend to select for the larger individuals, males would be the preferred catch, which would skew the sex ratio towards a female bias (Sadovy 1994). With gag grouper, McGovern et al. (1998) found that heavily harvested populations had a significantly reduced male to female ratio when compared to lesser harvested populations. Another consideration is that after males, the next most likely target would be the large females which would deprive the population of the most fecund females and the future source of males (see Section 3.3.1).

In a global study of spawning aggregation sites, only 60% of the known spawning aggregation sites had current status information; and of those, 79% were experiencing declining harvest levels (Sadovy de Mitcheson et al. 2008). Once found, spawning aggregations sites are vulnerable to overfishing because they (1) occur at predictable places and times and (2) contain fish at a higher than normal density (Domeier and Colin 1997). Further, modern technology (i.e., portable GPS units, improved fishing gear) allows fishers to better find and exploit spawning aggregation sites (Sadovy de Mitcheson et al. 2012). Since many fishers base their fishing activities (when, where, and who to harvest) upon the movement patterns of their target species, known spawning aggregation sites are desirable (Sadovy et al. 1994, Moreno-Báez et al. 2012). In 1982, the El Seco tiger grouper aggregation site was discovered near Vieques Island, Puerto Rico. Shortly thereafter, tiger groupers began to be harvested annually during their spawning aggregation season – after the full moon in late January through April – using hook and line and spearguns (to target males) (Sadovy et al. 1994). In 1992, an estimated 4,900 tiger groupers were harvested during the aggregation season (Sadovy et al. 1994). In subsequent years, annual tiger grouper harvest at El Seco declined to 2,500 by 1995 and to 877 by 1998 (Matos-Caraballo et al. 2006). Landings were male biased, increasing from 3.7 males per female, in 1995, to 12 males per female, in 1998. By 1999, the tiger grouper harvest was limited (121 fish), and fishing efforts had shifted to a different location for yellowtail snappers (Matos-Caraballo et al. 2006).

Sadovy and Eklund (1999) produced a synopsis of Nassau grouper biology which is also an aggregate spawner. From 1986 through 1993, they found that nearly 90% of Nassau grouper landings, outside of U.S. waters, occurred during their reproductive season. In Cuba, only one of the 21 previously fished, spawning aggregation sites still existed; and its landings were declining. In Puerto Rico, the Nassau grouper was noted as common in 1900, fourth most common shallow-water species landed in 1970, and commercially extinct by 1986. Overall, 25 to 50% of the Nassau grouper's spawning aggregation sites no longer existed, and those that did were severely depleted (Sadovy and Eklund 1999).

Since 1910, the Nassau grouper spawning aggregation site near Mahahual off the southern coast of Quintana Roo, Mexico had been fished (Aguilar-Perara and Aguilar-Dávila 1996; Aguilar-Perara 2006). Before the 1960s, Nassau grouper were only harvested using hook and line. In the early 1960s, fishers used dynamite which would result in the aggregation disappearing for the rest of the reproductive season (though it would return in subsequent seasons). After the 1960s, spearguns were used to harvest grouper and, by the 1980s, gill nets. Fisher accounts estimated harvests of up to 24 tons in the 1950s, which dropped to three tons by the early 1990s (Aguilar-Perara and Aguilar-Dávila 1996). In the early 1990s, visual censuses of the aggregation site and nearby locations observed fluctuating aggregation and sex ratio numbers, which is consistent with overfishing. In the commercial catch, reduced abundance along with decreased mean sizes and the disappearance of large individuals was noted. Since 1996, no Nassau grouper spawning aggregations have been observed forming in the area (Aguilar-Perara and Aguilar-Dávila 1996; Aguilar-Perara 2006).

This scenario of spawning aggregation sites disappearing under heavy fishing pressures has played out with other grouper species, including camouflage grouper (*Epinephelus polyphekadion*) (Rhodes and Sadovy 2002), gag grouper (McGovern et al. 1998), jewfish/goliath grouper (Sadovy and Eklund 1999), red hind (Beets and Friedlander 1998), and yellowfin grouper (Nemeth et al. 2006). Gulf grouper, predictably, can be found on their spawning aggregation sites before and during the full moon in May (Sala et al. 2004). In Bahía de Los Angeles, the prime gulf grouper harvest season is from April through June (Octavio Aburto-Oropeza, Scripps Institution of Oceanography, Aug 26, 2014, pers. comm.), which coincides with their spawning season. For gulf grouper, spawning aggregation sites within the GOC (e.g. Punta Lobos, San Bruno seamount) have disappeared after periods of heavy exploitation (Sáenz-Arroyo et al. 2005a). Currently, there are no fishery regulations protecting spawning aggregation sites. The loss and/or degradation of additional spawning aggregation sites are a continued threat to the gulf grouper persistence.

4.3.3 Commercial Shrimp Trawlers

In 2012, commercial shrimp trawlers harvested 42,310 metric tons of shrimp in the GOC at a value of nearly two billion pesos. Globally, commercial shrimp trawlers have been documented as capturing groupers as bycatch (Sadovy and Eklund 1999, Arreguín-Sánchez et al. 2002, Criales-Hernandez et al. 2006, Rodríguez-Romero et al. 2012). In the GOC, gulf grouper have been captured as bycatch in shrimp trawls (Ramírez et al. 2012). Since Mexican shrimp fisheries are not required to use bycatch reduction devices (BRDs), commercial shrimp fisheries in the GOC have historically had high levels of bycatch (Gillet 2008). In the 1980s, the GOC commercial shrimping industry was catching somewhere between 130,000 and 250,000 metric tons of bycatch annually with the a large portion of this bycatch, approximately 100,000 metric tons, dumped back into the water (Arvizu-Martinez 1987). Recent studies have placed the bycatch ratio (bycatch:shrimp) at 6.1:1 (85.9% bycatch rate; 2003-2009) with 116 fish species represented in the central GOC (Meltzer 2012) to 10.2:1 (91.1% bycatch rate; 1992-2004) with 209 species represented in the southern GOC (Madrid-Vera et al. 2007). In both of those studies, groupers and larger species (i.e., totoaba, loggerhead turtle, and scalloped hammerhead) were represented in the bycatch. In a paired trawl net study in which one trawl net was equipped with a BRD and the control was not, García-Caudillo et al. (2000) found that total bycatch was significantly reduced by 40.2% ($p<0.0005$) in the BRD equipped net. Additionally, the mean fish size of the bycatch was significantly smaller when BRDs are used (García-Caudillo et al. 2000). Thus, larger fish, such as gulf grouper, should benefit greatly if BRDs were required on commercial shrimp trawlers.

4.4 Shrimp Aquaculture

Mexico is the second largest shrimp producer in the western hemisphere with approximately 97% of the shrimp aquaculture ponds being located in the GOC region (Barraza-Guardado et al. 2013). In the early 1980s, the first shrimp farms began appearing around the GOC. By 1985, shrimp farms produced 35 metric tons of shrimp, increasing to 15,867 metric tons by 1995 and 33,480 metric tons by 2000 (Gillett

2008). From 2002 through 2012, the amount of farmed shrimp produced increased further from 39,899 to 97,363 metric tons with a peak of 125,609 metric tons in 2009 (Figure 6).

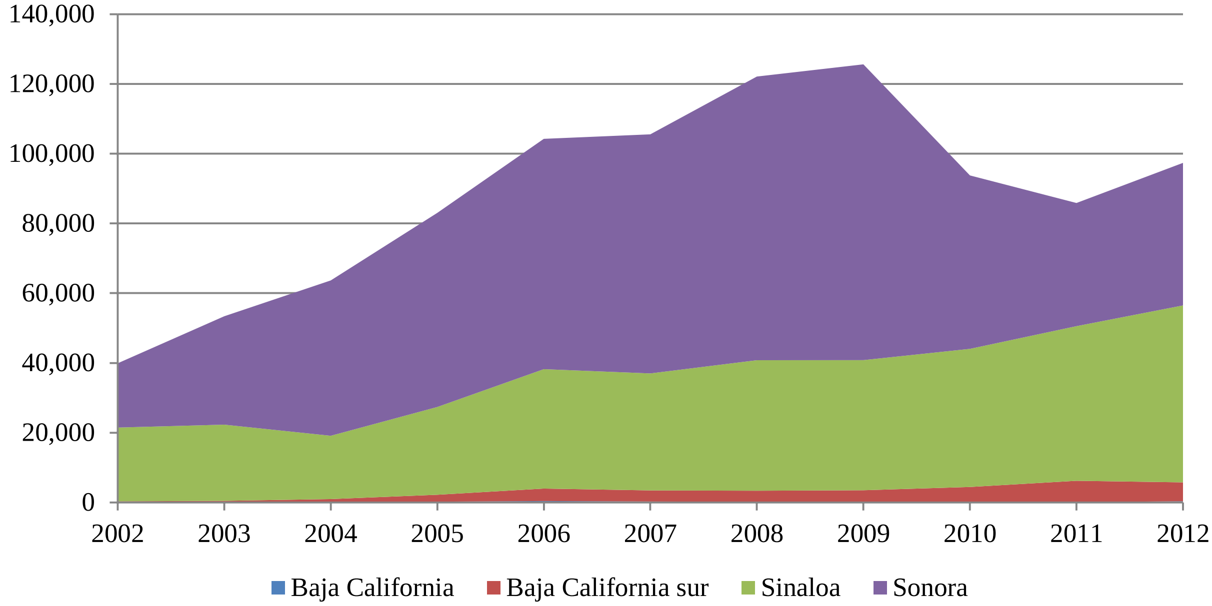

Figure 6. Cultivated shrimp (metric tons) produced from shrimp farms in the Gulf of California region by state from 2002 to 2012 (Source - http://www.sepescabc.gob.mx/x/estadisticas/).

Shrimp farms can impact gulf grouper in two ways: (1) habitat loss (direct loss of habitat) and (2) habitat degradation (impacts upon surrounding terrestrial and marine habitats). Using Landsat TM images, Berlanga-Robles et al. (2011) analyzed shrimp farm land use in Sinaloa and Sonora states from 1986 to 1999 and found that both land use for shrimp farms (3,732 ha to 74,044 ha; Table 6) and shrimp farm production (35 metric tons to 33,480 metric tons) increased exponentially. Further, from 2000 to 2012, shrimp farm production had nearly tripled (33,480 metric tons to 97,363 metric tons) (Figure 6). Converting saltmarshes into shrimp farms can result in loss of habitat and nursery areas, coastal erosion, reduced biodiversity, decrease of commercially important species, acidification, and alteration of water drainage patterns (Páez-Osuna 2001). Juvenile gulf groupers use these saltmarsh and mangrove habitats for the first few years of their lives, and, therefore, are impacted by shrimp farms due to habitat loss after shrimp farm construction and habitat degradation from shrimp farm operation (Berlanga-Robles et al. 2011).

Table 6. Land use changes produced by shrimp farming from 1986 to 1999 (Berlanga-Robles et al. 2011)

	Sinaloa		Sonora		Total	
Subsidiary Cover	**ha**	**%**	**ha**	**%**	**ha**	**%**
Aquatic surfaces	1,918	4.7%	268	0.8%	2,186	3.0%
Mangrove	689	1.7%	85	0.3%	774	1.0%
Saltmarsh	23,225	56.5%	10,779	32.8%	34,404	46.5%
Terrestrial covers	12,215	29.7%	21,133	64.2%	33,348	45.0%
Shrimp farms (present in 1986)	3,090	7.5%	642	2.0%	3,732	5.0%
Total shrimp farm extent	**41,137**	**-**	**32,907**	**-**	**74,044**	**-**

For the GOC region, semi-intensive shrimp ponds are the predominant management scheme (98%) with a stocking rate of 60,000 to 200,000 shrimp per hectare which requires fertilizers, supplemental feeding, and a daily water exchange of three to six percent (Páez-Osuna et al. 1998, Páez-Osuna et al. 2003). During these water exchanges, organic matter from unconsumed shrimp food, detritus, phytoplankton, zooplankton, and bacteria gets flushed out to the GOC as effluents through the discharge channels (Barraza-Guardado et al. 2013). These shrimp farm effluents contribute 10.2% of the nitrogen and 3.3% of the phosphorus inputs to the GOC (Table 7; Miranda et al. 2009). Adding these organic materials into the marine habitat, which is already receiving effluent from other anthropogenic sources, deteriorates water quality through oxygen depletion, light reduction, and changes in benthic macrofauna possibly resulting in eutrophication (Páez-Osuna 2001). For example, the Altata-Ensenada del Pabellón lagoon receives effluent from shrimp farms, intensive agriculture (i.e., sugar cane), and sewage from local cities leading to phytoplankton blooms and anoxia and fish kill events (Páez-Osuna 1999). In the Bahía de Kino region, Barraza-Guardado et al. (2013) found that shrimp farm effluents provide significantly increased salinity, suspended solids, organic particulate matter, chlorophyll, and bacteria levels to coastal ecosystems as well as reducing dissolved oxygen and water transparency. Further, combining the shrimp farm effluents (and other sources of anthropogenic nutrient loading) with climate change, an increased incidence of hypoxia is expected due to enhanced ocean stratification, decreased oxygen solubility, increased metabolism, and increased production of organic matter (Rabalais et al. 2009). Even if hypoxia events do not lead to fish kills, they may still have impacts. For example, oxygen depletion has been shown to cause abnormal musculature development in larval seven-band grouper (*Epinephelus septemfasciatus*) (Uji et al. 2014).

Table 7. Nitrogen and phosphorus inputs into the Gulf of California by source from Sinaloa and Sonora states, Mexico (Miranda et al. 2009).

	Nitrogen		Phosphorus	
Source	**Metric tons**	**%**	**Metric tons**	**%**
Rivers	16,350	20.7%	9,638	24.8%
Agriculture	49,356	62.5%	26,119	67.2%
Municipal	5,271	6.7%	1,845	4.7%
Shrimp farms	8,021	10.2%	1,272	3.3%
Total	**78,998**	**-**	**38,874**	**-**

Prorocentrum minimum is a planktonic dinoflagelle that produces harmful algal blooms known as red tides (Sierra-Beltrán et al. 2005). In the GOC, the first red tide blooms were reported in 1990. Between

1990 and 2003, 13 red tide events occurred with six occurring in shrimp ponds and seven occurring near aquaculture and agricultural areas (Sierra-Beltrán et al. 2005). Most recently, a red tide occurred in January 2015 near San Felipe, Baja California that resulted in fish, bird, and marine mammal mortalities.[20]

Shrimp farm construction and operation impact the GOC region through changes in hydrological patterns and hypersalinity (Páez-Osuna et al. 2003, Barraza-Guardado et al. 2013). Pond levee construction, required for seawater exchanges and roads, displaces seasonal streams and tidal channels which disrupt hydrological patterns and impact adjacent mangrove forests (Páez-Osuna et al. 2003). In the northern GOC, over 95% of mangrove forests are estimated to be impacted by shrimp farms (Glenn et al. 2006). Further, most shrimp farms in Sonora are located in an arid, low humidity environment that results in high water evaporation rates. Water evaporation in these shrimp ponds have been estimated to increase salinity by 50% when compared to natural wetlands, thus creating hypersaline water that gets flushed out to the GOC (Páez-Osuna et al. 2003).

Disease, or the attempt to prevent disease, also has an impact upon the environment. While there is no known direct link between disease and gulf grouper, the response of shrimp farmers to disease may impact juvenile gulf grouper and their environment. Viral diseases [such as white spot syndrome (WSSV), Taura syndrome, yellow head disease, infectious hypodermal and haematopoietic necrosis, infectious myonecrosis, and white tail disease] have high mortality rate upon farmed shrimp, with WSSV being the most devastating by causing over $1 billion of losses globally since it emerged in 1999 (Walker and Winton 2010). Bacterial disease in farmed shrimp is commonly caused by the *Vibrio* genus and that, along with other bacteria, are often treated preemptively with large amounts of antibiotics (Kautsky et al. 2000). Prophylactic antibiotics are administered both directly and as an additive to commercial feeds (Holmström et al. 2003). Overuse of antibiotics can result in antibiotic resistance and reduced natural microbial activity, leading to waste accumulation due to decreased degradation and nutrient recycling (Kautsky et al. 2000).

4.5 Climate Change

Climate change is expected to increase ocean temperatures and acidification throughout the range of the gulf grouper. Increased ocean temperatures can impact the gulf grouper by changing its habitat and that of its predators and prey. Ocean acidification can have deleterious impacts upon corals (coral bleaching and mortality) and fish (egg and larval development) survival (Section 4.5.1). Corals, a major component in gulf grouper habitat, are particularly impacted by climate change; corals are sensitive to ocean acidification and warming, imperiling coral growth and persistence (Section 4.5.2).

[20] Source - http://www.profepa.gob.mx/innovaportal/v/6759/1/mx/marea_roja_causo_mortandad_de_aves_marinas_en_baja_california_revelan_analisis_declaran_autoridades_locales_alerta_sanitaria.html

4.5.1 Ocean temperature and acidification

Of the anthropogenic CO_2 produced in the past two centuries, approximately two-thirds has remained in the atmosphere and one-third has been absorbed by the oceans (Sabine et al. 2004). Increased atmospheric CO_2 has increased air temperatures resulting in increased ocean water temperatures and sea levels (Hoegh-Guldberg et al. 2007). The absorption of CO_2 into ocean water has impacted marine life by decreasing calcium carbonate saturation and disturbing acid-base physiology (Fabry et al. 2008). At present, ocean temperatures are warmer (+0.7° C) and more acidic (-0.1 pH) with lower carbonate ions concentrations than any time in the past 420,000 years (Hoegh-Guldberg et al. 2007).

Since the heat capacity of the atmosphere and cryosphere is small, approximately 90% of the total heat content is stored in the oceans (Chen and Tung 2014). From 1971 through 2010, ocean temperatures (sea surface to 75m depth) have increased by approximately 0.11° C per decade (Rhein et al. 2013). However, oceans are not uniformly warming by ocean basin or depth (Chen and Tung 2014). From 1980 through 2000, sea surface temperatures warmed at trends greater than atmospheric warming; but since 2000, sea surface temperatures have experienced a hiatus from warming as the sea surface heat has been transported to deeper ocean layers. Historically, this heat-sequestration pattern has occurred on a 20 to 35 year cycle (Chen and Tung 2014). How this impacts gulf grouper is unknown, but with Nassau grouper, Sadovy and Eklund (1999) suspect that global warming could impact reproduction due to their specific temperature requirements.

El-Niño/Southern Oscillation (ENSO) is a two to seven year cyclical pattern in the Pacific Ocean that impacts temperature, rainfall, and other weather phenomena. ENSO is influenced by subsurface ocean structure, easterly trade winds, and shifts in atmospheric convection (Collins et al. 2010). El Niño is the warm phase of the ENSO cycle that during its last major event (1997-1998) created positive sea surface anomalies of more than 1.5° C for over 6 months in the southern GOC (Bonilla 2001). The temperature anomalies associated with major El Niño events have resulted in coral bleaching and death, reduced sargassum beds, and poor grouper recruitment (Bonilla 2001, Aburto-Oropeza et al. 2008). El Niño may serve as an approximation of future ocean temperature increases and the impact it can have upon the ocean environment. Though the impacts of climate change are expected to change the processes that control ENSO, it is currently unknown what that impact will be (Collins et al. 2010).

Ocean acidification impacts marine life in many ways. Inorganic carbon is largely responsible for controlling seawater pH. When CO_2 is dissolved into seawater, carbonic acid is formed which acidifies seawater (Fabry et al. 2008). During the past 150 years, anthropogenic CO_2 production has dropped worldwide ocean pH by 0.1 units resulting in a 26% increase in acidity (Doney et al. 2012). By 2100, pH will drop another 0.3 to 0.4 units under current emission scenarios (Orr et al. 2005). Seawater acidification changes fish responses to olfactory cues with clownfish and damselfish larvae response to predator chemical cues ranging from ignorance to attraction (Munday et al. 2010) and with predators like brown dottyback being unable to find injured prey (Cripps et al. 2011). Also, ocean acidification reduces the saturation state of aragonite, the soluble state of calcium carbonate ($CaCO_3$) in seawater. As the saturation state decreases, calcium carbonate shell and skeleton formation becomes impaired in pteropods, gorgonians, plankton, mollusks, echinoderms, crustaceans, and corals (Orr et al. 2005, Fabry et al. 2008, Doney et al. 2009, Feely et al. 2009). However, ocean acidification may not negatively impact development of tropical fish eggs and larvae (Munday et al. 2009)

4.5.2 Impacts upon corals

Corals are formed by invertebrate animals, polyps, which live colonially and extract calcium from the ocean to create structures that become the reefs. The coral polyps live symbiotically with zooxanthellae, algae that provide nutrients while the coral provides structure. Corals support more species per unit area than any other marine environment, including gulf grouper and its prey.[21] Corals are impacted by climate change due to both increasing water temperatures and ocean acidification.

Corals are susceptible to increased water temperatures. The zooxanthellae, which provide the coral's color and about 90% of the coral polyp's energy, cannot photosynthesize sunlight under increased temperatures without releasing harmful oxygen radicals. This results in a degeneration or release of the zooxanthellae from the coral (Marshall and Schuttenberg 2006). A moderate bleaching event can result in reduced growth rates and reproductive output, while severe bleaching results in coral death (Doney et al. 2012). Without its symbiotic partner, coral bleaching, or death, can occur with temperature anomalies of just +1°C for a few weeks (Marshall and Schuttenberg 2006).

During the 1997-1998 El Niño event, sea surface temperature anomalies of greater than 1.5°C occurred from July 1997 through January 1998. Coral bleaching was extensive throughout the southern GOC with over 30% of live coral cover bleached. Of these bleached corals, nearly 70% of the corals died a few months later (Bonilla 2001). When coral cover declines, this results in changes to the adult fish communities (Wilson et al. 2008) which may negatively impact gulf grouper. Though the 1997-1998 coral bleaching event was related to ENSO, similar impacts may be expected due to increasing ocean temperatures expected with climate change.

As discussed in the previous section, coral formation will be impacted by ocean acidification due to a decreased saturation state (Ω) of aragonite. The chemical threshold for aragonite saturation (Ω=1) is the point where calcium carbonate is deposited (saturated) or dissolved (undersaturated) in the oceanic environment equally (Feely et al. 2009). However, most marine organisms require a higher Ω of aragonite, a biological threshold. Corals, for example, require a Ω of 3.3. Based upon current models, this saturation level would be reached in the tropics as atmospheric CO_2 approaches 480 ppm (Hoegh-Guldberg et al. 2007). Reduced calcification would impact reef building corals by decreasing size and skeletal density while increasing energy demand (Hoegh-Guldberg et al. 2007).

[21] Sources – International Coral Reef Initiative (http://www.icriforum.org/) and NOAA Ocean Service Education (http://oceanservice.noaa.gov/education/kits/corals)

5.0 EXISTING REGULATORY MECHANISMS

5.1 Federal Regulations – United States

Gulf grouper was added to the National Marine Fisheries Service's (NMFS) Candidate Species list on February 24, 2014 (79 FR 10104). NMFS uses the term "candidate species" to refer to "(1) species that are the subject of a petition to list and for which we have determined that listing may be warranted, pursuant to section 4(b)(3)(A), and (2) species that are not the subject of a petition but for which we have announced the initiation of a status review in the Federal Register" (71 FR 61022). In response to a petition from WildEarth Guardians (received July 15, 2013), NMFS determined that the petition presented substantial scientific or commercial information and that the petitioned action (listing the species as threatened or endangered under the ESA and designating critical habitat under the ESA) may be warranted for gulf grouper (*Myctoperca jordani*). Designation as a "Candidate Species" carries no procedural or substantive protections under the ESA. Thus, no ESA-mandated federal measures that would provide protection for gulf grouper are currently in place. This status review was initiated in response to the "warranted" determination of the 90-day petition finding.

5.2 Federal Regulations – Mexico

5.2.1 Fisheries Regulation - Historical

Espinoza-Tenorio et al. (2011) studied the impact fishery regulations have had upon the fishery resources in Mexico during six different periods from 1934 to present day. From 1934 through 1940, foreign fleets exploited major fishery resources while domestic vessels were limited to coastal areas with U.S. fishing fleets were more than doubling the catch of Mexican fisheries in Mexican waters (Espinoza-Tenorio et al. 2011). During this time, California fishers began to harvest grouper populations along the Pacific coast of the Baja Peninsula (Croker 1937). From 1941 through 1970, Mexico began to develop its domestic fisheries with fishery offices (1941), fishery laws (1947), and analyses of its maritime zone catches that extended out 12 miles (1949). Though Mexico began to express sovereignty over its maritime waters, international fleets continued their large harvests in Mexican waters (Espinoza-Tenorio et al. 2011). California fleet grouper harvests from Mexican waters peaked at 376 metric tons in 1951 and crashed to 3 metric tons by 1970 (Figure 3). From 1971 through 1982, Mexican domestic fisheries expanded rapidly due to improved technology and government subsidies. Total annual catch during this period quadrupled from 300,000 to 1,200,000 metric tons (Espinoza-Tenorio et al. 2011). During the 1970s, gulf grouper were considered one of the most important fisheries in the GOC (Sala et al. 2004); however, its abundance declined steeply during this decade (Sáenz-Arroyo et al. 2005a). The California fishery for grouper never recovered, and California Fish and Game placed no-take regulations on its gulf grouper fisheries beginning in 1977 (see Section 5.2.1.1). From 1983 through 1994, Mexico endured economic crises and responded by privatizing its fishing sector. The new Federal Fishery Law (1986) and Federal Law of Ecological Equilibrium and Environmental Protection (1988) created Marine Protection Areas (MPAs) and fishery regulations to manage commercial and threatened species. However, damage from trawl nets and bycatch was resulting in habitat damage and further resource depletion. From 1995 through 2000, the Fisheries Law was amended, more MPAs were created, and a more sustainable development strategy was adopted towards the fisheries (Espinoza-Tenorio et al. 2011). Fishery statistics in Mexico were improving; but harvested species were placed into groups, making it difficult to track individual species. Gulf grouper were becoming rarer in the fishery but that was hard to discern with the harvest of smaller groupers (i.e., leopard grouper) increasing concurrently (Sala et al. 2004). From 2001 through 2009, Mexican fisheries averaged 1.3 million metric tons of harvest with 57% of fishery stocks considered to be at maximum exploitation levels and 25% overexploited (Espinoza-Tenorio et al. 2011).

5.2.2 Fishery Regulations - Current

In 2007, Mexico updated its fishing laws to their current status. While there are some improvements, problems still exist regarding the permit process and the level of enforcement (Cinti et al. 2010). Commercial fisheries are two tiered with the permit holders, who have the educational and financial means to apply, and the fishers, who do the harvesting. Fishing permits are granted to any corporate entity or individual for two to five year increments; and although the number of permits is limited, the catch under those permits is not (Cinti et al. 2010). Since only the permitees are allowed to own fishing boats and equipment and sell the harvested fish, the fishers are, therefore, dependent upon the permit holders for their livelihood. In Bahía de Kino, Cinti et al. (2010) found that 82% of the fishers do not possess fishing permits, and this is believed to be commonplace throughout the GOC. So this creates a scenario in which the people who have the vested interest in the fisheries do not hold the power because they do not hold the fishing permits.

5.2.2.1 Official Regulations[22]

In Mexico, the Comisión Nacional de Acuacultura y Pesca (CONAPESCA) publishes all fishery regulations for "the exploitation of those fisheries, areas and fishing gear restrictions, and rules for owners of fishing permits or authorizations and for anybody who catch some aquatic species, besides other obligatory rules." All fisheries are enforced by the Mexican navy (Article 10). Mexican fisheries are broken into three categories: (1) domestic consumption fisheries, (2) recreational/sport fishing, and (3) commercial fisheries.

Domestic consumption fisheries are solely for the purpose of obtaining food for the fisher and their dependents. Fish are caught without the purpose of profit and cannot be commercialized. Fishing is allowed only on the banks and coasts of waterbodies, and only nets and hand lines are allowed (Article 72). Though no licenses or permits are required, official rules and closures are expected to be observed (Article 72).

Recreational and sport fishing is allowed by national or foreign individuals through a single, non-renewable, non-transferrable permit (Article 67). CONAPESCA places limits upon these permits. For example, in ocean waters and estuaries, a limit of ten fish per person per day is allowed. Of those ten, a maximum of two gulf grouper are allowed to be retained (this is the only restriction on gulf grouper harvest in Mexico). Catch and release is allowed as long as the fish that exceeds the bag limit are

[22] The General Law of Sustainable Fisheries and Aquaculture ("La Ley General de Pesca y Acuacultura Sustentables") was signed into law on July 24, 2007 and is broken down into 150 articles.

"returned to their environment in good survival condition." Rubber-band, spring, or pneumatic harpoons are allowed during skin diving[23].

Commercial fisheries are for the purpose of economic benefit. Commercial fishing permits are only available to nationals and require a concession (either a cooperative or private business) (Article 40). Commercial fishery concessions are issued for five to twenty year durations and may be extended by a length similar to the original concession (Article 49). Concessions are granted for a fishery by area, species, or species group and are assessed by technical, administrative, and financial capacity of the applicant (Article 47). Permits are issued for two to five year durations (Article 51). Concessions and permits are issued by *La Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (SAGARPA) and are awarded per vessel or unit of fishing effort as defined by species, species group, or area (Article 46). If *El Instituto Nacional de Pesca* (INAPESCA) determines that the fishery is positively managed then the permit can be extended (Article 51). Permits define the area of catch, fishing gear and equipment, resource or permitted fishery resource, and operating conditions (Article 62). Multiple permits can be issued under a single concession (Cinti et al. 2010). On a weekly basis, harvest is reported through trip-tickets which provide dates, number of vessels, type of fishing gear, fishing and landing sites, and catch per species (kg) (Ramírez-Rodríguez 2011). Unfortunately, these fishery regulations do not set limits on harvest levels of any particular species, such as gulf grouper. Further, there are no regulations that regulate or prohibit harvest at spawning aggregation sites.

5.2.2.2 Enforcement of Regulations

The enforcement of Mexican fisheries regulations is considered poor, and the following three cases are emblematic of fishery issues within the range of the gulf grouper. Since 1996, shrimp fishers have been required to use Turtle Excluder Devices (TEDs) in Pacific waters; and in 2004, these regulations were further refined. However, TEDs were not being deployed in a functional fashion. So, on March 24, 2010, the U.S. prohibited shrimp harvested from Mexico from being imported to the U.S. due to the improper deployment of TEDs on their shrimp trawl boats [U.S. Public Law 101-162 (Section 609)]. In response, the Mexican government carried out 1,219 inspections and seized 40 trawlers and 33,500 kg of shrimp[24]. On October 15, 2010, the U.S. reinstated certification of the Mexican shrimp fishery. In the second case, the Mexican gill net fishery off of the Baja California coast was cited for its bycatch of 438 loggerhead sea turtles (*Caretta caretta*)[25] in 2012 (NMFS 2013). Since the turtles are a shared protected living marine resource, Mexico is required to have a regulatory program that is comparable in effectiveness to that of the United States (a requirement of the Moratorium Protection Act). Since Mexico does not have a regulatory program for turtle bycatch in its gillnet fisheries, it is in violation of this act. Further, Mexico is in violation of the Pelly Amendment for "conducting fishing operations in a manner or under circumstances which diminish the effectiveness of an international fishery conservation program." The result of these violations may result in sanctions including banning imports from these fisheries and losing port privileges in the United States (NMFS 2013; Christina Fahy, NMFS, Dec. 17. 2014, pers. comm.). Lastly, the vaquita[26] is currently a victim of (1) illegal gillnet fisheries that target the totoaba and

[23] Source - http://www.conapescasandiego.org/contenido.cfm?cont=regulations
[24] Source - http://www.globalissues.org/news/2010/04/20/5298
[25] Loggerhead sea turtles are listed as threatened by the ESA throughout their range (July 28, 1978; 43 FR 32800).
[26] Vaquita were listed as endangered by the ESA throughout their range (January 9, 1985; 50 FR 1056).

(2) commercial shrimp trawlers, both in the northern GOC (CIRVA 2014). By recent estimates, the vaquita is declining at an 18.5% annual rate, has an estimated abundance of 97 animals, and may be extinct as early as 2018. Entanglement in gill nets is considered to be the primary cause of their decline. To help avoid extinction, the Mexican federal government has recently expanded the "Area de Refugio Vaquita Marina" and prohibited gill net use in the northern GOC (CIRVA 2014).

Poor enforcement of fishery regulations creates a problem for protecting marine species, including gulf grouper. Overall, enforcement is underfunded and cannot sufficiently patrol or even provide a presence to the 26,000 fishing vessels that fish the GOC (Rife et al. 2012). Cisneros-Montemayor et al. (2013) estimated that nearly half of all fish harvest in Mexico is either unreported or illegal.

5.2.3 Marine Protection Areas

In Mexico, the *Comisión Nacional de Áreas Naturales Protegidas* (CONANP) manages 176 natural areas including several marine reserves within the range of the gulf grouper. Along the Pacific coast of the Baja Peninsula, marine reserves are limited to the two gray whale reserves (Laguna Ojo de Liebre and Laguna San Ignacio) of El Vizcaíno Biosphere Reserve. There are no recent records of gulf groupers at these locations (Section 3.1.4.2); however, this area was considered prime gulf grouper fishing grounds for California fishers in the 1930s (Section 3.1.4.1).

In the GOC, a combination of biosphere reserves, world heritage sites, marine sanctuaries, national parks, and marine protection areas protects nearly a fifth of the GOC's surface area (Table 8; Figure 7). Marine protection areas (MPAs) are a newer concept for Mexican waters by balancing the biological need of the marine species with the local's needs and desires to protect. Despite the establishment of multiple MPAs throughout the GOC over the past 15 years, overall protection of fisheries resources has not improved due to lack of proper regulations, management plans, and necessary resources to effectively allow fish stock recovery (Rife et al. 2013). Moreno-Báez et al. (2012) found that 79% of the northern GOC MPAs were used for harvest by multiple fishing communities year-round. With the exception of Cabo Pulmo, fish species richness and biomass have not increased since the establishment of the MPAs (Aburto-Oropeza et al. 2011).

Figure 7. Map of Marine Protection Areas within the range of the gulf grouper.

Table 8. Marine Protection Areas within the Gulf of California (Sources - Aburto-Oropeza et al. 2011, http://protectedplanet.net/, and http://www.conanp.gob.mx/regionales/).

Name	Established	Total Marine Area (ha)	No-take zone (ha)	Protected as
Islas y Áreas Protegidas del Golfo de California	2005	688,558	-	World Heritage Site
Reserva de la Biosfera Alto Golfo de California y delta del Río Colorado	1993	541,600	88,250	Biosphere Reserve
Área de Refugio Vaquita Marina[1]	2008	126,400	-	Marine Reserve
Puerto Peñasco Reserve Network	2000			Marine Reserve
Reserva de la Biosfera Bahía de Los Ángeles, canales de Ballenas y de Salsipuedes	2007	387,957	374	Biosphere Reserve
Parque Nacional Marina San Lorenzo Archipelago	2005	58,442	8,804	National Park (Marine)
Reserva de la Biosfera Isla San Pedro Martír	2002	30,165	1,110	Biosphere Reserve
Porción Marina Conocida como Ventilas Hidrotermales de la Cuenca de Guaymas y de la Dorsal del Pacífico Oriental	2009	145,600	-	Marine Sanctuary
Parque Nacional Bahia de Loreto	2004	183,700	130	National Park
Parque Nacional Archipielago de Espiritu Santo	2007	58,700	670	National Park
Parque Nacional Cabo Pulmo	1995, 2000	7,100	2,500	National Park
Área de Protección de Flora y Fauna Cabo San Lucas	1973	3,787	-	Flora and Fauna Protection Area

[1] The Area de Refugio Vaquita Marina partially overlaps with the "Reserva de la Biosfera Alto Golfo de California y delta del Río Colorado"

Islas y Áreas Protegidas del Golfo de California – In 2005, the United Nations Organization for Education, Science and Culture (UNESCO) inscribed the "Islas y Áreas Protegidas del Golfo de California" as a World Heritage Site. This site is composed of 244 islands, islets, and coastal and marine areas located throughout the GOC totaling 688,558 ha with a buffer zone of 1,210,477 ha. The site's establishment was justified by (1) its combination of "bridge islands" (connected to the mainland during glaciations) and oceanic islands, (2) its striking beauty, and (3) the diversity of terrestrial and marine life that makes it a high priority for biodiversity conservation. This site partially overlaps the "Área de Protección de flora y Fauna Islas del Golfo de California" which is administered by CONANP.

Reserva de la Biosfera Alto Golfo de California y delta del Río Colorado – In 1993, UNESCO established the "Reserva de la Biosfera Alto Golfo de California y delta del Río Colorado" as a Biosphere Reserve. This biological reserve is located north of a line from the fishing villages of San Felipe and Puerto Peñasco and encompasses the associated intertidal, delta, and estuary regions of the Río Colorado. Three fishing villages – Golfo de Santa Clara, San Felipe, and Puerto Peñasco – supporting 2,100 fishing boats – regularly fish these waters using primarily gill nets. Overall, 62% of the harvest from these three communities was occurring in the refuge (Rodríguez-Quiroz et al. 2010). Two other fishing communities – Desemboque de Caborca and San Luis Gonzaga – also actively fish this reserve with gulf grouper as one of the species targeted for harvest (Moreno-Báez et al. 2012). From 1995 through 2007, an average of 5,506 metric tons of catch was harvested annually from the reserve and the Vaquita Reserve waters with the primary targets being gulf corvina, shrimp, Spanish mackerel, bigeye croaker, and rays (Rodríguez-Quiroz et al. 2010).

Área de Refugio Vaquita Marina – In 2008, the "Área de Refugio Vaquita Marina" was set up to protect and conserve the critically endangered vaquita. The marine reserve was set up as a refuge that restricts gill and trammel net use (SEMARNAT 2008). Unfortunately, illegal gill net fishing activities have been targeting the endangered totoaba – their swim bladders are prized as a soup ingredient and medicinal remedy in eastern Asia. Due to these and legal fishing activities and a lack of enforcement, vaquita are declining at a rate of 18.5% annually with a current population estimated at 97. These same gillnet activities that are capturing totoaba and vaquita are, also, likely to impact gulf grouper (Moreno-Báez et al. 2012). In response to the vaquita's decline, a larger gill net exclusion zone was proposed to the Mexican government in August 2014 that would encompass the entire range of the vaquita (CIRVA 2014). On December 23, 2014, SEMARNAT approved these recommendations of a larger gillnet exclusion zone for a two year period with the exception of the gulf corvina fishery from February 1st through April 30th. Currently, five fishing communities – Desemboque de Caborca, Golfo de Santa Clara, Puerto Peñasco, San Felipe, and San Luis Gonzaga – actively fish 100% of this reserve (Moreno-Báez et al. 2012).

Puerto Peñasco Reserve Network – Puerto Peñasco is the largest community in the northern GOC and actively supports 120 shrimp trawlers and 230 small-scale fishing boats. Due to declining environmental resources, the community set up a series of three protected reserves – Sandy, Las Conchas, and Isla San Jorge – and two monitored fishing areas – La Cholla and Los Tanques – near Puerto Peñasco in 2000. Due to a lack of law enforcement, poaching has been a problem. In 2006, the federal government granted a fishing concession to the local community and developed a regional management plan which may lead to better resource protection (Cudney-Bueno et al. 2009).

Reserva de la Biosfera Bahía de Los Ángeles, canales de Ballenas y de Salsipuedes – Established in 2007, this biosphere reserve encompasses the western Midriff Islands and surrounding waters. This reserve serves a dual purpose of preserving ecological values and enhancing fishery productivity (Cinti et al. 2014). Six small no-take zones are established – Estero San Rafael (75 ha), Estero La Mona (75 ha), Ensenada los Choros (54 ha), Campo Polilla (27 ha), El Estero de las Caguamas Este (75 ha), and El Estero de las Caguamas Oeste (68 ha) – but none are considered important fishing areas. In 2009, a management plan was being developed to help combat the poor to non-existing law enforcement and overfishing (Cinti et al. 2014). Currently, six fishing communities – Bahía de los Ángeles, Bahía de Kino, El Barril, Las Ánimas, Puerto Libertad, and San Luis Gonzaga – actively fish 83% of this reserve (Moreno-Báez et al. 2012).

Parque Nacional Marina San Lorenzo Archipelago – Established in 2005, the "Parque Nacional Marina San Lorenzo Archipelago" is a marine national park adjacent to the southeast border of the "Reserva de la

Biosfera Bahía de Los Ángeles, canales de Ballenas y de Salsipuedes" and includes some of the Midriff Islands. The park contains three no-take zones – Zona Marina del Complejo Insular Partido y Partida (3,591 ha), Zona Marina Complejo Insular Rasito y Rasa (2,327 ha), and Zona Marina Complejo Insular las Ánimas y San Lorenzo (2,886 ha). Currently, five fishing communities – Bahía de los Ángeles, Bahía de Kino, El Barril, Las Ánimas, and Puerto Libertad – actively fish 38% of this park (Moreno-Báez et al. 2012).

Reserva de la Biosfera Isla San Pedro Martír – Isla San Pedro Martír is the southernmost member of the Midriff Islands and the most isolated island in the GOC (more than 60 km from either GOC shore). In 2002, the island and surrounding marine area were established as a biosphere reserve with a 900 ha core no-take zone (southeast and adjacent to the island) and a 29,000 ha buffer zone. From 2003 through 2008, researchers and MPA staff conducted 258 surprise visits and found that 39% of the time sport and commercial fishers were fishing in the core no-take zone including a large sport fishing derby targeting gulf grouper in 2004 (Cudney-Bueno et al. 2009). Two fishing communities – Bahía de Kino and El Barril – actively fish 74% of this reserve (Moreno-Báez et al. 2012).

Porción Marina Conocida como Ventilas Hidrotermales de la Cuenca de Guaymas y de la Dorsal del Pacífico Oriental – In 2009, the Guaymas basin marine sanctuary was created to protect deep sea habitats (>500 m deep) around hydrothermal vent systems. The sanctuary remains open for fishing activities and probably does not provide any gulf grouper habitat.[27]

Parque Nacional Bahia de Loreto – Established in 2004, the "Parque Nacional Bahia de Loreto" includes five islands and marine habitat, and it is adjacent to the city of Loreto. The park includes three general management zones: (1) Zones of restricted use, (2) Zones for the sustainable use of resources, and (3) Protection zones. Large scale fishing and shrimping activities are prohibited throughout the park. Two no-take reserves, Bajo del Murciélago and Bajo del Cochi, have been established over seamounts considered to be possible grouper/shark aggregation sites. However, these no-take reserves are small at 1,400 ha. The national park contains rocky reefs suitable for gulf grouper. As of 2009, the park still lacked a management plan and enforcement lagged. Research dives have shown a decline in reef fish diversity and abundance outside of the reserves while stable numbers have persisted within the reserves (Cudney-Bueno et al. 2009).

Parque Nacional Archipielago de Espiritu Santo – Established in 2007, Espiritu Santo was established as a national park for sustaining natural resources, contributing to regional coastal fisheries, and promoting sustainable tourist activities (TinHan et al. 2014). The three no-take reserves – Bahía San Gabriel, Los Islotes, and Punto Lobos – cover 670 ha of marine waters and habitat.

Parque Nacional Cabo Pulmo – In 1995, Cabo Pulmo was established as a national park to protect its large coral communities with a 2,501 ha no-take reserve (35% of the park). Cabo Pulmo lies in the transition zone between the tropical and temperate Pacific and supports 13 coral species and 99 fish species including gulf grouper (Aguilar-Medrano and Calderon-Aguilera 2015). In a ten year study, fish species richness and biomass significantly increased from 1999 to 2009 in Cabo Pulmo, and this was not observed in any other marine reserve in the GOC (Aburto-Oropeza et al. 2011). Multiple studies have observed gulf grouper in park waters (Aburto-Oropeza et al. 2011; Appendix A).

[27] Source: http://deepseanews.com/2009/07/new-mpas-in-mexico-protect-vents-whale-sharks/

Área de Protección de Flora y Fauna Cabo San Lucas – Established in 1973, this protected area is located along the southern tip of the Baja California peninsula and provides habitat to turtles and sea lions.

5.2 State Regulations

5.2.1 United States

5.2.1.1 California

In 1976, the California Fish and Game Commission adopted no-take regulations on broomtail and gulf groupers (Title 14, Section 28.12). These regulations went into effect on March 1, 1977 and are still in effect today (pers. comm., Chuck Valle, California Department of Fish and Wildlife, April 14, 2014).

5.2.2 Mexico

No state regulations exist that would limit impacts to gulf grouper.

5.3 International Regulations

No international regulations exist that would limit impacts to gulf grouper.

6.0 EXTINCTION RISK ANALYSIS FOR THE GULF GROUPER

6.1 Introduction

According to section 4 of the ESA, the Secretary (of Commerce or the Interior) determines whether a species is threatened or endangered as a result of any (or a combination) of the following factors: (A) destruction or modification of habitat, (B) overutilization, (C) disease or predation, (D) inadequacy of existing regulatory mechanisms, or (E) other natural or man-made factors. Collectively, I refer to these factors as "threats" (Section 4). In addition to reviewing the best available information on threats to the gulf grouper, I considered demographic risks to the species, similar to approaches described by Wainwright and Kope (1999) and McElhany et al. (2000). The approach of considering demographic risk factors to help frame the evaluation of extinction risk has been used in many NMFS status reviews, including: Pacific salmonids, Pacific hake, walleye pollock, Pacific cod, Puget Sound rockfishes, Pacific herring, scalloped hammerhead sharks, and black abalone (see http://www.nmfs.noaa.gov/pr/species/ for links to these reviews).

For this extinction risk analysis, the collective condition of individual populations will be considered at the species level according to four demographic viability criteria: abundance, growth rate/productivity, spatial structure/connectivity, and diversity (McElhany et al. 2000). These viability criteria reflect concepts that are well founded in conservation biology and that individually and collectively provide strong indicators of extinction risk. When these viability parameters are at appropriate levels, they maintain a population's capacity to adapt to various environmental conditions and allow it to sustain itself in the natural environment. These attributes are influenced by survival, behavior, and experiences throughout a species' entire life cycle; and these characteristics, in turn, are influenced by habitat and other environmental conditions.

Using these concepts, as well as their links to the threats discussed above, I analyzed the likely overall extent of extinction risk faced by the gulf grouper. Because species-specific information (such as current and historical abundance) is sparse, and levels of historical fishing effort on the species and subsequent removals are unknown or uncertain, quantitative models depicting likelihood of extinction are unavailable.

6.2 Abundance

Population abundance is an important determinant of risk to gulf grouper, both by itself and in relation to other factors. Small populations are subject to a host of risks intrinsic to their low abundances while large populations can exhibit a greater degree of resilience. Abundance generally refers to the number of adults in the natural environment (McElhany et al. 2000).

Based upon LFK and fishing statistics, I conclude that gulf grouper abundance has severely declined from the mid-20th century. Direct harvest has been the major factor in their decline. As an aggregate spawner, gulf grouper are particularly susceptible to harvest due to the predictability of their locations at higher than normal densities. Other factors impacting their abundance include bycatch in the commercial shrimp trawl industry and illegal totoaba fishery, habitat degradation and loss, and climate change.

Sadovy de Mitcheson et al. (2012) lists three biological factors – late onset of reproductive maturity, aggregate spawning, and restricted geographic range – as contributing to the susceptibility of groupers to harvest. Gulf groupers exhibit these biological factors. First, gulf grouper are a long-lived, protogynous hermaphroditic fish; they mature as females (at six to seven years of age) and later transition into males. Recent studies have shown that 99% of gulf grouper harvested are immature fish, depriving the population of reproductive age fish (Aburto-Oropeza et al. 2008). Second, gulf grouper aggregate spawn. Once a year, adult gulf grouper aggregate for reproduction at a known time (full moon in May), at known locations (reefs and seamounts), at higher than normal densities, and at an adult size. Third, gulf grouper are restricted to a small geographic range (Morris et al. 2000).

Direct harvest is the major reason for gulf grouper decline (Sala et al. 2004, Sáenz-Arroyo et al. 2005a, Aburto-Oropeza et al. 2008); and due to the lack of protective regulations in Mexico, there is no reason to expect fisheries to be a diminishing threat. For nearly half a century (1930s-1970s), gulf grouper were a prized fish that was sought after frequently by both commercial and artisanal fisheries. Since there are no direct studies of gulf grouper abundance, we have to rely upon LFK for this time period. In the GOC, LFK indicates that gulf groupers were once abundant and represented 45% of the artisanal fishery in 1960, but declined to 10% by the 1970s, and is now less than 1% of the fishery (Sáenz-Arroyo et al. 2005a). As gulf grouper harvest has decreased, so has their capture size. For heaviest gulf grouper caught, weight per fish decreased significantly ($p<0.0001$) from $\geq$ 80 kg (1940s through 1960s) to 60 kg (2000) (Sáenz-Arroyo et al. 2005a). Further, the decrease in the harvest levels since the 1970's was not due to fishing effort (which had increased) or protective regulations (which were limited, at best) but rather due to a drop of abundance. Since 1970, 38 recent marine studies have been conducted throughout the gulf grouper's range with only eight of these studies (four field studies and four literature reviews) observing the once abundant, gulf grouper.

Along the Pacific coast, even less is known about gulf grouper. Beginning in 1927, these populations were harvested by Californians recreationally and commercially (selling them as "golden bass" at fish markets in southern California) until the harvest rates neared zero in the 1960s and a no-take/no-possession rule was enacted in California during the late 1970s (Croaker 1937 and California Department of Fish and Wildlife - http://libraries.ucsd.edu/apps/ceo/fishbull/). Gulf grouper populations along the Pacific coast have not recovered and are believed to be rare, at best. Currently, there is no known gulf grouper fishery though they are still legal to harvest in Mexico (though illegal to possess or take in California).

Overall, direct harvest of gulf grouper, especially at spawning aggregation sites, is the biggest risk to the species' existence. As with other grouper species (i.e., camouflage grouper, gag grouper, goliath grouper, Nassau grouper, red hind, tiger grouper, yellowfin grouper), gulf grouper are extremely susceptible to harvest at spawning aggregation sites. Harvest at these sites has a direct impact on abundance. After heavy harvests, some historical gulf grouper spawning aggregation sites have disappeared (e.g. Punta Lobos, San Bruno seamount) (Sáenz-Arroyo et al. 2005a). Harvest of the largest fish results in fewer males and a skewed sex ratio can negatively impact reproduction. In grouper species with recovering populations, the protection of spawning aggregation sites, a seasonal fishing ban during the reproductive season, or a combination of the two has proven helpful (Sadovy de Mitcheson et al. 2012). Unfortunately, with the exception of Parque Nacional Cabo Pulmo, no such protections or regulations exist or are effectively enforced for the gulf grouper.

Lesser, but still significant, threats to gulf grouper abundance include bycatch in the commercial shrimp industry and illegal totoaba fishery, habitat degradation and loss, and climate change. Commercial shrimp trawlers in Mexican waters are not required to use BRDs and, therefore, harvest a large amount of bycatch (6.1:1 to 10.2:1 bycatch to shrimp ratio) (Madrid-Vera et al. 2007, Gillet 2008, Meltzer 2012). With the lack of BRDs and a high bycatch ratio, gulf grouper adults are caught as bycatch by the commercial shrimp trawl industry (Ramírez et al. 2012). Further, shrimp trawlers reduce the amount of forage available to gulf groupers.

Gulf grouper are believed to be captured in the illegal totoaba fishery. The totoaba, currently ESA listed as endangered, are currently harvested via gillnets in the northern GOC for their swim bladders, which garner $8,500 per kg (CIRVA 2014). Although it is unknown whether or not this totoaba fishery is also harvesting gulf grouper, this fishery is currently using the same fishing ports (i.e., San Felipe, Golfo de Santa Clara, Puerto Peñasco) and harvest methods (i.e., gill nets) being used to capture gulf grouper (Moreno-Báez et al. 2012).

For habitat, adult gulf groupers are dependent upon rocky reefs as their primary habitat and for spawning aggregation sites (Sala et al. 2005). Continued habitat destruction and degradation is a threat from development, fisheries, and environmental conditions [i.e., climate change, pollution, dead zones (hypoxic waters)] (Wilder et al. 2012b). Habitat threats will be discussed further in the Productivity section (Section 6.3).

Climate change is expected to have a large, and ever increasing, impact upon the gulf grouper and its environment. If the gulf grouper's current distribution is based upon residing within a range of ocean temperatures, then they would be severely impacted by increasing sea surface temperature. Gulf grouper have a small distribution which may restrict their ability to move and adapt (Morris et al. 2000). Since most of their distribution is within the GOC, they would not be able to retreat to the cooler waters of the higher latitudes. Indirect impacts may include a loss of forage due to the movements and/or shift in their prey species.

As adults, gulf groupers reside in, are a top predator of, and aggregate spawn in the rocky reef ecosystem (Sala et al. 2005). Further, corals are an important component of rocky reefs; and they have a narrow temperature range above which they suffer bleaching and mortality events (as has been observed during and after major El Niño events in the GOC) (Bonilla 1993, Bonilla 2001). During strong El Niño events, ocean temperatures rise on a level that may be similar to the increased ocean temperatures expected later this century under current climate change emissions scenarios (Rhein et al. 2013). During the last major El Niño event (1997-1998), ocean temperatures increased over 1.5°C, resulting in coral bleaching and death, reduction in leopard grouper productivity, and reduction in sargassum beds (Bonilla 2001 and Aburto-Oropeza et al. 2008). Further, as a calcium secreting organism, they are expected to be impacted by ocean acidification which is expected to reduce coral growth and persistence (Hoegh-Guldberg et al. 2007). Overall, climate change is expected to impact the reefs that gulf grouper depend upon.

6.3 Productivity

Productivity (i.e., population growth rate) is a measure of how well a population is performing in the habitats that it occupies during its life cycle. Productivity and related parameters are integrated indicators of how a population, or a species, responds to its environment (McElhany et al. 2000).

Based upon gulf grouper life history, I conclude that gulf grouper productivity is severely impacted by direct harvest. Gulf groupers are a large, long-lived, sought after fish. Gulf grouper size/age at harvest has significantly dropped since the 1940s (Sáenz-Arroyo et al. 2005a), and they are now primarily harvested as juveniles (Aburto-Oropeza et al. 2008). Immature gulf groupers are being harvested not because they are preferred, but due to the lack of adult sized fish. Since harvest is limiting the number of juveniles that are able to mature to adults (especially to males), harvest severely impacts productivity.

Direct harvest at spawning aggregation sites impacts gulf grouper productivity in multiple ways. First, gulf grouper aggregate only once annually to spawn, and interrupting these activities may result in a lost year of reproduction (Aguilar-Perera and Aguilar-Dávila 1996). Second, harvesting of a spawning gulf grouper directly removes a reproducing individual permanently from the population (Sadovy and Domeier 2005). Third, fishing activities target the largest and most important reproductively individuals (Sadovy 1994). As a protogynous hermaphrodite, the largest individuals are male; and their removal would result in a sexually skewed population (Sadovy 1994). After the males, the next largest individuals are the largest females who are more fecund than the smaller females (Collins et al. 1998).

Gulf grouper rely upon two habitat types throughout their lives – coastal habitat, as young juveniles, and reefs, as older juveniles and adults (Aburto-Oropeza et al. 2008). The loss or deterioration of either one of these habitats impacts the effectiveness of the other habitat (Almany et al. 2013). For example, fertilized gulf grouper eggs drift from their spawning aggregation sites to their settlement habitats as they develop into larvae. If one of these habitats is deteriorated or lost, then the effectiveness of the other habitat is diminished.

Though settlement habitat may be somewhat widespread throughout the GOC, the distance to (or association with) spawning aggregation sites may be a limiting factor as to what locations are available as settlement habitat; thus negatively impacting recruitment (Sadovy and Eklund 1999). Currently, the Mexican government has increased development spending to build highways and upgrade ports and harbors for trade, tourism, and urban growth adjacent to the GOC (Wilder et al. 2012b). This is expected to increase resource use (i.e., fresh water inputs, fisheries, shrimp aquaculture) throughout the region while increasing pollution. With the shrimp aquaculture industry, over half of the growth has occurred by transforming coastal habitats into shrimp farms while adjacent habitats are degraded through the release of effluents and the rerouting, reduction, and degradation (i.e., hypersalinity) of freshwater inputs (Páez-Osuna 2001, Berlanga-Robles et al. 2011). Further, coastal habitat may be impacted by tidal power and desalination plants (Wilder et al. 2012b). Desalination plants impact the environment by both their huge power requirements and the wastewater discharges which include brine plumes (at twice the salinity of marine waters), antiscalents, coagulants, heavy metals (especially copper), and membrane preservatives that get released into the marine environment (Roberts et al. 2010).

Coastal habitats (i.e., estuaries, mangrove swamps) are dependent upon their freshwater inputs mixing with marine waters to produce their rich environments (Glenn et al. 2006). For example, the largest watershed, Río Colorado, has been severely impacted (90% reduction in flow over the past century), which has had deleterious effects upon the northern GOC. For the totoaba, these changes have resulted in delayed maturation and a reduced lifetime fecundity which likely impedes the recovery of this species (Rowell et al. 2008). In a survey of fishing villages in the northern GOC, the majority of fishers cited that the physical and biological conditions in the northern GOC had declined due to decades of intense fishing, wetland habitat loss, and changes in salinity (Lozano-Montes et al. 2008).

Climate change may also impact coastal habitats and gulf grouper productivity. Higher ocean temperatures would impact the juvenile rearing habitats of gulf grouper (i.e., decreased sargassum beds) and, thus, affect gulf grouper production (Aburto-Oropeza et al. 2008). For Nassau grouper, Sadovy and Eklund (1999) suspect that global warming could impact reproduction due to their specific temperature requirements. Also, the combination of climate change and anthropogenic nutrient loading is expected to increase incidence of hypoxia through enhanced ocean stratification, decreased oxygen solubility, increased metabolism, and increased production of organic matter (Rabalais et al. 2009).

6.4 Spatial Structure

Spatial structure is composed of both the geographic distribution of individuals in the population and the processes that generate that distribution. A population's spatial structure depends fundamentally on habitat quality and spatial configuration and the dynamics and dispersal characteristics of individuals in the population (McElhany et al. 2000).

Gulf grouper harvest has occurred most proximate to fishing ports which has reduced their abundance near these locations (Sala et al. 2004). As local fishing grounds are fished, catch size and species composition and abundance changes; and the fishery becomes less productive (Pauly 1995 and Sala et al. 2005). Many gulf grouper harvest locations from previous decades no longer support harvests though fishing effort has increased (Sáenz-Arroyo et al. 2005a and Aburto-Oropeza et al. 2008). For example, California fisheries frequently harvested gulf grouper from the 1930s to the 1960s along the Pacific coast until the harvests dropped to near zero, even though California fishers still plied the sea.[28] Outside of a known population in Bahía Magdalena (Octavio Aburto-Oropeza, Scripps Institution of Oceanography, Aug 29, 2014, pers. comm.), there is no published evidence of gulf grouper still persisting along the Pacific coast of the Baja California peninsula. In the GOC, gulf grouper presence has been reduced or even lost. In the 1950s and 1960s, gulf grouper were the primary target for fishers at Punta Lobos and San Bruno seamount, but gulf grouper are now rarely found at these locations (Sáenz-Arroyo et al. 2005a). Up into the 1980s, the gulf grouper was still considered one of the most important fish species for fishers in the GOC (Sala et al. 2005). Currently, gulf grouper make up less than 1% of the fishery with 99% of harvested gulf grouper immature (Sáenz-Arroyo et al. 2005a and Aburto-Oropeza et al. 2008).

Gulf grouper are most susceptible to harvest on their spawning aggregation sites. Once found, spawning aggregation sites are vulnerable to overfishing; and when numbers at spawning aggregation sites reach a critical threshold, they no longer form. This is theorized in two ways: (1) not enough adults are present and/or (2) the individuals that knew of the spawning aggregation site no longer exist to lead others to the site (Colin 1996, Bolden 2000, and Aguilar-Perera 2006). Loss of spawning aggregation sites appears to

[28] Source: California Department of Fish and Wildlife - http://libraries.ucsd.edu/apps/ceo/fishbull/

have happened at a few known sites with gulf grouper after periods of heavy exploitation (i.e., Punta Lobos and San Bruno seamount). Another unknown is how far a sexually mature gulf grouper will travel to get to a spawning aggregation site. The loss of spawning aggregation sites from parts of their range may fragment their populations and negatively impact the spatial structure of the species.

Concerning settlement habitat, some coastal habitats have been more impacted than others, which can, theoretically, create an uneven, fragmented distribution of juvenile gulf grouper habitat. Mexico is the second largest shrimp producer in the western hemisphere with approximately 97% of the shrimp aquaculture ponds being located adjacent to the GOC (Barraza-Guardado et al. 2013). Further, pollution and nutrient overload from cities and agriculture has degraded water quality threatening coastal habitats. Increasing anthropogenic nitrogen from sewage, shrimp farms, and agricultural sources is directly utilized by macroalgae, creating more frequent blooms and corresponding anoxia throughout coastal habitats in the GOC (Piñón-Gimate et al. 2009). Even though settlement habitat may appear to be abundant, the distance and direction from spawning aggregation sites is important. In a genetic parentage analysis study, Almany et al. (2013) found that half of the squaretail coral grouper larvae settled within 14 km of the spawning aggregation site. That distance for gulf grouper is unknown and may be a limiting factor.

6.5 Diversity

Diversity is important for species and population viability because diversity (1) allows a species to use a wider array of environments, (2) protects a species against short-term spatial and temporal changes in the environment, and (3) provides the raw genetic material for surviving long-term environmental changes (McElhany et al. 2000).

Gulf grouper diversity is unknown, but there are reasons for concern. First, gulf grouper are currently a rare species that used to be abundant (Sáenz-Arroyo et al. 2005a). Second, they are rare, or mostly absent, from a large portion of their range (i.e., along the Pacific coast of the Baja California peninsula). Third, spawning aggregation sites have been lost (Sáenz-Arroyo et al. 2005a). Spawning aggregation sites pull adult groupers in from long distances, thus the loss of an aggregation site can impact a large area for the species (Sadovy de Mitcheson et al. 2008). Although, no genetics studies have been performed on gulf grouper, these factors (i.e. major reduction in abundance, possible loss of range, loss of spawning aggregation sites) may have reduced their diversity.

6.6 Significant Portion of Its Range

On July 1, 2014, the United States Fish and Wildlife Service (USFWS) and NMFS issued its final policy on the interpretation of "Significant Portion of Its Range" (SPOIR) in the ESA (79 FR 37578). SPOIR is defined as "A portion of the range of a species is 'significant' if the species is not currently endangered or threatened throughout all of its range, but the portion's contribution to the viability of the species is so important that, without the members in that portion, the species would be in danger of extinction, or likely to become so in the foreseeable future, throughout all of its range." Due to the paucity of current and historic data for gulf grouper, SPOIR will not be considered for gulf grouper due to the inability to separate out the importance of any portion of its range from the whole.

6.7 Conclusion

In conclusion, gulf groupers are at a high risk of extinction. The gulf grouper was once considered abundant, but they are now considered rare (Jenkins and Evermann 1889, Croker 1937, and Sáenz-Arroyo et al. 2005a). Direct harvest is the major reason for gulf grouper decline (Sala et al. 2004, Sáenz-Arroyo et al. 2005a, Aburto-Oropeza et al. 2008); and due to the lack of protective regulations in Mexico (no meaningful quotas nor protective regulations for gulf grouper), there is no reason to expect fisheries to be a diminishing threat. In the GOC, LFK indicates that gulf groupers were once abundant and represented 45% of the artisanal fishery in 1960, but declined to 10% by the 1970s, and are now less than 1% of the fishery (Sáenz-Arroyo et al. 2005a). Further, best day's catches for gulf grouper has decreased significantly ($p<0.001$) from 25 fish daily (1940s and 1950s) to 10 - 12 (1960s) to 1 - 2 (1990s) while weight per fish also decreased significantly ($p<0.0001$) from $\geq$ 80 kg (1940s through 1960s) to 60 kg (2000) (Sáenz-Arroyo et al. 2005a). Though a series of MPAs have been set up in the GOC, only one, Cabo Pulmo, has an enforced no-take marine zone and is the only protected marine zone in the GOC that has seen improved marine fish life diversity and density over the past decade (Aburto-Oropeza et al. 2011). Overall, enforcement is underfunded and cannot sufficiently patrol or even provide a presence to the 26,000 fishing vessels that fish the GOC (Rife et al. 2012).

Gulf groupers are further susceptible to harvest due to the following three biological factors: (1) late onset of reproductive maturity, (2) aggregate spawning, and (3) restricted geographic range (Sadovy de Mitcheson et al. 2012). First, gulf grouper are a long-lived, protogynous hermaphroditic fish; they mature as females (at six to seven years of age) and later transition into males. Recent studies have shown that 99% of gulf grouper harvested are immature fish, depriving the population of reproductive age fish (Aburto-Oropeza et al. 2008). Second, gulf grouper reproduce at aggregate spawning sites. Once a year, adult gulf grouper aggregate for reproduction at a known time (full moon in May), at known locations (reefs and seamounts), at higher than normal densities, and at an adult size. For gulf grouper, spawning aggregation sites within the GOC (e.g. Punta Lobos, San Bruno seamount) have disappeared after periods of heavy exploitation (Sáenz-Arroyo et al. 2005a). Third, gulf grouper are restricted to a small geographic range (Morris et al. 2000). Overall, the historic and current range distribution for gulf grouper is considered restricted, less than 800,000 km^2, making them more vulnerable to local stochastic events (Morris et al. 2000).

Lesser, but still significant, threats to the gulf grouper include: (1) bycatch in the commercial shrimp industry, (2) bycatch in the illegal totoaba fishery, (3) habitat degradation and loss, (4) shrimp aquaculture, and (5) climate change. First, commercial shrimp trawlers capture gulf grouper as bycatch. In Mexican waters, shrimp trawlers are not required to use BRDs and, therefore, harvest a large amount of bycatch (6.1:1 to 10.2:1 bycatch to shrimp ratio) including gulf grouper (Madrid-Vera et al. 2007, Gillet 2008, Meltzer 2012, Ramírez et al. 2012). Second, gulf grouper are believed to be captured in the illegal totoaba fishery due to the overlap of capture methods and locations. Currently, totoaba are harvested intensively in the northern GOC via gillnets for their swim bladders at $8,500 per kg (CIRVA 2014). Third, gulf grouper habitat is being degraded and lost due to the upgrading of infrastructure (i.e., ports, highways, housing) throughout and adjacent to the GOC (Wilder et al. 2012b). Gulf grouper rely upon two habitat types during their lives – coastal habitat, as young juveniles, and reefs, as older juveniles and adults (Aburto-Oropeza et al. 2008), and the loss or deterioration of either of these habitats would impact the effectiveness of the other (Almany et al. 2013). Fourth, Mexico is the second largest shrimp producer in the western hemisphere with approximately 97% of the shrimp aquaculture ponds being located adjacent to the GOC (Barraza-Guardado et al. 2013). With the shrimp aquaculture industry, over half of the growth has occurred by transforming coastal habitats into shrimp farms while adjacent habitats are degraded through the release of effluents and the rerouting, reduction, and degradation (i.e., hypersalinity) of freshwater inputs (Páez-Osuna 2001, Berlanga-Robles et al. 2011). Fifth, climate change may also impact coastal habitats and gulf grouper productivity. Higher ocean temperatures would impact the juvenile rearing habitats of gulf grouper (i.e., decreased sargassum beds) and, thus, affect gulf grouper production (Aburto-Oropeza et al. 2008). For Nassau grouper, Sadovy and Eklund (1999) suspect that global warming could impact reproduction due to their specific temperature requirements.

Due to the aforementioned threats and demographic risk factors associated with this species, I conclude that the gulf grouper is at a high risk of extinction throughout all of its range. Overall, these threats place the current viability of the species at risk and likely influenced by stochastic and/or depensatory processes.

7.0 REFERENCES

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8.0 APPENDIX

Table 9. Marine surveys conducted throughout gulf grouper range in Mexico (from north to south).

Location	Begin	End	Gulf grouper present	Total species seen	Method	Habitat	Reference
Bahía de Los Ángeles	2004	2004	No	93	Visual census	Reef	Viesca-Lobatón et al. 2008
La laguna costera La Cruz (Sonora)	1989	1991	No	96	Plankton net, trawl net, beach seine, cast net	Fine materials (bottom)	Grijalva-Chon et al. 1996
Guerrero Negro Lagoon; Ojo de Liebre Lagoon	1994	1995	No	59	Seine, cast net, hook and line, spear gun, gill net	Sand, sandstone; fine sediment, sand, clay (lagoon)	de la Cruz-Agüero et al. 1996
Ojo de Liebre Lagoon	1995	1995	No	59	Gill net, beach seine, otter trawl	Shallow lagoon, seagrass beds	Acevedo-Cervantes 1997
Laguna San Ignacio	1989	1993	No	81	Stomach samples, trawl, gill net, speargun	Sandy/mud bottom, rocky bottom	Danemann and de la Cruz-Agüero 1993
Bahía Concepción	1944	1976	No	212	Lit review	Sandy, rocky, marsh, boulders	Rodríguez-Romero et al. 1994
Bahía Concepción	1985	1989	No	146	Gill net, shrimp trawl, skin diving, harpoon gun	Sandy, rocky, marsh, boulders	Rodríguez-Romero et al. 1992
Loreta Marine Reserve	1997	1998	No	66	Gill net	Rocky shore (bottoms varying from sand to boulders)	Campos-Dávila et al. 2005
Bahía de Topolobampo	1995	1996	No	77	Otter trawl, shrimp net	Unknown	Gutiérrez-Barreras 1999
Isla San José	2000	2001	No	63	Gill nets	Rocky reef	Irigoyen-Arredondo 2013
Isla San José	**2001**	**2002**	**Yes**	**112**	**Visual census**	**Rocky reef**	**Barjau-González et al. 2012**
Isla San José	2001	2002	No	84	SCUBA	Rocky reef	Villegas-Sanchez 2004
El Pardito inlet (Isla San José)	2004	2006	No	61	Hook and line, cimbra, gill net	Bay	Montoya-Campos 2009
Bahía de la Paz	1993	1993	No	92	Gill net, beach seine	Sandy, rocky, coral, shallow	Galván-Piña 1998
San Jose, San Francisquito, and El Pardito Islands	**2000**	**2001**	**Yes**	**298**	**Gill net, charalera net, visual census**	**Reef**	**Palacios-Saldago et al. 2012**
Bahía Magdalena	1988	1989	No	75	Otter trawl	Soft bottoms	Gutiérrez-Sánchez 1997
Espiritu Santo-La Partida (Bahía de la Paz)	1994	1998	No	74	SCUBA	Boulders, black coral, rhodoliths	Aburto-Oropeza and Balart 2001
Los Islotes	1994	1995	No	33	SCUBA	Rocky reef	Aburto-Oropeza 1999
Bahía de la Paz	1981	1986	No	390	Gill net, hook, longline, trawl, harpoon, speargun	Bay	Abitia-Cárdenas et al. 1994

Location	Begin	End	Gulf grouper present	Total species seen	Method	Habitat	Reference
Isla Espiritu Santo	1995	1996	No	120	SCUBA	Rocky/coral reef	Rodríguez-Romero et al. 2005
Bahía de la Paz	1995	1995	No	80	SCUBA	Rocky/coral reef	Arreola-Robles 1998
Bahía de la Paz	1993	1993	No	58	Gill net	Sandy and rocky	Galván-Piña et al. 2003
Bahía Magdalena	1985	1990	No	161	Shrimp net, gill net, beach seine, hook and line, speargun	Estuaries, channels, lagoon	de la Cruz-Agüero et al. 1994
Cueva de Leon	1992	1993	No	75	Visual census	Rocky/coral reef	Pérez-España et al. 1996
Cerralvo Island	1998	2002	No	86	Submarine	Rocky reef (sandy, coral)	Cálapiz-Segura 2004
Bahía de la Paz	**1978**	**1993**	**Yes**	**132**	**Gill net, trawl net, local fisheries, sea lion scat**	**Sandy bottom, near mangroves on coast**	**Balart et al. 1995**
Cerralvo Island	1998	1999	No	89	SCUBA	Sandy to rocky bottom	Jiménez-Gutiérrez 1999
Isla Cerralvo	**1944**	**1993**	**Yes (lit)**	**174**	**Lit.Review, gill net, longline, harpoon, hand-held net, SCUBA, visual transect**	**Unknown**	**Galván-Magaña et al. 1996**
Bahía de la Paz	1995	1996	No	42	Trawl net	Mud/sandy bottom	Malpica-Maury 1999
Bahía de la Paz	1996	1998	No	55	Flume net	Mangrove estuary	González-Acosta et al. 1999
Cabo Pulmo	**1986**	**1998**	**Yes (lit)**	**236**	**Lit. Review, visual**	**Coral reef**	**Villarreal-Cavazos et al. 2000**
Cabo Pulmo	2003	2004	No	62	Underwater observation	Rocky to coral reef	Alvarez-Filip et al. 2006
Bahía Pulmo	1972	1973	No	108	Underwater observation	Coral reef	Brusca and Thomson 1975
Cabo Pulmo	**1987**	**2008**	**Yes**	**109**	**Visual census (19 surveys)**	**Reef**	**Saldívar-Lucio 2010**
El Verde, Sinaloa (Mazatlan)	1977	1978	No	55	Beach seine	Estuary	Chan-Gonzalez 1980
Los Frailes (Cabo Pulmo NP)	2004	2006	No	89	Visual census	Reef (rock, sand, corals)	Moreno-Sánchez 2009
Laguna Ojo de Liebre, Laguna de San Ignacio, Bahía Magdalena, Bahía Concepción, and Bahía de La Paz	-	-	**Yes**	**446**	**Lit. Review, museum specimens**	-	**Martínez-Guevara 2008**
Gulf of California	-	-	**Yes**	**615**	**Lit. Review, museum specimens**	-	**del Moral-Flores et al. 2013**

Table 10. **Local Folk Knowledge (LFK) fishery studies in the Gulf of California (GOC).**

Source	Year(s) of Interview	Location	No. interviewees	No. fishing communities	Age Groups	Years covered		Gulf Grouper Abundance	Fishing locations
						Begin	End		
Lozano-Montes et al. (2008)	2003	Northern GOC	49	3	Young (15-30; n=11), middle-aged (31-55; n=19), old (>55; n=19)	1950	2000	n/a	-
Moreno-Báez et al. (2010 and 2012)	2005-2006	Northern GOC	376	17	-	-	-	n/a	El Borrascoso, La Choya-Los Tanques, Bahía Tepoca, and Punta Tepopa
Sáenz-Arroyo et al. (2005a and 2005b)	2002	Central GOC	108	11	Young (15-30; n=40), middle-aged (31-54; n=34), old (≥55; n=34)	1940	2000	n/a	-
Sala et al. (2004)	2002	Southern GOC	63	4	-	1970	2000	n/a	-