Title

Testing Sustainability in Triggerfish and Leopard Grouper Fisheries in the Northern Gulf of California

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Fisheries represent the principal economic activity in the Northern Gulf of California, Mexico, but few targeted species are managed by any type of harvest controls. This study assessed the sustainability of two main fisheries in the area: Fine-scale Triggerfish (Balistes polylepis) and Leopard Grouper (Mycteroperca rosacea) by comparing estimates of annual landings (fisheries production) with the surplus biomass produced on fishing grounds (biological production) of each species. The specific objective of the study was to determine for each species whether fisheries production exceeds biological production, which would indicate that overfishing is occurring. Results of this comparison show that fishing is more than 3 times higher than surplus production for leopard grouper and 15 times higher than surplus production for triggerfish. These results suggest that both species are in an overfishing state.

1. Introduction

The Gulf of California (also known as the Sea of Cortez) is located in Northwestern Mexico and was described as the world's aquarium by Jacques Cousteau due its uniqueness and high biodiversity. The Gulf is one of five marine ecosystems in the world with the highest diversity of wildlife (Echeverria, 2008) and rates of primary productivity due to a combination of its topography, warm climate, and upwelling systems (Wilkinson et al. 2009).

The Gulf of California is divided into three main regions, the Northern Gulf of California (NGC), Central Gulf of California (CGC) and the Southern Gulf of California (SGC) (Brusca & Hendrickx 2008). The Northern Gulf extends from the Colorado Delta

River southwards including the Midriff Islands, also known as Islas del Cinturon (Cartron et al. 2005). The region is characterized by rocky shores and coastal plains of Baja California Norte and Sonora. The combination of solar radiation, ocean trenches and complex currents and eddies cause strong upwelling leading to a high marine productivity. The region features high biodiversity and high levels of endemism. Its waters include large aggregations of fish, turtles, marine mammals and both terrestrial and marine birds (WWF Mexico, 2007)

Although the Gulf of California is a resilient large ecosystem, in part of its coastal wetlands and submarine topography/surface wind patterns that cause the upwelling of nutrients; factors such as overfishing, river water diversions, sedimentation, pollution, and aquaculture installations have significantly altered the region's ecosystems (Wilkinson et al. 2009). While human population on the Gulf's numerous islands is minimal or absent (WWF, 2007), humans have been a part of the ecosystem for 10,000 years, which has affected both terrestrial and inshore marine biota (Bahre & Bourillon 2002). Evidence of prehistoric habitation has been found on the Midriff coasts of Sonora and Baja California and on the four largest islands: Tiburon, Angel de la Guarda, San Lorenzo, and San Esteban (Bowen, 1976, 2000). The harmful human uses began in the nineteenth century with the start of guano mining on Patos, Rasa, and San Pedro Martir islands. Since then, most of the major human impacts affecting Northern Gulf are related to rapid population growth in northwestern Mexico due increasing demands for the fishery and tourist resources of the region (Bahre & Bourillon 2002).

The NGC is very important for economic activities, especially fishing. In the last decades, the main economic activities are small scale and industrial fishing (Cisneros-Mata et al. 2010). For instance, the major Mexican settlement in the region began with the growth of the totoaba and shark-fishing industries in Bahia Kino in the early 1930s (Bahre et al. 2000). After that, the settled fishermen began to exploit other species, and they continue their efforts to meet expanding markets for seafood in Mexico, the United States and Asia. Since the early 1970s, commercial fishing, especially for shrimp, sharks and rays (Chondrichthyan fishes), Pacific sardines (*Sardinops sagax caerulea*), northern anchovies (*Engraulis mordax*), lobster (*Panulirus sp.*), scallops (*Lyropecten subnudosus* and *Agropecten circularis*), giant sea cucumbers (*Parastichopus fitscus*), groupers (*Mycteroperca spp.*), fine-scale triggerfish (*Balistes* polylepis), snappers (*Lutjanus spp.*), bass (*Paralabrax spp.*) among others, has increased significately (Hammann & Cisneros-Mata 1989; Thomson et al. 1996).

Fishermen from different communities of Baja California and Sonora are the ones who exploit the NGC, therefore, are who receive the economic benefits from the biodiversity (Meza et al. 2011). The principal fishing communities are Bahía de Kino, Guaymas, Puerto Peñasco, Golfo de Santa Clara, Puerto Libertad, in Sonora and Bahia de los Angeles, San Francisquito, and San Felipe, in the Baja Peninsula (Meza et al. 2011; Moreno-Baez et al. 2012).

According to the General Law of Fishing and Sustainable Aquaculture in Mexico (LGPAS by its acronym in Spanish), fisheries management in Mexico is based on fishing permits. Each permit allows one boat to harvest certain, species not limiting the catch amount. In addition, the permit-based system has limited enforcement, resulting in an unsuccessful effort to maintain fish stocks and leading to unsustainable fisheries (Sala et al. 2004).

The National Commission of Aquaculture and Fishing in Mexico (CONAPESCA) produces a fisheries landings database, but it operates on a coarse spatial scale and does not provide reliable information on fishing sites or how much is harvested from particular regions (Ramírez-Rodríguez & Ojeda-Ruíz 2012). This limits our ability to estimate fishing impacts on particular areas. It is known, however, that fishing throughout Gulf occurs on a regional scale (Erisman et al. 2011), such that fishers from particular communities tend to predictably fish certain areas (Moreno et al. 2012; Erisman et al. 2011) for certain species.

In Northwestern Mexico, scientists, regional non-governmental organizations, and the Mexican federal government are promoting efforts that utilize ecosystem-based management (EBM) approaches to define conservation and fishery-management priorities for the region (Erisman et al. 2011), but the lack of accurate on fine-scale fisheries catches complicates the accurate development of these management programs (Cinti et al. 2010). There are different efforts from different Non-governmental Organizations (NGOs) and government institutions to accomplish conservation, one of the steps to accomplish it is performing different projects to obtain useful data.

The purpose of my study was to determine whether the fishing effort in the NGC is lower or higher than the amount of fish is being produced in that area, trying to understand why the population is decreasing. To answer this question, fisheries dependent data from the Mexican government (CONAPESCA) were combined with spatial data of fishing activities from the NGC (Moreno-Baez et al. 2012), population structure data of reef fishes from the NGC (Aburto-Oropeza, unpublished data), and underwater survey data gathered from rocky reefs of the NGC (PANGAS Project, Unpublished data [1]).

As this study is a pilot project, I focused in two main species: finescale triggerfish (*Balistes polylepis*) and leopard grouper (*Mycteroperca rosacea*), which are highly exploited by commercial fisheries in the NGC. These two species are among of the most economically important reef fisheries in the Gulf of California (Erisman et al. 2011), and fishermen and scientists are realizing that their populations are decreasing, due it is harder to catch them, and sizes are smaller compared to past years (Personal Conversation with fishermen).

2. Materials and Methods

The project was divided into two components. Component A was to determine the fishing effort of the area, and component B was to calculate the Standing Crop Biomass (SCB) and surplus production of each species in such area. In component A, I integrated the results of Moreno-Baez et al. (2012), about the spatial and temporal dimensions of fishing activities in the NGC; then combined them with the landings

[1] PANGAS stands for "Pesca Artesanal del Norte del Golfo de California – Ambiente y Sociedad", Small-scale Fisheries in the Northern Gulf of California – Environment and Society). http://www.pangas.arizona.edu/en/what-pangas

database of CONAPESCA, in order to estimate the fishing effort in more detail regarding the exploitation (kilograms and tons) in different fishing grounds of the NGC.

Component B of the project involved calculating surplus biomass production of each species in certain areas. The term of surplus biomass production refers to the change in the population biomass; by definition, is the production from a fish stock beyond the required to replace losses due to natural mortality (Quinn and Deriso, 1999). To do this, I relied on data from the PANGAS Project, an organization that acquired monitoring data for rocky reef fishes during cruises in 2007, 2010 and 2011. In addition, I used the intrinsic growth rate (r) and carrying capacity (K) of each species in order to calculate the surplus biomass production (Octavio Aburto Oropeza, unpublished data).

2.1 Component A – Fishing effort

The CONAPESCA database and the publication of Moreno et al. (2012) were the main sources of information to calculate annual harvest rates catch harvested in the fishing grounds of each species in the NGC.

2.1.1 Fishing areas by community

The data from Moreno-Baez et al. (2012) provides a regional-scale resolution of the fishing activity related to 43 different commercial species in 17 main coastal communities in the NGC. Data collection were obtained through interviews conducted with fishermen in 2005 and 2006, to obtain fishers local knowledge. For this particular project, information about two species *M. rosacea* and *B. polylepis* were utilized from Moreno-Baez et al. publication (Figures 1 and 2). The information generated by

Moreno-Báez et al. (2012) only describe the area covered by a particular fishery related to a particular species.

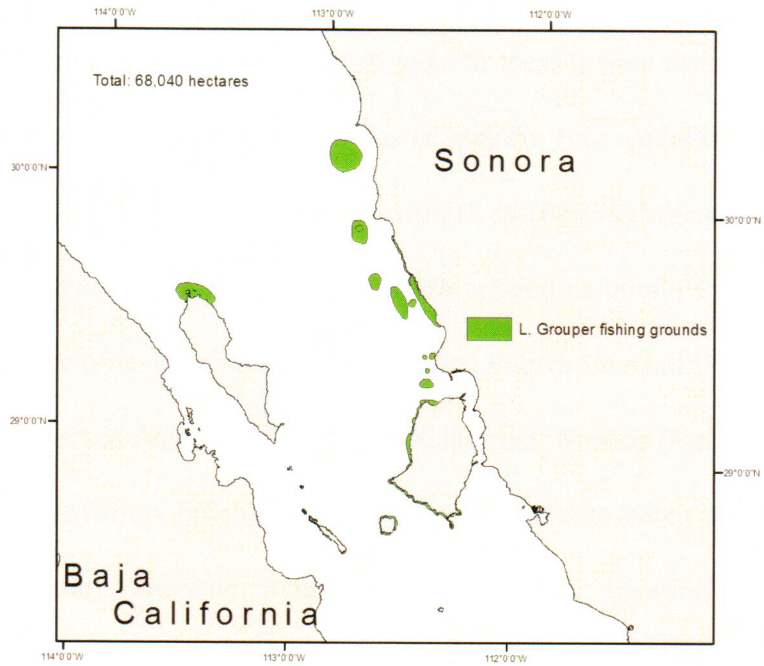

Figure 1. The map shows leopard grouper fishing grounds, representing a total of 68,040 hectares.

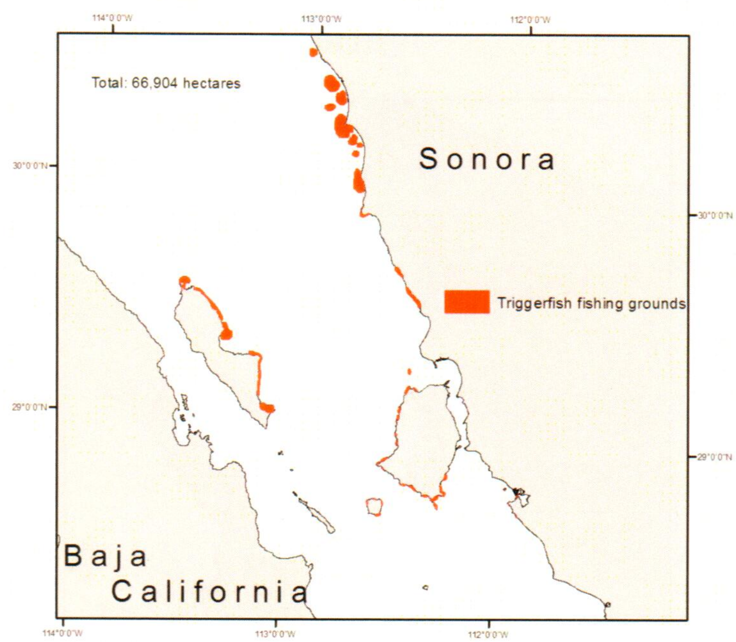

Figure 2. The map shows the fishing grounds of triggerfish, representing a total of 66, 904 hectares.

2.1.2 CONAPESCA Database

Landing databases provided from CONAPESCA supply information on the total volume (kg) of fish landed and reported each year to local fishery offices located in major ports and important fishing communities in Mexico. Nine years of data (2001-2009) were analyzed in order to obtain the annual catches registered in different offices. For the purpose of this study, queries were applied to obtain the landings of three different fishery offices: Bahia de Kino (BKI) and Puerto Libertad (PLI) in Sonora, Mexico, and Bahia de Los Angeles (BLA) in Baja California, Mexico (Figure 3). Puerto Peñasco and Guaymas fishery offices were excluded from this research because much of their landings reports are from industrial fishermen (i.e., trawling fisheries). In addition, fishing practices in this community cover large extensions throughout the Gulf of California, resulting that landings from this office are only partially comprised of fishing grounds in the NGC (Erisman et al. 2011).

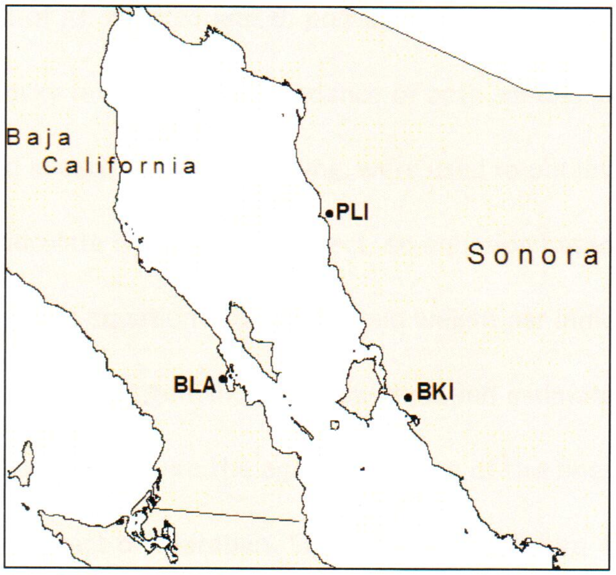

Figure 3: Three Local Fishery Offices of which the landings were included in this research. BLA: Bahia de los Angeles; PLI: Puerto Libertad and BKI: Bahia de Kino.

2.2 Component B – Surplus biomass production

2.2.1 Subtidal Monitoring Data

PANGAS has completed multiple cruises across the NGC to do a subtidal monitoring with the objective to measure the biodiversity of the place. Among other census, they conduct a fish monitoring where they capture abundance and length per individual. They use the subtidal sampling protocols of The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), in which a total of 48 transects is performed at each site: 24 transects on the bottom and 24 transects in mid water; six transects in each four different depths (5, 10, 15 and 20 m). For each transect, two divers swim 30 m, the first diver in the bottom and the second diver in mid water, meters above the first diver. They record each individual fish present within one meter to the right and one meter to the left of the transect (1440 square meters in total).

For this study, I focused only in transects performed on the bottom, to obtain a more accurate biomass of *M. rosacea* and *B. polylepis,* since mid-water transects are not representative of rocky reef fish. The abundance of both species and the length of the individual registered in each subtidal sampling, were used to obtain the SCB.

As a means to calculate the SCB per transect, an equation based on the relation length-weight was used. This equation allows to obtain weight per individual present in each transect. To do this with triggerfish, I used the equation estimated in Ithandehui Barroso-Soto et. (2007) use to acquire the age and growth of the finescale triggerfish, *Balistes polylepis* on the coast of Mazatlán, Sinaloa, Mexico (Figure 4A). For leopard grouper, we design an equation from a biological monitoring database of Comunidad y

Biodiversidad A.C.[2];, where species were sampled in order to obtain the biological characteristics for a study is being performed by PANGAS and SCRIPPS Institution of Oceanography (SIO). The equation was created with relationship between length and weight of 354 the leopard grouper samples (Figure 4B).

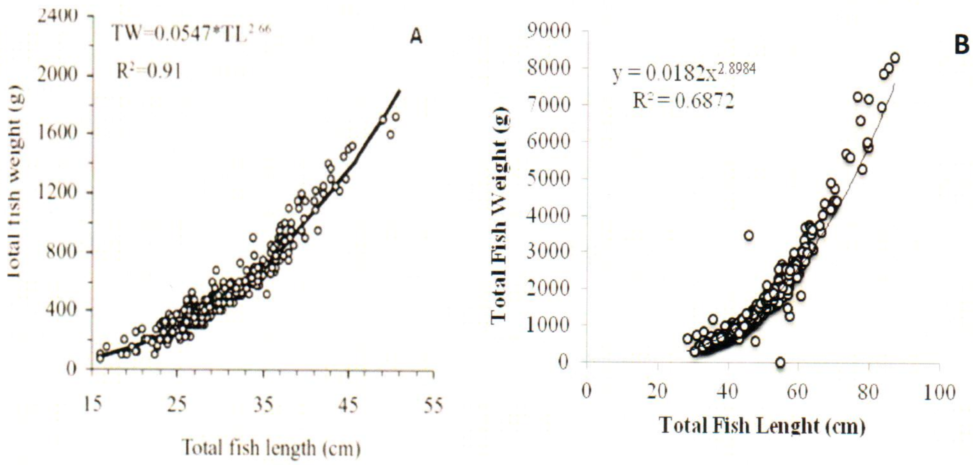

Figure 4. Relation weight-length utilized to obtain the equation in order to calculate the weight needed to calculate the biomass. A) The graph on the left indicates the equation to calculate triggerfish weight, obtained from Ithandehui Barroso-Soto et al., 2007. On the other hand, graph B) represents the equation for leopard grouper, created by doing the relation weight-length of 354 samples of *M. rosacea*. Data acquired from COBI biological monitoring.

After each individual weight was obtained, the SCB estimations were calculated with the average weight and abundance per transect, multiplying the abundance with the average weight, and the result was divided by 60 m^2, which is the total area sampled in a transect. Having the results of SCB per transect in grams per square meter, a conversion was implemented in order to obtain SCB in tons per hectares. Results were obtained using the average of SCB per transect, calculated in tons per hectares per site by year (2007, 2011 and 2012).

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[2] Comunidad y Biodiversidad A. C. (COBI) is a nongovernmental organization located in northwestern Mexico and the Mexican Caribbean. This NGO is part of the PANGAS consortium. www.cobi.org.mx .

Next, the surplus biomass production per species were calculated, using the following formula: Surplus production = r* SCB * (1- (SCB/K)), where r is equal to the intrinsic growth rate, K represents the carrying capacity of each species and SCB was already calculated from PANGAS subtidal monitoring databases.

Intrinsic growth rate (r) values for both species were provided by Octavio Aburto-Oropeza from SIO (unpublished data) and Carrying capacity (K) was obtained using the Biomass from the pier in the community of Puerto Libertad. This site has been closed to fishing for approximately 15 years, by national security due its closeness to a power plant managed by the Federal Electricity Commission (CFE). Due to this management measure, the place increased its biomass and it is believed that the pier is closer to represent a pristine site.

Species	Growth rate	Carrying capacity (ton/ha)
Mycteroperca rosacea	0.31	1.81
Balistes polylepis	0.08	1.11

Table 1. Intrinsic growth rate and carrying capacity of both species.

The surplus biomass production was calculated with the average SCB per site, as long as with K and r for each species. Afterwards, an average surplus biomass production per each year (2007, 2010 and 2011) was obtained. In addition, the standard deviation and the error for each year estimations were calculated.

2.3 Comparison

A comparison of results from the nine years annual catch (CONAPESCA database, 2001-2009) and the average surplus biomass for three years (PANGAS databases 2007, 2010 and 2011), to analyze whether the harvest was higher or lower than the surplus biomass produced. The evaluation consisted in measure against the average kilos harvested in the nine years with the average kilograms of surplus biomass of the three years of calculation.

In order to normalize the data, the units of both components A and B had to be equal, reason why the surplus biomass estimations calculated (kg/ha) were multiplied by the total hectares of the fishing grounds of each species (Figure 1 and 2). This allowed to obtain the amount of kilos per area.

3. Results

The analysis for triggerfish showed that 2007 presents the highest SCB with 0.0083 tons per hectares, followed by 2010 with a standing crop biomass of 0.0069 tons per hectares (Figure 5A). The analysis of average surplus biomass production of such species demonstrated as well that 2007 was the year when the highest amount of kilos were produced (0.066 kilos per hectare), while in 2010, a total of 0.055 kilos of triggerfish per hectares were produced. Lastly in 2011 only 0.039 kg per hectares of surplus biomass production was generated (Figure 5B).

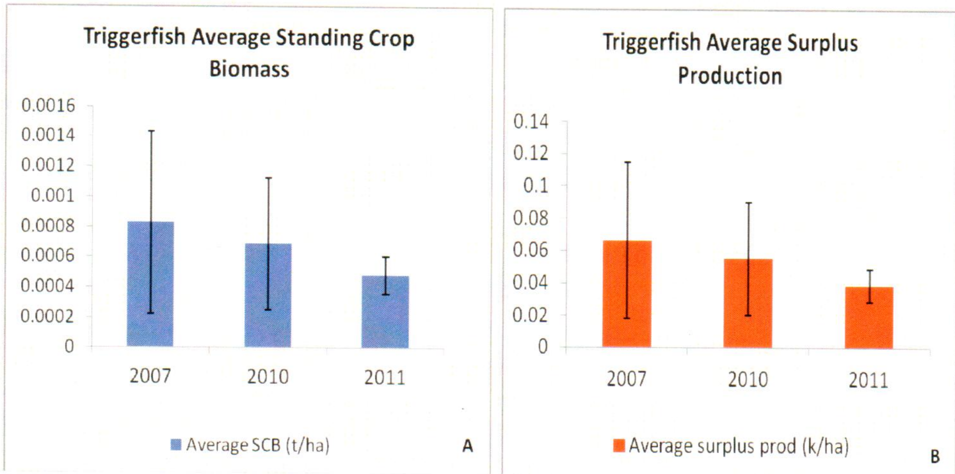

Figure 5. Triggerfish (*B. polylepis*) calculations of A) SCB in tons per hectares present in each year, and B) Surplus Biomass production in kilograms per hectares.

Calculations of leopard grouper demonstrated that 2010 was the year with higher SCB (0.0031 ton/ha) and surplus production (0.96 kg/ha) as well. Year of 2007 was the following year, where a total of 0.0019 tons per hectares of SCB were present, and the surplus biomass produced was 0.58 kilograms per hectares. Then again, 2011 was the year with the lowest SCB of leopard grouper present in the NGC (0.0011 tons/ha) and only 0.35 kilograms per hectare were the surplus production of such area (Figure 6).

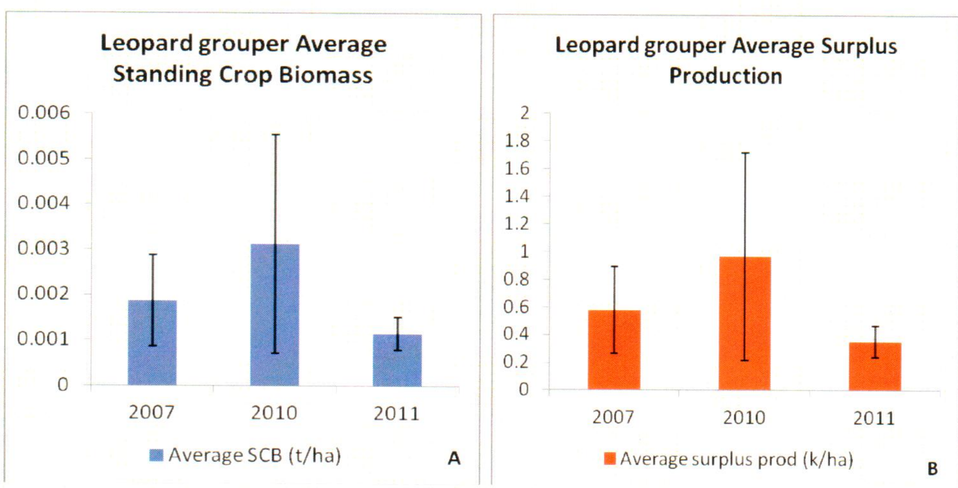

Figure 6. Leopard grouper (*M. rosacea*) calculations of A) SCB in tons per hectares present in each year, and B) Surplus Biomass production in kilograms per hectares.

The analysis of triggerfish landings registered in the three different offices (BLA, PLI and BKI) demonstrated that from the nine years, 2003 was the year with the highest amount of triggerfish harvested with a total of 91.7 tons landed. In addition, figure 7 shows that since 2004 the annual catch has been decreasing, 2009 being the year with the lowest catch amount, representing only 20.2 of tons triggerfish harvested.

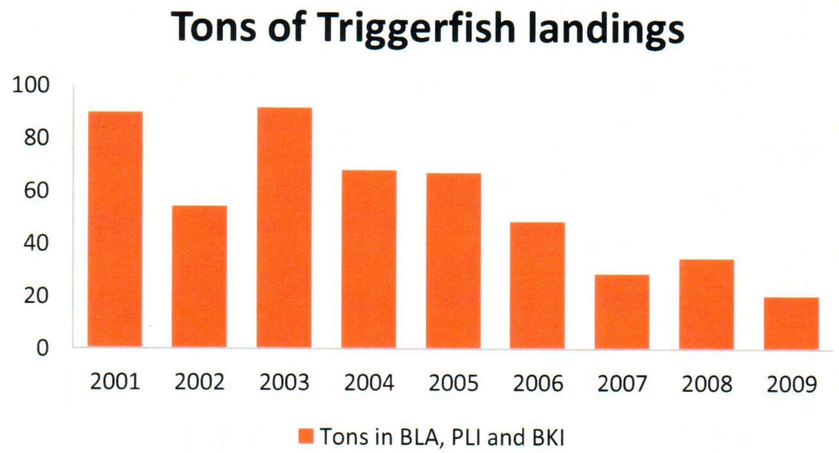

Figure 7. Catches per year of Triggerfish in the NGC registered in Bahia de los Angeles, Puerto Libertad and Bahia de Kino fishery offices.

Contrarily, the analysis of annual catches of leopard grouper showed that the catch amount has been increasing since 2005, where 2009 was the year with the highest amount harvested (230.9 tons) and the year with the lowest amount caught was 2003, where they fished only 70.6 tons (Figure 8).

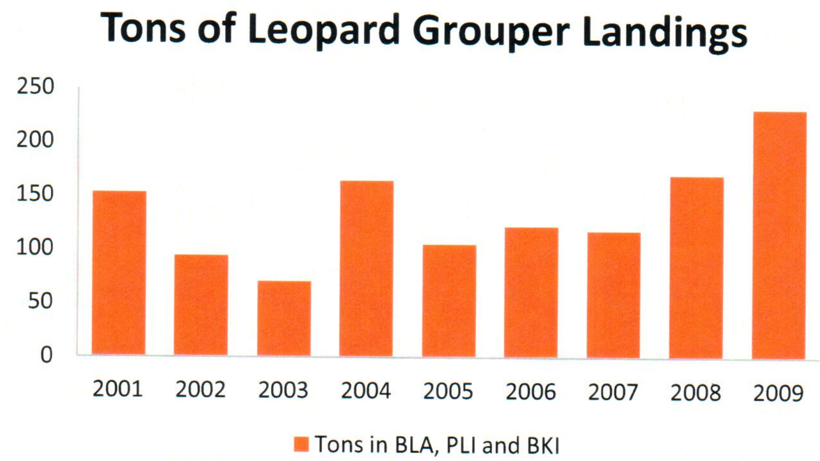

Figure 8. Catches per year of Leopard grouper in the NGC registered in Bahia de los Angeles, Puerto Libertad and Bahia de Kino fishery offices.

The comparison between the average surplus biomass production of the three years (2007, 2010 and 2011) and the average catch of the nine years of CONAPESCA (2001-2009) showed that triggerfish average surplus production (3,631 kilograms) was lower than the average catch per year registered in the three different offices (55,852 kilograms). Similarly, Figure 9 demonstrates that the average catch amount per year of leopard grouper landed in the fishery offices (136,105 kg) was higher than the average surplus biomass (43, 084 kg).

The results of this research reveal that high level of overexploitation is taking place in both fisheries. The calculations of the ratio of average surplus production versus average fishing landings demonstrate that in triggerfish fishery, shows that the harvested amount is 15 times higher than the surplus biomass being produced, and as well in leopard grouper fishery, the average catch amount of the nine years of analysis is three times higher than the average amount of fish produced.

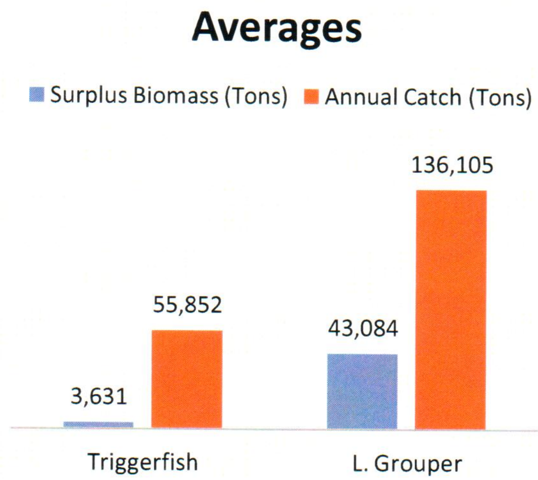

Figure 9. Comparison of average kilograms of surplus biomass produced in three years of sampling (2007, 2010 and 2011) with average kilograms per year harvested in the nine years of CONAPESCA databases (2011-2009) of Triggerfish and L. grouper.

4. Discussion

The results of the analysis of SCB and surplus biomass production demonstrated that triggerfish average SCB and average surplus biomass production are falling over the years, since both indicators have decreased 58% in 2009 compared to 2007 (Figure 5). In the other hand, leopard grouper does not present such trend, with the highest SCB and surplus biomass production average was in 2010, but still 2011 is the year with the lowest SCB and surplus biomass production, being 60% lower than 2007 (Figure 6).

Regarding to the catches per year in the nine years, triggerfish landings over the years demonstrates that the fishery effort presents a decreasing tendency. A reason for this could be because, as stated in figure 5, the surplus biomass production of this species is decreasing as well; and anecdotally, it is known that over the years, fishermen of the NGC are having more trouble in finding the fish. In the other hand, leopard grouper presents the contrary tendency where the amount of fish harvested is increasing, meaning that the leopard grouper fishery is growing as well.

Moreover, the results of average comparison analysis demonstrated that the amount of tons harvested in both species is higher than the amount of tons of surplus biomass produced; this confirms the suspicion that both species are being exploited in a non sustainable mode.

The question that arises after analyzing the results of this research is if the species are being exploited in such high level, and surplus biomass production is significantly low compared to the harvest, why the fisheries have not collapsed yet? One of the reasons could be because the NGC is not necessarily a closed system, it has been demonstrated in different publications that the recruitment of the area is not local, but is an open system where the recruitment comes from the outside (Cudney-Bueno et al. 2009; Soria, 2011; Marinone, 2012). This means that the area is nurtured with recruitment from the Central and Southern Gulf of California, this helped with the currents.

Another factor that requires acknowledgement is the application of an equilibrium-based model. Natural populations that are harvested rarely appear to be in equilibrium. By definition, the rate of change of a population with respect to time at equilibrium is zero, so that the yield from the fishery exactly equals the population growth due to recruitment, growth of individual fish, and natural mortality (Jensen 1984). Equilibrium surplus production models assume that for each level of fishing, there is an equilibrium sustainable yield and the stock is assumed to be at some equilibrium level of biomass producing a certain quantity of surplus production (Haddon 2001, Quinn and Deriso 1999). Yield is always assumed to be surplus production from a population in equilibrium. Changes in fishing regimes, whether due to environmental factors or harvest strategies, immediately lead to a different stable biomass with its associated surplus production. This assumption ignores the difference in standing crop between the two different biomass levels and the transition time as the system responds to new conditions. Parameters are constant in time, whereas the environment in which the population is found is constantly changing, so that model parameters may in reality be a function of environmental variables.

Aburto-Oropeza et al. (2010) illustrates the impact of environment on the equilibrium assumption. He shows that fisheries landings of reef fish in the Gulf of California are related to climatic conditions that occurred at the time of settlement, in which recruitment appeared to be modulated by El Niño/La Niña events. This demonstrates that fish dynamics are inherently non-equilibrium because the environmental factors are part of the systems.

The estimation method for the surplus production model in this analysis assumes an equilibrium stock-production relationship. Estimation using equilibrium methods when using surplus production models consistently overestimates the sustainable yield of a fish stock that is in decline (Haddon 2001). A number of estimation strategies have been derived to handle non-equilibrium conditions (Quinn and Deriso 1999, Haddon 2001), but these strategies are beyond the scope of this paper.

Equilibrium based models have been used to manage fisheries in the past, and the results usually have not been successful. Although this research should not be used to decide the management of fisheries, this study was conducted in order gain understanding of the fisheries dynamics of the NGC.

As mentioned before, one of the probable reasons why the fisheries have not collapsed is the spillover and regional recruitment, and these factors help the NGC to recover from the overfishing. But it is hard to predict how long the system would linger if the level of exploitation do not drop, because it is noticeable that the SCB is already decreasing (Figures 5A and 6A). In addition, it is possible that environmental factors could affect the fish dynamics; an example of this is in years with El Niño phenomenon, when the water gets warmer and affects decreasing the nutrient concentrations in seawater, therefore, algal growth decreases as well and this result in a consequent decrease in leopard grouper recruitment (Aburto-Oropeza et al. 2010).

If levels of harvest remain at the same level of unsustainable exploitation, there is not much buffer left to the fish stocks to recover; in addition, there could be an environmental effect resulting in bad years for the fishery (i.e. long period of El Niño years, affecting the recruitment of leopard grouper directly) it is possible that the recovering of such species becomes low or absent, damaging the fish stock dynamics.

5. Conclusions

This study concludes that fisheries of triggerfish and leopard grouper in the NGC are being over exploited and may be leading to extinction if changes are not implemented in actual fisheries management. Alternatives to Fishery Permit program must take place in the Gulf of California, where catch limits, catch shares, season closures among other restrictions could mitigate the problem. Likewise, there must be an improvement in enforcing the law, while in Mexico there exists a lack of enforcement and high illegal fishing take place, and such harvest is not recorded in CONAPESCA landing databases.

May exist information bias due data limitations (i.e. CONAPESCA databases) but best available science was used to estimate a better proxy of the fisheries situation in the NGC. Moreover, in this study we tried to break down the fisheries of these two species in a simpler way, converting it from a giant scale to a smaller scale, in order to gain a better understanding of the fisheries dynamics. For further evaluations of fisheries, a more accurate model must be implemented, meaning that it would be more precise to implement a non equilibrium model.

Even though, this study could be representing a good guess of the harvest-production relationship, alternatives must be implemented in order to obtain a trustworthier analysis. For instance, while the databases from CONAPESCA might not very accurate due the information bias, we should find another way to try to measure the fishing effort. One example of this could be the Bitacoras project that PANGAS is implementing in the Northern Gulf of California, where fishermen through fishery diaries record how much they fish, where they fish, target species and by-catch, among other significant information. It was not possible to utilize this data source for this study because even though Bitacoras project is well developed in Bahia de Kino, it is not as well implemented in other communities as Puerto Peñasco and Puerto Libertad, reason why this could be a poor representation of the fishing effort of the NGC are.

Investing in obtaining better science and information should lead to a better approach of the real situation regarding fisheries in the Gulf of California, and with a better understanding and knowledge is easier to achieve sustainability and better management of the resources.

6. Acknowledgments

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