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Fisheries Potential of the Gulf of Mexico

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Abstract
In the Gulf of Mexico with an area of 1,600,000 km2, American and Mexican fleets exploit about 535,000 tons. From these, a harvest of nearly 500,000 tons belongs to the Gulf menhaden. In recent years, mud feeders fish like mullets, increased their presence in catch records, suggesting a bottom-up process in the trophic web. By comparing catch records from the northern and southern Gulf of México, it was assumedanunexploited biomass of the Gulf menhaden or other similar sardine-like stock,suggestingthat a significant harvest could be obtained in the southern portion. A difference in Cla of an order of magnitude higher in the northern Gulf than in the southern Gulf, explains the differences. A significant correlation between the Cla concentration and fish production was found, being stronger in the northern Gulf, where it was straight, as compared to the southern Gulf, where the correlation was lower and it was found with one year-delay. In addition, it seems that in the northern Gulf, theGulf menhaden stock has been under a chronic over exploitation of juveniles; in this case, the perspective suggests that yield may double by opening the mesh to the suitable size,restoring the harvest levels once exploited.

Key words: Fisheries; potential production; Gulf menhaden; Cla; stock assessment

Introduction
Fish production worldwide has been of major concern for several decades [19, 17, 23, 24, 15]. Estimates of the world harvest has decreased from more than 150 Million (M) tons recorded nearly fifty years agoto somewhat more than 90 M tons nowadays [19, 17]. This decline isconsequence of over exploitation in most cases [20] and the prevalence of economic interests driving the fisheries development(14). The excess in fishing effort and fishing capacity has left most world oceans with low perspective of further development, as evidenced in recent overviews [19, 3, 4].

Nearly seventy stocks are included in catch records of the Gulf of Mexico (GoM) waters of the US and Mexico. Total catch amounts to 535,000 tons, whose relative production is 0.333 tons per km^2. From this volume, at least 90% belongs to a single stock, the Gulf menhaden [3], despite it was suggested that a "dead zone" without oxygen may constrain marine production [8, 13]. Apart from this species, the remaining volume is exploited by the US and Mexican fleets in proportion of 2 to 7 respectively. The Gulf menhaden fishery provides job to more than 500 fishers and the economic activity has profits higher than $12 Million. Unfortunately, recent catch displays a declining trend [3, 4, 29], whose maximum level, roughly equivalent to the maximum yield (MSY), was estimated in 800,000 tons [4], attained in the middle eighties. Catch production of Cuba,whose mean catch amounts to 14,400 tons, was deliberately ignored from this analysis by assuming that the strength of the Yucatan current imposes a barrier, constraining the free exchange of biomass of most stocks between the GoM and Cuban waters, whose insularity also contributes to a critical decliningtrend of 88 percent of its catches [12, 5].

Background
In apreviousanalysis of the fisheries of the GoM [4], striking differences in yields of the southern and northern regionsare evident, stimulating the interest to explore fish production in more detail in order to find an explanation to these differences. The catch landings of the Gulf menhadenattained up to nearly one million tons in the years 1983 and 1984 (with 963,000 and 985,000 tons) and a significant decline to only 487,000 tons (mean for the years 2000-2009) as a probable consequence of over exploitation of juveniles. Its current catch still represents a huge proportion as compared to the remaining exploited stocks of both north and south GoM waters. A MSY of around 830,000 t was estimated by Sedar [27], with a stock biomass of over 5 M tons in 2015 [14].

Methods
With the intention to proceed accordingly, foursteps of the analysis were followed, starting with ananalysis of the current yield, based on the catch statistics from FAO and NOAA since the year 1950. Secondly, a comparison of yield from the southern GoMin reference to mean catch per unit area of the northern GoM, assuming the same density in north and south. The third step of the analysis was the estimation of the yield in reference to the catch of the gulf menhaden in the northern GoM, which does not appear in FAO catch statistics for Mexico nor the Caribbean countries.

Cla as the basis of trophic web. For some time, it is known that in fish species low in the trophic web, there is a close relationship between fish biomass and Cla as food source [11, 25, 9], so this relationship was explored by evaluating the Cla density and fish production. In first place, a series of 121 satellite images, eleven per year, were analyzed from the years

2002 to 2012 for the Cla concentration over the northern GoM and another 121 images were analyzed for the southern Gulf. In the northern Gulf, these images were composed of the SeaWiFS, MODIS, Aqua/Terra, and MERIS sensors, with a spatial resolution of 1.1 Km at the nadir, provided by the Scripps Institution of Oceanography in hierarchical data format (HDF). These images were analyzed aided with the software Windows Image Manager [18], obtaining inter annual averages in order to detect variations in the study period, showing years with higher and lower concentration with quite regular seasonal variability.

Potential yield in reference to mean catch per unit area. An estimation of the biomass of all of the exploited stocks of the Gulf of Mexico suggests a stock biomass of 1.6 M tons at the MSY level, and the MSY = 800,000 tons [3, 4]. By comparing the catch of the northern and southern GoM, apart from the Gulf Menhaden, it is remarkable to realize that the economic exclusive zone of the north GoM comprises an area of 770,540 km^2 and in the south GoM occupies 829,540 km^2 (including the shelf on the Caribbean side, Table 1). The catch volume of 65 stocks caught in the north GoM amounts to 17,400 tons (the mean for the years 2000-2009). On the Mexican side, the mean catch for the same period amounts to 92,400 tons, including records of 74 stocks. The comparison of relative yield of each zone shows that by considering all of the exploited stocks, the yield of the northern GoM is 0.65 ton.Km^{-2}, six times higher than the southern GoM. If the catch of the Gulf menhaden is not considered, then the yield is only 0.02 ton.Km^{-2}, as compared to the southern GoM, with 0.11ton.Km^{-2}. A way to tackle the problem was by developing a function of the catch as a variable depending on the primary production, evaluated after monthly satellite images for a 12-year period.

Table 1. Yield of the exploited stocks of the Gulf of Mexico (average for the years 2000-2009, t, in reference to the Economic Exclusive Zone (EEZ).

GoM		Other		Yield (t/km^2)	
EEZ	Area (Km^2)	menhaden	stocks	w menhaden	w´t menhaden
N GoM	770,540	487,000	17,400	0.65	0.02
S GoM	829,540	0	92,400	0.11	0.11
Total	1,600,080	487,000	109,800	0.37	0.07

Results

Current yield.Source data proceed from the catch statistics from FAO [12, 29]. Catch records over a series of sixty years, provided the first approach to diagnose trends and to detect the main characteristics of fish production in the southern and northern GoM. An estimation of harvest equivalent to the Maximum Sustainable Yield (MSY) was previously made [3]. The trend line of a second-degree regression suggests that the MSY = 800,000 tons, was attained in the middle eighties. Afterwards, a clear consistent decline trend indicatesthat the Gulf menhaden yields amount to near 500,000 tons in 2010, with a recent increase in the biomass of two-year old fish in 2015, probably implying the use of larger mesh openings by part of the fleet.

Two striking facts are remarkable and deserve tomention. In first place, by looking at the whole catch data records, the real number of species is higher than the stocks recorded which in many cases a given common name includes several species. Theserecords including all the exploited stocks, suggest a deficit of almost 412,000 tons on the Mexican side (Fig. 1). A former estimation of the maximum yield of the GoM, also including all of the exploited stocks, suggests a MSY of almost 800,000 tons[4]. This figure exceeds in nearly 300,000 tons the recent catch records, but it isabout 400,000 tons lower than the years when the gulf menhaden catch was in its highest level.

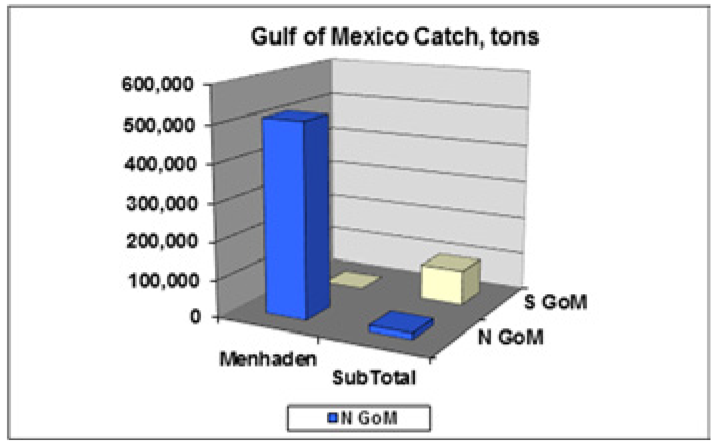

Figure 1: Total fish production of the north and south Gulf of Mexico, according to FAO fisheries statistics.

The huge catch of Gulf Menhaden (BrevoortiapatronusGoode) deserves special consideration, as compared to other exploited stocks, which in 1983 and 1984 attained a catch of almost one million tons. Afterwards, it was followed by a 50% decline, caused by an apparent overexploitation of recruits, despite an accurate assessment recently made [14, 25, 29]. The fishery could restore its high levels of biomass as long as the age of first catch increases to the age of first maturity in first place, and afterwards to a probable increase in the fishing mortality. To evidence the suggestion that potential yield and potential biomass can be doubled also as a function of F, but caught at tc as maturity age, the potential current yield and stock biomass as a function of fishing mortality (F), was estimatedthrough the application of a simulation age-structured simulation model [25, 26, 6] and is shown in Fig. 2.

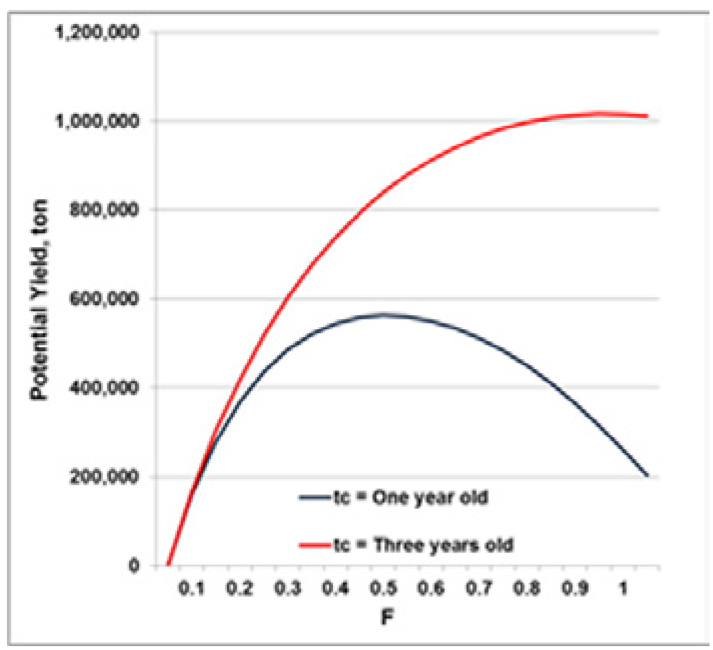

Figure 2: Potential yield and stock biomass of the Gulf menhaden as a function of F. The lower line corresponds to tc = 1, the upper line describes the yield if tc = 3 is adopted [6].

Harvest and Cla.T he overall mean Cla value found was 4.0185 mg/m3; in the southern Gulf, the average was 0.4679 mg/m3. The eleven-year trend of monthly average Cla values in the north and south GoM is displayed in Fig. 3, showing a strong seasonality in both cases, and evidencing significant differences of one order of magnitude, being higher in the north GoM than in the south GoM, which is remarkable. This explains with no doubt, why the northern Gulf is capable to withstand up to one million tons more than the fish production in the southern Gulf. Evidently, the gulf menhaden takes advantage of this surplus productivity exploiting food resources low in the food chain filtering phytoplankton, zooplankton, and detritus [11, 21].

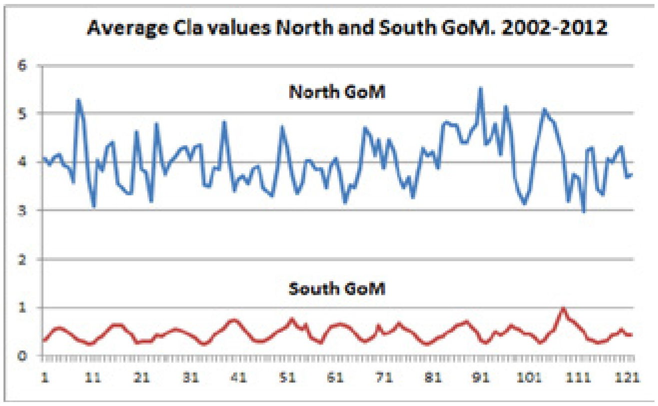

Figure 3: Eleven-year trend of average monthly Cla values in the north and south GoM showing a strong seasonality in both cases.

In addition, we found significant correlations between mean values for each year of Cla as independent variable and the catch; in the northern Gulf, correlation with one-year delay of catch respecting to the Cla was higher (Fig. 4A). In the southern Gulf,the correlation of catch and Clawas found for the same year, although it was not as high as in the former case (Fig. 4B).

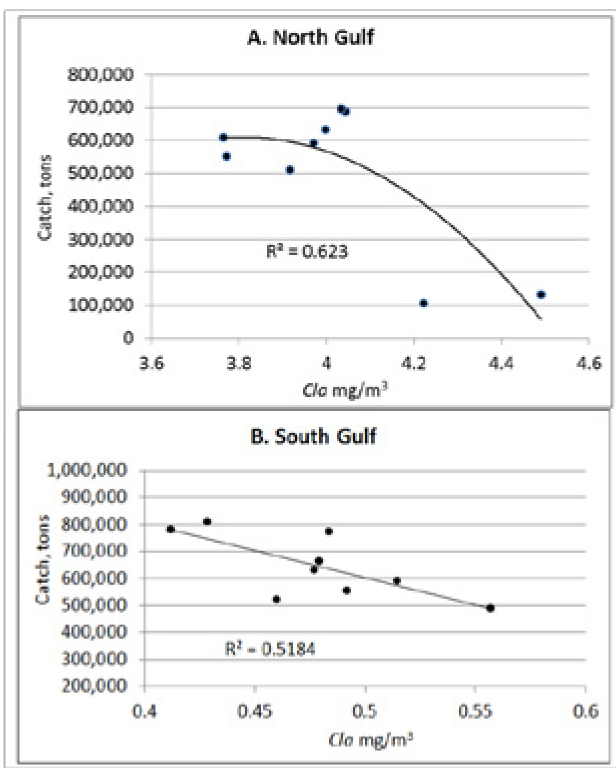

Figure 4: Catch and Cla correlation at, A. The northern GoM, where a second degree equation was fitted to catch data with one-year delay, showing a significant correlation; B. Significant linear correlation fitted to data of the southern GoM with no time delay.

Discussion

Initial indirect evidence suggested that there was a significant amount of unexploited biomass in the southern GoM, leading to an unexpected and optimistic wrong perspective of fisheries development of the southern GoM. We found that catch records involve just a certain proportion of the total number of species, and this is more evident with the records of tropical fisheries. However, the most abundant species are well represented, and statistics provide a useful guideline for an initial diagnosis of the status of the main fisheries [22]. Finally, as a final corollary, the use of Cla values extracted from satellite images, and their correlations with fish production, provided the evidence that they are good indicators of the fisheries potential of the GoM, confirming what has been found elsewhere [20, 16, 9].

Conclusions

- The fisheries of the GoMareexploited to their maximum capacity.
- A small proportion of stocks still withstand further catch increase, but their contribution to the overall yield is not significant.
- The Gulf menhaden is the most abundant stock of all other exploited fisheries in the GoM, representing>90% of total catch.
- It was detectedoverexploitation of juveniles of the Gulf menhaden keeping the stock in a steady state.Therefore, with the current age of first catch of one-year-old fish (12 cm), the MSYwould be 562,000 tons.
- If mesh size age is changed to increase the age of first catch from one year-old fish (12 cm)to 3 years (19 cm), the age of first maturity, then potential yields are expected to reach a little more than one million ton, equivalent to the Gulf menhaden catch landed during the middle eighties.
- Anearly assumption that this or a similar species may remain unexploited in the southern GoM, is wrong.
- There is a significant difference in Claan order of magnitude higher in north GoM respecting to the south GoM, explaining without any doubt, why fishing yields in the north GoMaresix times higher than in the south GoM.
- The use of Cla data in a geographic scale provides unequivocal reference for an estimation of the potential fisheries development, in particular when sardine-like stocks support them.

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Author contributions

E.A.Ch. conceptualized the idea of this paper and carried on the stock assesment and simulation. A.Ch. organized the catch data bases and reviewed the early versions of the manuscript. E.P.L. downloaded and analyzed the satellite images and estimated the Cla data.

Competing interests

The authors declare no competing interests.

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