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Article

Evaluation of Cuban oyster resource status (*Crassostrea* spp.) and reference points for its management

Evaluación del estado del recurso ostra (*Crassostrea* spp.) en Cuba y estimación de puntos de referencia para su manejo

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Resumen.- En Cuba, la ostra *Crassostrea* spp. es el molusco bivalvo de mayor volumen comercial. La evaluación de sus poblaciones es necesaria para su manejo y conservación, pero se ha realizado con diferentes metodologías y solo en localidades puntuales, lo que dificulta su evaluación y comparación entre periodos y regiones. Por lo tanto, se determinó el estado actual del recurso según el rendimiento máximo sostenible (MSY), biomasa para el rendimiento máximo sostenible (B_{MSY}) y la tasa de mortalidad por la pesca (F_{MSY}) correspondiente. Se aplicó el modelo CMSY con método de Monte Carlo, y se evaluó la biomasa y la explotación del recurso para las regiones noroeste (NW), noreste (NE), sureste (SE) y suroeste (SW) de la plataforma insular, así como por periodos (1960-1991 y 1992-2020). Durante 1992-2020 se registró una reducción del 50% en los desembarques de ostras respecto al periodo 1960-1991, lo que se reflejó en los indicadores poblacionales según los puntos de referencia evaluados. De acuerdo con el modelo y método aplicados, la gestión pesquera actual de la ostra se percibe no-sostenible, con agotamiento del stock y sobrepesca en las regiones NW, NE y SW. La región SE del país presenta un estado más favorable. Se sugiere incrementar la ostricultura para obtener mayor producción y biomasa de reproductores para disminuir el esfuerzo de pesca sobre las poblaciones silvestres.

Palabras clave: Producción de ostra, gestión pesquera, modelo CMSY

Abstract.- Oyster *Crassostrea* spp. is the bivalve mollusk with the largest commercial volume in Cuba. Populations should be assessed for their management and conservation, which has been performed but with different methodologies and only in certain localities, making it difficult to evaluate and compare between periods and regions. Therefore, current state of the resource was to be determined according to maximum sustainable yield (MSY), biomass for the maximum sustainable yield (B_{MSY}), and corresponding fishing mortality rate (F_{MSY}). Catch Maximum Sustainable Yield (CMSY) model was applied with Monte Carlo method, resource biomass and exploitation were evaluated for northwestern (NW), northeastern (NE), southeastern (SE), and southwestern (SW) regions of the insular platform, as well as for periods (1960-1991 and 1992-2020). From 1992-2020, a 50% reduction in oyster landings was recorded when compared with 1960-1991 period, which was reflected in population indicators according to estimated fishery reference points. Based on applied model and method, current oyster fishery management is perceived as unsustainable with stock depletion and overfishing in NW, NE, and SW regions. Cuban SE region shows a more favorable status. Oyster farming should increase to obtain higher production and broodstock biomass to decrease fishing effort on wild populations.

Key words: Oyster production, fishery management, CMSY model

Introduction

Cuba has recorded the natural presence and commercial catch of two Ostreidae species – Antillean mangrove oyster *Crassostrea rhizophorae*, Guilding, (1828) and American oyster *Crassostrea virginica*, Gmelin, (1791), locally known as “bottom oyster” (Betanzos-Vega *et al*. 2018a). Mangrove oyster *C. rhizophorae* is the species with the broadest distribution and abundance, contributing to more than 70% of oyster production (Mazón-Suástegui *et al*. 2019). *C. virginica* has been included in commercial landings since 2007 after discovering natural banks in two hydrographic basins at southern Cuba, which contribute 25-30% of the total annual oyster production (Betanzos-Vega *et al*. 2018a).

Oyster marketing in Cuba is limited to specific domestic market niches. Great annual landings (> 2,000 t) and meat yield (10-14%) occurred before 1990, in part due to oyster farming (Frías & Rodríguez 1991, Buesa 1997). Current production is about 1,200 t in annual oyster-in- shell landings, with average meat yield from 5 to 8% (Betanzos-Vega *et al*. 2018b).

In Cuba, oyster fishery statistics are not differentiated according to production (extractive and culture fishery), but it is known that 80% of the national production came from wild populations and 20% from oyster farming from 2016 to 2020 (Betanzos-Vega *et al*. 2021). Oyster farming is performed with *C. rhizophorae*, starting from natural medium pediveliger larval fixation in collectors mainly made with mangrove branches. All the rearing process up to harvest is performed in palisade farms adjacent to natural banks (Betanzos-Vega *et al*. 2014, Mazón-Suástegui *et al*. 2017). This rearing technique is considered 100% artisanal, and its methodology imitates mangrove oyster natural life cycle, which is why biomass in culture is considered to contribute to restoration of wild populations. Thus, both biomasses complement themselves during the reproduction process contributing larvae to the natural environment (Betanzos-Vega *et al*. 2021).

Biomass or productivity studies per area for both species (*Crassostrea* spp.) in Cuba have been performed in particular localities, not always during the same time period nor using the same methodologies (Buesa 1997, Betanzos-Vega *et al.* 2018a, 2020), which makes analyses and comparisons between periods and regions difficult. Additionally, oyster production is not managed similarly in all Cuban regions, thus, available data related to this fishery is insufficient to apply traditional fishery evaluation models (Betanzos-Vega *et al*. 2018a). According to different criteria, fishery reference points can be applied, such as gross catch and productivity to estimate biomass and maximum sustainable yield (MSY) (Martell & Froese 2013), because a temporal catch series can be seen as a sequence of yields produced by the available biomass in relation to productivity (Hilborn & Stokes 2010, Froese *et al.* 2017).

Therefore, the objective of this study was to evaluate oyster resource status by regions of the Cuban insular platform, according to time periods with greater and lesser annual landings, making emphasis on the current stock status by determining relative biomass and annual exploitation rate, and the prediction of the maximum sustainable yield (MSY). Results may be important not only in terms of resource assessment but also to promote sustainable fishery management.

Materials and methods

Description of the study area

Cuban archipelago is located in the Greater Antilles at the Gulf of Mexico entrance, which includes Isla de Cuba, Isla de la Juventud, and more than 1,600 keys, islets and islands. The Northern and Southern Isla de Cuba coasts have a length of 3,208 and 2,537 km, respectively, and the insular platform is divided into four regions with depths lower than 50 m (ACC 1989). In northwestern (NW), northeastern (NE), southeastern (SE), and southwestern (SW) regions, coastal water bodies are influenced by fresh water thus having estuarine characteristics, these is where natural oyster beds are distributed (Fig. 1).

NW region extends from Cabo de San Antonio (21°52.047’N-84°57.081’W) to Punta del Barco (23°00.956’N-82°57.569’W), including shallow areas of Archipiélago de Los Colorados and some bays. NE region comprises shallow waters from Archipiélago Sabana Camagüey and bays at NE Cuba from Punta Hicacos (23°12.344’N-81°08.645’W) to Punta Lucrecia (21°04.403’N-75°37.193’W). SE region includes lagoons and inlets at the southeastern part of the country and the gulfs of Ana María and Guacanayabo, from Punta Aserradero (19°59.022’N-076°10.315’W) to Punta María Aguilar (21°44.651’N-80°01.376’W). SW region extends from Punta Palmillas (22°03.032’N-81°12.847’W) to Punta Cortés (22°01.999’N-83°57.584’W), and also the coastal marine areas in the Golfo de Batabanó (Fig. 1).

To evaluate oyster resource, data were obtained from the fishery entities involved in their production according to the inventory of Mazón-Suástegui *et al*. (2019), which includes commercial natural beds and artisanal oyster farms of this resource.

Methods for evaluating oyster resource by region and time period

Because a clear statistical differentiation does not exist among oyster species nor their origin (extractive and culture fishery), data of total oyster landings in tons (t) were used and globally considered as catch (C). With these data, the catch maximum sustainable yield (CMSY) model with a Monte Carlo approach developed by Froese *et al*. (2017) was applied to evaluate biomass (B) and oyster exploitation level by regions (NW, NE, SE, SW) from the insular platform. The model, developed for the assessment of data-limited stocks, was applied to annual gross catch series (oyster-in-shell landings) from the fishery. This model uses an estimate of the species resilience and allows determining reference points (RP) for fishery management.

With CMSY model, estimated values of stock parameters were obtained by stages: carrying capacity according to unexploited stock size (K) and maximum intrinsic rate of population increase (r). The model also allowed determining maximum sustainable yield reference point (MSY), corresponding biomass (B_{MSY}) and fishing mortality rate (F_{MSY}). 80% of MSY was estimated as a precautionary approach, in addition to related biomass ($B_{80\%MSY}$) and fishing mortality rates ($F_{80\%MSY}$). MSY should be taken into account as a RP limit to avoid overfishing (Hilborn 2007), whereas 80% MSY may be considered as a precautionary RP objective to maintain fisheries in an efficient and sustainable status (Hilborn 2010).

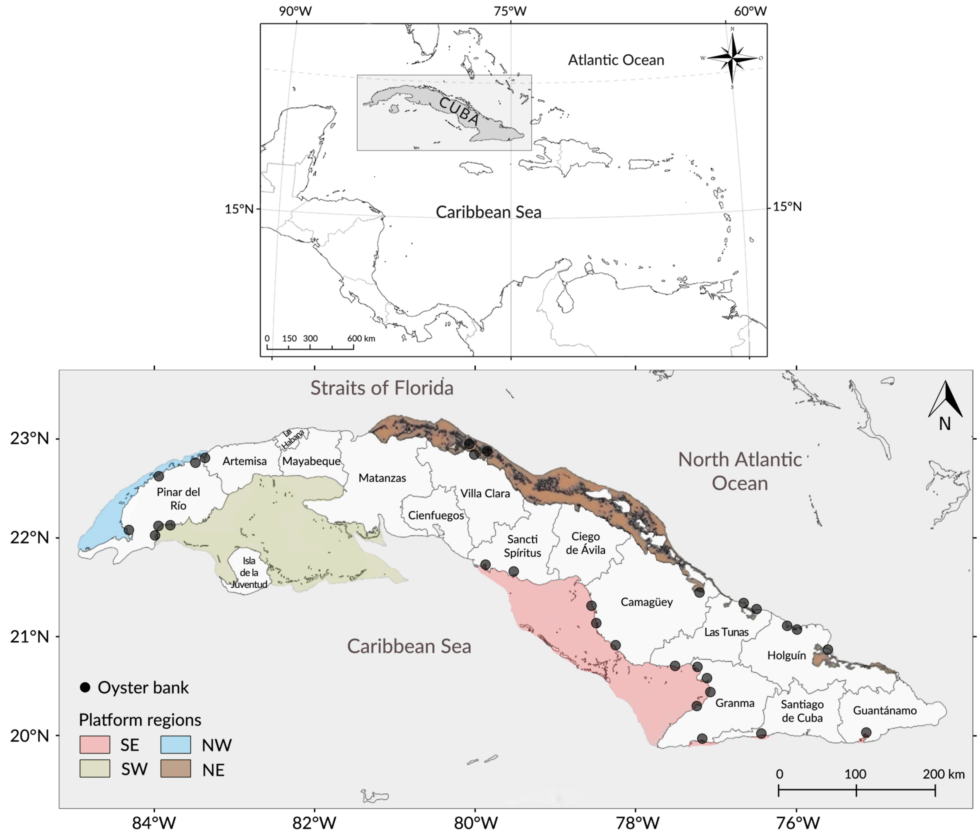

Figure 1. Regions of the Cuban insular platform and natural sites with commercial oyster presence (*Crassostrea* spp.) (black circles) / Regiones de la plataforma insular cubana, y sitios naturales con presencia comercial de ostra (círculos negros)

Two periods were selected for evaluation since the historical oyster production in Cuba has passed through two different stages: (1) maximum exploitation of wild biomass and oyster culture development (1960-1991), in which biomass per culture contributed to more than 50% of the national production (Frías & Rodríguez 1991), and (2) a second stage (1992-2020) in which the number of fishery establishments dedicated to oyster production was reduced and a progressive reduction of oyster culture occurred, whose current contribution is lower than 20% of the total annual production (Betanzos Vega *et al*. 2014, 2021).

Analyses to assess the resource status

With the parameter results for the second stage (1992-2020), theoretical long-term equilibrium values of catch (C) and biomass (B) were determined for specific fishing mortality rate ranges (F), and C equilibrium curves were graphically represented in function of B. Additionally, Kobe plots (Maunder & Aires-da-Silva 2012) were made, with F and B trajectories relative to the values corresponding to MSY were located. The model indicates that if the current biomass (B) is below the sustainable biomass ($B/B_{MSY} < 1$), the resource is considered depleted. The model also offers overfishing information in case that fishing mortality (F), caused by fishery effort, is greater than F corresponding to the maximum sustainable yield ($F/F_{MSY} > 1$).

Statistical analyses

For the comparative statistical analyses, the program STATGRAPHICS® Centurion XV (2007)[1] was used with a level of confidence of 95%; following the recommendations of Zar (1984), data normality tests were performed [F-Test and equality of variance to compare deviation standard (DE)]. To determine statistically significant differences between oyster landings by periods (1960-1991 *vs.* 1992-2020) and region (NW, NE, SE, and SW), the non-parametric Kruskal-Wallis test was used.

[1]Statgraphics Centurion XV. 2007. Edition Multilingual. Version 15.2.05. Stat Point, Inc. <http://www.statgraphics.com>

Results

Periods and regions

National landings –according to historical series– denote a period of maximum production up to 1991 (average C > 2,200 t) and a subsequent decreasing tendency (average C < 1,300 t) (Fig. 2). A significantly statistical difference (KW= 199.894; $P = 0.001$) was found for maximum landings between NE and SE Cuba (Fig. 3). Although a lower production was evidenced in all the regions during 1992-2020 with respect to 1960-1991, a significant difference between both periods was found only when evaluating NE region (Fig. 3).

For both periods, the maximum landings occurred in eastern regions (NE and SE), with a drastic decrease in NE region during 1992-2020 (Fig. 3). According to the reference points, all the stock status markers and prediction to reach the indicated MSY showed a decrease in 1992-2020 with respect to 1960-1991 (Table 1). Average C for NW and SW regions shows that landings decreased 33 and 37%, respectively, from 1992-2020 to 1960-1991; a reduction of 16% was recorded at SE, but at NE the decrease was 65%. With respect to estimated biomass (average B), it decreased 26 and 33% at SE and SW regions, respectively, and 63 and 65% at NW and NE regions, respectively. Total average biomass decreased by 48%, which evidenced a greater loss of biomass in the north of Cuba, where the maximum intrinsic rate of population increase (r) decreased in contrast to the south. Carrying capacity (K) was lower in all the regions in the most recent period (1992-2020).

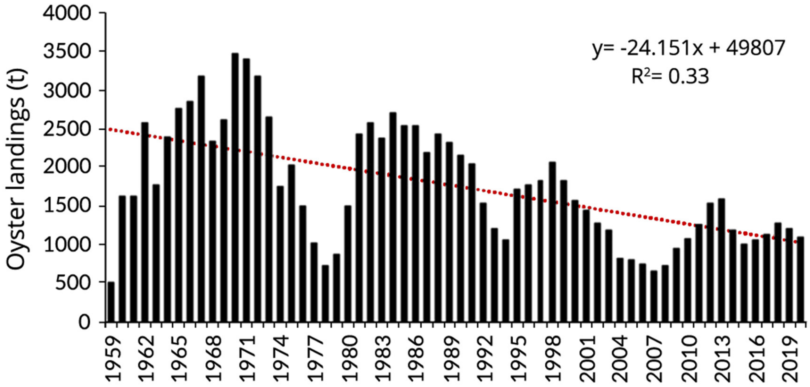

Figure 2. Total oyster (*Crassostrea* spp.) landings in Cuba, 1959-2020 / Desembarques totales de ostra (*Crassostrea* spp.) en Cuba, 1959-2020

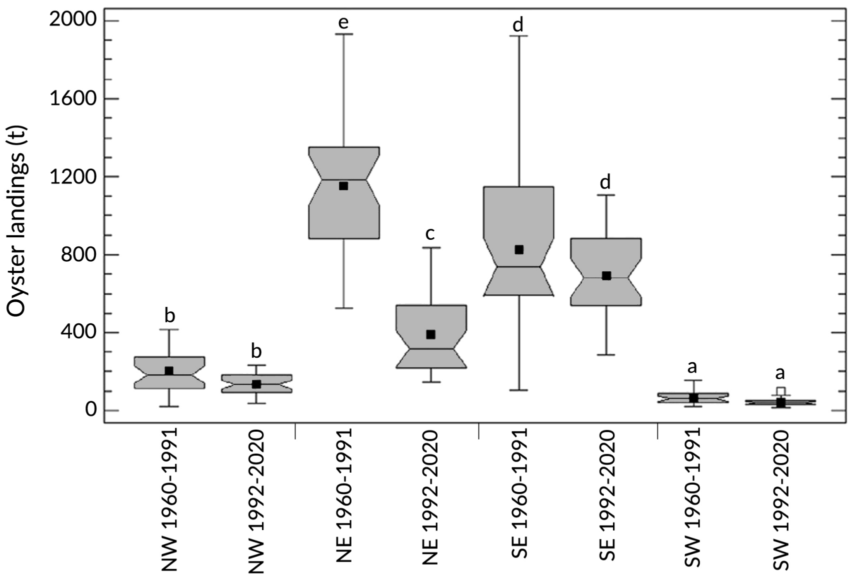

Figure 3. Comparison (Kruskal-Wallis) between oyster (*Crassostrea* spp.) landings by regions and periods. Different letters indicate statistically significant differences with a level of confidence of 95.0% / Comparación (Kruskal-Wallis) entre desembarques de ostra (*Crassostrea* spp.) por regiones y periodos. Letras desiguales indican diferencias estadísticamente significativas con un nivel del 95,0% de confianza

Table 1. Oyster (*Crassostrea* spp.) resource status in Cuba by periods and regions according to stock indicators: maximum intrinsic rate of population increase (r), carrying capacity (K), average catch (C), average biomass (B), estimated limit reference points (MSY, BMSY) and precautionary (80% of MSY) for its management / Estado del recurso ostra (*Crassostrea* spp.) en Cuba por periodos y regiones según indicadores del stock: tasa máxima de crecimiento de la población (r), capacidad de carga (K), captura promedio (C), biomasa promedio (B), puntos de referencia límite estimados (MSY, BMSY) y precautorio (80% de MSY) para su manejo

	1960-1991					1992-2020				
	NW	NE	SE	SW	Total	NW	NE	SE	SW	Total
R	0.479	0.448	0.304	0.376		0.400	0.314	0.519	0.501	
K	2212	10513	11828	740	25293	1375	6154	5714	377	13620
MSY	260	1166	881	70	2376	135	466	722	46	1369
80%MSY	208	932	705	56	1901	108	372	578	37	1095
BMSY	1106	5257	5914	370	12646	688	3077	2857	188	6810
C avg.	204	1152	827	70	2253	136	389	692	44	1260
B avg.	1586	4905	4369	344	11203	556	1816	3254	232	5858

Status of the oyster resource

In NW region, catches were excessive when compared to model predictions for equilibrium conditions and higher or very close to MSY (135 t) during 1992-2000 and 2013-2020 (Fig. 4a), and very far from the precautionary point $80\%_{MSY}$ (108 t). Correspondingly with this situation and according to Kobe plot (Fig. 4b), overfishing condition ($F/F_{MSY} > 1$) was confirmed for 1992-2001 and 2012-2020, which caused an unfavorable status of stock depletion ($B/B_{MSY} < 1$), starting from 1995 but mainly during 2000-2003. Decrease of F starting in 1998 reached values lower than F_{MSY} from 2002, favored a biomass recovery tendency starting from 2004, which stopped and subsequently reverted by F increase since 2008. Recent status turns out to be very unfavorable, given the simultaneous conditions of overfishing and resource depletion from 2012-2020.

In NE region the situation is also adverse. Catches were higher than those predicted by the model and beyond MSY (466 t) from 1992-2002 (Fig. 4c), and have maintained below the expectations since 2004. According to CMSY model, the oyster biomass in Cuban NE region has been at 50% of the necessary sustainable biomass (B_{MSY}) since 2002. In 2020 it was estimated at 1,728 t, 56% of B_{MSY}. Consequently, the resource is classified as very adverse overfishing and depletion conditions for all the assessed period (Fig. 4d), although a light tendency to B recovery can be observed facing F decrease since 2014.

A MSY of 722 t was estimated for SE region. Catches exceeded MSY and theoretical values expected in 1995-2001 and 2010-2014 with landings above 800 t (Fig. 4e). Nevertheless, biomass has maintained within the sustainable limits, except for some occasions from 2016-2020, when it was slightly lower the limit. Catch maximum was associated to minor increases in fishing mortality rate above F_{MSY} during 2012-2013, but this situation did not lead to overfishing or stock depletion conditions, as indicators are maintained within the most adequate quadrant of Kobe plot (Fig. 4f). Oyster resource status in SE region is favorable but requires a precautionary approach for catch limits.

In SW region, CMSY model indicated a catch limit for maximum sustainable yield (MSY) of 46 t, corresponding to a sustainable biomass (B_{MSY}) of 188 t. During 1992-2012, B maintained sustainable levels between B_{MSY} and $B_{80\%MSY}$, despite of higher catches than MSY in some years from 1995-2014 (Fig. 4g). Increase of fishing mortality rate above F_{MSY} from 2012-2015 motivated biomass reduction to depletion levels (below 188 t since 2013), as shown in Kobe plot (Fig. 4h). Results point out that oyster current status (2020) in the region is located within a high exploitation level and stock status tends to be unfavorable.

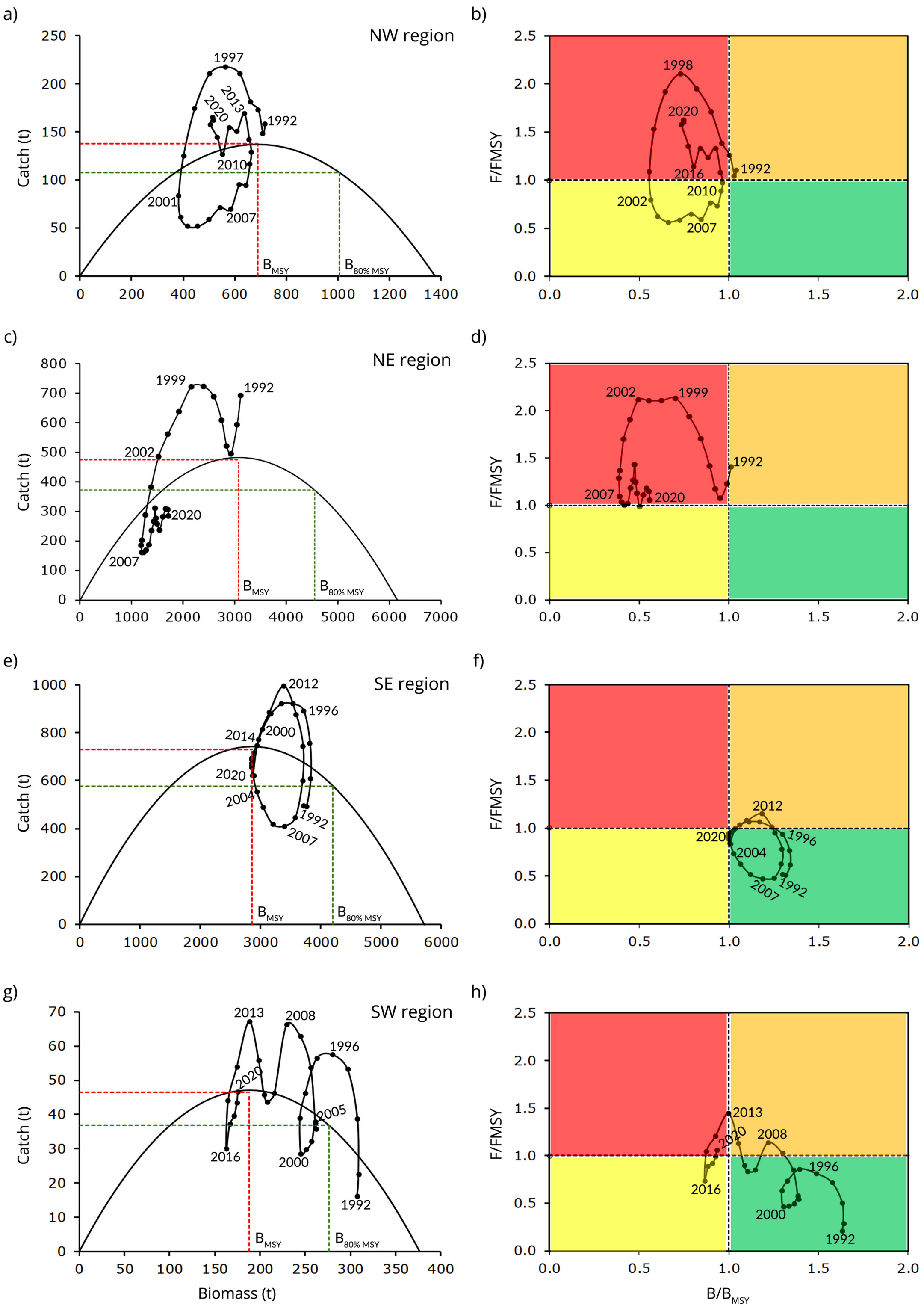

Figure 4. Oyster resource status according to catch maximum sustainable yield (CMSY) model for all regions of Cuban insular platform. Graphs on the left (a, c, e, g): theoretical equilibrium catch curves in function of biomass is shown, trajectory observed 1992-2020 and reference points for its management. Graphs on the right (b, d, f, h): Kobe plot with 1992-2020 trajectories by fishing mortality (F) and biomass (B) corresponding to MSY (green quadrant= favorable, red quadrant= unfavorable) / Estado del recurso ostra según el modelo CMSY para las cuatro regiones de la plataforma insular de Cuba. Gráficos a la izquierda (a, c, e, g): curvas de equilibrio teórico de captura en función de biomasa, la trayectoria observada 1992-2020 y puntos de referencia para el manejo. Gráficos a la izquierda (b, d, f, h): diagramas de Kobe con trayectorias 1992-2020 de mortalidad por pesca (F) y biomasa (B) correspondientes a MSY (cuadrante verde= favorable, cuadrante rojo= desfavorable)

Discussion

During 1960-1975, the period of maximum exploitation of wild mangrove oysters in Cuba, average annual oyster-in-shell production was 2,288 t, and MSY was estimated in 2,500 t $year^{-1}$ (Buesa 1997). However, in nine of those years, catches exceeded MSY recording landings over 3,000 t, which according to Mazón-Suástegui *et al*. (2019) caused an overexploitation of *C. rhizophorae* natural banks.

No episodes of oyster mortality due to diseases caused by pathogens and symbionts have been reported in Cuba, and aquaculture health analyses show acceptable values for human consumption (Leyva-Castillo *et al*. 2013, Martínez-Alfonso & Lantero-Abreu 2019). However, overfishing, damming of rivers and events of cultural contamination -due to eutrophication- in specific mangrove oyster habitats are pointed out as important causes in the 50% reduction of oyster landings (Baisre & Arboleya 2006, Betanzos-Vega *et al*. 2020). This situation was solved in the decade of the 1980s with oyster culture generalization (20 hatcheries in selected sites), which added more than 1,000 t to annual total oyster production (2,357 t) (Frías & Rodríguez 1991). For 1960-1991 and as a result of CMSY model, national capture for MSY was estimated in 2,376 t annually with average annual landings of 2,253 t, a value that does not differ in a greater measure to was pointed out by Buesa (1997). During that period, oyster biomass (B average) and landings (C average) in northern Cuba (NW+NE) constituted 58% and 60%, respectively, of the national total.

After 1991, other negative impacts were added, such as increases in salinity in the coastal area due to greater river damming, and greater frequency and intensity of hurricanes (Puga *et al*. 2013), plus a progressive reduction of oyster farms (Mazón-Suástegui *et al*. 2019). Consequently, annual minimum national average of 750 t occurred from 2004-2008. With the exploitation since 2007 of the natural oyster *C. virginica* banks that contribute about 350 t per year (Betanzos-Vega *et al*. 2018a), total oyster landings increased (1,100-1,200 t annual). However, *C. rhizophorae* landings currently do not exceed 900 t per year (Betanzos-Vega *et al*. 2021). CMSY model allowed estimating a national MSY of 1,369 t during 1992-2020, with annual landings around 1,260 t. For this period, gross catch (average C) of northern Cuban regions (NW+NE) constituted 41% and biomass (average B) was 40% of the national total.

A drastic decrease in biomass and landings of oysters is evident in the Cuban north coast, especially in NE region with respect to 1960-1991, which is corroborated by the statistically significant difference (Kruskal-Wallis; $P < 0.05$) of landings found between periods and regions. A similar result was obtained by Betanzos-Vega *et al*. (2021) for 2016-2020, with a difference (ANOVA; $F_{(1,8)} = 33.3$, $P = 0.0012$) between northern (397.4 t) and southern (731 t) coastal production. These authors consider that oyster production is currently increasing towards the east of Cuba with the maximum productivity to the southeast, maybe related to greater fluvial runoff and primary productivity. Independently of the environmental causes, reduction of oyster farms has been a major factor in declining landings with only six oyster farms currently operating out of 20 in use from 1980 to 1992. During 1960-1977, 74% of the sites with populations of wild oyster were located on the north coast, and 61% of them in the NE region. Inventories from the 1980s also indicated a greater number of oyster farms (75%) in northern Cuban region, with respect to the national total (Cigarria 1991, Frías & Rodríguez 1991, Buesa 1997).

In NW and NE regions, annual landings were higher than those predicted by the model and above the MSY during 1992-2020, with signs of population depletion and overfishing. This situation occurred after 2013 in SW and SE regions with a decrease in biomass below sustainability (B_{MSY}), starting from 2015. This scenario may be reverted with a decrease in fishing effort, or a seasonal wild oyster catch moratorium, which would imply an important decrease in current oyster production. Artisanal oyster culture should be increased by selecting culture sites, which according to Urbano *et al*. (2005) and Betanzos-Vega *et al*. (2021) would favor population recruitment by providing more larvae to maintain/increase wild natural oyster biomass.

Currently, *C. virginica* has a reproductive closed season, minimum legal capture size (60 mm), and total allowable catch in Cuba, but for the mangrove oyster there is only a regulation of commercial size (40 mm). According to Betanzos-Vega *et al*. (2021), oyster populations in northern Cuba are composed of mangrove oyster *C. rhizophorae*. Results in this study indicate depletion of the natural populations due to overfishing, which makes it necessary to review and update current regulations.

In conclusion, current fishery management of oyster resource in Cuba is not perceived as sustainable. An unfavorable status is observed in population stocks for NW, NE and SW regions with clear signs of overfishing. Oyster farming would be a technological option to increase productivity and contribute to restore/increase wild populations.

CMSY model results for estimating oyster maximum sustainable yield regionally and its corresponding biomass have as an advantage -besides a regional and general biomass assessment- generating information on the annual fishery trajectory and determining reference points to establish objectives and limits for national fishery regulation. Moreover, this model offers the possibility of comparing recent results with previous periods in function of the same reference points.

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