



Article Bioeconomic Analysis of Snook *Centropomus viridis*, *C. nigrescens*, and *C. medius* for the Development of Mariculture in Northern Sinaloa

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Abstract: The bioeconomy offers an opportunity to implement a truly sustainable global economy based on biological resources, which, thanks to biotechnologies, become renewable. In this study, we conducted a bioeconomic analysis of the three most important species of sea snook in northern Sinaloa using fishery and mathematical models to support the selection of the species with the highest growth and feasibility. Our results showed a condition factor lower than 1 (K < 1) for the three species. The size condition factor was higher in younger organisms for the three snook species. The growth rates were K = 0.320, K = 0.160, and K = 0.440 for C. viridis, C. nigrescens, and C. medius, respectively. Individual growth was 1.8 g/day for C. viridis, 1.47 g/day for C. nigrescens, and 0.91 g/day for *C. medius*. The length-to-weight ratio indicated negative allometric growth (b = 2.82, b = 2.72, and b = 2.73, respectively) for C. viridis, C. nigrescens, and C. medius. The simulation for possible commercial cultivation reflected varied sizes: 600 g for C. viridis and C. nigrescens and 400 g for C. medius. The financial projection of C. viridis produced IRRs of 14% and 48% in captured fishing and aquaculture models, respectively, with positive NPV. However, simulations for C. nigrescens and C. medius were not economically viable. We conclude that, according to the aquaculture model, the most financially feasible species to farm in the north of Sinaloa is C. viridis, which showed the highest growth based on fishery data compared to those for C. nigrescens and C. medius.

Keywords: fisheries; potential aquaculture; growth; snook; financial projection

Key Contribution: The bioeconomy offers an important opportunity to implement a truly sustainable global economy based on biological resources that, due to biotechnologies, become renewable. In this study, we conducted a bioeconomic analysis of the three most important species of sea snook in northern Sinaloa, using fishery data and mathematical models to support the selection of the species that will promote mariculture with the greatest chance of success.

1. Introduction

Fisheries and aquaculture are two of the most important economic activities in terms of global food production; in 2020, capture fisheries contributed 90 million tons and aquaculture contributed 88 million tons, with a total sale value of USD 406,000 million [1]. Importantly, aquaculture is contributing to the rapid increase in the fish supply by somewhat compensating for the reduction in natural fish populations, thus partially making up



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Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). for the lack of products derived from the sea [2]. However, it cannot entirely counter the collapse of half of the existing fisheries in the Mexican Pacific [3].

As part of attempts to do so, one of the great challenges ahead in marine aquaculture in the near future is the selection of suitable candidate species. There are over 120 families of fishes but only two families with good aquaculture potential—Sciaenidae and Serranidae. A study prepared for the World Aquaculture Society reviewed the species of croakers of the family Sciaenidae [4], using Fishbase and other records, revealing that 60 species have aquaculture potential and a market future [5]. There are some markets already well established for certain members of the family Centropomidae, which is a species of the genus *Centropomus*, in the Pacific Ocean. However, there are many more species to explore in developing mariculture to avoid vulnerability due to the overproduction in fisheries, which is predicted in the region [6].

There are several other suitable candidate species to choose from, the selection of which depends on geographical location, cultural conditions, and seafood-marketing strategy. The criteria for potentially successful marine fish-farming candidate species are (1) product attributes—market demand, taste, texture, color, versatility, shelf life, freezing, and nutritional composition; (2) aquaculture performance—growth, survival, yield, and feed conversion ratio (FCR); (3) availability of complete production technology; (4) native distribution in warm–temperate to tropical oceans; (5) few existing commercial fisheries; and (6) reproduction, the technological development of juvenile mass production and its growth [7,8].

The genus *Centropomus* meets the criteria described, and some species have been studied to develop the technology for their cultivation, as in the cases of *C. viridis* in the Pacific [9] and *C. undecimalis* in the Atlantic [10–14]. Advances have mainly been made in reproductive biology, physiology, nutrition, and farming techniques. To extend these, the Fisheries Management Plan proposes carrying out bioeconomic studies of fisheries to avoid the stagnation of extraction, which is thought to have begun in 2015 and is expected to continue until 2030 [1].

In general, all species of snook are considered of high commercial value due to the flavor of their meat and the sizes reached in the adult stage [15,16]. In the Mexican Pacific Ocean, the state of Sinaloa occupies second place in fishery production, with 511 tons annually [17]. *C. viridis* is one of the most commercially important species, which generates important economic gains for fishermen in the coastal areas of the North Pacific [18].

Snook (*Centropomus* spp.) are among the most appreciated and best-valued species of marine fish in the American tropics, and some are being studied to develop the technology for their culture. Advances have been made in reproductive biology, physiology, nutrition, and cultural techniques, mainly for chucumite snook (*Centropomus parallelus*) [19] and common snook (*C. undecimalis*) in the Atlantic [12–14] and black snook (*C. nigrescens*) [20] and white snook (*C. viridis*) in the Pacific [9,21].

One of the mathematical models used to estimate the growth of marine species, in particular, is based on the age structure of a population, as reported by Beverton and Holt [22]. This model accurately describes the behavior of a fish population in which individuals experience changes related to population composition and usage [23]. The model predicts the consequences of management strategies, facilitating the evaluation of complex interactions (biological, environmental, technological, and economic) of fisheries and aquaculture systems [24–26].

The bioeconomy constitutes an opportunity to achieve a sustainable global economy for biological resources. Related research supports corresponding decision-making at the business level, including considerations of innovation, sustainability, economic growth, and employment [27–29]. Bioeconomic analyses are relevant in the study of species that are vulnerable to overexploitation, since inadequate fisheries management is likely to lead to the collapse of the fishing industry and put species in danger of extinction [6,30,31].

Consequently, it is necessary to recognize the species that have the greatest qualities within aquaculture, and research with a view to developing technological packages for their

cultivation is required to optimize the efforts and resources available for this purpose [32]. In this work, the levels of financial potential of the three most important species of snook in northern Sinaloa, Mexico—*Centropomus viridis*, *C. nigrescens*, and *C. medius*—were evaluated through fishery analyses and financial models.

2. Materials and Methods

2.1. Study Areas

The sampling area is located in the north of the state of Sinaloa, Mexico $(25^{\circ}54'43'' \text{ N}, 109^{\circ}10'26'' \text{ W} \text{ and } 25^{\circ}34'28'' \text{ N}, 108^{\circ}28'16'' \text{ W})$ (Figure 1). During the period from December 2020 to December 2021, monthly biological sampling was carried out of 30 fish caught with drift nets (3.5-inch mesh bale of 100×50 m) by local fishermen at each site. The total length (TL, cm) and the eviscerated weight (Pe, g) were obtained for each organism. The obtained length frequencies were grouped in intervals of 7 cm according to Sturges' Rule to describe the structure of the population extracted through fishing and to define the main population parameters: growth and natural mortality. The species were identified using the taxonomic keys of the FAO [33,34]. The length–weight relationship was analyzed to determine the type of growth [35], as follows:

$$Pt = a (Lt)^b \tag{1}$$

where

Pt = Weight of the organism in grams.

Lt = Total length in centimeters.

a = Parameter of the ordinate to the origin related to the condition factor [36,37].

b = Slope of the exponential equation or allometric factor.



Figure 1. Locations of the study areas in the north of Sinaloa, Mexico.

2.2. Growth Parameters

Growth parameters were estimated using the new Shepherd's length-compositionanalysis (NSLCA) method in the FISAT II (version 1.2.2) evaluation program [38] and using the empirical equation of Pauly [39,40]:

$$t_0 = Log(-t_0) = -0.3922 - [-0.2752(Log L_{\infty})] - [1.038(Log k)]$$
(2)

The growth parameters were modeled by applying the following growth equation:

$$Lt_t = L_{\infty} \left[-e^{-k(t-t_0)} \right]$$
(3)

where

 Lt_t = Total length at time t.

 L_{∞} = Infinite or asymptotic length.

k = Growth factor or speed at which the curve reaches the asymptote.

 t_0 = Theoretical length at age 0.

Natural mortality was estimated using the empirical equations of Pauly [40] and Rikhter and Efanov [41] included in FISAT II (version 1.2.2). Pauly's equation includes temperature as a factor that influences natural mortality and the growth parameters $L\infty$ and k:

$$Log M = -0.0066 - (0.279 Log L_{\infty}) + (0.6543 Log k) + (0.4634 Log T^{\circ})$$
(4)

where

M = Natural mortality.

 L_{∞} and k = Parameters of the growth equation.

 T° = Sea surface temperature.

The factor or condition status was estimated using the Fulton index [42]:

$$\mathbf{K} = (\mathbf{P}/\mathbf{L}^3) \times 100 \tag{5}$$

The farming simulation was based on previous results [43] from fishery models in the three *Centropomus* species, such as natural mortality, estimation of growth parameters, and condition factor. We completed aquaculture performance projection in growth and survival in Excel spreadsheets. We integrated information on stocking density, survival rate, FCR, number and weight of organisms, and initial and final biomass. For growth performance, the following biological variables were simulated: specific growth (SG), defined as final weight minus initial weight divided by number of days; specific growth rate (SGR), defined as mean final weight minus mean initial weight and divided by the number of days multiplied by 100; and feed conversion ratio (FCR), defined as the total feed consumed divided by final biomass [7,43–45].

Stocking density: Fish number stocked per cubic meter.

$$SD = \frac{Fish}{Volume} \tag{6}$$

Survival Rate: Fish harvested/stocked times 100.

$$Survival\% = \frac{FH}{FS} \times 100 \tag{7}$$

Initial Biomass (kg): Fish stocked times the initial mean weight.

$$IB = (FS \times MW_i) \tag{8}$$

Final Biomass (kg): Fish harvested times the final mean weight.

$$FB = (FH \times MW_f) \tag{9}$$

Specific Growth Rate (%): Daily weight gained in percentage of individual biomass.

$$SGR\% = \frac{Log(W_f) - Log(W_i)}{t} \times 100$$
(10)

Specific Growth (g): Daily weight gained in individual biomass.

$$SG = \frac{W_f - W_i}{t} \tag{11}$$

Feed Conversion Rate (FCR): Total feed consumed divided by final biomass.

$$FCR = \frac{TF}{FB}$$
(12)

2.3. Economic Analysis

A financial analysis was conducted for a complete production cycle. The investment of capital expenditure in infrastructure and operating costs in the simulation of a single fattening stage are presented in detail in Table 1. The same investment was assumed for the 3 snook species of the captured fishing and aquaculture models.

Table 1. Investment of capital concepts for total production in USE
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Concept	Original Amount of Investment (OAI) 2023
Initial cash	6115.46
Guarantee deposit	3140.90
Initial inventory	65,958.90
Production equipment	55,332.19
Furniture and equipment	1806.38
Transportation equipment	4187.87
Computer equipment	759.57
Materials inventory	532.78
Installation team	2617.42
Total investment	148,451.48

The difference between total projected revenues and operating costs was determined for a one-year period. The data were used to calculate the cash flow of the three species of snook.

The net cash flow equals total revenues minus total expenses and is represented by the following formula:

$$NCF = Total Income - Total Expenses$$
 (13)

The net present value (*NPV*) is calculated as the sum of future cash flows discounted to the present value, minus the initial investment. The future value and present value were calculated using the following formula:

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{NCF}{(1+k)t}$$
(14)

The indicators of financial viability in the captured fishing and aquaculture scenarios were calculated using the following economics formulas:

$$IRR = \sum_{t=0}^{n} \frac{Fn}{(1+I_0)} = 0$$
(15)

where

IRR = Internal rate of return. Fn = Cash flow in period n. n = Number of periods. I_0 = Initial investment.

MARR = i + f + if(16)

where

MARR = Minimum acceptable rate of return.

i = Risk–reward. f = Inflation.

f = Inflation.

$$Payback = \frac{I_0}{F} \tag{17}$$

where

 I_0 = Initial investment in project. F = Value of cash flow.

3. Results

The growth values of the three snook species were estimated and compared using the von Bertalanffy method (Table 2), obtaining a growth rate for *C. viridis* of k = 0.320 year⁻¹, an asymptotic length $L_{\infty} = 77.70$ cm of Lt, a zero size $t_0 = -0.218$, and a growth of 1.8 g/day. For *C. nigrescens*, an asymptotic length $L_{\infty} = 81.90$ cm of Lt, a growth rate of k = 0.160 year⁻¹, a zero size $t_0 = -0.90$, and a growth of 1.47 g/day were found. Considering the above, the maximum asymptotic growth of white (*C. viridis*) and black snook (*C. nigrescens*) was estimated at six years of age (Figures 2 and 3). The growth of *C. medius* resulted in an asymptotic length $L_{\infty} = 52.50$ cm of Lt, obtaining a growth rate of k = 0.440 year⁻¹, a zero size $t_0 = -0.180$, and a growth of 0.91 g/day. It can be observed that the maximum asymptotic growth of this species is at five years of age (Table 2).

Table 2. Comparison of growth rates of the three snook species.

Growth Rate	C. viridis	C. nigrescens	C. medius
L_{∞}	77.70	81.90	52.50
k	0.320	0.160	0.440
t_0	-0.218	-0.90	-0.180



Figure 2. Growth curves of white-snook C. viridis, C. nigrescens, and C. medius in northern Sinaloa.

The condition index varied throughout the year, with us obtaining the maximum values for the three species in spring and the lowest for *C. nigrescens* and *C. viridis* in summer, while for *C. medius*, the lowest values were recorded in autumn and winter. There was a significantly lower condition index in summer compared to spring (p < 0.05) (Figure 3).

Condition factor by sizes: n = 243 organisms were analyzed (n = 69 *C. nigrescens,* n = 115 *C. viridis,* and n = 59 *C. medius*) with an average TL of 52.46 cm and a structure

length between 43 and 79 cm TL for *C viridis*, from 39 to 78 cm for *C. nigrescens*, and from 25 to 51 cm for *C. medius*. The morpho-physiological values for *C. viridis* were the highest between 43 and 49 cm and the lowest between 71 and 79 cm. *C. nigrescens* presented the highest values between 39 and 54 cm and the lowest between 71 and 78 cm. For *C. medius*, the condition factor was the highest between 32 and 39 cm and the lowest between 48 and 55 cm. Paired with the previous results, we surmised that the condition of the individuals decreases with age (Figure 4).



Figure 3. Condition factors of *C. viridis, C. nigrescens,* and *C. medius* during the four seasons of the year in northern Sinaloa (Different letters explain the group differences).



Figure 4. Condition factors by length interval of white-snook *C. viridis*, *C. nigrescens*, and *C. medius* in northern Sinaloa (Different letters explain the group differences).

Length–weight ratio: The potential model of the length–weight relationship of *C. viridis* was $Pt = 0.0164Lt^{2.8163}$, of *C. nigrescens* was $Pt = 0.0236Lt^{2.7188}$, and of *C. medius* was $Pt = 0.0231Lt^{2.7256}$. The three species of snook showed negative allometric growth (b = 2.82, b = 2.72, and b = 2.73, respectively), which, biologically, means that the species tend to become slimmer as they increase in length (Figure 5).



Figure 5. Analysis of the length–weight relationship of white-snook *C. viridis, C. nigrescens,* and *C. medius* in northern Sinaloa.

Farming simulation: After generating an investment model with aquaculture based on the statistics established in the fisheries biological analysis, two analyses were performed for the first and second scenarios with the captured fisheries and aquaculture data, respectively, in a single production cycle until the fattening stage. A density of 234 organisms per cubic meter, initial weight of 1 g, feed ration of 3%, and survival of 55 or 60% were assumed. The aquaculture model was simulated in floating cages of 225 m³. We found the following results for the three snook species (Tables 3 and 4) [43].

Table 3. Farming simulation of *C. viridis, C. nigrescens,* and *C. medius* in a single stage of production (fattening), according to data from the fishing model.

Variable	C. viridis	C. nigrescens	C. medius
Stocking density (fish/m ³)	234	234	234
Culture days	336	413	364
Initial weight (g)	1.0	1.0	1.0
Final weight (g)	600	600	330
Initial biomass (kg)	18	18	18
Final biomass (kg)	6325	5473	3289
Specific growth rate (%)	178	145	90
Weight gained per day (g)	1.8	1.47	0.91
Feed conversion ratio (FCR)	3.16	3.15	3.19
Survival (%)	60	55	55

Variable	C. viridis	C. nigrescens	C. medius
Stoking density (fish/m ³)	234	234	234
Culture days	273	364	364
Initial weight (g)	1.0	1.0	1.0
Final weight (g)	600	600	400
Initial biomass (kg)	18	18	18
Final biomass (kg)	7364	5956	3974
Specific growth rate (%)	219	164	109
Weight gained per day (g)	2.20	1.65	1.10
Feed conversion ratio (FCR)	2.84	3.19	3.19
Survival (%)	60	55	55

Table 4. Farming simulation of *C. viridis*, *C. nigrescens*, and *C. medius* in a single stage of production (fattening), according to aquaculture model.

The production costs incurred in the project correspond to inputs for production (juveniles and feed). Sales expenses correspond to the commercialization of snook (salaries, benefits, electricity, water, depreciation, etc.), as well as administrative expenses (water, electricity, rent, benefits, salaries, etc.) and financial expenses. The latter corresponded to financing that will be used as part of the initial investment of USD 2,427,000.00 with an annual interest rate of 15% for five years, to acquire inputs and infrastructure that will be used to conduct the operations.

The difference between the total projected income and the operating costs was determined for a one-year period. The data were used to calculate the cash flow of the three species of snook; however, only the species with the best economic feasibility in the captured fishing and aquaculture models is shown, in this case, *C. viridis* (Tables 5 and 6).

	Income Stream	Expense Flow	Future Value	Present Value
Initial investment	-148,451.48	-148451.48	-148,451.48	-148,451.48
2023	270,761.99	227,544.56	43,217.43	38,255.00
2024	309,995.40	308,447.16	1548.23	1213.10
2025	354,913.73	325,748.37	29,165.36	20,228.12
2026	406,340.73	343,976.11	62,364.62	38,287.39
2027	465,219.50	363,102.50	102,117.00	55,493.85

Table 5. Cash flow of captured fishing model of *C. viridis* (USD).

Table 6. Aquaculture-model cash flow for C. viridis.

	Income Stream	Expense Flow	Future Value	Present Value
Initial investment	-148,451.48	-148,451.48	-148,451.48	-148,451.48
2023	315,239.73	235,050.16	80,189.56	70,981.83
2024	360,917.96	316,478.16	44,439.80	34,820.17
2025	413,214.98	334,341.53	78,873.44	54,703.97
2026	473,089.82	353,170.80	119,919.02	73,621.65
2027	541,640.54	372,940.82	168,699.72	91,677.16

A sensitivity analysis was executed to calculate the economic viability of the project in two different scenarios: (1) the model based on captured fishing data and (2) the simulation of aquaculture farming based on daily growth and survival. A final sale price for whole fish of 8.55 USD/kg was considered based on real market prices in Mexico. The same price was used in the two models for the three species of snook to evaluate the influence on the internal rate of return (IRR) and the net present value (NPV) of the initial investment [46].

The financial results of this study, according to the sensitivity analysis of the two models, showed a more favorable NPV for the aquaculture model, with a value of USD

177,353.30 and an IRR of 48%, compared with the captured fishing model, which yielded a value of USD 5025.98 and an IRR of 14% (Table 7). In both scenarios, a final sale price of USD 8.55 was established, showing the economic feasibility of the project. Meanwhile, the financial projections made for *C. nigrescens* and *C. medius* in the captured fishing and aquaculture models were not profitable.

Table 7. Indicators of financial viability in the captured fishing and aquaculture scenarios of C. viridis.

Financial Indicator	C. viridis		
Scenario	Captured fishing model	Aquaculture model	
MARR	26%	26%	
IRR	14%	48%	
NPV (USD)	5025.98	177,353.30	
Pay-back	5 years 3 months	2 years 8 months	

4. Discussion

The condition-factor analysis of the three snook species studied in the present work presented a value of K < 1. This result differs from that reported by Tapia Varela et al. [47], who showed results for *C. viridis* indicating a value of K \geq 1 in males, while the females presented a condition lower than 1 (0.98 < 1). Our results may indicate that fishing efforts could be generating variations in the fishing conditions of the populations of the three species in the study areas.

The size range obtained in this study for *C. viridis* is similar to that reported by Labastida-che et al. [48] in Chiapas, with an average length of 47.02 cm TL and a maximum of 78.5 cm TL. However, the results are lower than those reported by Briones Avila et al. [49], where the frequency distribution of white-snook *C. viridis* in the Teacapán–Agua Brava lagoon system, south of Sinaloa and north of Nayarit, covered sizes from 31 to 91 cm with a measurement of 55.37 cm TL.

Other snook studies focused specifically on *C. viridis*, the species with the greatest presence on the north coast of Sinaloa and Nayarit, and a maximum length of 131 cm was reported for this species [47], 11 cm longer than the previous length reported [34]. Such a variation in size structure can arise due to the selectivity of the fishing gear, its size, and the fishing technique used [50–52]. The size distribution can also vary from one region to another and even within the same region [53,54] because growth is affected by food availability.

The negative allometric growth for *C. viridis* reported in the present study is similar to that estimated by Tapia Varela et al. [47] on the north coast of Nayarit (in the general analysis of length and weight for males and females, b = 2.958 was reported). However, Labastida-che et al. reported isometric growth for both sexes of white snook in the lagoon systems of the state of Chiapas (b = 2.99) [48]. The allometry coefficient (b) has great biological importance, since it indicates the weight gain in relation to the growth in length. Variations in the estimate of b could reflect changes in the condition of individuals related to food availability, reproductive seasons, or migratory activities [55].

The estimation of the growth parameters, according to Shepherd's method in the present work, produced values of K = 0.320 for *C. viridis*, K = 0.160 for *C. nigrescens*, and K = 0.440 for *C. medius* and thus growth rates of 1.8, 1.47, and 0.91 g/day, respectively. The results regarding the value of K are lower than those reported by Labastida-che et al. [48] with white bass in Chiapas, who obtained a value of K = 0.57. However, the authors' report of a maximum estimated age for this species of six years corresponded with our results for *C. viridis* and *C. nigrescens*.

The growth rate of *C. nigrescens* in this study was 1.47 g/day according to fishery data, which was similar to that reported by Barreno [56], who established that this species could reach commercial sizes of 500 g in 6 months of cultivation, with rates of growth between 1.5 and 3.2 g/day. However, both growth rates are lower than the result obtained by Escárcega [32] for the same species cultivated in ponds on the coast of Michoacán

(1.84 g/day). Furthermore, a growth value by Álvarez [57] exceeds those for other species of marine fish of commercial interest, such as spotted snapper (*Lutjanus guttatus*), yellow snapper (*L. argentiventris*), sea bream (*Sparus aurata*), sea bass (*Dicentrarchus Labrax*) (these last two from the Mediterranean Sea), goliath grouper (*Epinephelus itajara*), and sand cabrilla (*Paralabrax maculatofasciatus*).

According to the method of Rikhter and Efanov, the populations of white snook (*C. viridis* M = 0.529; *C. nigrescens* M = 0.626) and brown fin snook (*C. medius* M = 0.674) presented a natural mortality. These results are lower than those [48] for the species *C. viridis* in Chiapas (M = 0.94); however, the high natural-mortality rates in the latter case are suggested to be due to events such as disease, migration, or predation and due to recommendations for aquaculture in Latin America [9,21]. Therefore, the culture of *C. viridis* is suggested, given the results of our analysis of natural mortality, to support the recovery of natural stocks and also generate alternatives for the management of its fishery.

Snook is one of the fastest-growing capture fisheries in Mexico, with production doubling from 8000 tons in 2013 to more than 18,000 tons in 2017. This rapid growth in demand has placed snook at number 16 in terms of catch volume and number 7 in terms of value [21].

The normal market price for white snook is 10 USD/kg in whole ungutted presentation (from 800 g to 1.5 kg) and 28.52 USD/kg in fillet presentation. These prices are suggested by the federal government but are subject to fluctuations in supply and demand [17]. Accordingly, in our study, for the culture of snook, economic viability was tested with a final sale price of 8.69 USD/kg. However, a final price of 11 to 13 USD/kg could be established, since it is an aquaculture product that will be available upon request by the client, guaranteeing quality, freshness, and sustainability in the product and production process [17].

This aquaculture model is based on previous work [17] where an investigation into the viability of cultivating *C. viridis* in floating cages revealed a net present value (NPV) of USD 40,291.83 (MXN 811,074.54 exchange rate on 7 March 2022) in a conservative scenario and USD 165,822.63 (MXN 3,338,009.54 exchange rate as of 7 March 2022) in an optimistic scenario, at final sale prices of 7.5 and 10 USD/kg and IRRs of 39% and 99%, respectively. However, in the present study, we obtained a higher IRR of 48% and an NPV of MXN 3,625,101.50 for *C. viridis* in the aquaculture-model scenario [17]. Our findings were comparable to the results of the inversion analysis of Martinez-Cordero et al. [58] for the culture of the snapper *Lutjanus guttatus* in sea cages, where an NPV of USD 119,360 was obtained in a 10-year scheme.

5. Conclusions

This study concludes that the three fish species show negative allometric growth, which indicates that the growth in body weight is slower than the growth in length. In addition, the best biological condition for the three species occurs in summer and the worst in winter due to the higher water temperature in summer, which favors the growth and development of the fish. The economic viability was ascertained, with a final sale price of (8.55 USD/kg), which revealed a positive net present value (NPV) at the end of the 5 years projected and an internal rate of return (IRR) of 48%. Therefore, the project can generate profits and provide an attractive return on investment. Regarding natural mortality, a high rate was observed in all three species, suggesting events such as disease, migration, or predation. It is important to conduct further research to determine the specific causes of natural mortality in these species and to identify appropriate measures to prevent them. The culture of *C. viridis* is suggested, given the conclusions obtained in our analysis of natural mortality, to support the recovery of natural stocks and also generate alternatives for the management of its fishery. This work shows that C. viridis is the most financially feasible species to cultivate according to the aquaculture model in northern Sinaloa, since based on a captured fishing model, it has better growth in culture within a shorter time

compared to *C. nigrescens* and *C. medius*, resulting in a profitability of USD 177,253.30 and recovery in 2 years and 8 months.

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