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Sustainability Study of Scalloped Hammerhead Shark (*Sphyrna lewini*) in Indramayu Waters

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Abstract: Hammerhead shark (*Sphyrna lewini*) population decline is a global problem experienced by various ocean basins worldwide, including Indramayu waters. As the regency known by its fishery barn that supplies 65% of captured fisheries in West Java, Indonesia, illegal fishing practices towards this protected species is inevitable. In 2017, 2869 tons of sharks were landed in Indramayu with the production value of IDR 44.01 billion, which hammerhead shark catch reaches 268 tons. This research aimed to observe the sustainability of hammerhead shark in Indramayu waters using a bio-economic model of Gordon Schaefer (GS) and Gompertz. The results showed the overfishing of hammerhead shark in Indramayu waters on actual conditions in 2012, 2014, 2015, 2016, 2017, and 2018, both in the GS and Gompertz models. The abundant number of hammerhead sharks started to deplete from 2015 to 2018, and the highest depletion was found in 2017, with a depletion value of 16 tons and depreciation value of IDR 164 million. The depletion rate suffered the most significant decline in 2011 to 2012 for all types of sharks, including hammerhead. The prohibition of consistent fishing and more pronounced law enforcement for hammered shark fishing are needed to maintain the sustainability of this resource.

Keywords: hammerhead shark; sustainability; Indramayu waters; depletion and depreciation; standard bio-economics model

1. Introduction

Hammerhead shark (*Sphyrna lewini*) belongs to the Sphyrnidae family and is a common caught species in Indonesian waters for its fins as export commodity [1–3]. The hammerhead shark was originally a by-catch in fisheries but became catch target in some areas, including Indramayu waters, West Java [1,4,5]. Known as one of the biggest fishery barn in West Java, Indramayu waters contributed more than 65% of West Java marine fisheries production and is one of the backbone of fishery production throughout the nation [1]. Yet, having the highest production of catch fishery every year resulted in a high number of by-catch (or supposedly, catch target) of protected, endangered fish, such as Hammerhead Shark. Shark is one of the fishery commodities that are economically important, yet the capture of this endangered species caused a problem for the sustainability of the species itself [6]. In 2017, shark production in Indramayu waters reaches 2869 tons with the production value of Indonesian Rupiah (IDR) 44.01 billion. The sharks are sold for their fins, skin, meat, and fish bones.

Data from Maritime Affairs Office of Indramayu Regency that covers fisheries catch from 2006–2017 showed that the production of shark fin in Indramayu reached 140 ton with a production value of IDR 14.47 billion [1], thus showing high demand for shark fin [7,8]. The fins are the most sought body part due to their high economic value, especially for large fins [4]. Shark hunting is increasingly even and based on Food and Agriculture Organization (FAO) Indonesia, ranks as the country that produces the most sharks and rays each year [6,9,10].

Ten types of shark found in Indramayu district belong to the endangered category based on the International Union Conservation of Nature (IUCN) and most of the existing shark species have been listed as red in IUCN [11]. One of the red-listed sharks that were often caught is a hammerhead shark. Hammerhead shark is one of the most common fish species found in Indonesia [4] and the most common shark species captured in Java and Borneo waters [9]. The scalloped hammerhead (*Sphyrna lewini*) is a globally exploited species of shark [12,13], including in Indonesia, and its abundant number were greatly decreased by the capture fisheries industries, either by catch or target species [3,14]. Hammerhead sharks exhibit extremely specialized traits and complex behaviors that have increased their vulnerability to human exploitation [15]. Based on the Regulation of the Minister of Maritime and Fisheries of the Republic Indonesia no. 5/PERMEN-KP/2018 oceanic whitetip shark (*Carcharhinus longimanus*) and hammerhead shark (*Sphyrna* sp.) are prohibited to be exported from the Republic of Indonesia to other territories. Furthermore, hammerhead sharks are categorized under Appendix II, which under endangered species of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and the Government of the Republic of Indonesia has issued regulations regarding the prohibition of hammerhead sharks through the Minister of Marine Affairs and Fisheries Regulation Number: 59/PERMEN-KP/2014, Decree of the Minister of Marine Affairs and Fisheries Number: 18/KEPMEN-KP/2013 for hammerhead shark (*Sphyrna lewini*), Oceanic Whitetip Shark (*Carcharhinus longimanus*), Largetooth Sawfish (*Pristis microdon*), Whale Shark (*Rhincodon typus*), and Pelagic Thresher (*Alopias pelagicus*).

Shark is categorized as the predator of the food chain system to keep ecosystems in balance. Sharks generally occupy the peak position, providing significant top-down control over many other pelagic and benthic marine species [5]. The presence of sharks indicates that marine ecosystems are in good condition; thus, when the presence of sharks is threatened or decreased, it is feared that it will disturb the balance of the marine ecosystems. Biologically, sharks have low fecundity, slow growth, need longer time to reach adulthood, and have a high risk of death at all levels of age [6,9,16,17] and, at the same time, sharks are also vulnerable to overfishing [3–20]. If this species experienced an over-exploited state, sharks are at higher risk of extinction than other fish groups. Thus, shark populations can only be protected by controlling shark fisheries to avoid depleting their stocks [4,21].

Hammerhead sharks are the target and sideline catches of longline fisheries (fishing rods) and gill nets [22]. Population decline for hammerhead shark has occurred, as a result of high catch rate and intensive trade, especially for its fins as an export commodity [5,23]. High levels of exploitation of hammerhead sharks occur in Indramayu waters with the total production of hammerhead shark catch reached 277 tons in 2016, while, in 2017, it was decreased to 268 tons. This indicates that the hammerhead shark population has decreased, and this will certainly have an impact on the biodiversity of Indramayu waters.

Hammerhead shark population decline has been a global problem for a long time, as published scientific studies have estimated the declines from various ocean basins worldwide [5,24]. South Africa experienced decline of more than 99% in 1952 to 1972 due to coastal beach nets [5,25]. Mediterranean Sea also experienced the same percentage of decline in 1900 to 1995 due to the coastal artisanal fishery [5,25]. The East Coast of the U.S. experienced hammerhead shark decline of 98% due to fishery-independent survey [5,25], and the Northwest Atlantic experienced decline of 76–89% from 1986 to 2005 with the use of commercial longline logbook [24,25]. Ferretti and colleagues (2008) showed that, at one of two studied beach sites, scalloped hammerheads experienced the most severe population declines in the analysis, as well as that hammerhead shark populations declined the fastest of any assessed

species. Baum and colleagues (2007) affirmed that the hammerhead population declines were among the most severe of any studied species; and Baum and Blanchard (2010) most recently reaffirmed that hammerhead population declines were “precipitous” and remained the most severe of any studied species [5,24,25]. Gallagher and colleagues (2014) further explained that the continuous decline of hammerhead shark population is caused by the destructive fishing practices and ineffective conservation methods, which are incapable of preventing its decline under current levels and modes of exploitation [25]. Indonesia has shown the same severe cases of hammerhead shark exploitation and overfishing due to fishing gears, but the unregulated and unsupervised practices were the roots of the main problem where Indramayu fishers took advantage of them.

There are ±2.7 million fishers in Indonesia, with the majority at the threshold of the poverty line and contributing to 25% of the national poverty rate [26]; this condition creates a severe disadvantage in terms of access to markets, education, and health care [27]. For the fishermen, fishing is an important source of income, therefore making sharks, one of the most valuable fisheries commodities, an ideal product to harvest and sell. No management instruments are actually in place to prevent fishing for these protected sharks either [28]. Strict law enforcement upon the catch of endangered shark species in this area is difficult to be implemented because of this condition.

For over two decades, Indonesia has reported higher average shark landings than any other nation, but very little local information exists on the fishery and life histories of targeted species. This poses severe challenges to shark sustainability and conservation in this vast archipelago. Even across the world, there has not been sufficient specific research on the condition of hammerhead shark stocks using bio-economic models, due to the availability of input data that do not exist in other countries, mainly because of the prohibition of their fishing that were strictly enforced and followed. Most studies on sharks are more about trade and their economic value [29–31]. Other studies only discuss parts of the similar study as this, for example, Sibarani et al., 2019, only discusses the Gordon Schaefer standard model, not including its depreciation and sustainability analysis [32], therefore presenting a calculative review of the sustainability of this species is hoped to benefit international community and/or professionals about this endangered species condition in Indramayu, Indonesia.

This study aimed to illustrate the sustainability of hammerhead sharks in Indramayu waters. One of the ways of maintaining sustainable fisheries and obtaining the maximum economic benefits is by observing the relationship between the efforts of capturing fish resources from biology and economic aspects through bio-economics model, which hopefully could raise concern to re-socialize the prohibition of fishing for hammerhead sharks to law enforcers and fishermen.

2. Materials and Methods

The survey of this research was conducted at the fish landing Base (PPI) Karangsong, Indramayu Regency, West Java, the landing place for most numbers of Scalloped Hammershead sharks in Indramayu. The data collected consists of primary and secondary data, both qualitative and quantitative. The primary data were obtained from interviews of 150 fishermen from the 0–5 GT fleet of ships that caught sharks using fishing nets and fishing rods. The primary data includes shark production, trip, the cost structure of shark fishing effort in each fishing gear, and the fisheries business pattern. Secondary data were obtained from relevant agencies (Indramayu’s fisheries Agency and West Java fisheries Agency) consisting of necessary information, including production data and capture effort of fishing gears in time series, that specifically differ each shark catch as main target or bycatch, using fleet no more than 5 GT from 2006 to 2018. The fleet with less than 5 GT particularly operates within the Indramayu territorial waters.

The fishing gear used was a gill net drift and fishing line. To measure in equal units, standardization efforts are made between devices with standardization techniques by King (1995) [33], where:

$$E_{jt} = \phi_{jt}D_{jt}, \quad (1)$$

$$\phi_{jt} = \frac{u_{jt}}{u_{st}} \tag{2}$$

E_{jt} = Effort of the fishing gear j when standardized at t time,
 D_{jt} = Number of fishing days of the fishing gear j at t time,
 ϕ_{jt} = The value of fishing power of fishing gear j at t time,
 u_{jt} = Catch per unit effort (CPUE) of fishing gear j at t time, and
 u_{st} = Catch per unit effort (CPUE) of the fishing gear used as the basis of standardization [25].

This model estimates biological parameters from Fox (1970) [34], Clarke et al., (1992) [35], Walters & Hilborn (1976) [36], and Schnute (1977) [37]. Each biological parameter, including r , q , and K , was obtained as described in Table 1.

Table 1. Formula for Biology Estimation Model, where, $U_t = h_t/E_t$, r is the intrinsic growth rate, K is the carrying capacity of the environment, q is a coefficient of catchability, E_t is a catch effort, and h_t is the capture rate or pace of retrieval [25–28].

Parameters	Formula
Fox (1970) [34]	$\frac{U_{t+1}-U_{t-1}}{2U_t} = rLn(qK) - rln(U_t) - qln(E_t)$
Clarke et al. (1992) [35]	$ln(U_{t+1}) = \frac{2r}{2+r}ln(qK) + \frac{(2-r)}{(2+r)}ln(U_t) - \frac{q}{(2+r)}(E_t + E_{t+1})$
Schnute (1977) [36]	$ln\left(\frac{U_{t+1}}{U_t}\right) = r - \frac{r}{kq}\left(\frac{U_{t+1}+U_t}{2}\right) - q\left(\frac{E_{t+1}+E_t}{2}\right)$
Walters and Hilborn (1976) [37]	$\left(\frac{U_{t+1}}{U_t}\right) - 1 = r - \frac{r}{kq}U_t - qE_t$

The fish stocks are used as surplus production models which assume fish stock as a summation of biomass:

$$\frac{\partial x}{\partial t} = F(x_t) - h_t, \tag{3}$$

where $F(x_t)$ is the natural growth rate or the rate of addition of biomass assets, and h_t is a functional model to describe biomass stock, in the form of logistics.

$$\frac{\partial x}{\partial t} = r.x_t.\left(1 - \frac{x_t}{K}\right) - h_t. \tag{4}$$

Assume that the rate of capture is linear against biomass and effort:

$$h_t = qE_t x_t. \tag{5}$$

Assuming the equilibrium condition, hence the yield effort-curve:

$$\text{Logistic : } h_t = q.K.E_t - \left(\frac{q^2.K}{r}\right).E_t^2. \tag{6}$$

The above equation can be written as:

$$h = \alpha E - \beta E^2 \rightarrow \alpha = qK, \beta = \frac{q^2 K}{r}. \tag{7}$$

Based on Schaefer’s Model, the best management of the fish resource is when sustainable production is at the highest point of the yield curve effort. This point is known as maximum sustainable yield (MSY). At the output level of MSY, the input required is at E_{my} . Mathematically, this level of input can be determined by solving the first derivative of the equation against effort or:

$$\frac{\partial h}{\partial E} = qK - \frac{2q^2 KE}{r} = 0. \tag{8}$$

or

$$E_{MSY} = \left(\frac{r}{2q}\right) \text{ atau } E_{MSY} = \left(\frac{\alpha}{2\beta}\right). \quad (9)$$

The substitution of this value into the equation will get a catch at the MSY level or equal.

$$h_{MSY} = \left(\frac{rK}{4}\right) \text{ atau } h_{MSY} = \left(\frac{\alpha^2}{4\beta}\right). \quad (10)$$

By knowing of these two values at the MSY level, the level of biomass (stock) at MSY level can be identified:

$$x_{msy} = \frac{h_{msy}}{qE_{msy}} = \frac{(rK/4)}{q(r/2q)} = \frac{K}{2}. \quad (11)$$

To calculate socially optimal management:

$$TC = cE, \quad (12)$$

$$TR = ph = p(\alpha E - \beta E^2) = p\alpha E - p\beta E^2, \quad (13)$$

$$\max \pi = TR(E) - TC(E), \quad (14)$$

$$\frac{\partial \pi}{\partial E} = \frac{\partial TR}{\partial E} - \frac{\partial TC}{\partial E} = \text{slope}TR = \text{slope}TC, \quad (15)$$

where Total Revenue (TR) and Total Cost (TC), and thus optimal effort (Effort MEY), can be produced as follows:

$$E_{MEY} = \left(\frac{\alpha p - c}{2p\beta}\right). \quad (16)$$

And the optimal capture value is:

$$h_{MEY} = \alpha \left(\frac{\alpha - c}{2p\beta}\right) - \beta \left(\frac{\alpha - c}{2p\beta}\right)^2. \quad (17)$$

As for the open-access fisheries regime, it can be determined by calculating the economic rent and lost where $\pi = 0$, then:

$$TC = cE, \quad (18)$$

and

$$TR = ph = p(\alpha E - \beta E^2) = p\alpha E - p\beta E^2, \quad (19)$$

$$\pi = 0, \text{ thus } TR = TC. \quad (20)$$

The value is 2 times, as well as the value of production in the open-access fisheries will be determined by the following formula:

$$E_{OA} = 2.E_{MEY}, \quad (21)$$

$$h_{MEY} = \alpha.E_{OA} - \beta E_{OA}^2. \quad (22)$$

For the analysis of the Gompertz model, the following fish stock dynamics as follows:

$$\frac{\partial x_t}{\partial t} = rx_t \ln \left[\frac{K}{x_t} \right] - h_t. \quad (23)$$

Thus, the sustainable catch curve of the Gompertz model:

$$h_t = qKE_t \exp \left[\frac{-qE_t}{r} \right]. \quad (24)$$

Analysis of the degradation of the capture fisheries resources and its depreciation will be performed as a reflection of the depletion level of the resource using a formula developed by Amman dan Duraiappah (1999) [38], for land case in Kenya, and modified by Anna (2003) and Anna et al. (2017) [39,40], for fisheries as follows:

$$\phi_{Dt} = \frac{1}{\left(1 + e^{\frac{h_s}{h_t}}\right)}, \quad (25)$$

where ϕ_{Dt} is the degradation coefficient in period t , h_t is production in period t , and h_s is sustainable production [38,39]. Depreciation resulting from fishing activities is determined by a formula developed by Anna (2003) [39], as follows:

$$\phi_t = \frac{1}{\left(1 + e^{\frac{\pi_s}{\pi_t}}\right)}, \quad (26)$$

where ϕ_t is depreciation in the period t , π_t is the economic rent in the period t , and π_s is the economic rent in sustainable conditions [39].

3. Results

3.1. The General Condition of Hammerhead Sharks in Indramayu Waters

According to secondary data from Karangsong fish barn and interviews with local fishermen, shark fishing activities in Indramayu water are carried out by fishermen using gillnets and mini purse seine, with the size of the floating gill fleet and the fishing gear is 0–5 GT. 0–5 GT is a ship made from wood with a machine size of 25 HP or outboard engines that serve as a ship drive engine and 8 Hp as a ship moving engine. The operation area is within the Indramayu waters to the surrounding of Biawak Island, Gosong Island, and Cendikia Island. Based on the survey, the fleet of 0–5 GT shark catching will take one-day fishing.

The sharks at the TPI Karangsong were not the target catch, but they got carried away when the fishermen caught other fish, due to the use of gill net and other fishing gears. The fishermen claimed to accidentally catch sharks because the sharks were in the same water as the target fish. The fishermen did not return the caught sharks because the net had been soaked overnight during the hauling process, and the hammerhead sharks had died, so they said that it will be useless to return them into the waters. The results found various types of sharks are still sold freely at the TPI Karangsong, among which are hammerhead shark (*Sphyrna lewini*) and two species of lanyam shark (*Carcharhinus falciformis* and *Carcharhinus amblyrhynchos*). This shows the shark catching is still massive in the Indramayu district, despite the accidental capture.

The hammerhead sharks caught in Indramayu waters were young hammerhead sharks below 100 cm. The size of the hammerhead shark can reach 370–420 cm; when a male hammerhead reaches adulthood, it is ready to reproduce at sizes between 165 and 175 cm [14]. The price of hammered shark is pegged at IDR 15,000 per kg, while its fins can reach IDR 200–300 thousand per kg. High demand for sharks, especially shark fins, resulted in increasingly widespread fishing to hunt the species. The productions of hammerhead sharks are presented in Figure 1. In general, the average catch of hammerhead sharks experienced fluctuations from 2006 to 2018. Figure 2 illustrates the Catch Per Unit Effort (CPUE) for hammered sharks. The CPUE represents the productivity value of the gill net and fishing line.

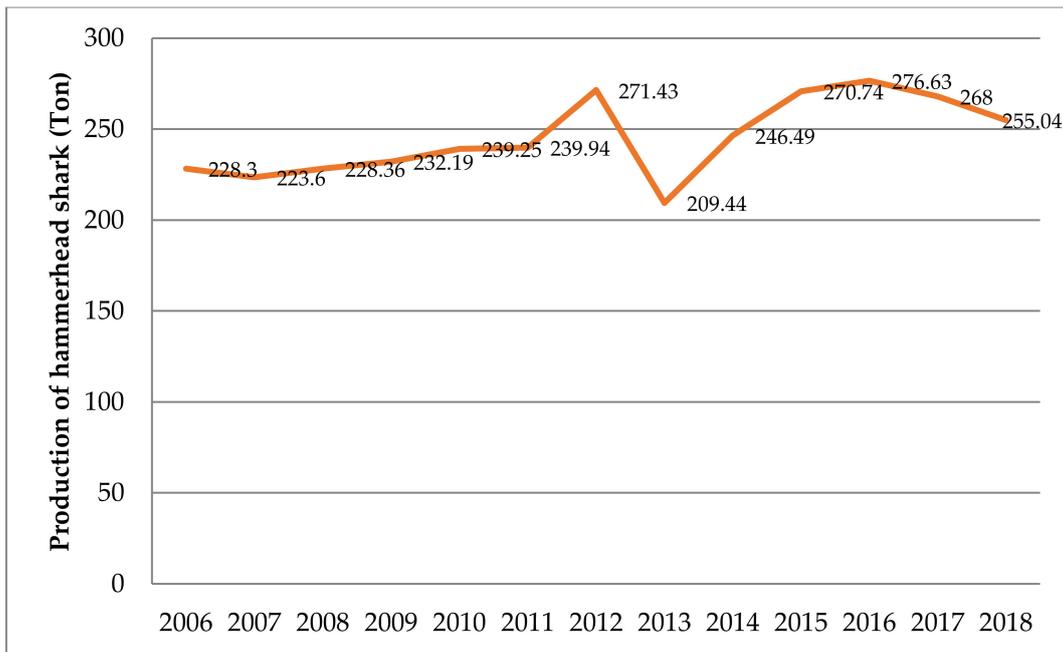


Figure 1. Production of hammerhead shark in Indramayu waters, Indonesia, in tons per year from 2006 to 2018. Diagram was made using Microsoft Excel with production of hammerhead shark in Indramayu waters datas gathered by Indramayu’s fisheries Agency and West Java fisheries Agency.

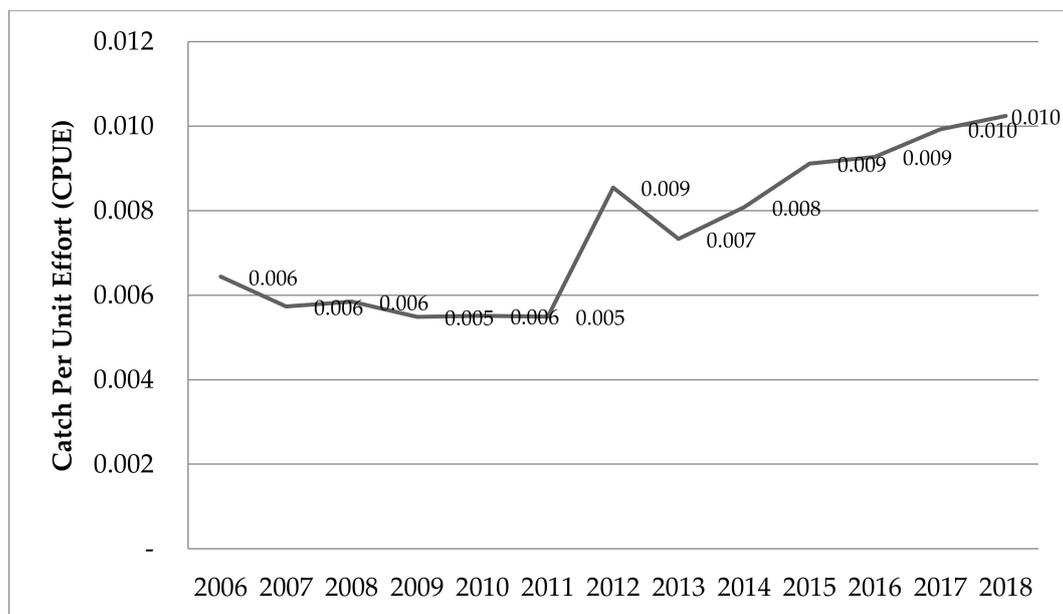


Figure 2. Catch Per Unit Effort (CPUE) of hammerhead sharks in Indramayu waters from 2006 to 2018. Diagram was made using Microsoft Excel with production of hammerhead shark in Indramayu waters datas gathered by Indramayu’s fisheries Agency and West Java fisheries Agency. The CPUE represents the productivity value of the gill net and fishing line.

Biological estimation of hammerhead sharks was using 4 models [39,40]—Fox algorithm model [34], CYP model [35], Walter Hilborn model [36], and Schnute model [37]. The estimated biological parameters include intrinsic growth rate (r), catchability coefficient (q), and the environmental carrying capacity (K). The regression results are presented in Table 2.

Table 2. Regression results for all biological parameter models of hammerhead shark.

Model	R Square	Multiple R
CYP	0.789	0.888
Fox Algorithm	0.859	0.927
Walter Hilborn	0.077	0.277
Schnute	0.455	0.675

The Fox algorithm has the best R square value. The selection of the four possible models allows predicting and describing of the condition of shark resource utilization in Indramayu waters. The estimation of biological parameters using the four models produced the following biological parameter values that can be seen in Table 3.

Table 3. Estimation of biological parameters for 4 models.

Parameter	Fox Algorithm	CYP	Walter-Hilborn	Schnute
Intrinsic Growth Rate (r)	0.2054	2.993	0.3583	1.824
Environmental Carrying Capacity (K) ton	4435.92	207.995	928.501	555.643
Catchability Coefficient (q)	0.0000032	0.000106	0.000014	0.000030

The value of biological parameters using the Fox algorithm model as follows:

- Intrinsic growth (r) of 0.205 means that hammerhead sharks resources in Indramayu waters will grow naturally without any disruption neither natural symptoms nor human activity by 20.5% per year.
- Catchability coefficient (q) of 0.0000032 means that any increase in the catch effort unit will have an effect of 0.0000032 kg per trip.
- The environmental carrying capacity (K) of 4435.92 tons shows the ability of the Indramayu marine ecosystem to support the production of hammered shark resources by 4435.92 ton per year.

Figure 3 illustrates the utilization pattern of hammered sharks in Indramayu waters in actual conditions from 2006 to 2018, where the years show that they have exceeded the number of captures of sustainable production.

3.2. Optimization Model of Hammerhead Shark Fisheries Resources

The sustainable and optimal value has achieved if Fox Algorithm and CYP models are considered to have the best fit compared to other models [39]. The analysis resulted in the optimal value of h , E , x , and π in various management regimes, namely Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access (OA), using Gordon Schaefer Model (Table 4).

Table 4. Sustainable value, optimal fisheries and open access for hammerhead sharks in Indramayu waters.

Variable	Management Regime					
	GS Model			Gompertz Model		
	MSY	MEY	OA	MSY	MEY	OA
Production (h) (Ton)	227.78	221.63	125.15	229.01	222.02	147.96
Effort (E) (Trip)	32,093	26,818	53,636	28,235	21,774	63,414
Biomass (x) Ton	2217.96	2582	729.16	76.51	104	22
Profit (pi) IDR (million)	2293	2.385	0	2,446	2568	0

The management of fish resources was initially based on biological aspects [41]. The essence of MSY is to harvest fishery resources that exceed the production capacity (surplus), so the stock of fish

will be able to survive sustainably. The condition of the hammerhead shark fisheries for biologically sustainable management in the MSY regime is the highest at 227.78 tons; catching less than 227.78 tons will remain sustainable (Table 3).

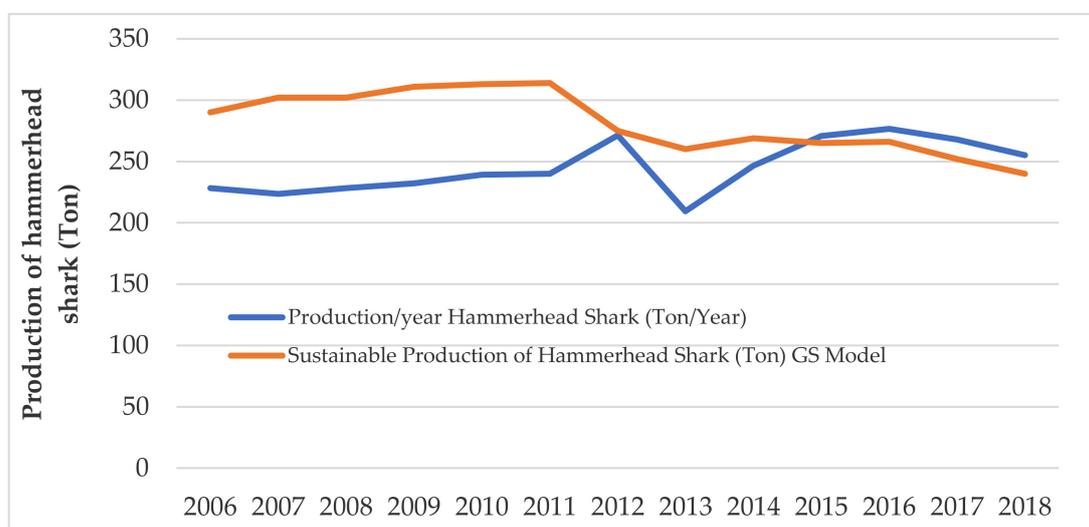


Figure 3. Actual production conditions and sustainable production of hammerhead sharks in tons per year from 2006 to 2008 of Gordon Schaefer Model with the estimation using Fox Algorithm in Indramayu waters. Diagram illustrates the utilization pattern of hammered sharks in Indramayu waters based on actual conditions from 2006 to 2018.

3.3. Depletion and Depreciation of the Actual Conditions of Hammerhead Sharks in Indramayu Waters

The hammerhead fishing condition in Indramayu waters has experienced depletion in 2012, where it was the highest production peak throughout the observation year (Table 5). The depletion of the hammerhead shark fisheries also occurred in 2006 and in the last years of observation, i.e., 2016, 2017, and 2018. The highest depletion occurred in 2017, with a depletion value of 16 ton and depreciation value minus IDR 164 million. In this condition, the missing value was due to the depletion of the shark resources caused by many factors; among them were overfishing triggered by fishing gear that catches all sizes and types of shark.

Table 5. Depletion value and depreciation of hammerhead shark fisheries resources in Indramayu waters.

Year	Total Standard Effort (Trip)	Actual Production (tons)	Sustainable Production (tons)	Depletion (tons)	Depreciation (Million IDR)	Depletion Rate
2006	35,477	228	290	61	618	−0.02
2007	39,004	224	302	78	783	0.02
2008	39,065	228	302	73	737	0.02
2009	42,318	232	311	79	789	0.03
2010	43,403	239	313	74	744	0.00
2011	43,692	240	314	74	744	0.13
2012	31,749	271	275	3	34	−0.25
2013	28,571	209	260	50	507	0.15
2014	30,494	246	269	23	228	0.10
2015	29,694	271	265	−5	−53	0.02
2016	29,825	277	266	−11	−106	−0.04
2017	26,998	268	252	−16	−164	−0.05
2018	24,900	255	240	−15	−153	−0.04

4. Discussion

Following the production, CPUE and utilization diagrams (Figures 1–3) has shown an increasing number of catch per year, explained in that the massive catch is increasing each year. Utilization pattern of hammerhead sharks in Indramayu waters shows that it has exceeded the number of captures of sustainable production, which means that the utilization of hammerhead shark resources in Indramayu waters has experienced biological overfishing; therefore, the condition of shark fisheries may potentially cause the depletion of fisheries resources.

The utilization of fish resources was considered overfishing when actual utilization has exceeded the sustainable catches and sustainable fishing efforts and no longer provides favorable revenue. The catching effort exceeded the maximum sustainable condition indicates more economic capture or economic overfishing. Given the hammerhead sharks is categorized under Endangered Species according to IUCN 2007 [24], it is necessary to strictly supervise hammerhead sharks to maintain the population. If the catching effort made is more than the permitted number, it can cause overfishing and then leads to an unsustainable condition.

In the OA condition, 125 tons is the lowest production, where the Total Cost and Total Revenue obtained are equal, no economic rent ($\pi = 0$). OA results in economic inefficiencies due to large fishing efforts and smaller catch. In other words, productions smaller than the fishing effort equals an inexistence of profits. This condition will lead to a decrease in hammerhead shark population due to excessive harvesting of resources (overfishing), and economic rent will suffer losses. The condition also will reduce the stock that later resulted in declining and unsustainable population.

The MEY management regime required less catching effort compared to others to produce maximum profit levels. MEY condition shows the highest economic rent, where biomass ability to recover is higher than harvesting, therefore shark resources will sustain until the carrying capacity of the ecosystem in which it occupies is achieved. The high economic rent of MEY relates to the high CPUE so that in one attempt of fishing effort gets abundant resources. Table 5 explains the continuous increase of CPUE value, which means that the fishing gears used in fisheries activities are getting more efficient in catching hammerhead shark throughout the year, which should be suspected, because of the low—or none—government supervision of fishing gears or hammerhead catch, in general, which might be the biggest cause of the CPUE value to increase. Hypothetically, no one gets to confirm whether the fishing gears used by fishermen were used accordingly; with no modification, that would increase the fishing amount of hammerhead shark as to gain more number of hammerhead shark catches due to its worth.

In the Gompertz model, each hammerhead shark management regime is not much different from the dynamics gained in the GS model, where the management in the MEY regime has the highest efficiency and more conservative biomass management. Optimization to maintain sustainability of hammerhead shark could be done by increasing the biomass management using MEY-MSY model, but that should not be the way to solve the problem because, initially, hammerhead shark is prohibited to be caught at all. A clear regulation and law enforcement in this situation are strictly needed, and that is the only way to solve the depleting numbers of hammerhead sharks in Indramayu waters.

The depletion is interpreted as the rate of reduction in the stock of natural resources (non-renewable resources); in this case, there is a decrease in the stock of natural resources far above the rate of the decline, or the exploitation is higher than it should be. A negative value on depletion means that actual production is higher than the level of sustainable production and has the potential loss of rent from shark fisheries. Based on the result, depletion rate happened in 4 out of 12 years calculation, with the highest depletion value occurring in 2017, with a depletion value of 16 ton and depreciation value minus IDR 164 million, which means a there is a chance of depletion rate happening to 3 different years per decade, and, without a proper law enforcement, the chances could go higher. From 2016, 2017, and 2018, it could be seen that there was depletion in hammerhead shark stock value that reached 15 tons and above due to the increasing number of production that is visibly uncontrollable, proving the negligence of law enforcement and government supervision.

Indonesian government has issued regulations regarding the export of hammerhead shark products from Indonesian territory both fresh or processed products (please refer to Regulation of The Minister of Marine and Fishery of The Republic of Indonesia Number 5/Permen-Kp/2018 Concerning the Prohibition of Oceanic Whitetip Shark (*Carcharhinus longimanus*) and Hammerhead Shark (*Sphyrna* sp.) expenditure from the state region of the Republic of Indonesia). Unfortunately, these regulations only prohibit the release of hammerhead shark products from Indonesian territory and do not manage or prevent the production of hammerhead shark for domestic trade. Although the Government of the Republic of Indonesia has issued regulations regarding the prohibition of hammerhead sharks to prevent domestic trade of this species, studies shows that hammerhead production increase from year to year in Indramayu water and reaches 255 tons in 2018. In the regulations related to article 85, every person who deliberately owns, controls, carries, and/or uses fishing gear and or fishing aids that interfere and damage the sustainability of fish resources in the Indonesian fisheries area, referred to in article 9, will be sentenced to prison with a maximum of five years and a fine with maximum amount of Rp. 2 billion. Yet, the reality shows that illegal catches are still rampant so that even the sharks protected by this law were landed on the formal fishing ports with no legal actions.

Although this regulation may not be the same for each country and the implementations of the policies regarding this matter were executed differently, several basins around the world have reportedly experienced decline of the same species with quite similar reasons. Based on these findings, it is known that artisanal fisheries and less strict policies have been the problem faced around the world in maintaining the sustainability of hammerhead shark. Policies that should be enforced firmly are the prohibition of fishing of hammerhead sharks and law enforcement to prevent it. There is also a need for a domestic ban on consumption of these types of fish, as well as an ongoing campaign to ban consumption due to a decline of shark stocks in the sea.

5. Conclusions

Hammerhead sharks in Indramayu waters have exceeded the number of catches according to MEY-MSY formula in 2012, 2014, 2015, 2016, 2017, and 2018, exceeding sustainable production which means utilization of hammerhead shark resources experienced biological overfishing. The depletion rate of hammerhead shark in Indramayu waters also has experienced the highest production peak throughout the observation years. The continuous increase in CPUE value shows that the fishing gear used gets even more efficient each year; this should be a concern on whether the fishermen use different fishing gears or modify their fishing gears to increase the catch rate of hammerhead sharks, making it even harder to confirm a bycatch case of the species. It is feared that massive fishing will lead to overfishing and depletion of this species in Indramayu waters, which will lead to ecosystem instability. Prohibition of consistent fishing and more pronounced law enforcement for hammered shark fishing are needed, so that the sustainability of this resource can be maintained.

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