Yield per Recruit and Spawning per Recruit of Brownbanded Bamboo Shark, *Chiloscyllium punctatum* in Southeast Asia

Supapong Pattarapongpan[1, 2], Sukchai Arnupapboon[2], Ahmad Ali[3] and Matsuishi Takashi Fritz[4*]

ABSTRACT

The brownbanded bamboo shark (*Chiloscyllium punctatum*) is a benthic shark species distributed in Southeast Asia. The species has been listed as "Near Threatened" by the IUCN, but only based on indirect information. In this study, yield per recruit (YPR) and spawning per recruit (SPR) analyses were conducted to determine the current stock status. Data were obtained from three major landing sites of this species: Sihanoukville, Cambodia (Sv); Songkhla, Thailand (Sk); and Kota Kinabalu, Malaysia (KK). The von Bertalanffy growth curve parameters L_∞ and K were estimated as 81.62 cm and 0.37 year^{-1} for Sv, 88.09 cm and 0.51 year^{-1} for Sk, and 86.48 cm and 0.40 year^{-1} for KK. The YPR and SPR analyses showed that the F_{curr}, $F_{0.1}$, and $F_{30\%}$ were 0.29, 0.26, and 0.21 year^{-1} for Sv; 0.39, 0.23, and 0.23 year^{-1} for Sk; and 0.06, 0.24, and 0.24 year^{-1} for KK. The results indicate that the fishery for brownbanded bamboo sharks in KK is efficient and sustainable, but in Sv and Sk, harvest is nearing inefficiency, and fishing mortality cannot sustainably be increased from the current level. Some fisheries management measures are recommended for the sustainability of these stocks.

Keywords: Brownbanded bamboo shark, BRPs, Per recruit analysis, Southeast Asia, Stock assessment

INTRODUCTION

The brownbanded bamboo shark (*Chiloscyllium punctatum*) is the largest member of the family Hemiscylliidae found in Southeast Asian waters, with the maximum recorded total length of over 140 cm. This shark species plays an important role in marine ecosystems by controlling the populations of small teleosts and invertebrates in coastal and coral reef areas (Ahmad and Lim, 2012; Krajangdara, 2017). Brownbanded bamboo sharks are caught by various kinds of fishing gear such as bottom trawls and gillnets, in traditional and commercial-scale fisheries, both for local consumption and for sale in the aquarium trade (Krajangdara, 2014; Dharmadi *et al*., 2015; Dudgeon *et al*., 2016).

Elasmobranchs are known to have low resilience to fishing activity due to their slower growth rate and smaller number of offspring compared to other teleost fish. Regarding their conservation status, the International Union for Conservation of Nature's Red List of Threatened Species (IUCN Red List) categorized the brownbanded bamboo shark as "Near Threatened" as recently as 2015, but without scientific stock assessments. The decision was based only on the rapid decline of total shark landings within the previous decade (Krajangdara, 2014; Dudgeon *et al*., 2016).

Previous inappropriate efforts at data collection make the status of this species unclear (Reuter *et al*., 2010). For example, the lack of

[1]Graduate School of Fisheries Sciences, Hokkaido University, Hokkaido, Japan
[2]Southeast Asian Fisheries Development Center/ Training Department, Samut Prakan, Thailand
[3]Southeast Asian Fisheries Development Center/ Marine Fishery Resources Development and Management Department, Terengganu, Malaysia
[4]Global Center for Food, Land and Water Resources, Faculty of Fisheries Sciences, Hokkaido University, Hokkaido, Japan
* Corresponding author. E-mail address: catm@fish.hokudai.ac.jp
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taxonomic skills has led to poor species identification and inaccurate catch information. Additionally, data on shark landings have not been collected annually in some areas. To respond to this situation, the Southeast Asian Fisheries Development Center (SEAFDEC), a regional inter-governmental organization, conducted a data collection project on elasmobranchs, including sharks, rays, and skates. This project aimed to improve data collection procedures and species identification techniques for elasmobranchs in the region during 2015-2016 as an attempt to conduct scientifically based fishery management (Wanchana *et al*., 2016).

For data-poor fisheries, where age determination is very difficult and long-term catch and effort series are not available, "per-recruit" analyses such as yield per recruit (YPR) and spawning per recruit (SPR) models can provide biological reference points (BRPs) based on limited data (Goodyear, 1993; Sparre and Venema, 1998; Noranarttragoon *et al*., 2011). In the case of YPR analysis, the BRPs provide indicators of "growth overfishing," when the fish stock cannot produce the maximum yield under the fishing pressure at that time. For SPR, BRPs provide indicators of "recruitment overfishing," which is unsustainable because the number of spawners remaining in the stock after harvest is insufficient for producing the next generation (Goodyear, 1993; Chen *et al*., 2007).

This study aims to investigate the stock status of brownbanded bamboo shark in Southeast Asia by using YPR and SPR analyses as growth and recruitment overfishing thresholds, respectively.

MATERIALS AND METHODS

Data collection

This study uses secondary data from the "Regional Sharks, Rays and Skates Data Collection" project, conducted during 2015-2016. All species were identified by SEAFDEC biologists or well-trained local experts following the Standard Operation Procedures (SEAFDEC, 2017). Data were collected from the commercial otter board trawl fishery landing sites in Sihanoukville, Cambodia (Sv); Songkhla, Thailand (Sk); and Kota Kinabalu, Malaysia (KK) (Figure 1), where *C. punctatum* represents 40 % of all elasmobranch landings (Wanchana *et al*., 2020).

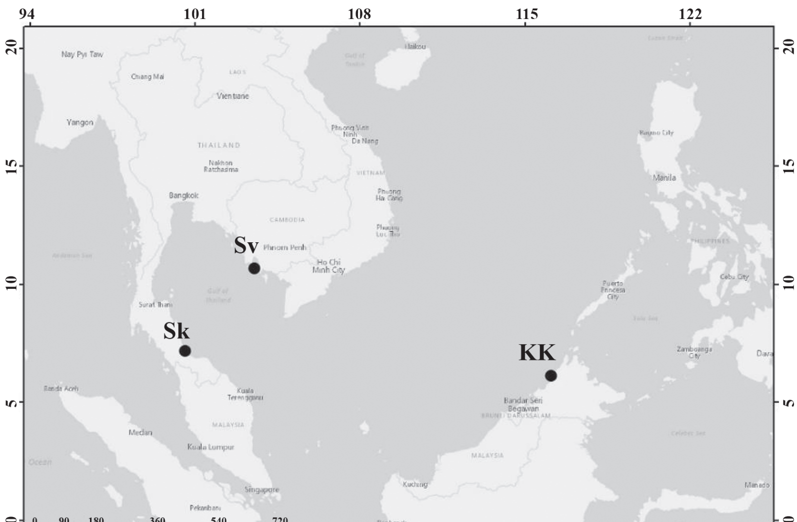

Figure 1. Sampling sites of brownbanded bamboo sharks: Sihanoukville, Cambodia (Sv), Songkhla, Thailand (Sk), and Kota Kinabalu, Malaysia (KK).

Length-weight relationship

The parameters used in the length-weight relationship shown in Equation 1 (Ricker, 1975) were estimated using linear regression after logarithmic conversion.

$$W = \alpha TL^{\beta} \quad (1)$$

Parameter symbols used in all equations are defined in Table 1.

Differences between sex and among sampling areas were tested for statistical significance from the log-linear transformation of Equation 1 using the R package 'FSA' provided by Ogle *et al.* (2016).

Table 1. Summary of parameter symbols used in equations in this study.

Symbol	Description
Φ'	Growth performance index
α	Condition factor for length-weight relationship
a	Intercept of the linear regression for the observed probability of capture
a'	Intercept of the linear regression for the estimated probability of capture
β	Regression factor for length-weight relationship
b'	Regression factor for the estimated probability of capture
c	Intercept of the linear regression for total mortality estimation
$C_{L1,L2}$	Number of fish caught at length interval between L_1 and L_2
E	Exploitation ratio
F	Fishing mortality (year^{-1})
F_{curr}	Fishing mortality of current situation (year^{-1})
$F_{0.1}$	Fishing mortality produced from the 10 % of the tangent of YPR curve (year^{-1})
F_{max}	Fishing mortality produced from the peak of YPR curve (year^{-1})
$F_{X\%}$	Fishing mortality that spares X% of spawning stock (year^{-1}) as $F_{30\%}$ and $F_{20\%}$
K	vBGC parameter (year^{-1})
M	Natural mortality (year^{-1})
mL	Mid-length between length interval (cm)
L_1 and L_2	Lower and Upper length interval (cm), respectively
L_{25}, L_{50}, L_{75}	Length at 25, 50, and 75 % selectivity, respectively
L_m, t_m	Length at first maturity (cm) and age at first maturity (year), respectively
L_r, t_r	Length at recruitment (cm) and age at recruitment (year), respectively
L_t	Length (cm) at age t (year)
L_∞	vBGC parameter (average maximum length) (cm)
S_t, S_t'	Observed and Estimated selectivity, respectively
TL	Total length (cm)
$\Delta t_{L1,L2}$	Difference in age between length L_1 and L_2 (year)
t_λ	Age endpoint (year)
t_{max}	Maximum age (year)
t_{mL}	Age at mid-length from length interval (year)
t_0	vBGC parameter (theoretical age at length 0) (year)
t_c	Age at first capture (year)
t_L	Age at length L (year)
W_∞	Average maximum weight (kg)

Growth parameters estimation

The von Bertalanffy growth curve is expressed as:

$$L_t = L_\infty \left(1 - e^{-K(t-t_0)}\right) \quad (2)$$

The parameters L_∞, K, and t_0 were estimated by electronic length-frequency analysis incorporated with the genetic algorithm ELEFAN_GA provided in TropFishR (Taylor and Mildenberger, 2017). The program searches for the best combination of L_∞ and K in a broader randomized manner by using the genetic algorithm, which is an optimising method inspired by genetic mutation and selection found in evolution (Scrucca, 2013). It is expected to find better growth parameters more quickly than previous algorithms even if the sample is small and data are not continuous (Mildenberger *et al*., 2017). The number of iterations for ELEFAN_GA was set as 1,000 as recommended, and the initial value for L_∞ was based on the estimator from Powell-Weatherall's method, in which the initial value for L_∞ is estimated from the ratio between the intercept and the slope of the curve between L' and $L - L'$ (Powell, 1979).

The inverse of von Bertalanffy's growth function (Mackay and Moreau, 1990) was used for age estimation:

$$t = t_0 - \left(\frac{1}{K}\right) \ln\left(1 - \frac{L_t}{L_\infty}\right) \quad (3)$$

Using the growth parameters from von Bertalanffy's growth equation, the growth performance index (Φ') can be calculated (Pauly and Munro, 1984) and used for comparison of growth curves between the same species or species with similar body shape. This index was calculated by the following equation:

$$\Phi' = \log K + 2 \log L_\infty \quad (4)$$

Estimation of mortality, gear selectivity, and maturation size at age

The length-converted catch curve (Pauly, 1983; 1984) was applied to estimate mortality and gear selectivity by utilizing the size frequency of the sample in each length class to estimate the negative slope of the catch curve as the total mortality.

Total mortality (Z) was estimated from a linear regression using Equation 5:

$$\ln \frac{C_{L1,\,L2}}{\Delta t_{L1,\,L2}} = c - Z t_{mL} \quad (5)$$

Where t_{mL} was estimated from *mL*, which is the middle length between L_1 and L_2, by using Equation 3.

The difference in age between upper and lower intervals ($\Delta t_{L1,\,L2}$) was calculated using Equation 6:

$$\Delta t_{L1,\,L2} = \frac{1}{K} \ln\left(\frac{L_\infty - L_1}{L_\infty - L_2}\right) \quad (6)$$

Natural mortality (M) was estimated using Tanaka's equation (Tanaka, 1960):

$$M = \frac{2.5}{t_{max}} \quad (7)$$

Where t_{max} is the maximum age (year). The t_{max} was estimated based on the maximum body length in the sample and using Equation 3.

Fishing mortality (F) was estimated by subtracting M from Z. The exploitation ratio (E) was estimated from the ratio F/Z.

The observed selection ogive (S_t) was estimated using Equation 8:

$$S_t = \frac{C_{L1,\,L2}}{\Delta t_{L1,\,L2}\, e^{a - Z t_{mL}}} \quad (8)$$

and the estimated selection ogive (S_t') was calculated using Equation 9:

$$S_t' = \frac{1}{1 + e^{a' + b'}} \quad (9)$$

Catch selectivity was parameterized by L_{25}, L_{50}, and L_{75}. The results are provided by age and converted to length. Size selectivity for YPR and SPR analyses was assumed to be knife-edge at L_{50}. The L_{50} and the length at first maturity (L_m) were converted to t_c and t_m using Equation 3.

The value of L_m was assumed to be 65 cm, based on previous studies (Ahmad and Lim, 2012; Dudgeon *et al*., 2016; Krajangdara, 2017).

Sensitivity test

A sensitivity test for the effect of growth parameters L_∞ and K, and of t_{max} on the estimate of current fishing mortality (F_{curr}) was performed by varying the parameters by ±1, 3, and 5 %, independently.

Per-recruit analysis

YPR was calculated via Equation 10, expressed as:

$$\frac{Y}{R} = FW_\infty e^{-M(t_c - t_r)} \times \sum_{n=0}^{3} \frac{A_n e^{-nK(t_c - t_0)}}{F+M+nK} \left\{1 - e^{-(F+M+nK)(t_\lambda - t_c)}\right\} \quad (10)$$

$$\begin{Bmatrix} n & = & 0, & 1, & 2, & 3 \\ A_n & = & 1, & -3, & 3, & -1 \end{Bmatrix}$$

The value of t_λ for YPR and SPR was assumed to be 20 years to include the possible maximum age of the species (Dudgeon *et al*., 2016). W_∞ was calculated by substituting L_∞ into Equation 1.

SPR analysis was conducted using the following equations:

For $t_c \leq t_m$,

$$SPR = W_\infty e^{-M(t_c - t_r) - (F+M)(t_m - t_c)} \sum_{n=0}^{3} A_n e^{-nK(t_m - t_0)} \left\{\frac{1 - e^{-(F+M+nK)(t_\lambda - t_m)}}{F+M+nK}\right\},$$

For $t_c > t_m$,

$$SPR = W_\infty e^{-M(t_m - t_r)} \sum_{n=0}^{3} A_n e^{-nK(t_m - t_0)} \left\{\frac{1 - e^{-(M+nK)(t_c - t_m)}}{M+nK}\right\} + W_\infty e^{-M(t_c - t_r)} \sum_{n=0}^{3} A_n e^{-nK(t_c - t_0)} \left\{\frac{1 - e^{-(F+M+nK)(t_\lambda - t_m)}}{F+M+nK}\right\} \quad (11)$$

$$\begin{Bmatrix} n & = & 0, & 1, & 2, & 3 \\ A_n & = & 1, & -3, & 3, & -1 \end{Bmatrix}$$

The %SPR was estimated from Equation 12:

$$\%SPR = 100\ \% \times \frac{SPR}{SPR_{F=0}} \quad (12)$$

Biological reference points (BRPs)

The reference points for YPR were $F_{0.1}$ and F_{max} (Chen *et al*., 2007). F_{max} provides the fishing mortality (F) which maximizes the yield at the given age at first capture and assumes constant recruitment. $F_{0.1}$ is a precautionary reference point for F where the slope of the YPR curve is 10 % of the slope at the origin (Goodyear, 1993; Zhou *et al*., 2020). $F_{0.1}$ is referred to as a target BRP, which isthe recommended upper limit of fishing mortality considering the uncertainties of the estimations. F_{max} is referred to as a limit BRP, which is the upper limit without considering the uncertainties.

For SPR, the BRPs were provided as X% SPR, the fishing mortality producing X% of the expected spawning stock biomass per recruit in the absence of fishing (Goodyear, 1993). The critical level is usually set in the range of 20-30 %. Zhou *et al*. (2020) noted that the $F_{\%SPR}$ for elasmobranchs should be higher than for teleosts. Thus, values for $F_{30\%}$ and $F_{20\%}$ were used as target and limit BRPs, respectively.

RESULTS

The total landings of brownbanded bamboo sharks were highest in Sv (7,282 kg), followed by Sk (3,875) and KK (2,201 kg). Among the elasmobranchs in the catch, brownbanded bamboo shark accounted for 52.36, 43.78, and 18.76 % by weight for Sv, Sk, and KK, respectively.

The mean total lengths of brownbanded bamboo sharks at Sv, Sk, and KK were 58.60±13.77, 55.78±14.68, and 74.38±11.06 cm, respectively, with sample sizes of 709, 2,704, and 957 individuals. The numbers of brownbanded bamboo sharks by length class at the three landing sites are shown in Figure 2.

Length-weight relationship

Estimates of the length-weight relationship parameters by landing site for brownbanded bamboo sharks are shown in Table 2. Significant differences were found among areas (p-value<0.001) but not between sexes.

Growth, mortality, and gear selectivity

The initial values of L_∞ were set as 78.82, 87.25, and 86.66 cm for Sv, Sk, and KK, respectively. The estimated growth parameters, mortality, and size and age at first capture are provided in Table 3. The growth curves fitted to the length-frequency data are shown in Figure 3.

The gear selectivity estimations were conducted separately for each of the landing sites and are presented in Table 4 and Figure 4.

Analysis of gear selectivity shows that the values for L_{25} and L_{75} were highest for brownbanded bamboo sharks caught at KK, followed by those from Sv and Sk. Estimates of this range were 53.10-57.90 cm for KK, 35.78-42.89 cm for Sv, and 26.28-34.26 cm for Sk. The length at first capture at Sv was slightly larger than at Sk, and largest at KK.

The results of the sensitivity test for F_{curr} to variation in L_∞, K, and tmax are provided in Figure 5. The sensitivity analysis shows that F_{curr} varies directly in response to these three parameters. However, parameter K produces the highest variation in Fcurr (approximately 8 % in the case of a 5 % difference in K) compared to other variables, while a change in tmax produces the smallest variation (approximately 3 % for a 5 % difference in K).

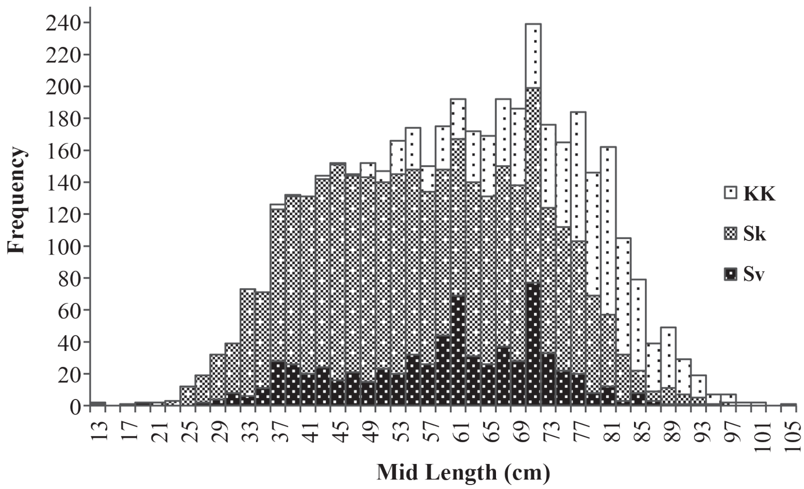

Figure 2. Length frequency of brownbanded bamboo sharks captured in three fishing grounds. Abbreviations KK, Sk and Sv are landing sites as detailed in Figure 1.

Table 2. Length-weight relationship parameters of brownbanded bamboo shark sampled at three landing sites (KK, Sk, Sv, as in Figure 1) from 2015 to 2016.

Landing site	α	β	95 % C.I.	r^2
Sv	6.90×10^{-6}	2.87	(2.81–2.95)	0.89
Sk	2.12×10^{-6}	3.15	(3.13–3.17)	0.97
KK	1.90×10^{-6}	3.15	(3.10–3.21)	0.93

Table 3. Estimated growth parameters for brownbanded bamboo shark at three landing sites (KK, Sk, Sv, as in Figure 1).

Landing site	L_∞	K	t_0	Φ'	Z	t_{max}	M	F	E	L_{50}	t_c
Sv	81.62	0.37	-0.43	3.39	0.54	10	0.25	0.29	0.54	39.49	1.36
Sk	88.09	0.51	-0.29	3.39	0.64	10	0.25	0.40	0.63	30.41	0.54
KK	86.48	0.40	-0.37	3.48	0.22	15	0.17	0.06	0.26	55.59	2.20

Table 4. Gear selectivity estimates of brownbanded bamboo shark from the three landing sites (KK, Sk, Sv, as in Figure 1).

	Sv	Sk	KK
L_{50} (cm TL)	39.49	30.41	55.59
t_{50} (year)	1.36	0.54	2.20

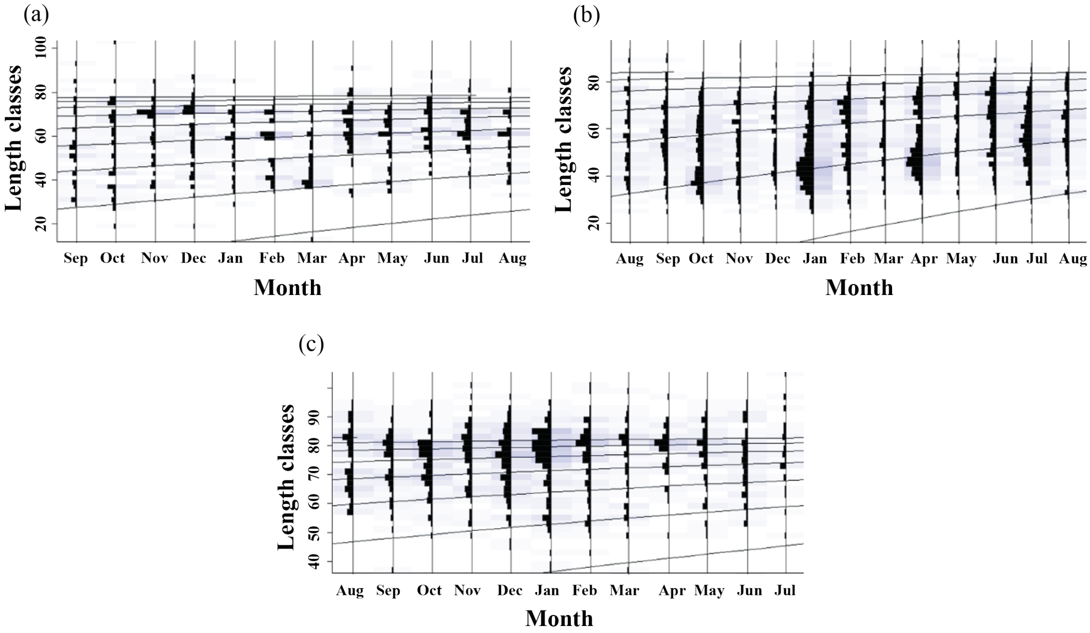

Figure 3. Growth curves of brownbanded bamboo shark fitted to monthly length-frequency data from three landing sites: Sv (a), Sk (b), and KK (c). The x-axis is month and y-axis is length class.

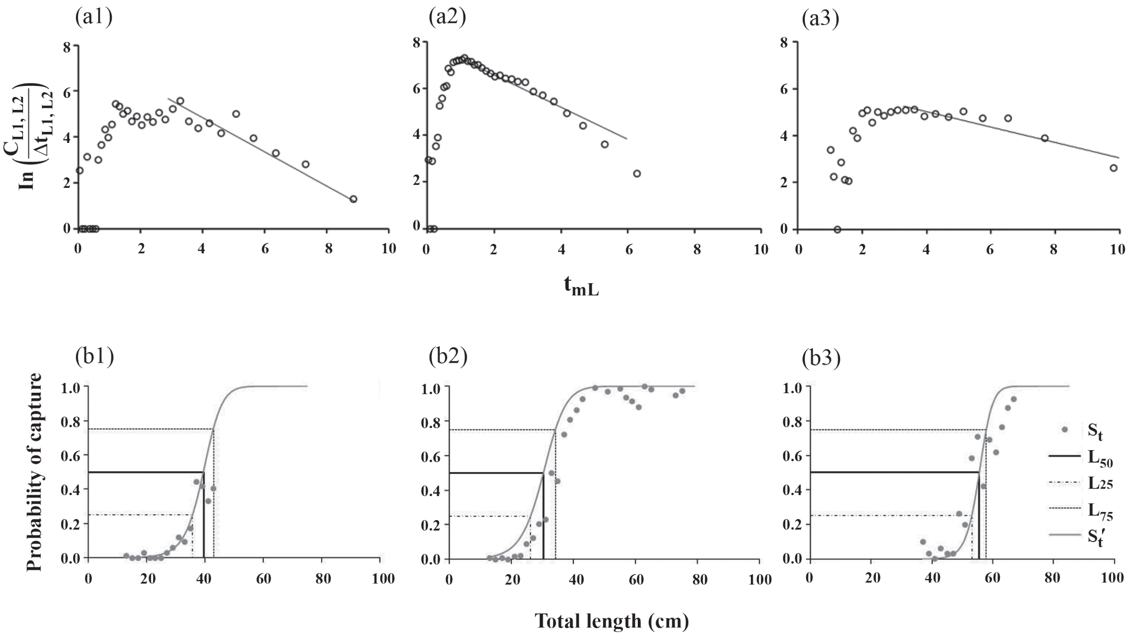

Figure 4. Catch curves of brownbanded bamboo shark by area (a), and selectivity curves by area (b) for Sv (1), Sk (2), and KK (3), where S_t, is the observed selection ogive and S_t' is the estimated selection ogive. The regression lines on the catch curves were used for the estimation of total mortality (Z). KK, Sk and Sv are landing sites as detailed in Figure 1.

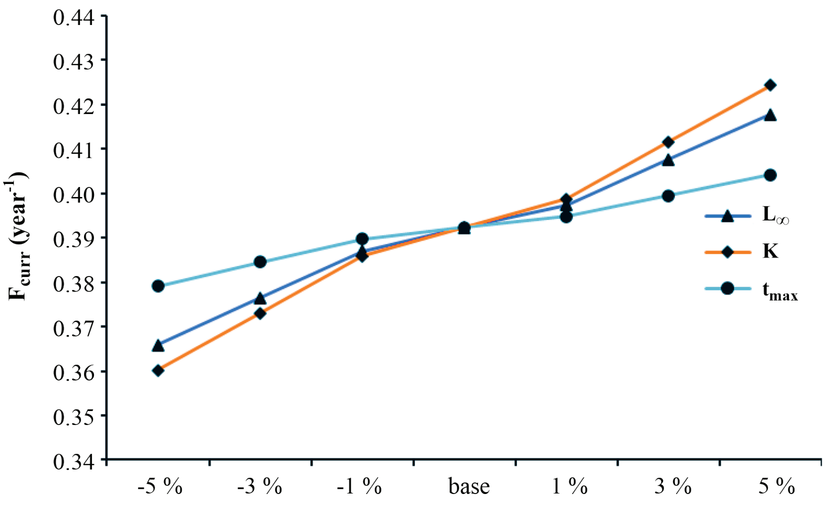

Figure 5. Sensitivity of Fcurr to variation in three parameters, L_∞ and K, and t_{max}.

Per-recruit analysis and implementation

The parameters t_m and t_r were estimated from values of L_m from literature and L_r from the smallest size caught in each area. These estimates were 3.87 and 1.15 years for Sv, 2.64 and 0.00 years for Sk, and 3.11 and 0.98 years for KK, respectively. The surface plots for YPR and SPR analyses for the three landing sites are displayed in Figure 6. The results show that the current fishing mortality exceeds the BRPs for YPR ($F_{0.1}$) at Sv and both $F_{0.1}$ and F_{max} at Sk, but not at KK. For SPR, only the current fishing mortality at KK is below all of the BRPs (20 % and 30 % SPR), as presented in Table 5.

For the fishery at Sv, F_{curr} exceeds $F_{0.1}$, $F_{30\%}$, and $F_{20\%}$ by 11.5, 40.3, and 0.02 %, respectively, but is still 33.7 % lower than F_{max}. At Sk, F_{curr} exceeds all of the reference points, $F_{0.1}$, F_{max}, $F_{30\%}$, and $F_{20\%}$, by 69.8, 15.5, 73.6, and 22.8 %, respectively. In contrast, F_{curr} at KK is smaller than all the reference points, $F_{0.1}$, F_{max}, $F_{30\%}$, and $F_{20\%}$, by 75.9, 88.0, 75.5, and 83.4 %, respectively.

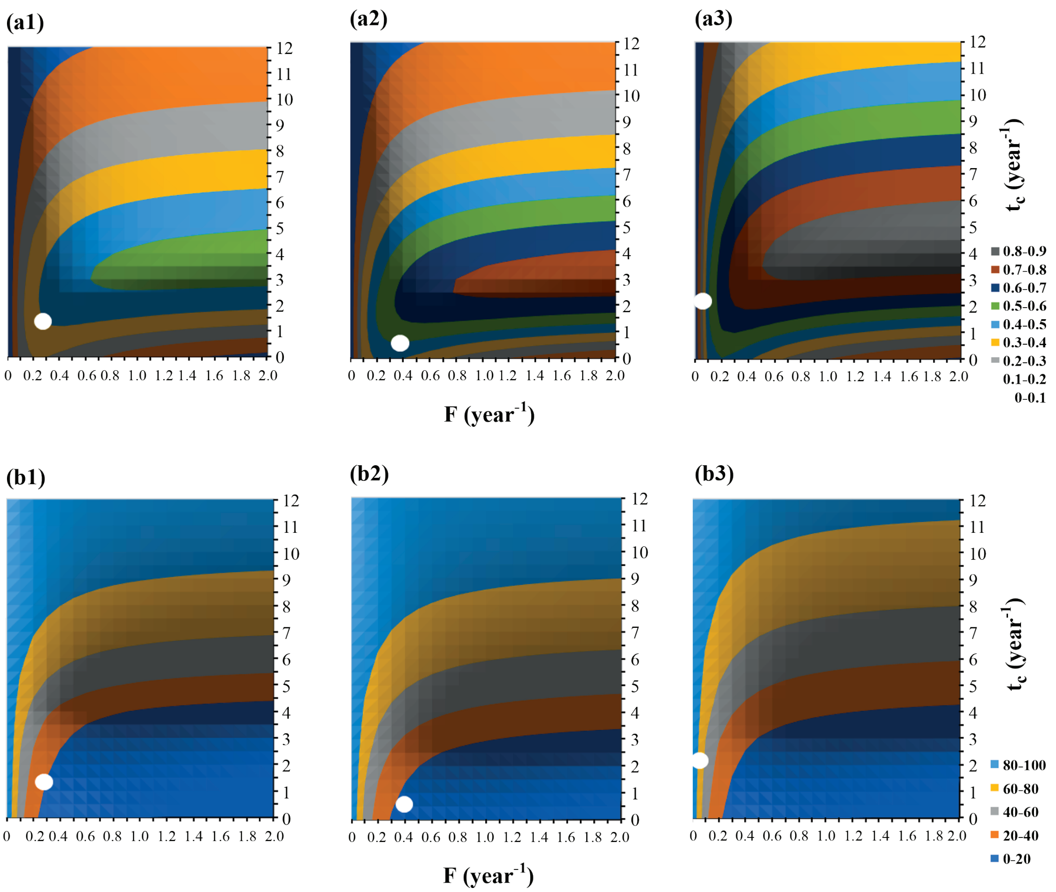

Figure 6. Yield per recruit (a) and spawning per recruit (b) of brownbanded bamboo sharks from Sv (1), Sk (2), and KK (3). White circles represent the current fishing situation (i.e., current t_c and F_{curr}); KK, Sk and Sv are landing sites as detailed in Figure 1.

Table 5. Results of yield per recruit (YPR) and spawning per recruit (SPR) analyses for brownbanded bamboo sharks from three landing sites (KK, Sk, Sv, as in Figure 1). The analyses compare current fishing mortality (F_{curr}) with biological reference points (F_{max}, $F_{0.1}$, 20 %SPR and 30 %SPR).

	Sv	Sk	KK
F_{curr}	0.291	0.392	0.058
BRPs			
$F_{0.1}$	0.260	0.231	0.243
F_{max}	0.438	0.340	0.487
30 %SPR	0.207	0.226	0.239
20 %SPR	0.290	0.319	0.354

DISCUSSION

Length-weight relationship and growth parameter estimation

The length-weight relationship can provide essential information about the biological growth pattern of a species. The regression value β is recommended to be in the range of 2.5 to 3.5 based on assumptions of the YPR and SPR models (Ricker, 1975; Sparre and Venema, 1998; Froese, 2006). Our results confirm that the length-weight relationships of brownbanded bamboo shark are suitable for these models. Significant differences in the length-weight relationships were found by landing site but not by sex. Therefore, catch data were assessed separately by site. Although sex may have an effect through an interaction with site, the analysis was not separated by sex due to uncertainties from gear selectivity and unclear life history between sexes.

The growth parameters for brownbanded bamboo shark (Table 3) have never been reported before. However, a related species, whitespotted bamboo shark (*Chiloscyllium plagiosum*) from Taiwan waters was found to have a slightly larger size with slower growth rate; estimates of L_∞, K, and Φ' were 98.4 cm, 0.21 year^{-1}, and 3.31 for males and 93.12 cm, 0.22 year^{-1}, and 3.28 for females (Chen *et al*., 2007).

Growth parameters have also been published for other tropical shark species. For the Halmahera walking shark (*Hemiscyllium halmahera*) from Indonesia and the Spadenose shark (*Scoliodon laticaudus*) from eastern India, estimates of L_∞, K, and Φ' were 81.5 cm, 0.51 year^{-1}, and 3.58; and 75.53 cm, 0.54 year^{-1}, and 3.49, respectively. According to the criteria of Branstetter (1987), brownbanded bamboo shark is fast-growing and with higher resilience, similar to Halmahera walking shark, spadenose shark, and whitespotted bamboo shark (Branstetter, 1987; Liu *et al*., 2015; Jutan *et al*., 2018).

The estimate of Φ' was compared among Hemiscyllidae sharks such as brownbanded bamboo shark, whitespotted bambooshark, and Halmahera walking shark. The difference of Φ' was smaller between the three estimates for brownbanded bamboo shark stocks in this study and Halmahera walking shark (0.08-0.20) than with whitespotted bamboo shark (0.05-0.14).

Mortality estimation, gear selectivity, and sensitivity test

The gear selectivity analysis shows that Sk has a smaller size at first capture than Sv and KK. Based on the relative ages of the catch curve (Figure 4), the usable slope can be observed between age 1 to 4 years. At higher ages in the catch curve, there may be an overestimation of Z and L_{50} which should be avoided (Sparre and Venema, 1998).

For the estimation of natural mortality (M), several empirical relationships have been proposed and widely used, including life-history parameters such as growth traits and longevity (Pauly, 1980; Hoenig, 1983; Then *et al*., 2015). The Tanaka model

(Tanaka, 1960), which incorporates a maximum age (t_{max}) was selected for this study because of the simplified equation and wide application, especially in official stock assessments.

In this study, the value t_{max} was based on the maximum age estimated from the length-converted catch curve by landing site: t_{max} = 10 years for Sv and Sk, and t_{max} = 15 years for KK. Brownbanded bamboo sharks can reach an age of 16–25 years in captivity (Chen *et al*., 1990; Harahush *et al*., 2007; Dudgeon *et al*., 2016). However, the specific longevity of populations may vary depending on environmental conditions. Therefore, the brownbanded bamboo shark in its natural habitat was assumed to have a longevity shorter than 16 years. Also, the assumption of t_{max} for determining M was for a situation without fishing pressure (Tanaka, 1960). Therefore, the values of t_{max} selected for this study were less than in previous reports.

The sensitivity test shows that the estimated F_{curr} will increase by increases of the growth parameters and by age at the endpoint with moderate sensitivity. For SPR, L_m affects the results because it directly affects the spawning stock biomass (Goodyear, 1993).

Per-recruit analysis

One of the input parameters for SPR is the age at first maturity (t_m), which was estimated from the length at first maturity (L_m). The value of L_m for populations of brownbanded bamboo shark in Southeast Asia ranges between 63 and 84 cm. In this study, the value of L_m for both males and females was selected as the size included in the L_m ranges for both sexes (Yano *et al*., 2005; Krajangdara, 2017).

The results from Sv and Sk indicate that fisheries for brownbanded bamboo shark in this area are nearing an inefficient state, and that fishing mortality cannot be increased sustainably. In KK, the stock is still in acceptable condition, with F_{curr} lower than the target reference points. This difference among sites is probably due to the implementation of fishing ground zonation in Malaysia (DOF, 2015; Ramli, 2015). The major fishing ground is up to 8 nautical miles from the shoreline in KK, but approximately 5 nm in Sv and Sk. Brownbanded bamboo sharks and several other elasmobranch species use the shallow coastal waters as nursery areas (Heupel *et al*., 2007; Davy *et al*., 2015; Dudgeon *et al*., 2016). Proper zoning will be effective for protecting small brownbanded bamboo shark, and will increase t_{50}.

Suggested management measures

Landings of brownbanded bamboo shark have been reported as bycatch in the region at a higher percentage compared to other elasmobranch species (SEAFDEC, 2006). In Southeast Asia, the fishing situation is far more complicated by multi-species fisheries, together with the lack of reliable data (Harlyan *et al*., 2019). In such situations, a species-specific regulation may not be fully effective.

The age or size at first capture can be simply increased through several approaches. One approach is to improve fishing gear design, such as with the Trawling Efficiency Device (TED), as a means of reducing the elasmobranch bycatch (Watson *et al*., 1986; Brčić *et al*., 2015). A second approach is zonation, which has the potential to conserve juvenile brownbanded bamboo sharks, as the larger individuals of this species can be found at higher density in the deeper waters, away from shore (Speed *et al*., 2010). A third option is the establishment of Marine Protected Areas (MPAs) to conserve juvenile sharks and other fishery resources (Heupel *et al*., 2007; 2018; Arai and Azri, 2019). Several previous studies identifying particularly important areas may be useful for establishing MPAs (Pennino *et al*., 2013; Giménez *et al*., 2020).

CONCLUSION

The fishery for brownbanded bamboo sharks in Kota Kinabalu in Malaysia was shown to be efficient and sustainable, with the estimated F_{curr} lower than the BRPs. However, in Sihanoukville, Cambodia, and Songkhla, Thailand, the fisheries are near a level of inefficiency and fishing mortality cannot be increased sustainably, as F_{curr} exceeds many or all of the BRPs.

Considering the issues related to bycatch and the multi-species fisheries that exist in the region, management actions should be considered such as fishing gear improvements, fishing zonation, and the establishment of MPAs.

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