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Review and proposal of key life history parameters for North Pacific blue shark stock assessment[1]

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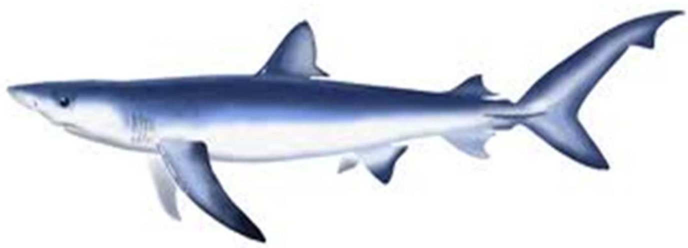

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Summary

This working paper provides a review of key life history parameters of North Pacific blue shark used in the previous stock assessment and a proposal of new biological parameters to be used in the next stock assessment. We recommend updating the following parameters: updated sex-specific growth parameters, sex-specific natural mortality at age, and parameters of stock-recruitment relationships. For the parameters of low-fecundity stock recruitment relationships, we recommend discussing the estimation method of the parameters in the upcoming meeting.

1. *Review of key life history parameters*

The biological assumptions and key life history parameters of the North Pacific blue sharks used in the previous stock assessment in 2017 (ISC 2017) were summarized (Table 1).

Growth and longevity

Sex-specific growth curves (Yokoi et al. 2017) were used in the previous stock assessment. The length at age relationships of males and females were estimated based on reading vertebrae samples from 620 females and 659 males, ranging from about 33.0 to 258.0 cm in PCL (precaudal length). The growth parameters of VBGF estimated using Bayesian approach were L_∞ = 284.8 cm PCL, k = 0.117 years^{-1}, $t_0 = -1.34$ years for males, and L_∞ = 256.3 cm PCL, k = 0.147 years^{-1}, $t_0 = -0.97$ years for females, respectively. Length at 1 year (L1) was 68.2 cm PCL for males and 64.4 cm PCL for females, and length at 20 years (L2) was 261.3 cm PCL for males and 244.6 cm PCL for females, respectively. Theoretical longevity estimated from Taylor's function (Taylor 1958) was 24.3 years for males, and 19.4 years for females.

Natural mortality

Sex-specific natural mortality at age, estimated using Method II in Walter et al. (2016) was used in the previous stock assessment (Semba & Yokoi 2016). In this method, average natural mortality described as "Target M" was allocated into age-classes using the growth curve described in the paper (Yokoi et al. 2017).

Maturity and fecundity

Reproductive parameters (length at 50% maturity and fecundity) were referred from the paper (Fujinami et al. 2017). The estimates of length-at-50% maturity for female blue sharks (n = 431) was 156.6 cm PCL and slope of maturity ogive was -0.16. The litter size (n = 124) was proportional to the body length, and slope and intercept of the fecundity were 0.46 and -45.54, respectively.

Weight-at-length relationship

Sex-specific weight-at-length relationships were referred from the paper (Nakano 1994). The sex-specific weight-length relationships were: $W = 5.388 \times 10^{-6} L^{3.102}$ for females (n = 2,890) and $W = 3.291 \times 10^{-6} L^{3.225}$ for males (n = 2,910).

Low-fecundity spawner-recruitment relationship (LFSR)

Kai & Fujinami (2017) estimated probable values of steepness (Beverton-Holt stock-recruitment relationships) for North Pacific blue sharks using the biological parameters. The estimated mean steepness was 0.67 with a standard deviation of 0.081. The parameter of LFSR was estimated based on the value of steepness and an equation from Taylor et al. (2013). The estimated value of S_{frac} was 0.391 after fixing the value of β (= 2).

2. *Proposal of key life history parameters*

Update of several biological assumptions and life history parameters (i.e. sex-specific growth curves, sex-specific natural mortality schedules, and the parameters of LFSR) were proposed to be used in next North Pacific blue shark stock assessment in 2022 (Table 1). For the remaining reproductive parameters (maturity and fecundity) and weight-at-length relationship, we considered that it is reasonable to use of same values with those in the previous stock assessment.

Growth and longevity

Fujinami et al. (2019) published a paper about age determination and growth for blue sharks in the western North Pacific. Length at age relationships were based on reading vertebrae samples from 620 females and 659 males, ranging from about 33.0 to 258.0 cm PCL. The growth parameters of VBGF estimated using the maximum likelihood approach were L_∞ = 284.9 cm PCL, k = 0.117 years^{-1}, $t_0 = -1.35$ years for males, and L_∞ = 257.2 cm PCL, k = 0.146 years^{-1}, $t_0 = -0.97$ years for females, respectively. Length at 1 year (L1) was 68.5 cm PCL for males and 64.3 cm PCL for females, and length at 20 years (L2) was 261.5 cm PCL for males and 245.2 cm PCL for females, respectively. Theoretical longevity estimated from Taylor's function (Taylor 1958) was 24.3 years for males, and 19.5 years for females.

Natural mortality

We updated sex-specific natural mortality at age using new growth parameters (Fujinami et al. 2019) with the same estimation method (Walter et al. 2016). Although theoretical longevity for female blue shark was estimated to be 19.5 (Taylor 1958), we calculated the natural mortality from age 0 to 24 years for both sexes (to be compatible with the setting of Stock Synthesis), according to theoretical longevity of males. Estimated sex-specific natural mortality at age was shown in Table 2. The updated sex-specific natural mortality was almost same with value used in the previous stock assessment.

Steepness and the parameters of LFSR

Steepness was updated using the same estimation method (Kai & Fujinami 2018) with new biological parameters of female blue shark (Table 3). The estimated mean value of steepness was 0.613 with standard deviation of 0.010. Our proposal is to estimate the parameter of LFSR (S_{frac}) using the new value of steepness (0.613). However, it is necessary to discuss appropriateness for the values of the recruitment at unfished equilibrium (R_0) and the corresponding equilibrium spawning biomass (B_0) because these values were arbitrarily given in the calculation of the S_{frac} in the past.

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Table 1. Biological assumptions and key life historical parameters of Stock Synthesis used in the previous stock assessment for North Pacific blue shark (ISC 2017) and proposal of the values (in bold) for the next stock assessment. Gray cells indicate that it is uneasy to propose these values.

Parameter	Values used in the previous stock assessment (2017)	Reference	Updated value	Reference
Natural mortality	Sex specific	Semba and Yokoi (2016)	**Sex specific (Table 2)**	**This working paper**
Reference age (a1)	1		1	
Theoretical longevity (Taylor 1958)	19.4 (Female)	Yokoi et al. (2017)	**19.5 (Female)**	**Fujinami et al. (2019)**
	24.3 (Male)	Yokoi et al. (2017)	**24.3 (Male)**	**Fujinami et al. (2019)**
Maximum age (a2)	20		20	
Female at first age	4		4	
Length at a1 (L1)	64.4 (Female)	Yokoi et al. (2017)	**64.3 (Female)**	**Fujinami et al. (2019)**
	68.2 (Male)	Yokoi et al. (2017)	**68.5 (Male)**	**Fujinami et al. (2019)**
Length at a2 (L2)	244.6 (Female)	Yokoi et al. (2017)	**245.2 (Female)**	**Fujinami et al. (2019)**
	261.3 (Male)	Yokoi et al. (2017)	**261.5 (Male)**	**Fujinami et al. (2019)**
Growth rate (k)	0.147 (Female)	Yokoi et al. (2017)	**0.146 (Female)**	**Fujinami et al. (2019)**
	0.117 (Male)	Yokoi et al. (2017)	**0.117 (Male)**	**Fujinami et al. (2019)**
CV of L1	0.25 (Female); 0.25 (Male)		0.25 (Female); 0.25 (Male)	
CV of L2	0.1 (Female); 0.1 (Male)		0.1 (Female); 0.1 (Male)	
Weight-at-length	$W=5.388\times10^{-6}L^{3.102}$ (Female)	Nakano (1994)	$W=5.388\times10^{-6}L^{3.102}$ (Female)	Nakano (1994)
	$W=3.293\times10^{-6}L^{3.225}$ (Male)	Nakano (1994)	$W=3.293\times10^{-6}L^{3.225}$ (Male)	Nakano (1994)
Length-at-50% Maturity	156.6 (Female)	Fujinami et al. (2017)	156.6 (Female)	Fujinami et al. (2017)
Slope of maturity ogive	-0.16 (Female)	Fujinami et al. (2017)	-0.16 (Female)	Fujinami et al. (2017)
Fecundity (Litter size; (4) embryos=a+b*L)	Proportional to body length	Fujinami et al. (2017)	Proportional to body length	Fujinami et al. (2017)
Slope of fecundity (b)	0.46	Fujinami et al. (2017)	0.46	Fujinami et al. (2017)
Intercept of fecundity (a)	-45.54	Fujinami et al. (2017)	-45.54	Fujinami et al. (2017)
Spawner-recruit steepness (LFSR)	$S_{Frac} = 0.391$ and $\beta = 2$			
Stock-recruitment steepness (mean value)	0.670 (SD=0.081)	Kai and Fujinami (2017)	**0.613 (SD=0.010)**	**This working paper**
Log of Recruitment at virgin biomass log (R0)	11.1358 (Initial value)			
Recruitment variability (σ_R)	0.3			
Initial age structure	5 yrs (1985-1989)			
Main recruitment deviations	1990-2013			
Bias adjustment	1990-2013			
F ballpark for tuning early phases	0.2			
F ballpark year	2013			
F-Method	3 (hybrid)			
Initial-F	0.315485 (Initial value) only Kinkai shallow (F4)			

Table 2. Estimates of sex-specific natural mortality at age based on Method II proposed by Walter et al. (2016) and growth parameters reported by Fujinami et al. (2019).

Age	Male	Female
0	0.7255179	0.7866483
1	0.4911633	0.4894907
2	0.3823831	0.3705408
3	0.3196515	0.3065298
4	0.2790127	0.2668048
5	0.2506926	0.2399697
6	0.2299452	0.2207964
7	0.2141844	0.2065442
8	0.2018796	0.1956361
9	0.1920663	0.1871000
10	0.1841068	0.1803031
11	0.1775618	0.1748162
12	0.1721193	0.1703374
13	0.1675512	0.1666482
14	0.1636869	0.1635869
15	0.1603963	0.1610307
16	0.1575784	0.1588854
17	0.1551537	0.1570771
18	0.1530587	0.1555474
19	0.1512421	0.1542493
20	0.1496619	0.1531449
21	0.1482838	0.1522033
22	0.1470790	0.1513988
23	0.1460236	0.1507104
24	0.1450974	0.1501206

Table 3. Summary of default parameters of female blue sharks for estimating at steepness of Beverton-Holt methos (stock-recruitment relationship).

No.	Function name	Parameter name	Symbol	Unit	Value	Reference
1	von-Bertalanffy growth curve	Asymptotic size	L_{∞}	cm in PCl	257.2	Fujinami et al. (2019)
		Growth rate	k	$year^{-1}$	0.146	
		Theoretical age at length at 0	a_0	year	-0.97	
2	Weight-length relationship		c_1		5.388	Nakano (1994)
			c_2		3.102	
3	Length-based maturity ogives		c_3		24.52	Fujinami et al. (2017)
			c_4		-0.16	
4	Littersize-length relationship		c_5		-45.54	Fujinami et al. (2017)
			c_6		0.455	
5	Natural mortality					
	Theoretical equation	Natural mortality at ages	M_a	$year^{-1}$	See table 2	Walters et al. (2016)
		Target natural mortality	M_T	$year^{-1}$	0.23	Campana et al. (2005)
	Gamma distribution		v		9.7	Mangel et al. (2010)
			λ		Not shown	
6		Maximum age	a_{max}	year	24	This paper
7		Sex ratio	r		0.5	Nakano (1994)
8	Pre-recruit survival					
	Beta distribution	Survival at stage 0	S_0	$year^{-1}$	0.965[a] (0.081[b])	Kai and Fujinami (2018)
		Survival at stage 1	S_1	$year^{-1}$	1	Kai and Fujinami (2018)
	Beta distribution	Survival at stage 2	S_2	$year^{-1}$	0.993[a] (0.026[b])	Kai and Fujinami (2018)
	Theoretical equation	Survival at stage 3	S_3	$year^{-1}$	Not shown	Walters et al. (2016)
9	Reproductive cycle					
	No function	Reproductive period	y		1	Fujinami et al. (2017)
		Days to recruit from partrition	d	day^{-1}	365	Nakano (1994)

[a] Mean value. [b] Standard deviation