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Updated biological parameters of Dissostichus mawsoni at Subarea 48.6

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EN

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Abstract

To achieve the milestone "Updating biological parameters for the population, suitable for inclusion in CASAL: Age Length Key (ALK), growth curves, maturity ogives" (SC-CAMLR-37 Report, para 3.130), this paper represents the updated length-weight relationship, growth curve, ALK, and maturity ogives as biological parameters of *Dissostichus mawsoni* at Subarea 48.6 up to the 2017/18 fishing season collected from a collaborative research program among Japan, South Africa, and Spain.
Due to the lack of sufficient aging data, it is not possible at present to calculate annual and sex-specific growth curve, ALK, and maturity ogive. Continuing both data collection and otolith aging will lead to the implementation of CASAL stock assessment with rich biological information.

Introduction

A collaborative research program is being undertaken by Japan and South Africa since 2013 to provide a comprehensive evaluation of existing management arrangements for Antarctic toothfish (*Dissostichus mawsoni*) in Subarea 48.6, and updated advice on precautionary catch limits as appropriate based on ISA models, such as CASAL. From the current fishing season (2018/19) Spain has joined the research program in order to contribute to the data acquisition and to speed up the achieving the objectives of this research program (FSA-18/34).
In CASAL, growth curve, Age Length Key (ALK), and Maturity ogive are key biological parameters to run the model. In order to achieve the milestone "Updating biological parameters for the population, suitable for inclusion in CASAL: ALK, growth curves, maturity ogives" (SC-CAMLR-37 Report, para 3.130), this paper represents the updated length-weight relationship, growth curve, ALK, and maturity ogives as biological parameters of *D. mawsoni* at Subarea 48.6 up to the 2017/18 fishing season.

Data

The data set, C2 and Observer data, was provided by the CCAMLR Secretariat on the 9th March, 2019. CCAMLR seasons are denoted by the end year throughout the paper. Research blocks were attributed to each haul using the Research blocks GIS layer available in the CCAMLRGIS online tool. Hauls outside the current research blocks (48.6_2, 48.6_3, 48.6_4, and 48.6_5) were treated as "Outside". Numbers of survey lines is summarized in Table 1. The data used in this paper has been gathered on two different boats, showing same fishing gears, Trotline. All data is prosessed and analysed with the statistical software R ver 3.5.0 (R Core Team, 2018).

Table 1: Numbers of survey lines by research block, vessel, fishing gear, and fishing season at Subarea 48.6. Season is abbreviated to the end year.

Block	Member	Vessel	Fishing System	2013	2014	2015	2016	2017	2018
486_2	JPN	Shinsei Maru No. 3	Trotline	100	74	58	81	88	76
486_2	ZAF	Koryo Maru No. 11	Trotline	94	41	24	61	59	89
486_3	JPN	Shinsei Maru No. 3	Trotline	6	13	7	22	18	19
486_3	ZAF	Koryo Maru No. 11	Trotline	8		17	26	28	15
486_4	JPN	Shinsei Maru No. 3	Trotline	54		55	46	10	23
486_4	ZAF	Koryo Maru No. 11	Trotline	64		11	67	23	94
486_5	JPN	Shinsei Maru No. 3	Trotline					78	91
Outside	JPN	Shinsei Maru No. 3	Trotline	19			30		
Outside	ZAF	Koryo Maru No. 11	Trotline	19					

Table 2 summarizes the samples from the catches of *D. mawsoni* in Subarea 48.6 for each biological information. Otoliths were collected from some of those individuals and, among them, some were read to estimate their age (Table3). Selected otoliths were checked damage and crack, and then are placed in a mold and processed into a transparent resin for easy cutting. Rings of sliced otolith were read by using a stereoscopic microscope. Annual rings were read twice with defining "difficulty of aging" with five stages (1: very easy to 5: cannot read). In 2018, 221 otoliths have been read by one Japanese scientist, bringing the total number of reading over the 2013-2018 period to 1330.

Table 2: Summary table of *D. mawsoni* biological data in Subarea 48.6. Values are the sample of fish observed for each biological information. Data are for all cruises pooled. Season is abbreviated to the CCAMLR season end year.

Research Block	Vessel	Season	Length	Weight	Sex	Maturity	Gonad	Otolith
486_2	2013	Koryo Maru No. 11	647	647	646	645	646	448
486_2	2013	Shinsei Maru No. 3	2278	1857	2072	2071	2072	801
486_2	2014	Koryo Maru No. 11	221	221	221	221	221	130
486_2	2014	Shinsei Maru No. 3	2103	1392	1459	1461	1461	546
486_2	2015	Koryo Maru No. 11	192	192	192	192	192	144
486_2	2015	Shinsei Maru No. 3	1852	1490	1490	1495	1495	594
486_2	2016	Koryo Maru No. 11	540	540	529	531	531	308
486_2	2016	Shinsei Maru No. 3	1329	1329	1329	1329	1329	1062
486_2	2017	Koryo Maru No. 11	1404	1404	1404	1404	1404	529
486_2	2017	Shinsei Maru No. 3	2229	1644	1641	1641	1641	1639
486_2	2018	Koryo Maru No. 11	1595	1595	1595	1595	1595	674
486_2	2018	Shinsei Maru No. 3	1603	1603	1603	1580	1581	731
486_3	2013	Koryo Maru No. 11	545	543	222	222	223	82
486_3	2013	Shinsei Maru No. 3	556	180	180	179	179	60
486_3	2014	Shinsei Maru No. 3	994	416	391	391	391	130
486_3	2015	Koryo Maru No. 11	360	360	360	360	360	130
486_3	2015	Shinsei Maru No. 3	580	213	213	213	213	73
486_3	2016	Koryo Maru No. 11	453	453	449	450	451	233
486_3	2016	Shinsei Maru No. 3	443	443	443	443	443	443
486_3	2017	Koryo Maru No. 11	399	399	399	399	399	235
486_3	2017	Shinsei Maru No. 3	458	458	458	458	458	275
486_3	2018	Koryo Maru No. 11	359	359	349	349	349	140
486_3	2018	Shinsei Maru No. 3	415	415	415	415	415	193
486_4	2013	Koryo Maru No. 11	1060	1060	914	914	914	541
486_4	2013	Shinsei Maru No. 3	1532	1216	1216	1216	1216	499
486_4	2015	Koryo Maru No. 11	99	99	99	98	98	75
486_4	2015	Shinsei Maru No. 3	1371	1227	1226	1227	1227	550
486_4	2016	Koryo Maru No. 11	1271	1271	1267	1268	1268	595
486_4	2016	Shinsei Maru No. 3	884	884	884	884	884	884
486_4	2017	Koryo Maru No. 11	351	351	351	351	351	172
486_4	2017	Shinsei Maru No. 3	282	282	282	282	282	100
486_4	2018	Koryo Maru No. 11	1618	1618	1597	1597	1597	802
486_4	2018	Shinsei Maru No. 3	583	583	583	583	583	235
486_5	2017	Shinsei Maru No. 3	2191	2191	2178	2191	2191	758
486_5	2018	Shinsei Maru No. 3	2922	2911	2911	2922	2922	906
Outside	2013	Koryo Maru No. 11	15	14	14	14	14	14
Outside	2013	Shinsei Maru No. 3	69	69	69	69	69	46

Table 3: Summary table of *D. mawsoni* ageing data from Subarea 48.6. Values are the number of fishes (otoliths). Data are for all vessels and cruises pooled. Season is abbreviation to the end year.

Research Block	2013	2014	2015	2016	2017	2018
486_2	112	165	55	64		
486_3	49	38	14	35	16	36
486_4	110		122	141	32	55
486_5					152	130
Outside	4					

Length-weight relationship

The length-weight relationship was estimated using GLM with two assumptions. First, we considered a model accounting for research blocks and sex effects (Table 4). To simplify the model assumption of CASAL, a second model which does not incorporate these two factors (Table 5).

Table 4: GLM results on length-weight relationship of *D. mawsoni* with effects of research blocks and sex at Subarea 48.6. The formula of GLM is "log(Weight)~log(Length)+Sex+Research_Block". N = 31568.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-12.2344725	0.0373473	-327.586246	0
log(LENGTH_CM)	3.1667586	0.0074256	426.465446	0
SEX_CODEM	-0.0363291	0.0017179	-21.147799	0
Research_Block_Over486_3	0.0202454	0.0026940	7.514889	0
Research_Block_Over486_4	0.1134781	0.0020543	55.239404	0
Research_Block_Over486_5	0.1660008	0.0024190	68.622860	0

Table 5: GLM results on length-weight relationship of *D. mawsoni* at Subarea 48.6. N = 31568. The fourmula of GLM is "log(Weight)~log(Length)". N = 31568.

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	-12.108982	0.0390951	-309.7312	0
log(LENGTH_CM)	3.150321	0.0078217	402.7663	0

As shown the GLM results (Table 4), fish caught at 48.6_4 and 48.6_5 were more obese than fish caught at 48.6_2 and 48.6_3 (Figure 1). In addition, it is also shown in the GLM that the weight of the female is slightly heavier than male.

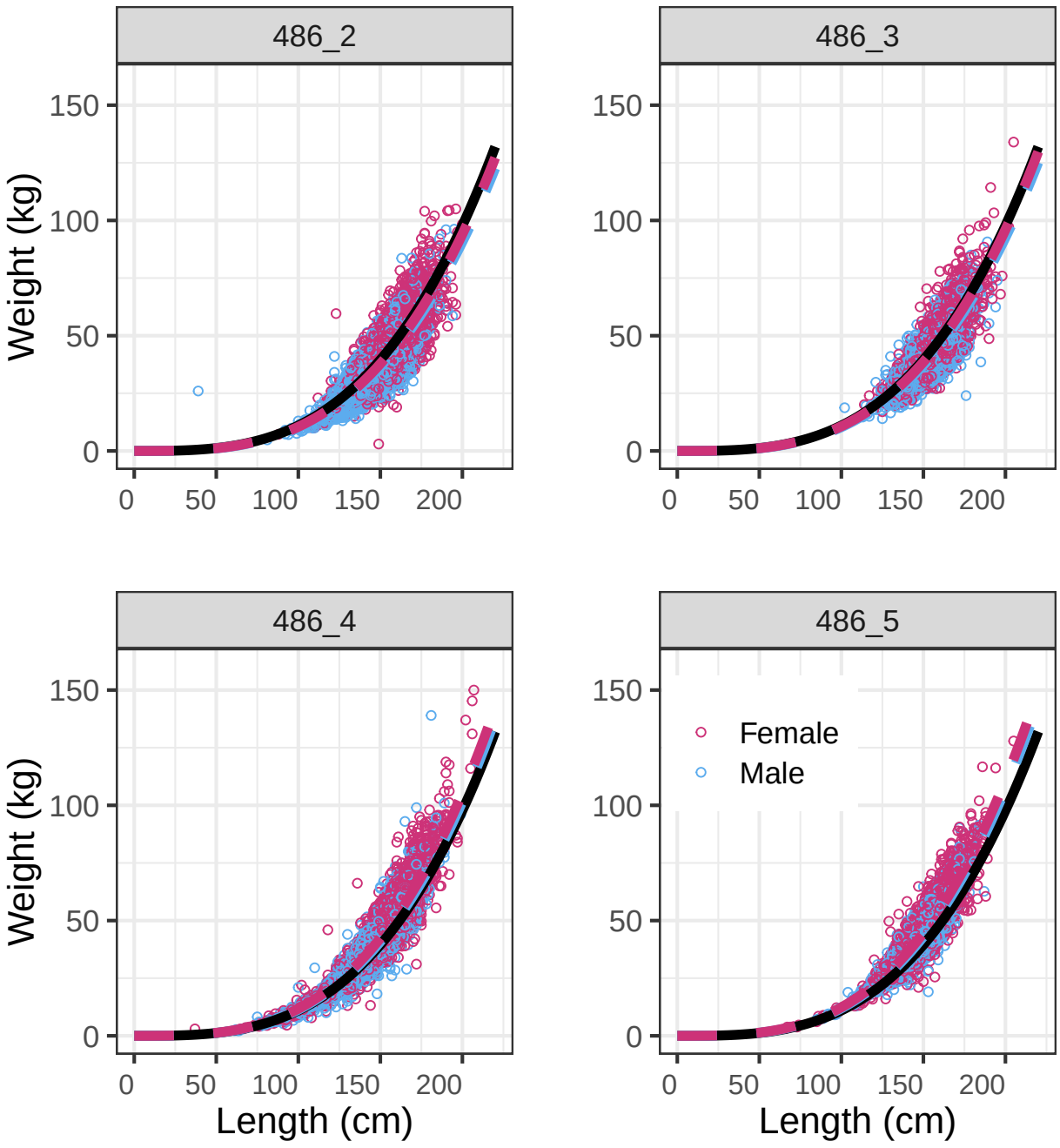

Figure 1: Length-weight relationship of *D. mawsoni* at Subarea 48.6. Dashed lines are the non-linear regression of length-weight relationship for male (blue) and female (red) at each research block obtained with the results of GLM represented in Table 4. Black lines are the non-linear regression of length-weight relationship obtained with the results of sex combined GLM represented in Table 5.

Growth curve

Growth curves (Table 6 and Figure 2) were estimated by maximum likelihood, mle() function from *bbmle* package (ver. 1.0.20, Bolker et. al., 2017) with R ver 3.5.0 (R Core Team 2018). The growth curves were calculated fpr both assumption with and without sex difference. Because *D. mawsoni* have been hypothesized to be using habitat with northward spawning migration and southward feeding migration (Okuda et. al., 2018, Söffker et. al, 2018), the growth curves were estimated with the pooled ageing data of four research blocks.

Table 6: Von Bertalanffy parameters of *D. mawsoni* at Subarea 48.6. Updated parameters have been obtained by using the mle() function from the *bbmle* package (ver. 1.0.20, Bolker et. al., 2017) in R.

	Linf	K	t0	Source
Combined xex	176.9084	0.0889	0.8817	2013-18
Male	185.1497	0.0894	1.2095	2013-18
Female	176.7086	0.0889	0.9736	2013-18

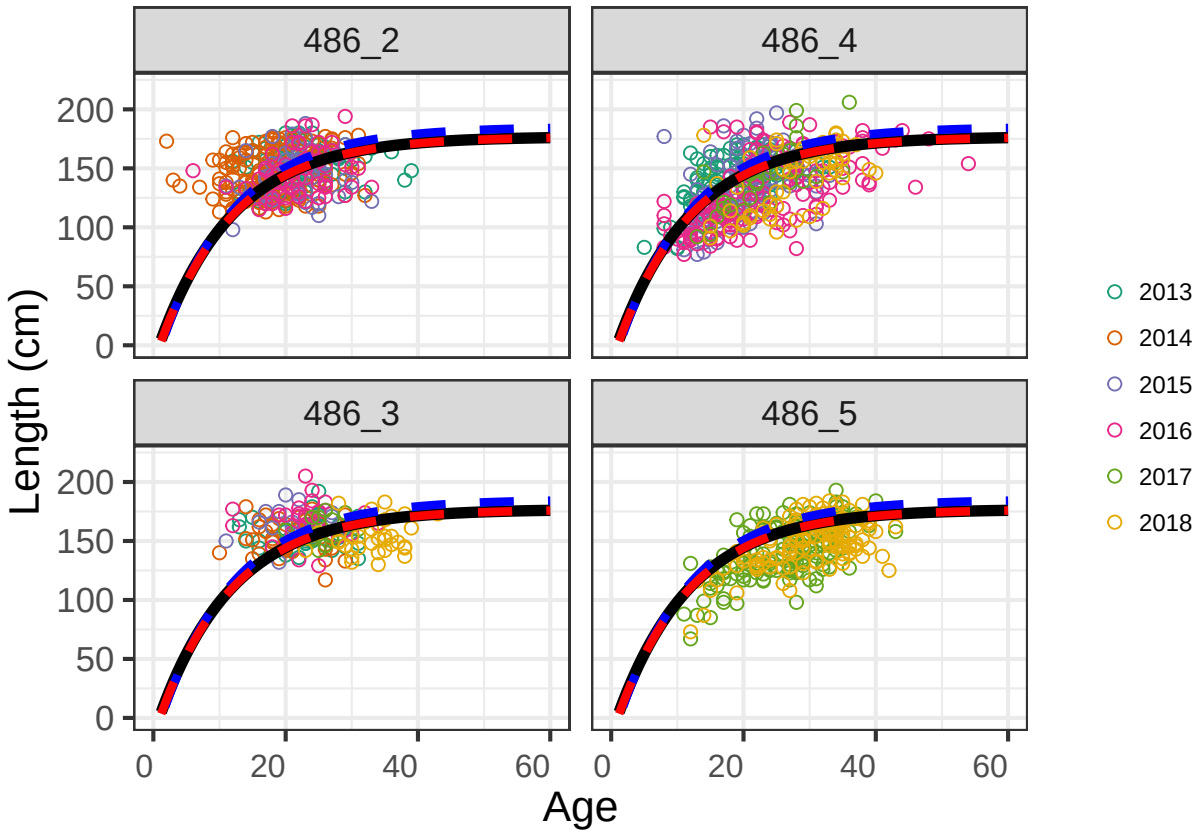

Figure 2: Von Bertalanffy growth curves for blocks 1 and 2 at Subarea 48.6 estimated by mle() function (*bbmle* package, ver. 1.0.20, Bolker et. al., 2017) for Statistical software R. Black line is obtained by using pooled all aging data during 2013-2017. Colored curves are calculated with aging data separated by sex (blue: male, red: female).

Age length keys

ALK is calculated by using the fish length of aged fishes (Tables 7-10). Individuals smaller than 40 cm were aggregated into a 40- cm group, and individuals larger than 200 cm into a 200+ cm group. Similarly, individuals younger than 4 years were integrated into age group 4-, and individuals olderer than 50 years were aggregatred into age group 50+. CV of the bootstraped age composition was calculated is added to CASAL input files. Similar to the growth curve, ALK is also constructed with pooled data through all years because of small sample size for each year.

Table 7: Age Length Key (ALK) obtained from the fish length of aged *D. mawsoni* at the research block 2 in Subarea 48.6 from 2012/13 to 2015/16 fishing season. Values are the number of fish. Rows are size classes (10 cm interval). Columns represent age of each fish.

	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
40																								
50																								
60																								
70																								
80																								
90									1															
100																								
110							1		2				3	1		1	2			1	1	2		
120						1		2		3	1	2	6	9	8	2	5		5	2		3	1	
130	1			1			1	4	1	3	5	5	4	6	3	3	5	6	5	4	1	1	6	1
140	1		1				1		1			1	4	6	7	7	3	11	4	3	6	3	3	1
150						1	1	2	4	2	2	1		6	4	4	7	1	6	9	6	7	4	
160								1	1	2	4	3	1	4	2	3	3	2	4	1	5	6	4	5
170	1								1		1	1	1	2	5	4	2	7	6	4	1	3	1	3
180																	1	1	1	2	2			
190																								

	28	29	30	31	32	33	34	35	36	37	38	39
40												
50												
60												
70												
80												
90												
100												
110												
120	1	2			1	1						
130		1	2		1	1						
140		2	1								1	1
150	2	2	2	2								
160	1	1	1		1	1			1			
170		3		1								
180												
190		1										

Table 8: Age Length Key (ALK) obtained from the fish length of aged *D. mawsoni* at the research block 3 in Subarea 48.6 from 2012/13 to 2017/18 fishing season. Values are the number of fish. Rows are size classes (10 cm interval). Columns represent age of each fish.

	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
50																								
60																								
70																								
80																								
90																								
100																								
110																	1							
120																1								
130						1	1			2	1		2				1			1	2	1		
140	1						1		3		5	3		3		1	4	2	1	2	1	2		1
150		1			2	1	1	1	2		3	3	2	5	10	3	1	2	6	1	2	1		
160			1	2			3		3	1	2	2	1	2	3	6		1	1	2	1	1	2	2
170			1		1	1		2		2	1		4	2	4	4	2	2		2		1	1	1
180											1		1		1		1		1					
190															1	1								
200														1										

	34	35	36	37	38	39	40	41	42	43
50										
60										
70										
80										
90										
100										
110										
120										
130	1				1					
140	1	1	1	1	2					
150	1	2	1							
160	2	1				1				
170			1		1					1
180		1								
190										
200										

Table 9: Age Length Key (ALK) obtained from the fish length of aged *D. mawsoni* at the research block 4 in Subarea 48.6 from 2012/13 to 2017/18 fishing season. Values are the number of fish. Rows are size classes (10 cm interval). Columns represent age of each fish.

	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
40																								
50																								
60																								
70							1		1	1														
80	1			1		2	3	1	1	1	1	1			1		1							1
90				1	1	1		5	3		7	4		2							1		1	
100				1	1		1	4	3	5	6	4	2	5	1	7	2	1		1	1	1	1	1
110				1				3	3	1	5	4	5	6	3	3	6	2	3	3	2	1		
120				1			2	2	2	2	4	5	5		1	2	4	3	4	4				
130							1		2	5	3	3	3	1	2	3	2	7	1	4	2	2	2	1
140								1	2	1	2	1		3	6	5	4	4	2	5	2	2	4	5
150									1	1	1	2	1	2	4	4	2	3	1	1	2	1	1	6
160								1			2	1	1	1	3	1	1	4	4	4	5	3	3	2
170				1						1					2	2	1		3	3	2	1		1
180											1		2		1			3					1	1
190																		1			1			1
200																								

	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
40																						
50																						
60																						
70																						
80																						
90																						
100		1	1																			
110	1		3	1																		
120	1		1		1																	
130	2	2	3	1	1		1				2							1				
140	1	1	2	1	2	1	2			1	1	1										
150	1	1	1	2	2	2	2	1		1												1
160	4	4		2			3	1					1									
170	2			2		4	1		1	2					1					1		
180		1				1				1						1						
190																						
200								1														

Table 10: Age Length Key (ALK) obtained from the fish length of aged *D. mawsoni* at the research block 5 in Subarea 48.6 from 2016/17 to 2017/18 fishing season. Values are the number of fish. Rows are size classes (10 cm interval). Columns represent age of each fish.

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
60		1																						
70		1																						
80	1		1	1	1																			
90				1			1		1									1						
100					1		1		1								1							
110			1		3	2	1	1		1	1		2			1	1			1	2			
120					1	1	4	1	2	2		4	1	2	2	1	5	2	2			1	2	
130		1					1			4	2	3	3	3	2	1	1	2	4		3	1	1	
140									2		1	1				2	8	5	3	3	2	2	3	4
150										1	1		2	2		1	2	4	7	3	3	3	4	5
160									1		1		3	1	5		1	5	1	4	5	5	2	4
170												1	1			1	1	2		2	3	3	1	2
180																	1		1		1		1	2
190																								1
200																								

	35	36	37	38	39	40	41	42	43
60									
70									
80									
90									
100									
110									
120		1						1	
130	3	1		1			1		
140	2	3	3		1				
150	3	2		1		1			1
160	4		2	2	4				1
170	4	1	2				1	1	
180	1			1		1			
190									
200									

Maturity ogive

Based on maturity stage data collected by scientific observers, we assumed that fishes classified into stage 2-5 are matured and therefore reproduction occures during the subsequent spawning season; late winter/early spring (Patchell, 2001). Figure 3 shown the frequency of *D. mawsoni* maturity stages by month and research block based on scientific observer data. Similar to growth curve, the mean age at 50% maturity and 95% maturity for all aged fishes have been estimated with the pooled ageing data of four research blocks (Figure 5 left figures). Furthermore, we also used "GSI method" which assumed a Gonado-Somatic index (GSI) >1 to be mature (Figure 4). The maturity ogive derived from "GSI method" is also shown in Figure 5 (right).

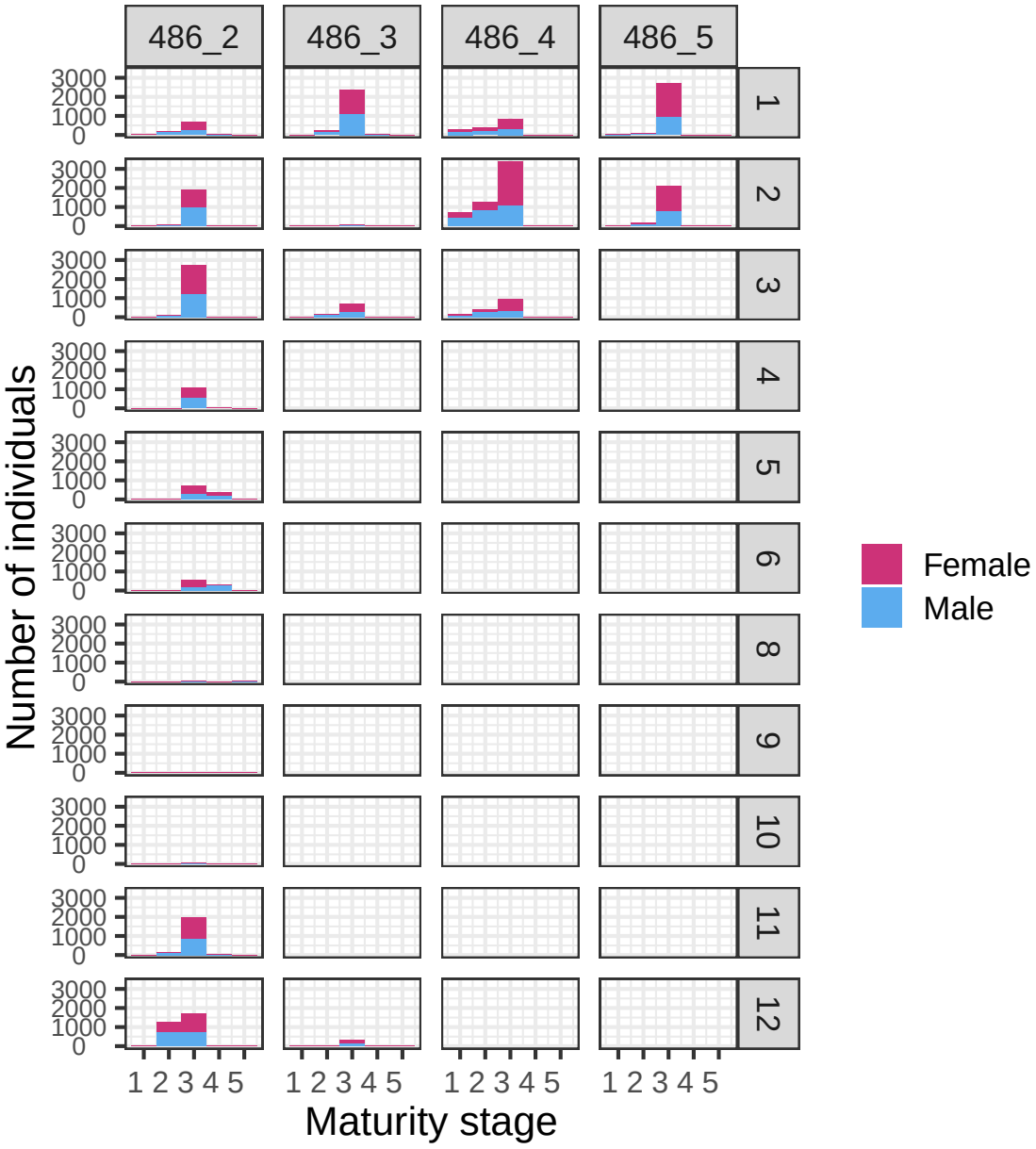

Figure 3: Frequency distribution of observed maturity stage of *D. mawsoni* by months and research blocks at Subarea 48.6 from 2012/13 to 2017/18 fishing season.

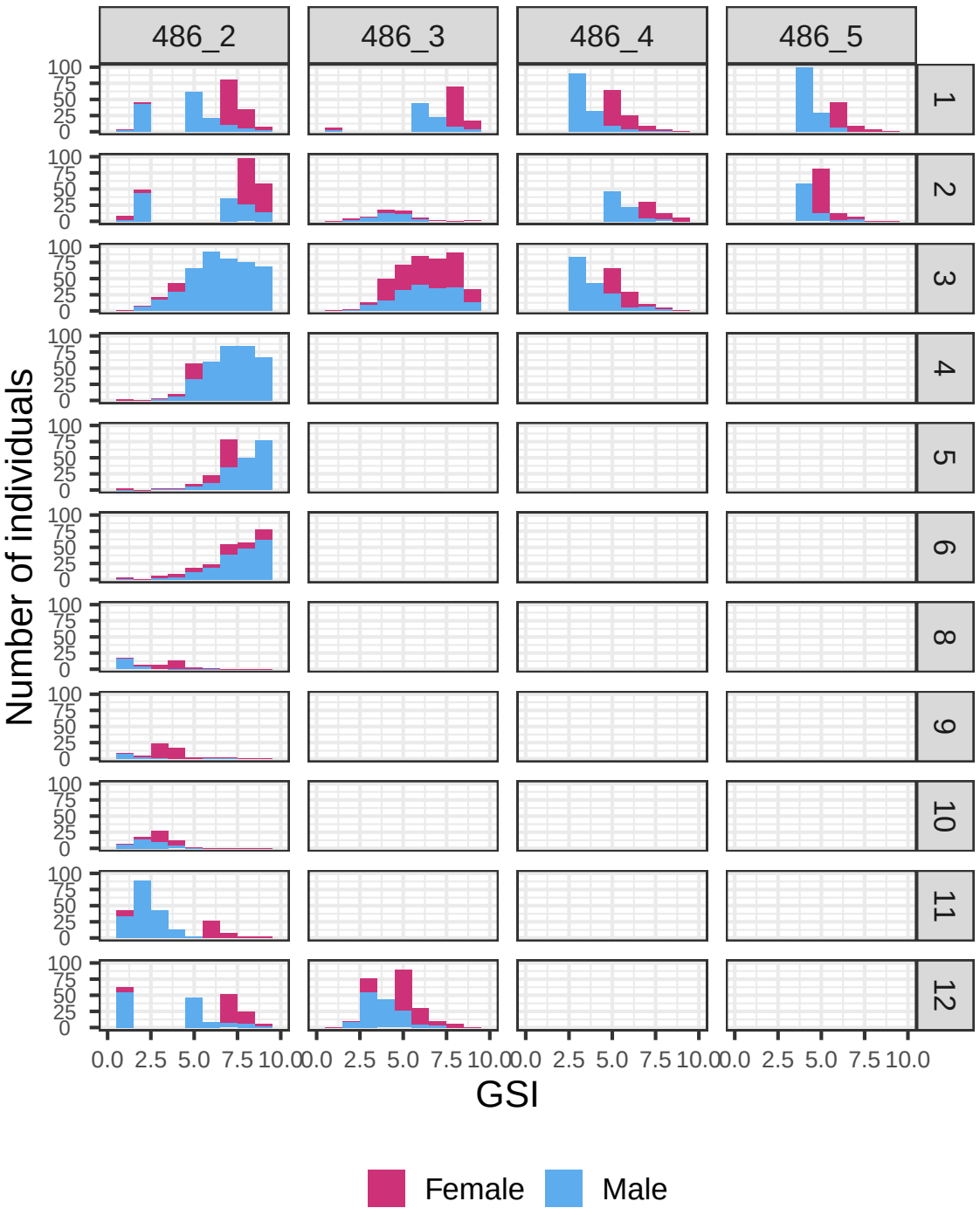

Figure 4: Frequency distribution of Gonado-Somatic index (GSI) *D. mawsoni* by months and research blocks at Subarea 48.6 from 2012/13 to 2017/18 fishing season. $GSI = Gonad/1000/Weight * 100$.

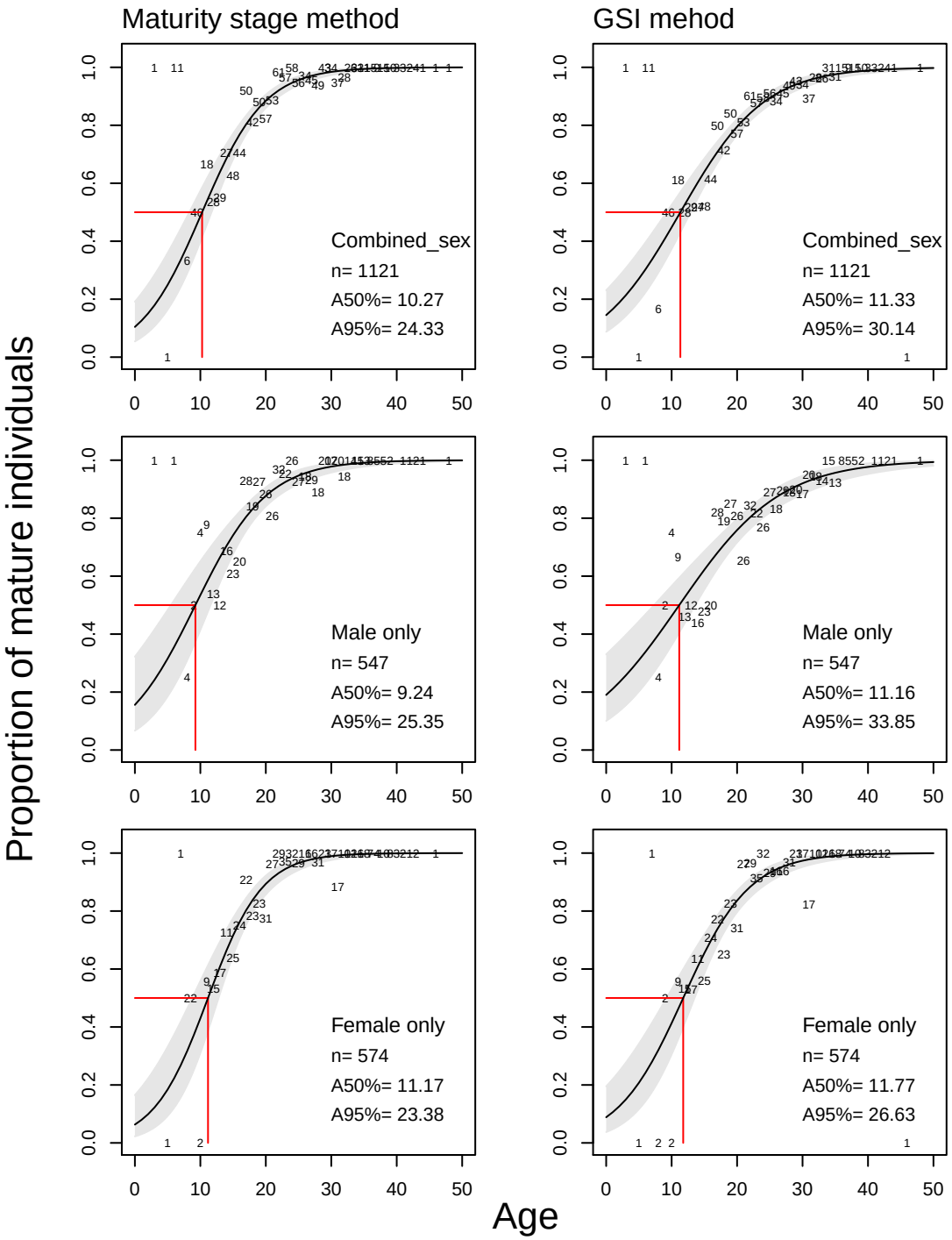

Figure 5: Proportion of maturity stage >= 2 (maturity stage method) and GSI > 1 (GSI method) at age of *D. mawsoni* in Subarea 48.6 from 2012/13 to 2017/18 fishing season.

Summary of updated biological parameters

Table 11 summarized length-weight relationship, growth, and maturity ogive as biological parameters, which were updated from WG-FSA-16/32Rev1.

Table 11: Summary of updated biological parameters of *D. mawsoni* at Subarea 48.6. In WG-FSA-16/32Rev1, maturity was estimated as "Maturity at length" (e.g., L50%).

	Parameter	WG-FSA-16/32Rev1	Updated value
Length-Weight	a	5.71e-6	5.510e-6
	b	3.221	3.1503
Von Bertalanffy	L_inf	159.1	176.9084
	K	0.138	0.0889
	t0	0.194	0.8817
Age at maturity:GSI method	A50%	-	11.33
	A95%	-	30.14

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