Appendix B. Summary of the model and parameters in the stock assessment of the Pacific stock of chub mackerel.

The stock assessment of Pacific chub mackerel has been conducted every year since 1997 by the Fisheries Research Agency in Japan. Our study used the stock assessment result in 2013 reported by Kawabata et al. (2013). The virtual population analysis (VPA) with ad hoc tuning procedures that adjusted terminal fishing mortality inputs by certain abundance indices were used for the assessment. The annual catch at age a and year y CA_{ay} was estimated from length measurements in port sampling and the age length key observed and used as the input data in the assessment model. Abundance indices were derived from research surveys and commercial fisheries of purse seine and brail net.

The numbers and fishing mortality at age a and year y, NA_{ay} and FA_{ay}, respectively, were calculated following Pope's approximation (Pope 1972) in the stock assessment.

$$NA_{ay} = NA_{a+1,y+1}\exp(M) + CA_{ay}\exp(M/2)$$

$$FA_{ay} = -\ln\left[1 - \frac{CA_{ay}}{NA_{ay}}\exp\left(\frac{M}{2}\right)\right]$$

where the natural mortality M was set to 0.4. Abundance indices and selectivity derived from recent years were used in estimating fishing mortality at the terminal year Y. Because the assessment model used Pope's approximation, population dynamics simulations in this study also used the same equation.

The numbers at age a at the beginning of the 2004 fishing year (July 1, 2004, to June 20, 2005) estimated by the assessment model $NA_{a,2004}$ (Table B1) were used as the starting point of the population dynamics simulations in this study. The selectivity at age S_{ay} (Table B2) was calculated from F_{ay} by $\frac{FA_{ay}}{\max_{a\in 1,2,\ldots,6+} FA_{ay}}$. Weight at age W_{ay} and maturity at age G_{ay} in our population dynamics simulations (Table B2) were that same as those used in the stock assessment model. The number of recruits per spawning biomass in year y (RPS_y) (Table B2) was calculated as $NA_{0,y}$ divided by the estimated spawning biomass of $\sum_{a=0}^{6+} NA_{ay} W_{ay} G_{ay}$. Although the estimated parameters could potentially include a range of uncertainty (Nakayama and Hiramatsu 2010), we did not consider the estimation uncertainty in the population dynamics simulation in this study.

TABLE B1. Numbers at age of Pacific chub mackerel at the beginning of the 2004 fishing year, $NA_{a,2004}$ (million fish)

Ages	0	1	2	3	4	5	6+
Numbers of fish	3872.0	299.3	168.9	43.3	7.2	3.0	2.8

TABLE B2. Fishery selectivity, weight and maturity rate at age, and the number of recruits per spawning biomass (RPS). Years are fishing years.

	2004	2005	2006	2007	2008	2009
Selectivity S_{ay}						
0	0.2	0.1	0.0	0.4	0.1	0.1
1	0.4	0.3	0.2	0.3	0.5	0.1
2	0.6	0.4	0.6	0.5	0.5	0.5
3	0.3	0.7	0.8	1.0	0.8	0.4
4	1.0	1.0	0.8	0.5	1.0	0.5
5	0.7	0.7	1.0	0.3	1.0	1.0
6+	0.7	0.7	1.0	0.3	1.0	1.0
Weight (g) W_{ay}						
0	132	118	136	121	138	120
1	280	316	362	314	312	377
2	569	477	528	469	385	503
3	742	578	631	537	589	557
4	835	787	726	683	672	599
5	1011	1002	1013	745	806	694
6+	1087	1089	1122	921	995	838

Maturity rate G_{ay}						
0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.1	0.1	0.0	0.0	0.0	0.0
2	0.8	0.8	0.5	0.5	0.5	0.5
3	1.0	1.0	1.0	1.0	1.0	1.0
4	1.0	1.0	1.0	1.0	1.0	1.0
5	1.0	1.0	1.0	1.0	1.0	1.0
6+	1.0	1.0	1.0	1.0	1.0	1.0
RPS (fish/kg) RPS_y	30.9	4.7	1.4	6.8	3.6	19.1

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