Update of length-based VPA in 2004

Hiroyuki Kurota and Norio Takahashi

National Research Institute of Far Seas Fisheries,

Shizuoka, Japan

Abstract: We updated a VPA model based on catch-at-length data for SBT, which had been originally developed for the 2001 SAG meeting. Recruitment was estimated in each year by sequentially calculating population dynamics at half-year interval, when growth of SBT was assumed to depend on length and age. Length-based CPUE of Japanese longline and age composition of Indonesian fishery on the spawning ground were used for tuning the model.

The analyses showed that recruitment estimates had declining trend from 1970 to mid-1980s, and afterward they were roughly stable. However, they dropped to very low levels after 1999. Estimated spawning biomass showed decreasing trend after fishing started, but it was generally constant these ten years. We also conducted sensitivity analysis with regard to some parameters and examined influences of historical data update.

体長データに基づくVPAの2004年におけるアップデート

黒田啓行・高橋紀夫 (遠洋水産研究所)

要旨: 体長別漁獲尾数に基づいたVPAモデルのアップデートを行った。このモデルはもともと2001年SAGのために開発されたものである。ミナミマグロの成長は体長と年齢に依存するという仮定のもと、半年毎に個体群動態を計算し、毎年の加入量を推定した。チューニングには、日本延縄の体長別CPUEと産卵場でのインドネシア漁業の年齢構成のデータを用いた。

解析の結果、ミナミマグロの加入は、1970年以降1980年代半ばまで減少し、その後安定していたが、1999年以降かなり低い水準にあることが示された。親魚資源量のトレンドは漁獲開始以降、減少傾向にあったが、近年は比較的安定していることが明らかになった。いくつかのパラメータに関する感度分析の結果、および過去の漁獲データの変更の影響などについても考察を行った。

Introduction

The ADAPT VPA currently used for SBT had some problems; overdependence of results on assumptions of plus group and inconsistency in CPUE trends between young ages and plus group. We considered that these problems resulted from cohort slicing used to make catch-at-age data, and developed this assessment model with catch-at-length (CAL) for the 2001 SAG meeting, although all the problems were not solved. To overcome the problems, some statistical models considering error of catch-at-age data, selectivity changes and so on have also been developing for SBT. However, they have too many assumptions to check each influence and their performance is not always acceptable. Thus, we consider that it is valuable to maintain a range of alternative assessment results, as the 2003 SAG meeting recommended (Anonymous, 2003), and updated this length-based VPA model.

After the previous stock assessment in 2001, several data were revised and added and our model formulation was also modified. The major differences are as follows:

a) revision of historical catch-at-age data and CPUE of Japanese longline (from 1965 to 2000; Tsuji et al., 2004)

b) addition of three years data of all fisheries (from 2001 to 2003)

c) recalculation of Indonesian catch data (from 1976 to 2003)

d) addition of a penalty term for yearly variation of recruitments to the objective function

e) change of mature age from 8 to 10 corresponding to the operating model used for the MP evaluation.

This report represents updated estimation result and results of sensitivity analysis corresponding to different model assumptions and input data.

Model structure

- Population dynamics

One year is assumed to consist of two fishery seasons to distinguish qualitatively different fisheries. Fishing is treated as a one-day pulse event. Australian surface fishery and Indonesian spawning ground fishery harvest on January 1, and Japanese longline and miscellaneous fisheries on July 1. Fish growth depends on both length and age and natural mortality depends on age. Recruitment occurs on January 1 at length 0 cm. This model is a type of forward VPA model and it estimates recruitment number in each year as parameters using the AD model builder (Otter Research Ltd., 2001).

First season. Australian surface fishery and Indonesian spawning ground fishery are assumed to harvest SBT on January 1. Population change by harvest is described as

$$N'(l,y,r) = N_1(l,y,r) - \frac{N_1(l,y,r)}{\sum_r N_1(l,y,r)} C_1(l,y) \tag{1}$$

where $N_1(l,y,r)$ is the number of fish born in year r in length class l on January 1 of year y just before harvest, $N'(l,y,r)$ is the population size immediately after harvest, $C_1(l,y)$ is catch in number of length l harvested on January 1 of year y. If $N'(l,y,r)$ becomes negative, $N'(l,y,r)$ is assumed to be 0.

Natural mortality is assumed to depend on age, and length growth rate depend on length, age and recruitment year.

$$N_2(l_2,y,r) = \sum_{l_1} N'(l_1,y,r)\exp(-M_a)L_1(l_1,l_2,y,r) \tag{2}$$

where $N_2(l,y,r)$ is the number of fish born in year r in length class l on July 1 of year y, M_a is instantaneous natural mortality for a half year in age a which we can calculate as a difference between r and y. $L_1(l_1,l_2,y,r)$ is the probability that fish born in year r grow from length l_1 category to length l_2 category in the first season of year y.

Second season. Japanese longline fishery and all remaining fisheries are assumed to harvest fish on July 1. As well as in the first season fishery, fishing and natural mortality and growth are modeled as the following.

$$N''(l,y,r) = N_2(l,y,r) - \frac{N_2(l,y,r)}{\sum_r N_2(l,y,r)} C_2(l,y) \tag{3}$$

$$N_1(l_2,y+1,r) = \sum_{l_1} N''(l_1,y,r)\exp(-M_a)L_2(l_1,l_2,y,r) \tag{4}$$

where $N''(l,y,r)$ is the number after the second season fishery, $C_2(l,y)$ is the catch number of fish length l in the second season of year y, and $L_2(l_1,l_2,y,r)$ is the probability that fish born in year r grow from length l_1 to length l_2 in the second season of year y. If $N'(l,y,r)$ is negative, $N'(l,y,r)$ is assumed to be 0.

- Objective function

The model is designed to estimate the number of recruitments in each year from 1912 to 2001 to minimize an objective function. The objective function consists of three components; 1) abundance indices from length-based CPUE of Japanese longline fishery from 1969 to 2003, 2) catch-at-age composition in Indonesian fishery for eight spawning seasons (1994/5, 1996/7, 1997/8, 1998/9, 1999/2000, 2000/1, 2001/2, 2002/3) and 3) a penalty term for inter-annual variation of recruitments.

We use length-based CPUE which is standardized by generalized linear model (GLM) explained in the following section.

$$F_1 = \sum_l w(l) \sum_y \left(\ln CPUE(l,y) - \ln\left(q(l) \sum_r N_2(l,y,r) \right) \right)^2 \tag{5}$$

where

$$q(l) = \exp\left(\frac{1}{n} \sum_y \left(\ln CPUE(l,y) - \ln \sum_r N_2(l,y,r) \right) \right) \tag{6}$$

where $q(l)$ is catchability dependent on length and n is the total number of years used in tuning (n = 35). The previous analysis showed that it was inappropriate to assume equal reliability of all length groups (Kurota et al., 2001). Therefore, as the base case, we regard higher absolute value of CPUE as more reliable information and determine weight $w(l)$ using temporal average of absolute CPUE values in CS assumption described in the following section. This method of weighting was examined in the previous analysis and the result was satisfactory.

Age distribution of Indonesian catch on the spawning ground is assumed to follow to the multinomial distribution.

$$F_2 = -w_a \sum_y \sum_a p_{obs}(y,a) \ln p_{pred}(y,a) \tag{7}$$

where $p_{obs}(y,a)$ and $p_{pred}(y,a)$ represent observed and predicted proportion of age a in year y, respectively and w_a is the effective sample size. w_a is set 10.0 in the base case. Predicted age distribution is calculated from observed CAL data of Indonesian fishery and predicted age composition in each length class.

A penalty term is introduced for yearly variation of recruitments to provide smoothness in recruits and obtain converged estimates robustly. Recruitment change is assumed to follow the log-normal distribution.

$$N_1(0,r,r) = N_1(0,r+1,r+1)\exp(\gamma_r), \qquad \gamma_r \sim N(0,\sigma_r^{\,2}) \tag{8}$$

Then, the penalty term is described as:

$$F_3 = \sum_r \frac{\gamma_r^{\,2}}{2\sigma_r^{\,2}} \tag{9}$$

where σ_r is dependent on recruitment year. Default values are σ_{r1} = 0.1 for 1912 to 1951, σ_{r2} = 0.5 for 1952 to 1968 and σ_{r3} = 5.0 after 1969. A small value for early times is necessary to obtain converged estimates, because there is little information for tuning the model. Objective function to minimize is sum of F_1, F_2 and F_3.

$$F = F_1 + F_2 + F_3 \tag{10}$$

- Other assumptions

The model is calculated under the following other assumptions.

- Fish life span is up to age 40. Plus-group is not applied.
- Fish grows up to age 21 and the length is constant afterward.
- M_a is half of that in V6 option (Anonymous, 1998).
- Maturity is age-dependent process and age-at-maturity is age 10. Spawning biomass is derived from age-weight relationship estimated by J. N. Ianelli in 2001.
- No fishery for SBT before 1951.
- Model calculation begins in 1912 so that fish population in 1951 can cover all age range. Recruitments before 1968 are constrained within a range of 1.0e+6 and 1.0e+8. Recruitments after 1969 are also limited within a range of 0 and 1.0e+8.
- CAL is treated in units of 10 cm (0-9, 10-19, ..., 190-199, 200+).

Data preparation

CAL data of Australian surface fishery was prepared from bi-monthly CAL data after 1952. Catch between July 1 and June 30 of the following year was considered to be taken on January 1. We did not adjust length according to actual time of catch.

CAL in Indonesian fishery at the spawning ground before 1993 was derived from total catch in weight of each season (from July to June), average weight of a fish from the 1993/4 and 1994/5 seasons, and average length frequency for the two seasons, which were provided by Australian scientists. CAL after 1994 was calculated from total catch in number and length frequency in each year, which were estimated by CSIRO and IOTC. We also used age composition data of Indonesian catch as a tuning index for eight seasons (from 1994/5 to 2002/3 except 1995/6).

CAL data by Japanese longline and miscellaneous fisheries was gathered from CAL of LL1, LL2, LL3 and LL4 (except Indonesian longline) prepared for the operating model of the management procedure development. Historical Japanese data before 1994 was updated and CAL in the second season was different from that used at the 2001 SAG meeting. Table 1 showed all CAL data each season used in this study.

Length-based longline CPUE

Length-based CPUE time series were estimated for tuning indices. The data source used in this estimation is CAL information (1969-2003) by 5×5 degree square / monthly basis in NRIFSF database. This data set includes only Japanese commercial longline fisheries data, and does not include data for joint venture fisheries with Australia and New Zealand.

Length groups used for the abundance index were defined through graphical examination of CPUE trends for length classes of every 10 cm interval by month. The CPUE examined here was monthly average of nominal CPUE of 5×5 / month. These 10 cm-interval length classes that showed similar CPUE trends to one another were lumped together, and eight length groups were defined for the abundance index estimations. The defined length groups were “60-80”, “90-100”, “110-130”, “140-150”, “160”, “170”, “180”, and “190+”. For example, length group "60-80" includes fish between 60 cm and 89 cm and so on.

The data set prepared for Generalized Linear Model (GLM) standardization contains catch numbers for these length groups and corresponding effort by year, quarter, month, SBT statistical area, and 5×5 latitude/longitude. The following model was fitted to the data:

$$\ln(CPUE_{yqmal} + \xi)$$
$$= \mu + Y + Q + M + A + L + Y*A + Q*A + Y*Q + \varepsilon \qquad (8)$$

where

ln	is the natural logarithm,
CPUE	is the nominal CPUE,
y	is y-th year (1969-2003),
q	is q-th quarter (2 and 3),
m	is m-th month (April-September),
a	is a-th SBT statistical area (4, 5 and 6, 7, 8, 9),
l	is l-th latitude (30, 35, 40, 45, 50),
ξ	is 10% of the mean nominal CPUE (cf., Campbell et al. 1996),
μ	is the mean CPUE (the intercept term),
Y	is the effect of year,
Q	is the effect of quarter,
M	is the effect of month,
A	is the effect of SBT statistical area,
L	is the effect of latitude,
*	indicates the interaction term, and
ε	is the error term, $\varepsilon \sim N(0, \sigma^2)$.

We prepared two set of time series, proxies of the B-ratio and geostatistical CPUE models, which were corresponding to the two interim abundance indices ($w_{0.5}$ and $w_{0.8}$) (Tsuji et al., 2004). However, we used only the geostatistical CPUE for tuning the model in the base case (Fig. 1). Because small fish below 25 kg (ca. 120 cm) were released in 1995 and 1996 (Itoh et al., 1998), we did not used CPUE of 60-80, 90-100, 110-130 length groups in the two years as tuning index.

Construction of length transition matrix

Length transition matrix was developed to reflect length variation observed in the direct aging study (Gunn et al., 1997). Fish growth was assumed as the following.

$$l(t+1) = l(t) + \Delta l(a)(1+\varepsilon) \qquad (9)$$

where $l(t)$ is individual length in time t, $\Delta l(a)$ is average growth for a half year in age a of the 1980 recruitment, which is estimated by J. N. Ianelli, ε is variance following the normal distribution (average 0, sd σ).

Variance of growth for a half year was estimated by the Monte Carlo method. We simulated 5000 individuals' growth until age 21 at half-year interval and looked for σ fitting to length variation data of Gunn et al. (1997) by the least square method. It was found that the value σ of 0.115 gave the best fit to the observed data.

We fixed σ at 0.115 and simulated 5000 individuals' growth again in order to calculate probability of growth from length class l to length class l, $l+1$, $l+2$, ... in age a. Because age-growth relationship of SBT was known to change in 1970's, transition matrices were constructed for each recruitment by applying different $\Delta l(a)$ corresponding to the sets of age-length relationship agreed to use in the 2001 assessment. $\Delta l(a)$ for each year and age was derived from cut-point table estimated by J. N. Ianelli.

Results and Discussion

- Base case

Fig. 2 showed model predictions in the base case, which was applied default assumptions (also see Table 2). Recruitments were estimated after 1912, but estimates before 1950s were strongly dependent on model hypothesis because there was little available information for tuning. Thus, we chiefly examined estimates of recruitment and spawning biomass after 1952 here.

Recruitments were at the peak in late 1950s and late 1960s, and they had declining trend until mid-1980s. Afterwards, they fluctuated and did not show a particular trend, but they decreased significantly after 1999 and reached the historically lowest level, although error bands of the estimates were very large. Spawning biomass was at the peak in 1950s and decreased up to mid-1990s in a general term. However, spawning biomass became almost constant in recent years at 30% of the maximum level. We also found a positive relationship between recruitments and spawning biomass, but the function form did not look clear.

Predicted CPUEs were reasonably well fit to observed data in length groups 90-100, 110-130 and 140-150, which had high weighting values as tuning indices. However, model predictions failed to explain CPUE trends of other size groups. This might indicate that there is inconsistency of CPUE among length groups, which our previous analysis also showed (Kurota et al., 2001). The model also predicted age composition on the spawning ground satisfactorily.

- Exploration of alternative formulations

Effective sample size w_a *of spawning ground age composition.* We checked inconsistency between stock trend indicated by the longline CPUE data and that by the age composition data in the spawning ground by changing effective sample size w_a, which meant relative weight of the age composition data in the objective function. As w_a became larger, recruitments and stock biomass were estimated to be lower (Fig. 3). Predicted spawning age compositions were also better fit to the data. However, the differences were very small except when the value was 5.0. Therefore, we considered that there was not large inconsistency between the spawning age composition and the CPUE information.

Relative weight $w(l)$ *of each length group.* In the base case, we regarded higher absolute value of CPUE as more reliable information and determined weight $w(l)$ using temporal average of absolute CPUE values. We explored two other assumptions to examine effects of relative reliability of longline CPUE data among length groups; (1) all length groups have the same reliability and (2) reliability is proportional to the square root of temporal average of absolute CPUE values.

When all length groups had the same weight, estimated results were different significantly from those in the base case (Fig. 4). Temporal pattern of recruitments was somewhat similar to that in the base, but the absolute values were much larger. Estimates of spawning biomass were also quite different. However, even if the same reliability was assumed, model prediction failed to explain high CPUE trend of large length groups over 140 cm in early 1970s, as our previous analysis also showed. In addition, fitting to the age composition of Indonesian catch was worse and the stock-recruitment relationship looked strange. Therefore, we considered that this equal reliability assumption was not acceptable. When relative weights were proportional to the square root of the absolute CPUE values, the result was between the base case result and the result in the equal reliability assumption. We considered that this assumption was not better than the base case from the viewpoint of the objective function value (Table 3).

Age of maturity. In this model, any relationship between recruitments and spawning biomass was not assumed and any index for matured adults was not used in tuning. Therefore, age of maturity did not affect estimation of recruitment itself (Fig. 5). However, historical trends of spawning biomass were different among assumptions on age of maturity. As maturity age became older, spawning biomass decreased more severely relative to that before fishing started (Table 1).

Penalty for recruitment variability, σ_{r2}. This parameter was originally introduced to restrict temporal change of recruitment from 1952 to 1968 and obtain converged estimates more robustly. We found that this parameter influenced significantly on recruitments and stock biomass before fishing started, but those estimates after 1970s were not different among assumptions (Fig. 6). This might indicate lower reliability for estimates in old times.

Data update. Some data were revised and updated for stock assessments in 2004 as follows:

a) revision of historical catch-at-age data and CPUE of Japanese longline (from 1965 to 2000)

b) addition of three years data of all fisheries (from 2001 to 2003)

c) recalculation of Indonesian catch data (from 1976 to 2003)

To examine influences of these data change, we compared with results in using (1) all new data up to 2004 (base case), (2) old data up to 2001 without any revision and recalculation ("2001old"), and (3) new data up to 2001 including revision of historical data and recalculation of Indonesian catch ("2001new"). Estimation model used here was a new version with a penalty term for recruitment variation.

Revised and recalculated historical data had some effects of recruit estimates before 1960s and in 1990s (Fig. 7). Estimated stock biomass using new data was lower than using old data, although the difference became smaller recently. Comparison between the base case and the "2001new" showed that data addition up to 2004 resulted in higher recruitments in mid-1990s. This is because CPUEs of middle size fish were high these three years. Difference in biomass in 1950s was also found between them. We considered that this is because influence of the age composition of Indonesian catch in the "2001 new" was small relatively in the objective function since the number of the age composition data decreased from eight to five. Therefore, we examined a condition that w_a was 16.0 and found that the results were quite similar between the base case and the "2001 new_wa16" except recent recruitments.

Acknowledgments

We are grateful to Ann Preece for providing us with Indonesian catch data.

References

Anonymous. 2003. Report of the fourth meeting of the stock assessment group. 25-29 August 2003, Christchurch, New Zealand. CCSBT.

Gunn, J., N. Clear, T. Rees, C. Stanley, J. Farley, and T. Carter. 1997. The direct estimation of age and growth of southern bluefin tuna. CCSBT-SC/9707/5.

Itoh, T., T. Nishida, and S. Tsuji. 1998. Southern bluefin tuna catch by Japan - 1998. CCSBT-SC/9807/15.

Kurota, H., S. Tsuji, N. Takahashi, K. Hiramatsu, and I. Itoh. 2001. Exploration of cohort analysis based on catch at length data for southern bluefin tuna. CCSBT-SC/0108/32.

Otter Research Ltd. 2001. An introduction to AD Model Builder version 6.0.3. Canada.

Tsuji, S., N. Takahashi, M. Nagasaka, T. Itoh. 2004. Preparation of Japanese catch/effort and size data and CPUE series for 2004 stock assessment and mechanical update of Operating Model. CCSBT-ESC/0409/31.

Table 1. Catch-at-length used in the model for the first season (Australian surface fishery and Indonesian fishery).

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200+
1952	0	0	0	0	0	21	248	1857	1370	1190	480	35	6	1	0	0	0	0	0	0	0
1953	0	0	0	0	0	107	1208	7952	5546	4521	1844	138	26	8	0	0	0	0	0	0	0
1954	0	0	0	0	0	210	2340	14587	9877	7769	3180	234	46	15	0	0	0	0	0	0	0
1955	0	0	0	0	0	184	2060	13135	9010	7201	2943	219	42	13	0	0	0	0	0	0	0
1956	0	0	0	0	0	137	1589	12825	9843	8877	3598	298	56	11	2	0	0	0	0	0	0
1957	0	0	0	0	0	350	4000	30564	22943	20244	8222	675	128	28	4	0	0	0	0	0	0
1958	0	0	0	0	0	405	4662	37154	28388	25488	10342	861	164	34	5	0	0	0	0	0	0
1959	0	0	0	0	0	802	9117	66924	49361	42781	17402	1413	271	64	7	0	0	0	0	0	0
1960	0	0	0	0	0	835	9684	80802	62881	57445	23286	1971	376	72	14	0	0	0	0	0	0
1961	0	0	0	0	0	1026	12048	108248	86534	81006	32786	2826	539	93	22	0	0	0	0	0	0
1962	0	0	0	0	0	748	9271	107766	92892	92549	37313	3355	636	82	33	0	0	0	0	0	0
1963	0	0	0	0	0	683	8616	106862	93545	94299	37991	3443	652	79	35	0	0	0	0	0	0
1964	0	0	0	0	0	1349	16549	184706	157604	155781	62843	5629	1070	143	54	0	0	0	0	0	0
1965	0	0	0	0	52	860	106137	170690	92122	137310	39577	16027	1323	191	10	3	0	0	0	0	0
1966	0	0	0	0	24	3137	10447	88083	219879	199793	43895	8671	2244	169	21	0	0	0	0	0	0
1967	0	0	0	0	171	14038	11825	105490	148067	94695	30846	7884	1027	205	26	8	22	0	0	0	0
1968	0	0	0	0	0	1784	39096	387515	107906	68166	19191	1827	223	7	8	0	0	0	0	0	0
1969	0	0	0	3312	7483	112205	545753	248428	101621	65510	7894	633	35	0	0	0	0	0	0	0	0
1970	0	0	0	10306	14405	195611	483437	308047	76180	28716	23556	2101	0	0	0	0	0	0	0	0	0
1971	0	0	0	1507	4009	127732	424617	242052	80107	26540	5743	76	0	0	0	0	0	0	0	0	0
1972	0	0	0	0	6592	40382	189138	387312	295570	72034	18580	1641	15	0	0	0	0	0	0	0	0
1973	0	0	0	0	2578	42972	154856	141834	206533	340852	50464	8829	644	0	0	0	0	0	0	0	0
1974	0	0	0	42	11598	229858	127766	168608	166231	94904	86189	10378	718	128	68	12	0	0	0	0	0
1975	0	0	0	0	22232	265803	168959	267893	135132	68561	52529	51653	22864	3363	181	19	0	0	0	0	0
1976	0	0	0	0	65784	275452	241183	266316	183106	114186	17131	8400	5747	2794	193	13	2	11	27	8	2
1977	0	0	0	0	94263	342978	203698	340778	114820	124654	12341	318	24	12	10	52	101	15	36	10	2
1978	0	0	0	10	47610	415888	313698	261451	74269	151243	80741	35852	4234	748	256	10	2	10	22	6	1
1979	0	0	0	0	79615	472243	232528	282506	97582	41020	28650	43400	22749	3437	934	406	237	45	25	7	1
1980	0	0	0	0	97404	474512	332808	352480	93148	52717	66133	17795	15903	7512	911	149	4	10	22	6	1
1981	0	0	0	0	45723	353174	315875	297688	154541	231492	86940	43107	7991	5910	1536	80	1	6	13	4	1
1982	0	0	0	0	42701	452287	427593	529654	196624	57775	51130	57078	42673	11495	2646	106	30	3	7	2	0
1983	0	0	0	0	66108	846998	574270	449407	211086	216804	72428	31345	26813	15725	8257	1237	165	7	16	5	1
1984	0	0	0	0	7461	421327	320541	383738	265606	115488	43188	27873	14535	12432	4292	307	29	18	36	10	2
1985	0	0	0	0	3322	58101	208383	229874	136234	127660	82252	58044	30959	10565	2892	361	173	108	45	9	2
1986	0	0	0	0	2206	101038	271276	267806	247498	182918	87898	30001	10118	5228	2689	477	36	10	22	6	1
1987	0	0	0	40	4863	80941	75682	125464	120039	284832	62703	29506	6612	2876	1565	266	30	20	47	14	3
1988	0	0	0	0	3054	87838	235808	316926	254285	115764	38728	14944	2887	580	126	14	45	191	435	126	29
1989	0	0	0	0	65	76115	74197	152182	158041	81983	10930	3244	306	221	18	10	150	713	1675	485	102
1990	0	0	0	0	207	5634	37922	39884	91341	133807	19427	2058	119	12	4	14	218	1035	2430	703	147
1991	0	0	0	0	0	716	29674	39019	24464	95791	16475	486	60	17	5	19	257	1217	2858	827	173
1992	0	0	0	0	173	1978	16447	13996	6288	61275	22721	3358	32	26	22	24	219	889	1980	575	120
1993	0	0	0	0	0	22	1499	234	11605	45559	23315	4380	848	350	147	97	550	2390	5389	1548	325
1994	0	0	0	0	0	3	220	71	1148	42292	37706	14659	2863	1431	513	197	330	1421	3157	919	191
1995	0	0	0	0	0	29	235	3181	14847	70021	36664	11802	3512	1321	506	192	701	2931	3428	588	108
1996	0	0	0	0	0	0	0	4289	17057	72067	98895	19200	2570	1525	641	335	1665	4009	3918	796	125
1997	0	0	0	0	0	810	1134	10612	22204	128030	55957	34994	8086	3008	2346	1022	2580	4236	5146	1521	319
1998	0	0	0	0	0	0	0	3	33203	111494	76272	14654	1928	1570	1249	2347	3773	4717	5647	1335	243
1999	0	0	0	0	0	0	0	0	29662	233335	20132	6280	4303	3120	2742	1899	2745	5571	5984	2029	441
2000	0	0	0	0	0	0	0	12350	22638	137467	78367	21159	1840	320	376	1144	2702	4647	3301	1305	237
2001	0	0	0	0	0	0	0	4154	28930	138331	95889	16543	3485	913	480	2023	3354	3284	2513	1017	123
2002	0	0	0	0	0	0	0	2083	20789	157235	81430	16572	2798	366	394	6296	6760	5367	3611	731	197
2003	0	0	0	0	0	138	0	8459	34576	81660	130312	20920	1099	868	303	1916	2453	1502	693	111	35

Table 2. Catch-at-length used in the model for the second season (Japanese longline and miscellaneous fisheries).

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200+
1952	0	0	0	0	0	0	0	0	0	0	0	0	1	2	6	32	48	11	0	0	0
1953	0	0	0	0	0	0	0	0	0	0	1	2	57	314	7425	13025	8240	902	1	0	0
1954	0	0	0	0	0	0	0	0	0	0	32	96	360	2347	10882	18093	7416	778	51	0	0
1955	0	0	0	0	0	0	0	0	0	0	6	0	91	333	4438	13122	4929	301	143	0	0
1956	0	0	0	0	0	0	0	2	0	2	14	54	157	1037	12009	22601	8322	787	17	0	0
1957	0	0	0	0	0	0	0	45	2285	19281	44914	57336	40030	43438	58303	81830	32690	4376	71	0	0
1958	0	0	0	0	0	0	0	80	1670	14095	22682	20268	18404	24339	61478	71742	26337	2824	178	0	0
1959	0	0	0	0	0	0	0	0	0	465	7970	38749	82184	172109	222205	127584	27400	2759	208	0	0
1960	0	0	0	0	0	0	0	0	0	1814	7555	17495	56061	265358	391489	223639	57723	5035	349	0	0
1961	0	0	0	0	0	0	0	0	817	6863	24814	51348	94409	288523	494941	327566	90332	10398	838	0	0
1962	0	0	0	0	0	0	104	1429	4675	14561	26940	31732	52511	121324	272611	237390	94024	12304	361	0	0
1963	0	0	0	0	0	0	0	1475	14204	22920	48948	81500	91813	140155	254853	211015	63502	7435	474	20	0
1964	0	0	0	0	0	0	72	914	7377	26415	36090	44299	65464	144568	272815	172409	44142	5612	399	0	0
1965	0	0	0	5	0	0	0	240	1107	10814	22256	61841	64607	210213	269414	119453	33442	5379	415	72	13
1966	0	0	0	0	0	0	0	62	1511	10494	30152	56323	91352	121743	199758	116920	43197	10820	771	47	6
1967	0	0	0	0	0	0	9	374	4259	24034	29939	45387	77653	159405	250975	207192	76762	13297	684	16	0
1968	0	0	0	0	0	87	290	4358	13579	35876	59467	57416	68348	138264	229790	239041	107819	25242	3418	378	0
1969	0	0	0	0	0	28	665	5145	17094	35468	48170	68593	91719	110105	183418	175124	87099	22966	3337	246	0
1970	0	0	0	0	0	32	293	3000	14470	37317	60319	68035	67183	82359	133932	131553	76721	22595	2918	179	0
1971	0	0	0	0	0	13	110	3127	15727	40713	63385	74247	81235	95857	136025	113451	59117	19989	3673	203	0
1972	0	0	0	0	0	0	0	1675	12555	69832	87181	114189	121613	114287	140355	97414	36749	8452	1032	83	0
1973	0	0	0	0	0	0	18	1829	18189	56523	70212	99406	88726	87623	98239	79024	38448	10849	1134	130	0
1974	0	0	0	0	0	0	83	1988	6830	24761	89626	99496	90168	90583	119352	95079	40386	11803	938	68	0
1975	0	0	0	0	0	24	456	2484	13078	15997	27376	38105	48858	67824	105673	82643	32834	6481	1009	31	0
1976	0	0	0	0	0	15	115	1924	20447	26732	26529	34137	59370	122566	155294	128070	49647	10438	553	34	0
1977	0	0	0	0	107	809	454	308	9416	34694	43558	33556	41041	98426	157815	82144	26733	6306	506	17	0
1978	0	0	0	2	2	0	290	4135	14050	29724	43471	56723	48484	82766	96265	53743	17645	4190	383	26	0
1979	0	0	0	4	0	5	62	3121	4315	20322	33681	82412	80243	58345	86788	83356	45973	18181	2753	469	22
1980	0	0	0	37	0	37	291	3576	9275	29748	37222	48624	59626	81847	124969	124140	50134	13003	1797	233	0
1981	0	0	0	0	0	0	1	2869	6310	16486	31807	60120	63280	61325	91231	86187	49071	11759	1616	130	0
1982	0	0	0	0	0	0	0	38	1425	5703	18838	30482	40014	44105	70470	64758	44372	13806	1461	123	0
1983	0	0	0	0	0	20	16	233	2115	13112	26996	46670	68177	72131	80908	60561	39899	14790	2414	218	0
1984	0	0	0	0	0	0	8	82	1047	8185	19397	40656	44769	44943	68031	71997	44352	19183	3051	148	0
1985	0	0	0	0	0	87	13	185	1512	6823	12293	23108	28723	43001	66415	62546	40505	18042	2770	217	8
1986	0	0	0	0	0	0	5	201	3588	8284	9322	10403	14002	16170	33289	51068	42060	20526	4604	349	12
1987	0	0	0	0	0	0	5	229	2467	3578	10956	15561	12614	16129	29327	42038	36027	19472	5731	465	58
1988	0	0	0	0	0	8	106	616	2648	4452	11788	18760	12878	9691	22153	34884	28063	15311	4228	627	71
1989	0	0	0	7	0	4	49	935	8088	17357	19400	21539	23921	16675	15982	25157	29748	17046	5318	950	209
1990	0	0	0	0	0	0	0	374	7474	16022	24174	17742	13193	13764	11318	17019	19228	11236	3211	439	50
1991	0	0	0	0	0	10	103	1009	14104	26977	33729	33113	19184	10779	10850	11280	17245	15997	5680	966	75
1992	0	0	0	1	0	0	19	3504	15090	29189	38982	48254	30796	16099	9186	9130	13083	15278	7860	1804	205
1993	0	0	0	0	0	0	267	220	9507	30631	45761	40826	45361	32177	17868	10294	11119	12775	5803	1447	135
1994	0	0	0	0	0	0	8	188	3618	15078	37326	37922	29662	27643	18205	12153	10817	12914	5049	681	43
1995	0	0	0	0	0	0	7	46	1595	9943	15517	26661	34285	29163	27185	15965	11181	10390	4578	903	62
1996	0	0	0	0	0	0	85	361	1965	2253	4090	17289	38490	28679	28473	21707	14859	12730	5333	784	201
1997	0	0	0	0	0	0	9	71	645	5275	12598	20654	34384	31348	29076	20352	10554	7899	4055	928	129
1998	0	0	0	3	0	1	21	569	18102	27574	28036	31514	25506	33826	41930	30708	15842	8339	3887	937	275
1999	0	0	0	0	1	1	36	426	9423	33345	44954	33352	27750	21125	34864	32706	17450	9478	4155	985	212
2000	0	0	0	1	0	14	150	656	3692	7482	18475	25974	26183	17931	22403	26352	14435	6027	2347	579	68
2001	0	0	0	0	0	270	1238	6078	11070	14168	19318	22934	29473	21484	20941	26960	16767	6549	2273	788	162
2002	0	0	0	0	3	26	64	106	1178	6605	21376	24989	27008	29607	25018	21419	14127	5347	1588	357	85
2003	0	0	0	0	0	0	2	133	866	3346	5424	13814	30292	26734	24855	17825	12207	5183	1554	308	51

Table 3. Parameter values and summary results of the base case and alternative model formulations. Highlighted cells show differences in model formulation from the base case.

	base	wa_5.0	wa_7.5	wa_15	wa_20	wl_10	wl_root	mature_8	mature_12	mature_15	mature_20	r2_0.2	r2_1.0	r2_5.0
Condition														
$sigma\_r_1$	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
$sigma\_r_2$	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.2	1.0	5.0
$sigma\_r_3$	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
w_a	10.0	5.0	7.5	15.0	20.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
mature age	10	10	10	10	10	10	10	8	12	15	20	10	10	10
w(l)														
60-80	0.156	0.156	0.156	0.156	0.156	1.000	0.481	0.156	0.156	0.156	0.156	0.156	0.156	0.156
90-100	1.323	1.323	1.323	1.323	1.323	1.000	1.401	1.323	1.323	1.323	1.323	1.323	1.323	1.323
110-130	3.099	3.099	3.099	3.099	3.099	1.000	2.145	3.099	3.099	3.099	3.099	3.099	3.099	3.099
140-150	2.453	2.453	2.453	2.453	2.453	1.000	1.909	2.453	2.453	2.453	2.453	2.453	2.453	2.453
160	0.634	0.634	0.634	0.634	0.634	1.000	0.970	0.634	0.634	0.634	0.634	0.634	0.634	0.634
170	0.253	0.253	0.253	0.253	0.253	1.000	0.613	0.253	0.253	0.253	0.253	0.253	0.253	0.253
180	0.059	0.059	0.059	0.059	0.059	1.000	0.296	0.059	0.059	0.059	0.059	0.059	0.059	0.059
190+	0.023	0.023	0.023	0.023	0.023	1.000	0.185	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Result														
f_value														
sum	271.18	147.46	209.75	393.66	515.73	303.84	286.45	271.18	271.18	271.18	271.18	273.51	269.97	268.72
CPUE	24.41	21.73	23.84	25.26	26.12	49.91	34.01	24.41	24.41	24.41	24.41	24.95	23.96	23.52
age comp	245.38	124.87	184.60	366.91	487.95	252.93	251.53	245.38	245.38	245.38	245.38	245.89	245.13	245.01
recruit	1.38	0.86	1.30	1.49	1.66	0.99	0.91	1.38	1.38	1.38	1.38	2.66	0.89	0.19
recruit														
2001/1952	0.17	0.13	0.17	0.18	0.19	0.16	0.14	0.17	0.17	0.17	0.17	0.09	0.32	0.55
2001/1960	0.07	0.06	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.07	0.06	0.07	0.07
2001/1980	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
2001/1999	0.16	0.16	0.16	0.16	0.16	0.21	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.16
2001/MAX	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04
2001/MIN	0.69	0.71	0.69	0.69	0.69	0.46	0.63	0.69	0.69	0.69	0.69	0.69	0.69	0.69
2001 (number)	553760	623519	560757	548746	547724	1231380	768423	553761	553761	553761	553761	562969	552009	550938
SSB														
2004/1952	0.29	0.31	0.29	0.30	0.30	0.69	0.56	0.34	0.27	0.19	0.11	0.26	0.40	0.54
2004/1960	0.35	0.35	0.35	0.36	0.38	0.93	0.65	0.41	0.31	0.21	0.12	0.26	0.64	0.99
2004/1980	0.53	0.49	0.51	0.55	0.56	0.75	0.62	0.51	0.60	0.56	0.43	0.52	0.53	0.53
2004/2001	0.96	0.95	0.96	0.95	0.95	0.93	0.93	1.00	1.17	1.22	0.80	0.96	0.96	0.96
2004/MAX	0.29	0.31	0.29	0.30	0.30	0.63	0.56	0.33	0.27	0.19	0.11	0.25	0.40	0.46
2004/MIN	1.10	0.99	1.08	1.12	1.14	1.34	1.03	1.08	1.25	1.22	0.98	1.08	1.11	1.49
2004 (wt ton)	56325	105987	60468	53582	49033	740225	243875	74681	45937	25697	9435	62141	53536	52877

	2001old	2001new	2001old_wa16	2001new_wa16
Condition				
$sigma\_r_1$	0.2	0.2	0.2	0.2
$sigma\_r_2$	0.5	0.5	0.5	0.5
$sigma\_r_3$	5.0	5.0	5.0	5.0
w_a	10.0	10.0	16.0	16.0
mature age	10	10	10	10
data	2001old	2001new	2001old	2001new
w(l)				
60-80	0.191	0.165	0.191	0.165
90-100	1.370	1.379	1.370	1.379
110-130	2.680	3.051	2.680	3.051
140-150	2.475	2.452	2.475	2.452
160	0.835	0.625	0.835	0.625
170	0.355	0.250	0.355	0.250
180	0.084	0.057	0.084	0.057
190+	0.013	0.020	0.013	0.020
Result				
f_value				
sum	179.47	178.26	274.29	272.78
CPUE	19.75	18.97	21.07	20.07
age comp	158.62	158.14	251.87	251.39
recruit	1.10	1.15	1.35	1.31
recruit				
1998/1952	0.26	0.39	0.29	0.43
1998/1960	0.15	0.17	0.16	0.17
1998/1980	0.21	0.23	0.21	0.24
1998/1998	1.00	1.00	1.00	1.00
1998/MAX	0.10	0.12	0.09	0.12
1998/MIN	0.64	0.78	0.63	0.78
1998(num)	1204380	1426350	1169630	1403960
SSB				
2001/1952	0.22	0.25	0.23	0.25
2001/1960	0.28	0.29	0.30	0.30
2001/1980	0.45	0.49	0.46	0.50
2001/1998	1.00	1.00	1.00	1.00
2001/MAX	0.22	0.25	0.23	0.25
2001/MIN	1.14	1.08	1.21	1.11
2001(wt ton)	69452	57929	57517	50822

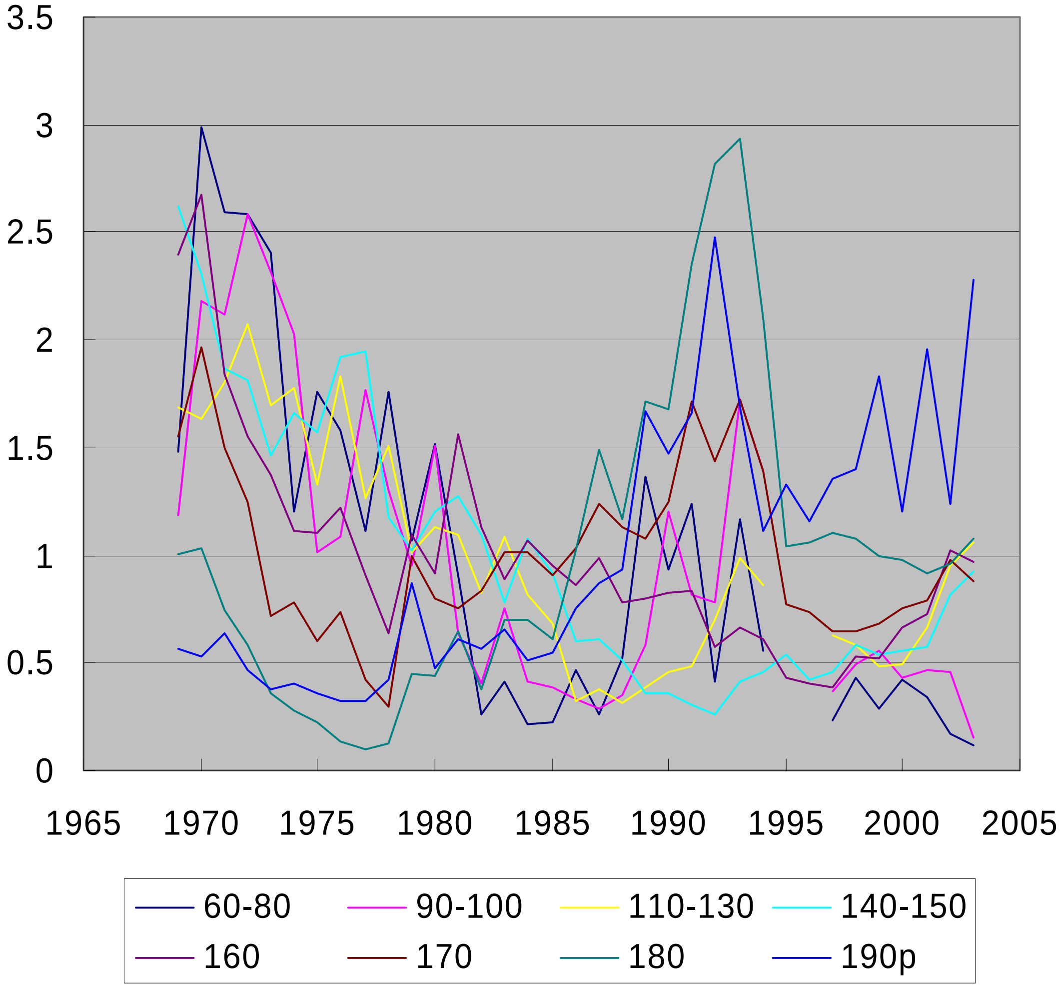


Fig. 1. Length-based CPUE of Japanese longline standardized by GLM in each length group from 1969 to 2003.

recruit		SSB		f_value		condition		size class	$w(l)$
2001/1952	0.17	2004/1952	0.29	sum	271.18	$sigma\_r_1$	0.2	60-80	0.156
2001/1960	0.07	2004/1960	0.35	CPUE	24.41	$sigma\_r_2$	0.5	90-100	1.323
2001/1980	0.09	2004/1980	0.53	age comp	245.38	$sigma\_r_3$	5.0	110-130	3.099
2001/1998	0.16	2004/2001	0.96	recruit	1.38	w_a	10.0	140-150	2.453
2001/MAX	0.05	2004/MAX	0.29			mature age	10	160	0.634
2001/MIN	0.69	2004/MIN	1.10			max rec	1.00E+08	170	0.253
2001(num)	553760	2004(wt ton)	56325			min rec	1.00E+06	180	0.059
						initial rec	3	190+	0.023

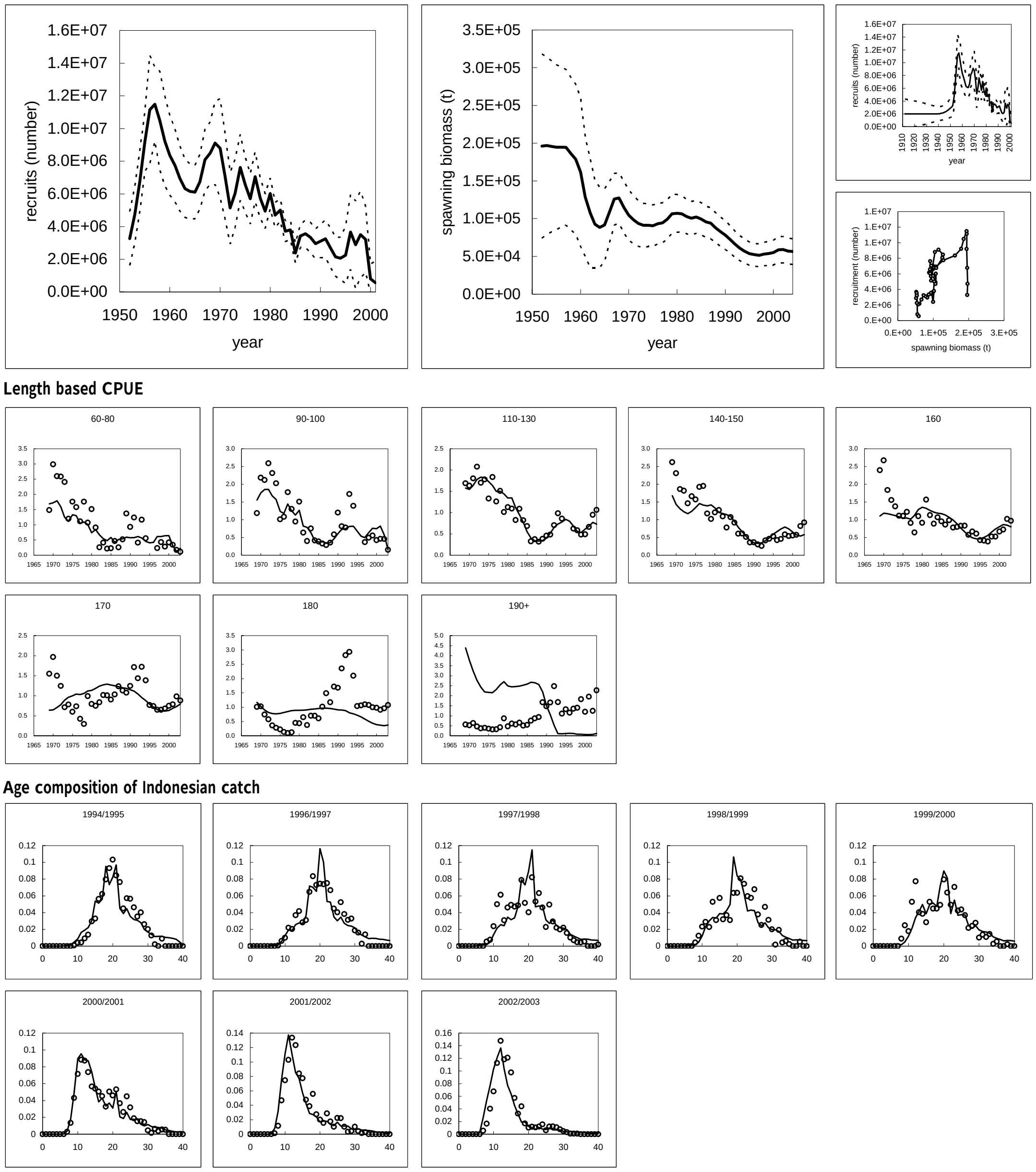


Fig. 2. Estimates of recruitment (1952-2001 and 1931-2001), spawning biomass (1952-2004) and stock-recruitment relationship (1952-2001), and fit to Japanese longline CPUE data and age composition of Indonesian catch in the base case (open circle: observed data, line: prediction). Error bands represent one standard error of the estimates.

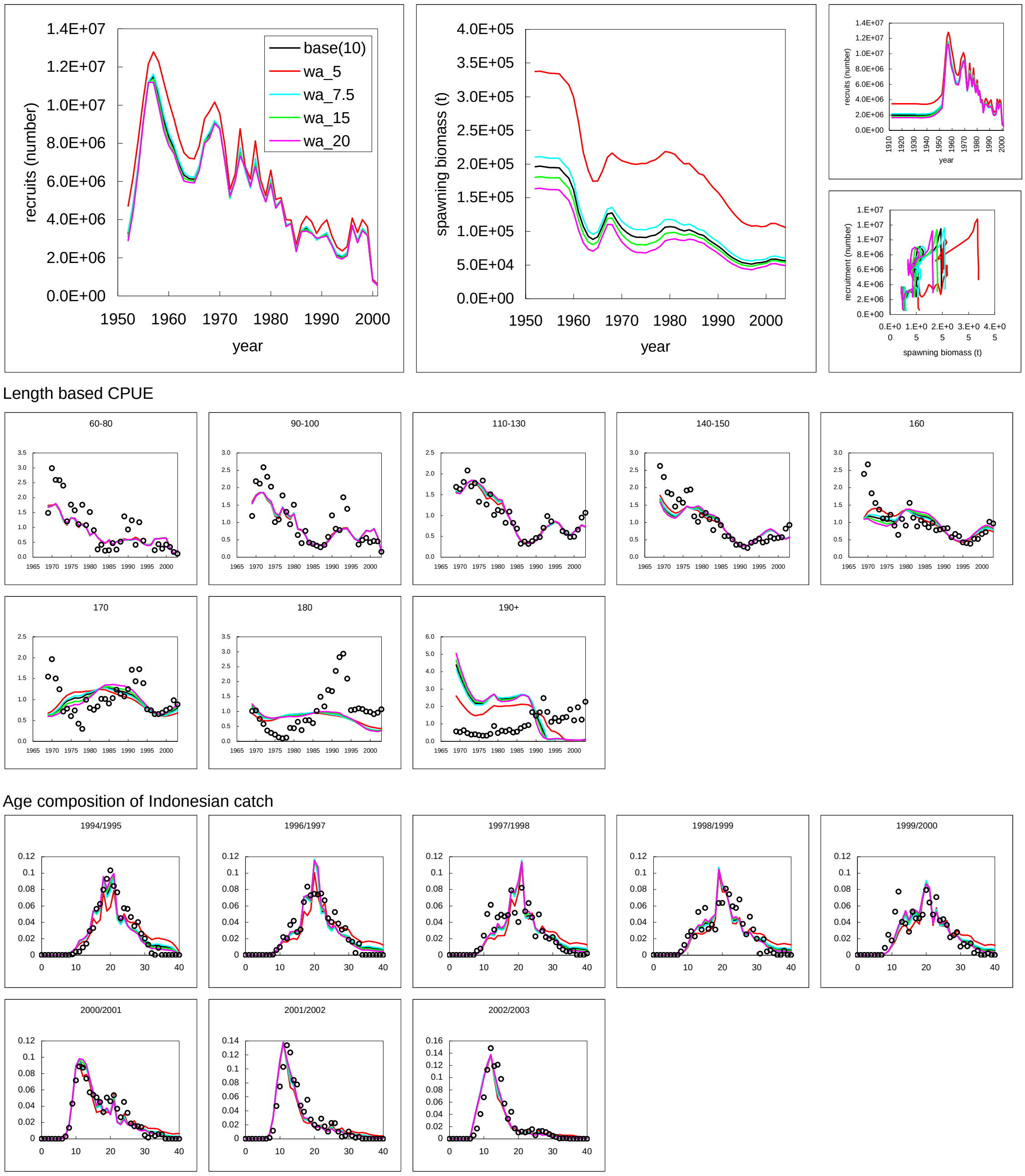


Fig. 3. Effects of w_a on estimates of recruitment, spawning biomass, stock-recruitment relationship, and fit to Japanese longline CPUE data and age composition of Indonesian catch (open circle: observed data, line: prediction).

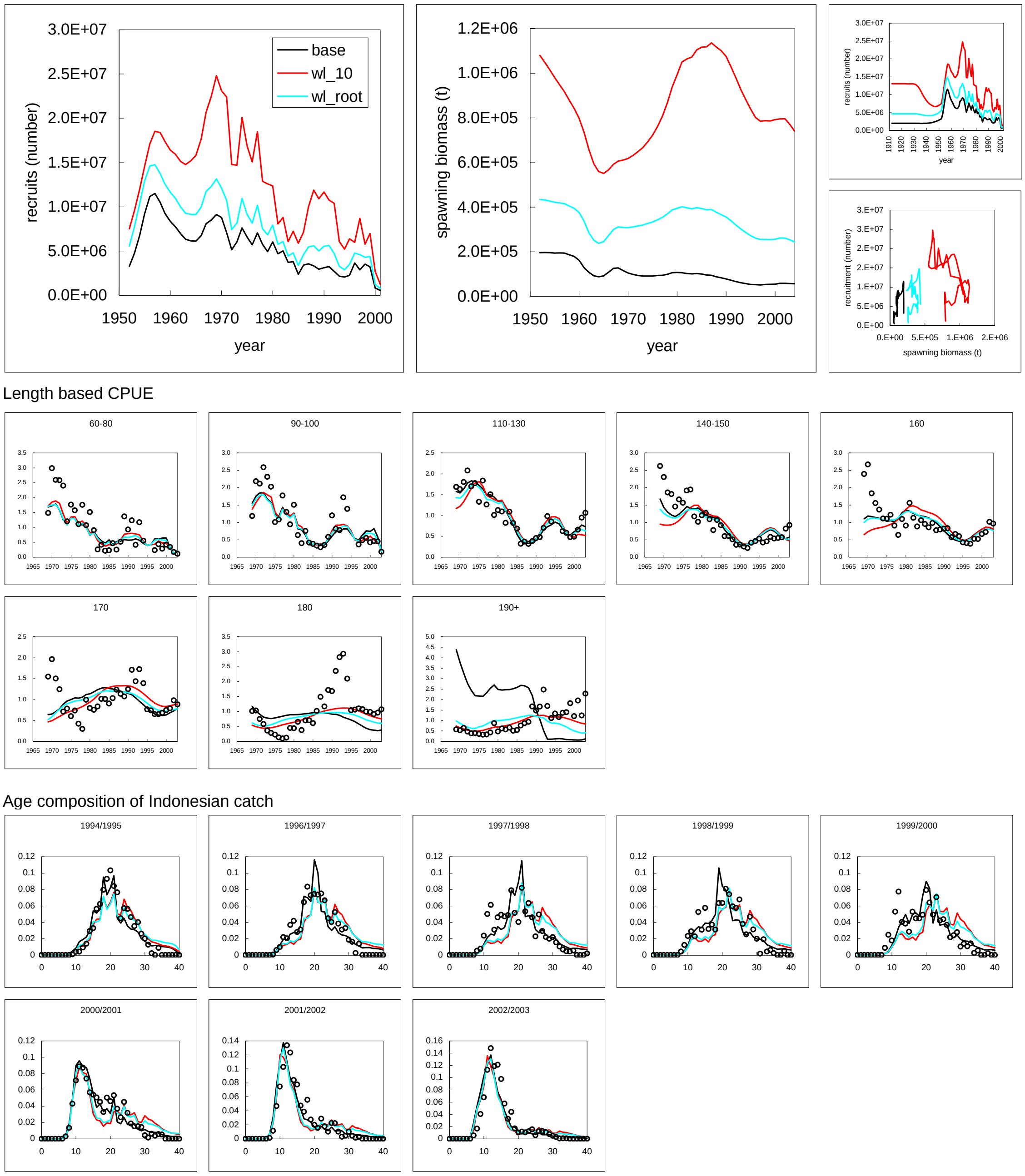
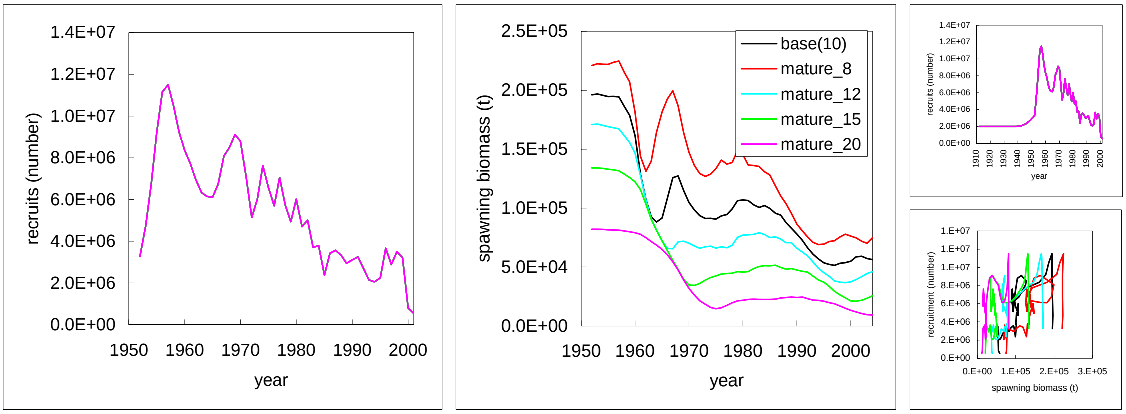
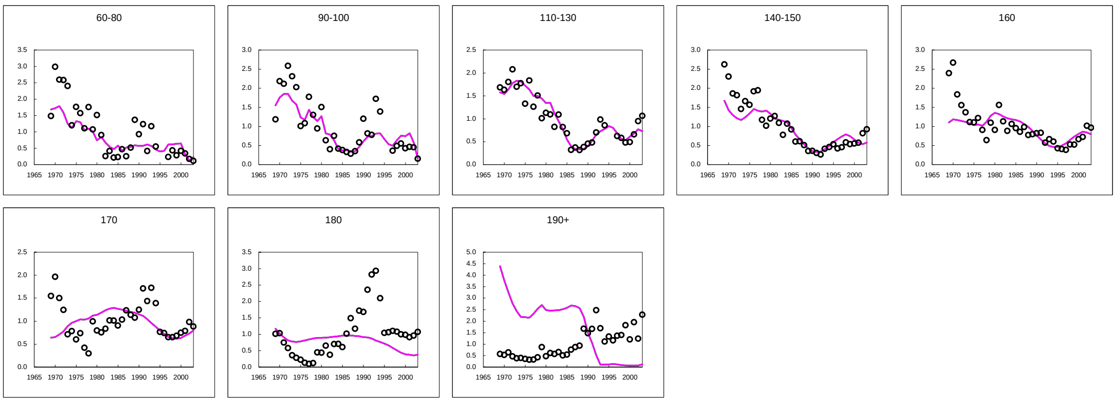


Fig. 4. Effects of *w(l)* assumption on estimates of recruitment, spawning biomass, stock-recruitment relationship, and fit to Japanese longline CPUE data and age composition of Indonesian catch (open circle: observed data, line: prediction).



Length based CPUE



Age composition of Indonesian catch

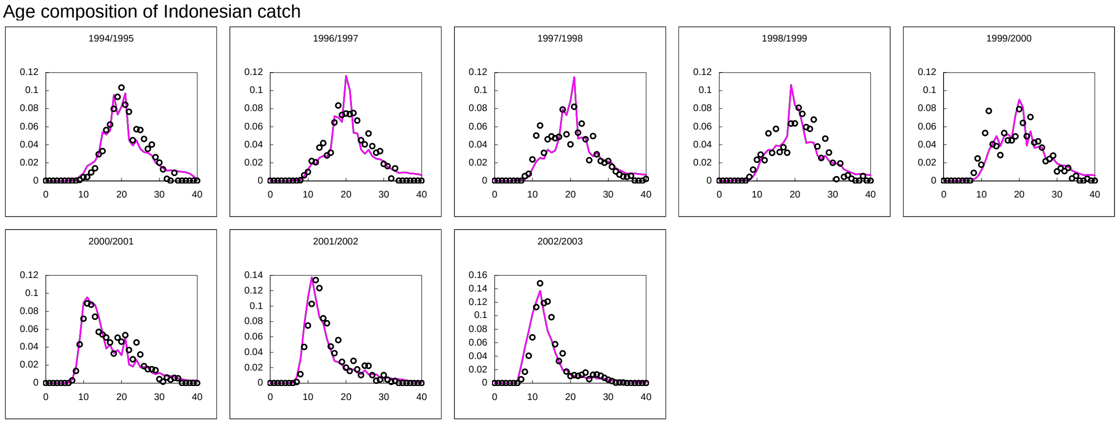


Fig. 5. Effects of age of mature on estimates of recruitment, spawning biomass, stock-recruitment relationship, and fit to Japanese longline CPUE data and age composition of Indonesian catch (open circle: observed data, line: prediction).

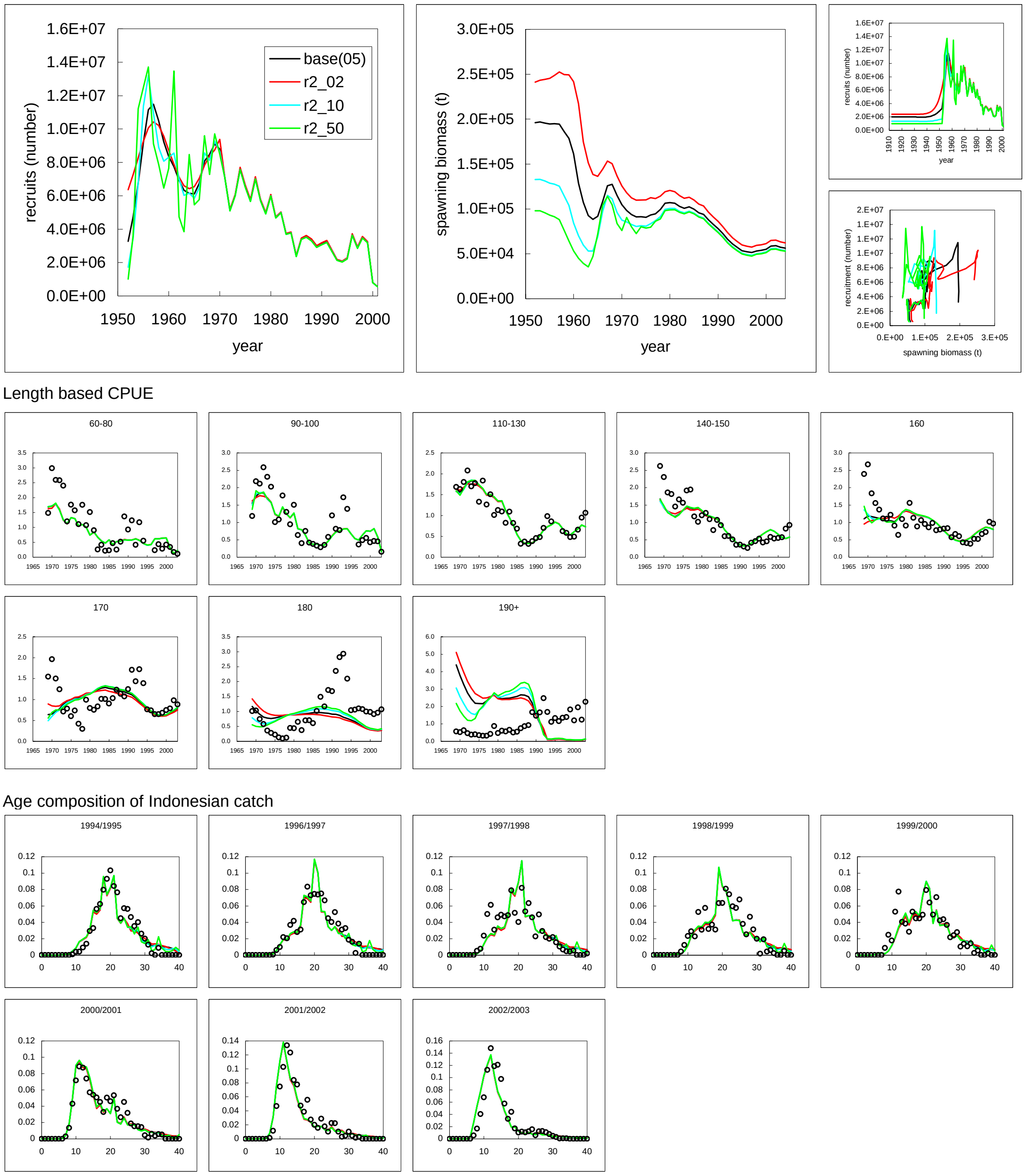
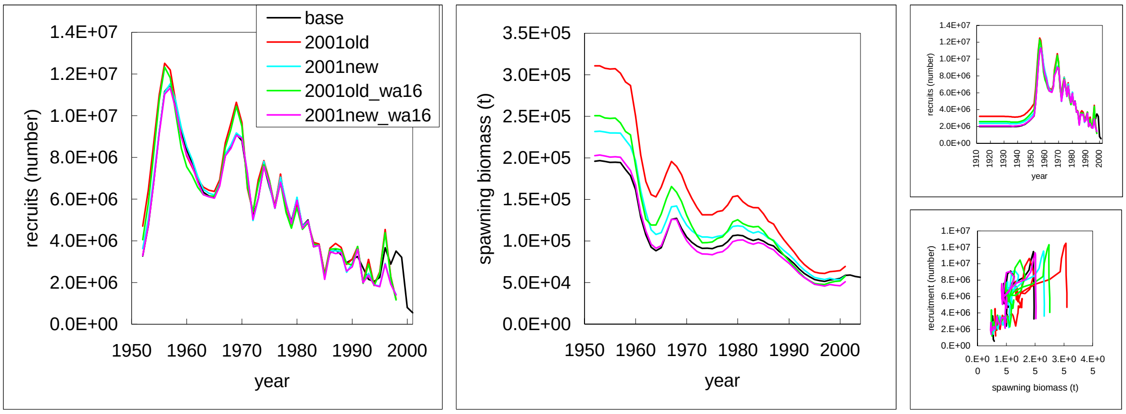
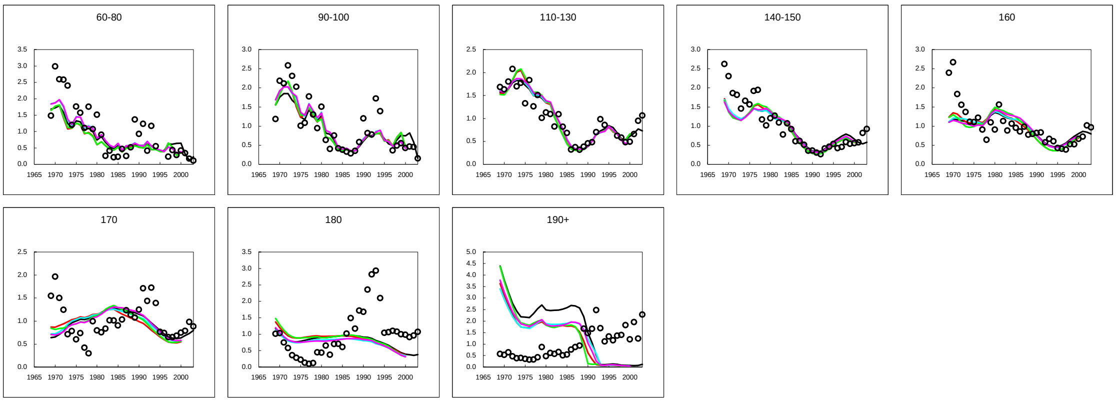


Fig. 6. Effects of σ_{r2} on estimates of recruitment, spawning biomass, stock-recruitment relationship, and fit to Japanese longline CPUE data and age composition of Indonesian catch (open circle: observed data, line: prediction).



Length based CPUE



Age composition of Indonesian catch

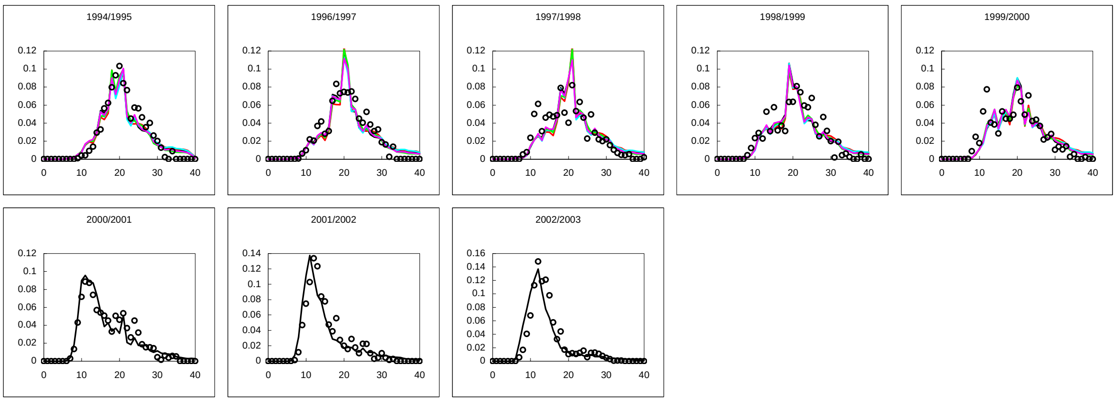


Fig. 7 Effects of used data set on estimates of recruitment, spawning biomass, stock-recruitment relationship, and fit to Japanese longline CPUE data and age composition of Indonesian catch (open circle: observed data, line: prediction).