Application of Surplus-Production Models to Splendid Alfonsin Stock in the Southern Emperor and Northern Hawaiian Ridge (SE-NHR)

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The Japanese trawlers commenced exploratory fishing operations in the Southern Emperor and Northern Hawaiian Ridge (SE-NHR) in 1969, and the trawl fishery have been developed after then. In this area, 2 to 13 trawlers have been conducting fishing activities every year, targeting mainly North Pacific armorhead (*Pseudopentaceros wheeleri*) and splendid alfonsino (*Beryx splendens*). The fisheries are the important component of the ecosystem in the fishing ground, and understanding the impacts of the fisheries is important for the sustainable use of the aquatic resources. To estimate the management benchmarks, first attempt has been made to apply surplus production model to the splendid alfonsino stock in SE-NHR (Nishimura & Yatsu, 2006). This paper describe the results from two different surplus-production model program runs with using unadjusted/adjusted CPUE, and with using catch statistics from Japan, Korea, and USSR/Russia.

1. Catch and CPUE data

Japanese fishery statistics in SE-NHR were complied by the Far Seas Fisheries Research Institute (Shimizu) and Hokkaido National Fisheries Research Institute (Kushiro) based on operation records submitted to the Fisheries Agency of Japan from commercial fishing vessels (Yanagimoto and Nishimura, 2007). Korea and USSR/Russia catch data of alfonsino was also prepared by Korea and Russian Institutes. These data sets of alfonsino were submitted to the Science Working Group of NWPBT meetings, and these data sets were combined and used for the following analyses. Statistics of fishing effort is available for only Japanese trawling duration (hours).

In the SE-NHR area, North Pacific armorhead fisheries started in 1969. The total Japanese landings increased to 22,000 to 35,000 t during 1970-1976, and with the compensation of armorhead catch decline, alfonsino catch increased remarkably in the late 1970s (**Fig. 1**, upper). Splendid alfonsino catch, mainly consisting of Japanese one, attained its maximum level of 11,831 t in 1980, and declined in the mid 1980s. In the last two decades, alfonsino catch have been fluctuating between 1,000 and 6,000 t under continuous fishing pressure. Although the dominant catches are occupied mainly by alfonsino in the last two decades, the armorhead catch abruptly increased in 1992 and 2004. Thus, SE-NHR trawl fishery can be characterized by continuous catches of alfonsino, and the dominant catches have shifted from alfonsino to armorhead depending on its pulse recruitments in the area.

Alfonsino CPUE were calculated in two different manners: 1) unadjusted CPUE (Japanese annual alfonsino catch divided by annual total Japanese fishing hours) and 2) adjusted CPUE (Japanese annual alfonsino catch divided by adjusted Japanese fishing hours), where annual fishing hours for alfonsino was assumed proportional to log-transformed annual catch of alfonsino to aggregated annual catch of alfonsino and armorhead (**Fig.1**, middle). The reason of this adjustment is based on the assumption of differential depth range between armorhead (mainly top of seamounts) and alfonsino (mainly slope area). Since adjusted CPUE (hereafter CPUE-a) was extremely low until 1975, probably due to slight interest of fisheries on alfonsino as a bycatch, we excluded data before 1976. Alfonsino fisheries during 1979-1982 produced extremely high CPUE-a ranging 5.32-10.77, whereas the CPUE-a after 1983 were lower level ranging 0.21-4.04 (**Fig. 1**, lower).

2. Surplus-Production Models

To estimate the maximum sustainable yield (MSY) and related parameters for stock management, surplus-production models (Schaefer, 1954) were adopted using time-series of abundance indices (CPUE in this case) and removal by fisheries from the stock. Under the models, sustainable yield can be represented by a dome-shaped function of abundance. The instantaneous change in stock biomass ($d\mathrm{Bt}/dt$) is shown by the function of biomass (B):

$$d\mathrm{Bt}/dt = r\mathrm{Bt} - (r/K)\mathrm{Bt}^2,$$

where r is the intrinsic rate of population growth, and K is carrying capacity.
For a fished stock, the catch from the population (C) also affect to the change in biomass,

$$d\mathrm{Bt}/dt = r\mathrm{Bt} - (r/K)\mathrm{Bt}^2 - \mathrm{Ct}.$$

Biological reference points can be calculated from the model parameters:

$$\mathrm{MSY} = K\,r / 4, \quad B_{\mathrm{MSY}} = K / 2, \quad F_{\mathrm{MSY}} = r / 2.$$

3. ASPIC program run

Non-equilibrium surplus production model - ASPIC program (Prager, 1994) was applied to catch and CPUE data of the alfonsino, under the assumption that CPUE is proportional to the abundance. As for a first step of the ASPIC analyses, all available CPUE data from 1969 to 2006 were used. Several trials were performed with changing initial parameters, however, we could not obtain plausible output. In the next step of analyses, extremely high CPUE data from the initial exploitation period from 1969 to 1984 were excluded, thus CPUE data from 1985 to 2006 were used as for a base case to indicate the biomass for the last two decade. The ASPIC runs were performed by using both CPUE and CPUE-a.

The model fits the CPUE data well (**Fig. 2**, upper), and reasonable parameters were estimated (**Table 1**).

In case of using unadjusted CPUE, the ASPIC run for alfonsino stock suggested that a MSY of 2,975 t could be produced by a total stock biomass of 3,876 t (B_{MSY}) at a fishing mortality rate on total biomass of 0.768 (F_{MSY}) (**Table 1**). Estimated biomass level in the 1980s was relatively high, and it decreased in the early 1990s, became the lowest level in the mid 1990s, and is showing increasing trend after 2000 (**Fig. 2**, lower). Prager (1994) defined 90% of F_{MSY} as $F_{0.1}$; $F_{0.1}$=0.69. A plot of annual fishing mortality and biomass rate relative to those producing MSY is shown in **Fig 4**. Fishing mortalities during 2000-2004 were relatively low, and close to F_{MSY} level. However, the estimated fishing mortalities in the 1990s and after 2005 were suggested to be higher level than optimum. In the 1980s, relative F (F/F_{MSY}) was below 1.0, while relative biomass (B/B_{MSY}) was significantly above 1.0. After 1990s, however, the relative biomass declined below 1.0, and the alfonsino stock is suggested to be depressed below the MSY level.

Even in the case of using CPUE-a, the model estimates suggested almost same results those were obtained by using unadjusted CPUE (**Table 1, Figs. 3 & 5**). These ASPIC runs indicate that the average fishing rates in the last decade were over acceptable ranges for the sustainable use of the alfonsino population in the area. In order to maintain the alfonsino stock to the MSY level, the fishing mortality should be depressed to the level of 2000-2004.

4. Improved analysis on Excel spreadsheets

A surplus production model was assembled on the MS Excel spreadsheets to improve the parameter estimation (Hilborn and Walters, 1992; Haddon, 2001). Considering the extremely high CPUE and CPUE-a during 1979-1982, we assumed that the parameters of this period were different from those of the other years. Three models were tested: (1) variable K with constant r and q, (2) variable K and r with constant q, (3) variable K and q with constant r, and (4) all parameters are variable. In this analysis, alfonsino catch data of 1976-2006 were used. Model parameters were determined by iteration using the solver function of Excel to find the best fit with maximizing the log-likelihood (LL),

$$LL = -\frac{n}{2}\left(\ln(2\pi) + 2\ln(\hat{\sigma}) + 1\right)$$

$$\hat{\sigma} = \sqrt{\sum_t \frac{\left(\ln\left(q(B_t - \frac{qX_tB_t}{2})\right) - \ln\left(\frac{Y_t}{X_t}\right)\right)^2}{n}}$$

where X is either adjusted or unadjusted fishing effort, n is number of observed years, t is year.

In consequence, the model (3) was selected, for the both case of using CPUE and CPUE-a, and the model showed good fitting between estimated and observed CPUE (**Figs. 6 & 7**, upper). In case of CPUE-a, the model (3) was selected with minimum AIC of 38.2, whereas AIC on model (1), (2) and (4) was 58.7, 58.7 and 39.1, respectively. Since difference in AIC values for model (3) and (4) were slight, all three parameters may have shifted during 1979-84. Accuracy of results need further examination, because **Fig. 8 & 9** suggest current situation is at the halfway from "one-way trip" type to "up and down isocline" (Hilborn and Walters, 1992), i.e., lacking low effort in recent years.

Under the constant *r* assumption using unadjusted CPUE, the estimated *q* of 1979-1982 was about 5 times of the recent *q*, and the estimated *K* of 1979-1982 was about 2500 times of the recent *K*. The estimated *K* for this period may not be a realistic value. In the period excluding 1979-1982, including recent 2decades, the model suggested a MSY of 4,432 t could be produced by a total stock biomass of B_{MSY}=9,247 t, at F_{MSY} =0.48 (**Table 2**). Since observed *F* for the last 10 years was 0.60 on an average, it is desirable to decrease about 20% of *F* to attain the F_{MSY} level of this stock.

The model parameters and management benchmarks estimated from adjusted CPUE (CPUE-a) were almost same as those from adjusted CPUE, in the period excluding 1979-1982. The model suggested a MSY of 4,482 t could be produced by a total stock biomass of B_{MSY}=8,355 t, at F_{MSY} =0.54 (**Table 3**). The model also suggested that it is desirable to decrease 24% of *F* to attain the F_{MSY} level of this stock. In the period of 1979-1982, the estimated *K* value from CPUE-a was almost 10 times bigger than *K* estimated for the other years. In this model fit, relationship between biomass and surplus production appears dome-shaped with extremely high surplus production and biomass period (1979-82), suggesting "alfonsino regime shift" (**Fig. 11**). When we deal with the catch data before 1985, CPUE adjustment seemed to be inevitable procedure. In both cases, estimated biomass was suggested to be higher level in the 1980s and then showed quick decrease in the early 1990s (**Fig. 6 & 7**). In the last decade, surplus production is stable in lower level with a slight recovery, however, current biomass level is still considerably below B_{MSY} (**Fig.6**).

5. Conclusions

For SE-NHR alfonsino stock, there were highly productive regime during 1979-82 and "ordinary" regime lasting to present. Both ASPIC model and the best regime-dependent spreadsheet model suggested alfonsino is overfished in some years in the recent decades. Both models also suggest that current fishing effort is above F_{MSY}, thus should be reduced considerably. In this programs run, CPUE was based on the catch and effort data from whole SE-NHR area to estimate the management benchmarks of this stock. However, each separate seamount may have its own characteristic, and this consideration invite further detailed analysis of the fishery production from each separate seamount area. Also, assumption of closed population within the study area is not verified. Despite these unresolved problems, it is recommended to reduce current fishing effort as a first step of active adaptive learning.

6. References

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Table 1. Results of ASPIC based on splendid alfonsino data (1985-2006) in the SE-NHRarea.

	unadjusted effort			adjusted effort
		Confidence limits (Bootstrapped analysis)		
	Point estimate	80% lower	80% upper	Point estimate
Directly estimated parameters				
r	1.535	1.478	1.579	1.547
K	7,753	7,596	7,961	7,783
q	0.0001448	0.00013	0.0001627	0.000311
Management benchmarks				
MSY	2,975	2,940	3,002	3010
B_{MSY}	3,876	3,798	3,980	3891
F_{MSY}	0.768	0.739	0.789	0.774
observed $F_{10yrsAV.}$	1.025			1.076
ratio $F_{MSY/10yrs}$	75%			72%

Table 2. Results of Excel run under the assumption of constant *r* and variable *K* and *q*, with using unadjusted CPUE.

Year period	1976-78 and 83-2006	1979-82
Directly estimated parameters		
r	0.959	0.959
K	18,494	47,206,536
q	8.38E-05	4.28E-04
Management benchmarks		
MSY	4,432	11,312,568
B_{MSY}	9,247	23,603,268
F_{MSY}	0.48	0.48
observed $F_{10yrsAV.}$	0.60	
ratio $F_{MSY/10yrs}$	80%	

Table 3. Results of Excel run under the assumption of constant *r* and variable *K* and *q*, with using adjusted CPUE.

Year period	1976-78 and 83-2006	1979-82
Directly estimated parameters		
r	1.073	1.073
K	16,710	159,173
q	1.82E-04	8.07E-04
Management benchmarks		
MSY	4,482	42,694
B_{MSY}	8,355	79,586
F_{MSY}	0.54	0.54
observed $F_{10yrsAV.}$	0.70	
ratio $F_{MSY/10yrs}$	76%	

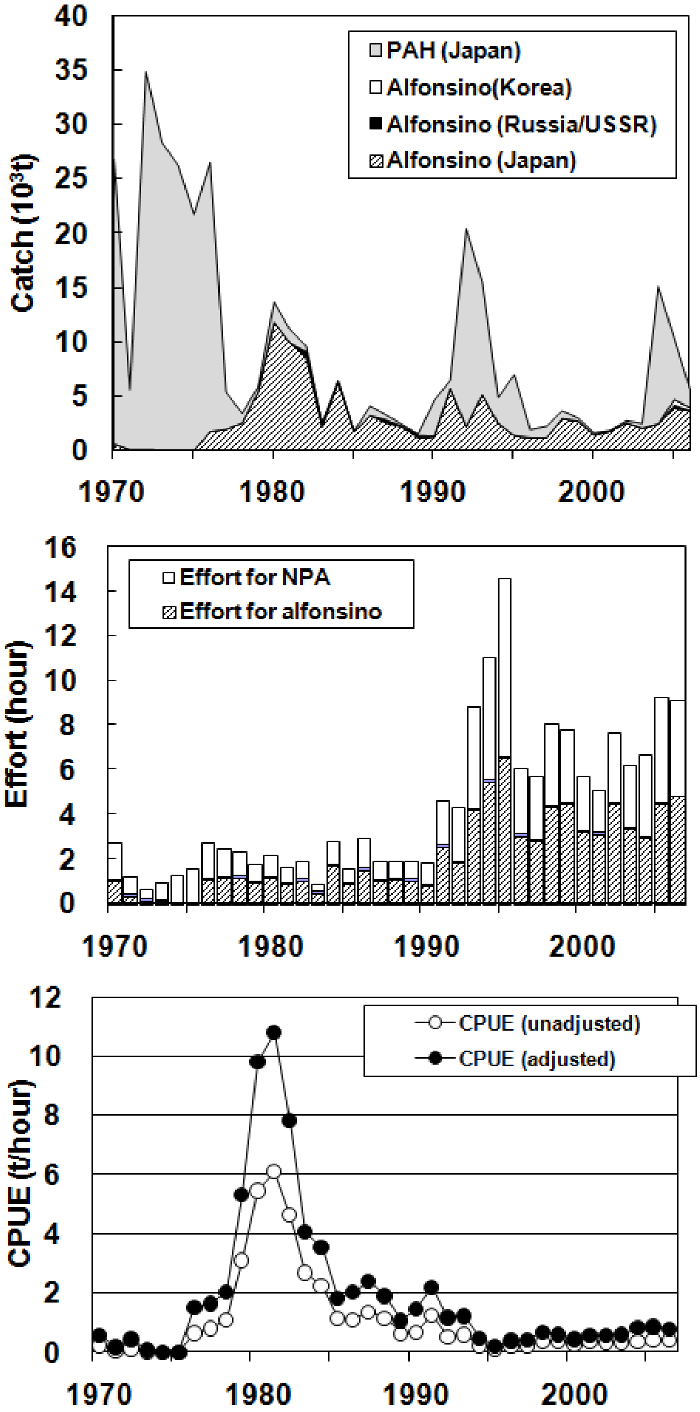

Fig. 1. Upper: Historical catch record of Emperor Seamount trawl fishery. NPA; North Pacific armorhead (*Pseudopentaceros wheeleri*), Splendid alfonsino (*Beryx splendens*). Middle: Corrected fishing effort (hour) for alfonsin catches, and for NPA. Lower: CPUE calculated by adjusted effort for the alfonsin catch, and unadjusted effort.

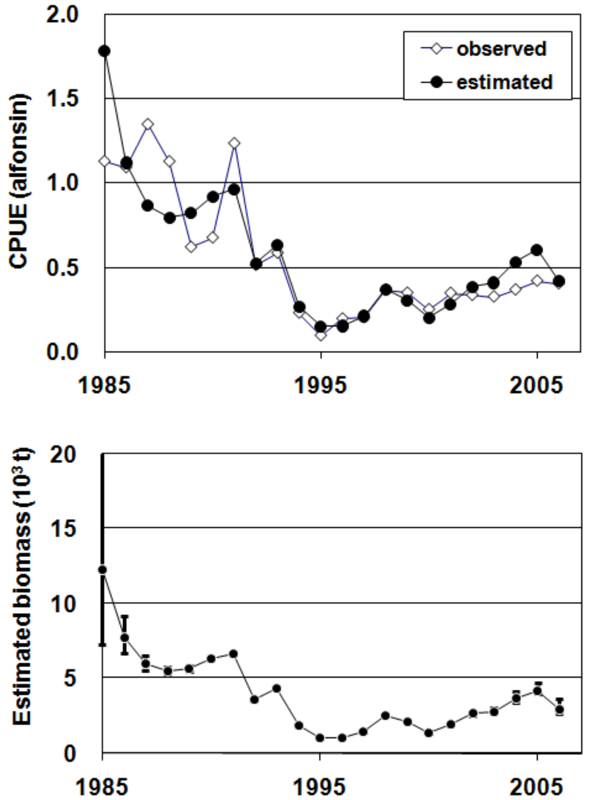

Fig. 2. ASPIC run output, with unadjusted CPUE. Upper: Observed (◇) and model estimated (●) CPUE trajectories. Lower: Trajectory of estimated biomass of alfonsino, with 80% confidince limit from bootstrapped analysis.

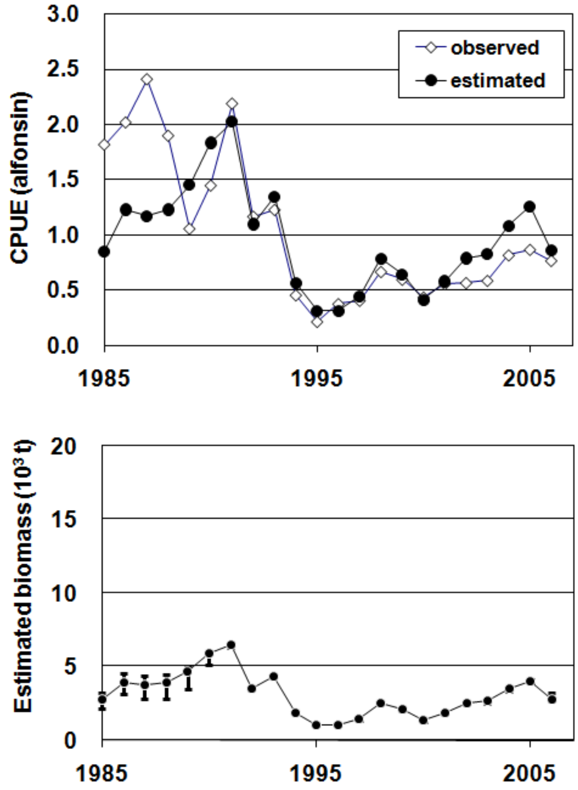

Fig. 3. ASPIC run output, with adjusted CPUE. Upper: Observed (◇) and model estimated (●) CPUE trajectories. Lower: Trajectory of estimated biomass of alfonsino, with 80% confidince limit from bootstrapped analysis.

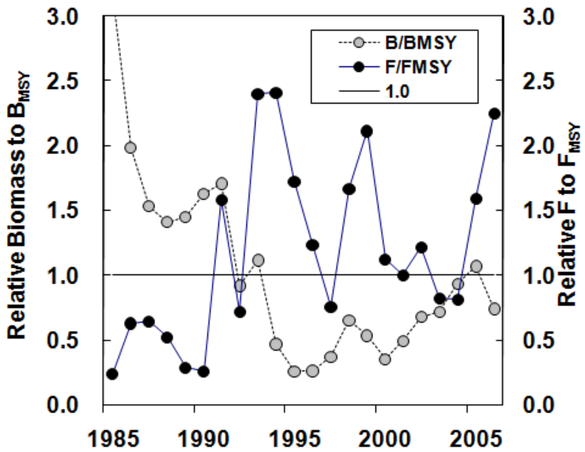

Fig. 4. Plot of estimated F/F_{MSY} and B/B_{MSY} from the ASPIC run with unadjusted CPUE.

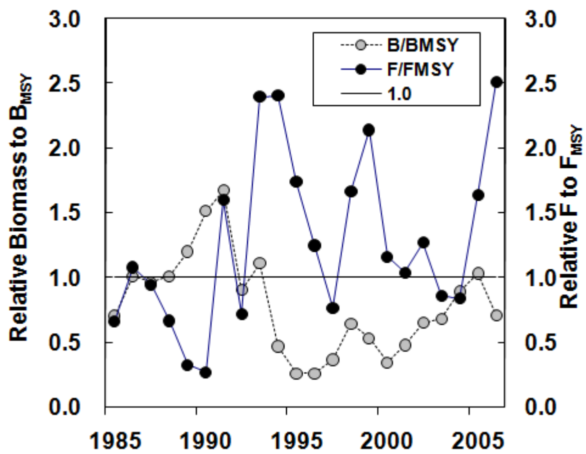

Fig. 5. Plot of estimated F/F_{MSY} and B/B_{MSY} from the ASPIC run with adjusted CPUE.

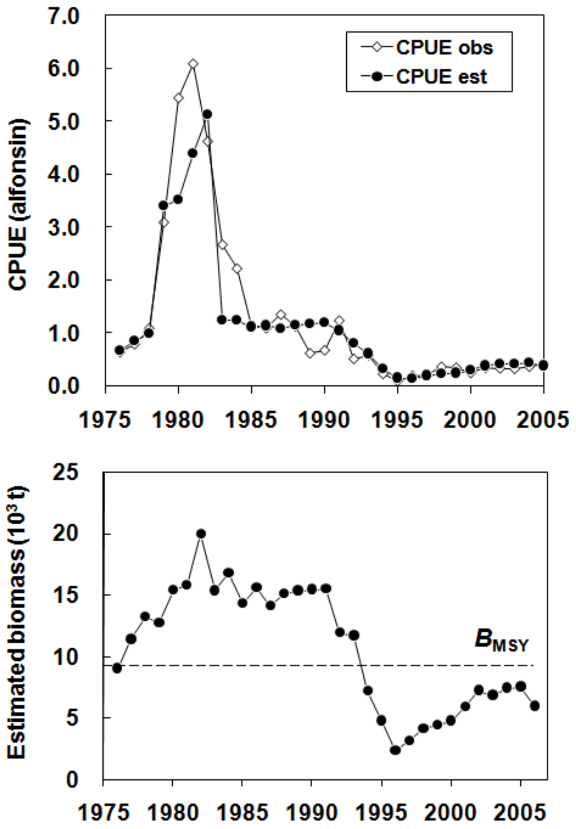

Fig. 6. Excel Solver run output with unadjusted CPUE. Upper: Observed (◇) and model estimated (●) unadjusted CPUE trajectories. Lower: Trajectory of estimated biomass of alfonsin, with B_{MSY} level.

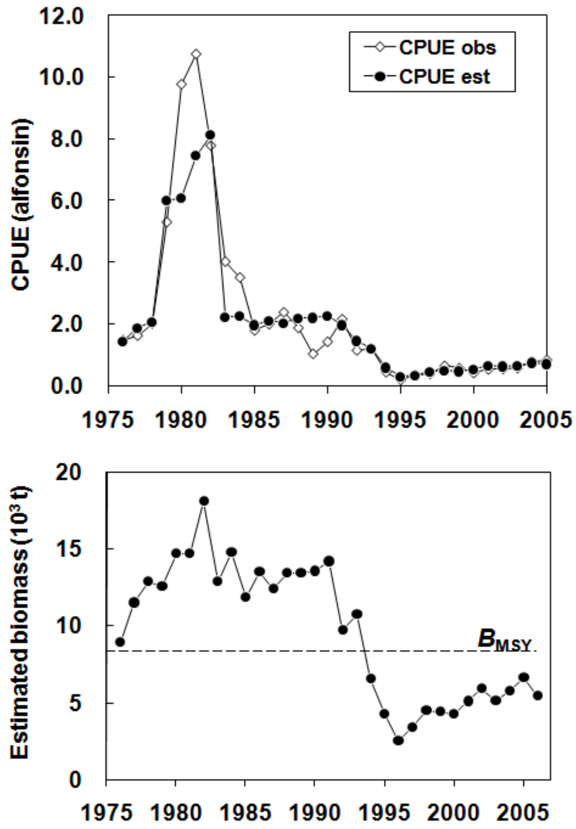

Fig. 7. Excel Solver run output with adjusted CPUE. Upper: Observed (◇) and model estimated (●) adjusted CPUE trajectories. Lower: Trajectory of estimated biomass of alfonsin, with B_{MSY} level.

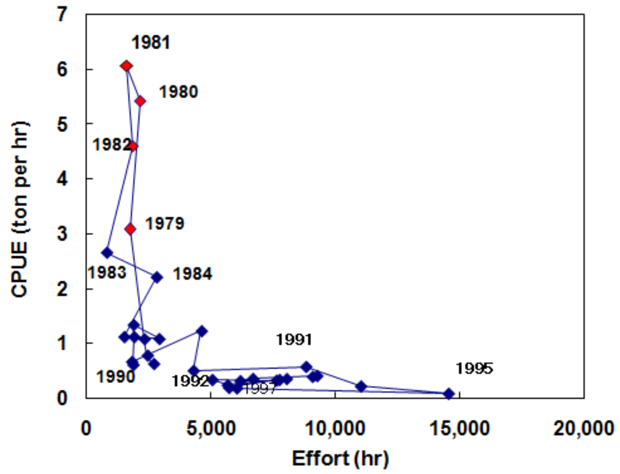

Fig. 8. Excel Solver run output with unadjusted CPUE. Relationship between fishing effort and unadjusted CPUE.

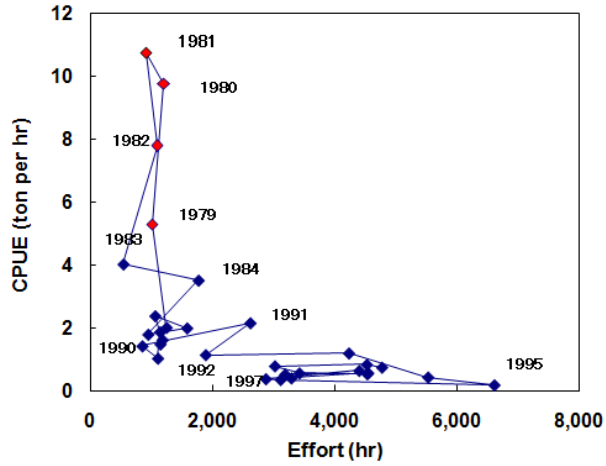

Fig. 9. Excel Solver run output with adjusted CPUE. Relationship between fishing effort and adjusted CPUE

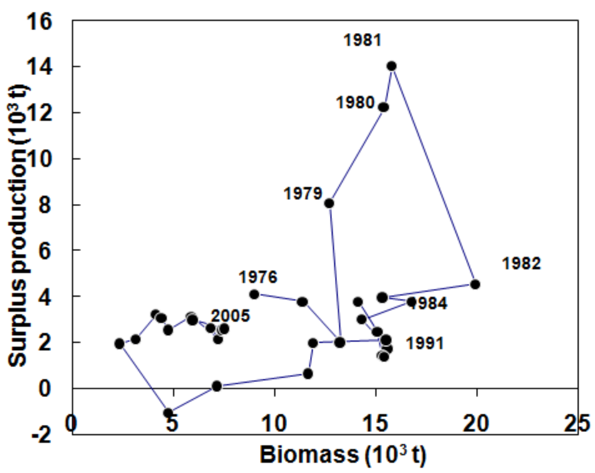

Fig. 10. Excel Solver run output with unadjusted CPUE. Biomass-surplus production trajectories during 1976-2006.

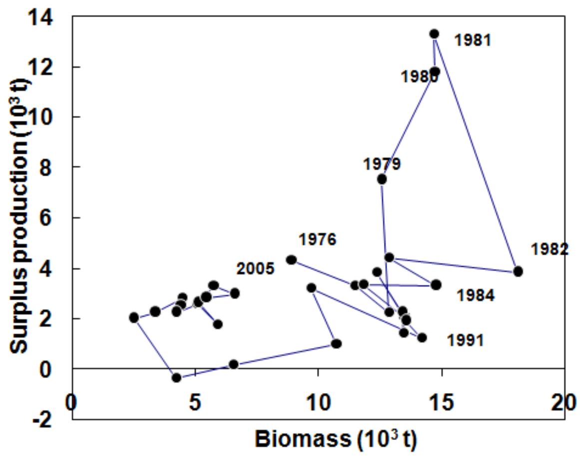

Fig. 11. Excel Solver run output with adjusted CPUE. Biomass-surplus production trajectories during 1976-2006.