シミュレーションモデルによる人工種苗の効果的放流計画の検討

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Effective Releasing Program of Artificial Fingerlings Using a Simulation Model[*1]

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A more effective releasing program was examined by designing a simulation model which can indicate the survival and growth of released artificial fingerlings. Effects of a carrying capacity on the releasing program were also discussed. Red sea bream in Shijiki Bay was chosen as the subject of the report.

Knowledge on the growth, survival and predation, hypothetical suitabilities of the period (June-August) and site for the releasing and carrying capacity were used as the components by formulating. A biomass of released red sea bream was simulated at intervals of five days until the last day of September, using 243 ($=3^5$; three initial values of five variables on the program) initial conditions. Three kinds of the judging criterion were used for evaluating the effectiveness.

When a biomass in the last day of September was used as a judging criterion, the importance of each item of releasing program can be observed in the following order: size of fingerlings, number of released fish, releasing site, releasing period and number of wild fish. Using the increase rate criterion, superior importance of the releasing site can be indicated. In the case of the unit price index of survival criterion, only the releasing period showed extremely little importance and other items showed similar importances. As the effect of carrying capacity increased, the importance of the releasing period increased and that of the number of released fish decreased.

In sea-farming, the investigation of an effective releasing program (size/number of artificial fingerlings, releasing period/site or the like) is an important subject. Such an investigation can be regarded as a basic purpose for estimating the restocking effectiveness. There are a few theoretical studies for restocking effectiveness on prey-predator system,[1,2)] and competition in relation to the fluctuation of abundance.[3,4)]

In the present work, a more effective releasing program was examined by designing a simulation model which can indicate the survival and growth in the released artificial fingerlings. Effects of the carrying capacity on the releasing program were also discussed. Red sea bream *Pagrus major* was given as the example of this report, because it is an important species in sea-farming. Shijiki Bay (area, ca. 10 km^2), Hirado Island, Nagasaki Pref., was chosen as the subject site, where ecological knowledge of 0-age red sea bream has been accumulated abundantly.

Methods

Outline of the Simulation

The procedures of the simulation are outlined in Fig. 1. Knowledge on the growth, survival and predation, hypothetical suitabilities of the period (June-August) and site for the releasing, and carrying capacity were used as the components by formulating. In order to determine the best releasing program, five variables shown in Table 1 were selected and used in the model, on the basis of the assumption that the effects on the growth and survival of artificial released fish would depend on the initial conditions of various items of the program. Definite setup of the initial values (Table 1) and the components (Fig. 1) was made presupposing the releasing of artificial fingerlings of red sea bream in Shijiki Bay.

The daily changes in the growth and survival

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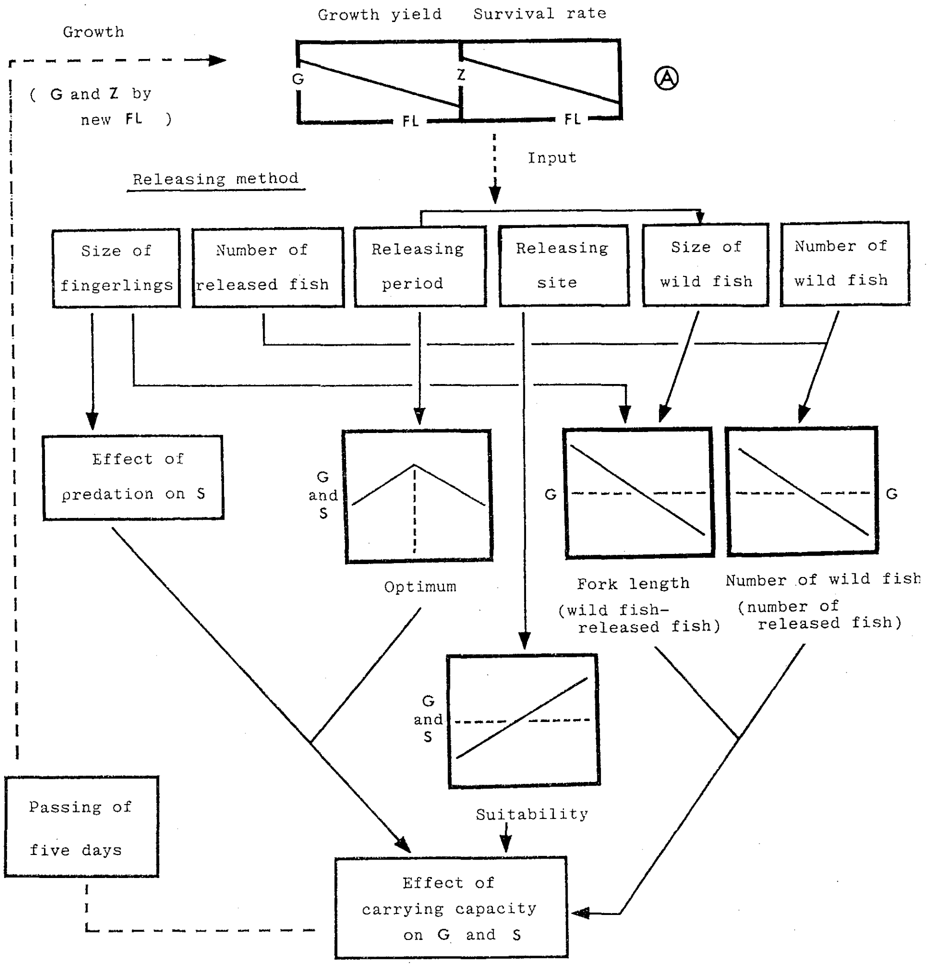

Fig. 1. Outline of the simulation procedures (G, Z, S and FL: see the text and Table 2).

Table 1. Variables on the releasing program, their three initial values and quality measures

Varlabie	Initial value		
	Quality measure[*1]		
	1	2	3
Size of fingerlings (mm)	30	60	90
Releasing site (relative index)	−1	0	+1
Releasing period	Aug. 30	July 15	June 1
Number of released fish ($\times 10^4$)	2	4	6
Number of wild fish[*2] ($\times 10^4$)	15	10	5

[*1] 3 being "good" and 1 being "bad".

[*2] Abundance of wild 0-age red sea bream that inhabits in the releasing area on the releasing period.

of red sea bream was approximated by stepwise profiles at intervals of five days. Regarding the mode of effects, both or each of the growth and survival rate were multiplied by a relative ratio calculated from the initial conditions or later body length.

The biomass (the number of surviving fish × body weight) of the released red sea bream was simulated at intervals of five days until the last day of September, using 243 ($=3^5$; three initial values of five variables) initial conditions. The judging criteria used for evaluating the effectiveness were: 1) biomass in the last day of September, 2) ratio of biomasses in the initial and final day (increasing rate) and 3) unit price index of survival, supplied with economic effects (the number of survivals in the last day of September/the number of released fish/unit price of fingerlings).

Model Components

Relations of growth (G; mm/day) and survival (Z; total mortality coefficient per day) to

Table 2. Functions to describe each component and effect-receiving variables

Effect-receiving variables	Survival of released fish (Y)	Growth of released fish (Y')	Growth of wild fish (Y')	Concrete functions[*1]	
Effect of releasing site	S	G	G	$Y=0.975+0.0250\,x$	$(-1\leqq x<1)$
($x\geqq -1$, relative index)				$Y=1.0$	$(x\geqq 1)$
				$Y'=1.0+0.1\,x$	$(-1\leqq x<1)$
				$Y'=1.1$	$(x\geqq 1)$
Effect of releasing period	S	G		$Y=0.950+0.000667\,x$	$(0\leqq x<75)$
($0\leqq x<150$; number of days				$Y=1.050-0.000667\,x$	$(75\leqq x<150)$
from May 1 to releasing date)				$Y'=0.900+0.00267\,x$	$(0\leqq x<75)$
				$Y'=1.300-0.00267\,x$	$(75\leqq x<150)$
Effect of fingerlings size		G		$Y'=1.1$	$(x<-50)$
(x=fork length of wild fish[*2]				$Y'=1.0-0.002\,x$	$(-50\leqq x<50)$
−fork length of released fish, in mm)				$Y'=0.9$	$(x\geqq 50)$
Effect of released number		G		$Y'=1.1$	$(x<0.1)$
(x=number of wild fish				$Y'=1.0-0.1\log_{10} x$	$(0.1\leqq x<10)$
/number of released fish)				$Y'=0.9$	$(x\geqq 10)$
Effect of predation	S			$Y=1.0$	$(\mathrm{FL}<36,\ \mathrm{FL}\geqq 73)$
(FL; mm)				$Y=1.154-0.00427\,\mathrm{FL}$	$(36\leqq \mathrm{FL}<58)$
				$Y=0.543+0.00627\,\mathrm{FL}$	$(58\leqq \mathrm{FL}<73)$

[*1] Y and Y' indicate the relative ratio to survival rate and to growth yield, respectively. x corresponds to each effect of the relative ratio Y and Y'.

[*2] Fork length of wild fish on the releasing date bases on FL (mm)=49.26+0.509 T (T: number of days from July 9). After releasing, wild fish grow at the same rate as released fish.

fork length (FL; mm) were estimated as follows (Fig. 1, A), on the basis of various data obtained from releasing experiments which have been performed at various areas in Japan:

$$G=0.927-0.00390\,\mathrm{FL}$$

$$Z=0.0378-0.000267\,\mathrm{FL}\,.$$

Table 2 shows functions used to describe each component and effect-receiving variables, which were decided on the basis of common knowledge (tendency) and sensitivity analysis by trial and error. The variable X corresponds to each effect of the relative ratio Y to survival rate (S; $S=e^{-z}$) and the relative ratio Y' to growth yield (G) calculated at intervals of five days. The plausible ranges of Y and Y' were set to be $0.95\sim1.00$ and $0.9\sim1.1$, respectively.

The effect of predation (related to FL) was analogized from stomach contents examination of predators by Matsumiya *et al.*[5] The range of Y is $0.906\sim1.0$. The effect of suitability of the releasing site was set so as to increase the initial value at the time of releasing at a rate of 0.025 (no units) per five days (it reflects gradual movement of red sea bream to more suitable sites). When the relative value of the site suitability exceeded 1.0, this value was modified to be 1.0.

Establishment of Carrying Capacity and its Effects

A carrying capacity was established on the presumption that the biomass of wild and released red sea breams at one period affects their growth yields and survival rates at the next period (five days interval). Effects of the carrying capacity were modelled according to Azeta *et al.*[6] and Matsumiya *et al.*,[7] for simplicity, growth and survival are not affected before the biomass reaches a certain level but influenced when it exceeds the level. Since both the survival and growth of wild and released fishes were affected by the carrying capacity, ranges of the relative ratios to survival rate and growth yield were fixed at $Y=0.1\sim1.0$ and $Y'=0\sim1.0$, respectively (Fig. 2).

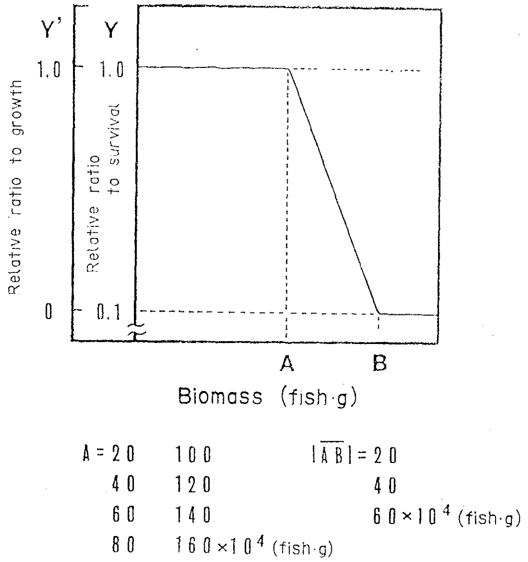

Fig. 2. Effect of the carrying capacity on growth and survival.

The boundary point A was varied with eight levels at intervals of 20×10^4 from 20×10^4 to 160×10^4 fish·g and the slope between A and B ($|\overline{AB}|$) with three levels of 20×10^4, 40×10^4 and 60×10^4 fish·g, resulting in 24 (8×3) combinations (Fig. 2). The carrying capacity was expressed as "the number of wild fish×body weight+the number of released fish×body weight" and the body weight (BW; g) was converted from fork length (FL; mm) as follows: $\mathrm{BW}=4.957\times10^{-6}\times\mathrm{FL}^{3.3204}$.

Results

Tendencies among 243 initial conditions of the releasing program were examined in detail, by rearranging the values of each criterion in order of their magnitudes. As an expedient measure of the examination, quality measures (3, 2 and 1; 3 being "good" and 1 being "bad") were given to the initial conditions in each releasing method (Table 1). The 243 results were classified into nine groups (each containing 27 results) according to their magnitudes, and the degree of the quality measures in each group was illustrated as exampled by Fig. 3.

Next, the order of values of the judging criteria arranged in accordance with their magnitudes (X; $1\sim243$) and the quality measures of the judging criteria (y) were applied to the linear regression line ($y=a+bX$) in order to obtain the regression coefficient, b. The $|b|$ can be used as a relative measure of degrees of contribution of the suitability of releasing programs to the judging criteria. In addition, $|b|$ of each programs was divided by the smallest $|b|$, in order to standardize $|b|$ among the programs.

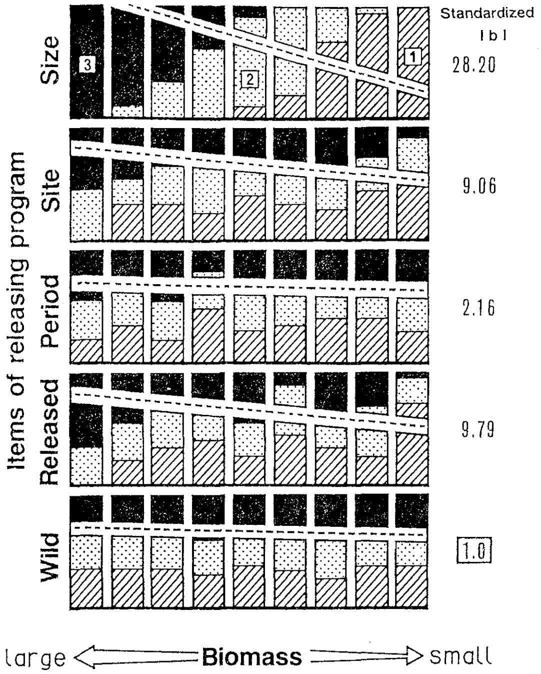

Fig. 3. Relationship between the quality measures in releasing initial conditions and the biomass in the last day of September. As for quality measures (3, 2 and 1; 3 being "good" and 1 being "bad"), see Table 1. Broken lines indicate $y=a+bX$ (see the text, for details). Size: Size of fingerlings. Site: Releasing site. Period: Releasing period. Released: Number of released fish. Wild: Number of wild fish.

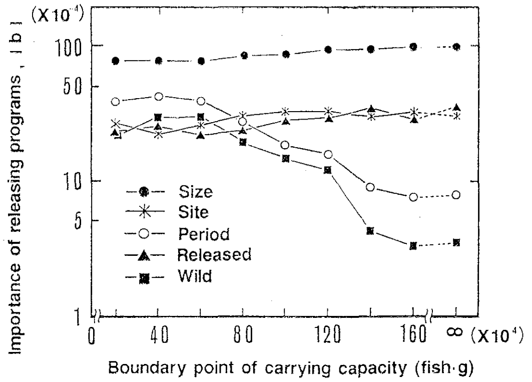

Fig. 4. Changes on importance of items of releasing programs along with the boundary point when biomass is used as a judging criterion. Slope of the carrying capacity function is fixed to 60×10^4 fish·g.

Biomass as a Judging Criterion

Results obtained by the above-described procedure are depicted in Fig. 3. From this figure, the importance of the releasing programs can be observed in the following order: size of fingerlings, number of released fish, releasing site, releasing period and number of wild fish. In particular, the superior importance of the size of fingerlings can be indicated.

Calculations were performed using the carrying capacity as a component and its effects were considered. An example on the changes in $|b|$ is shown in Fig. 4 when $|\overline{AB}|$ in Fig. 2 was fixed to 60×10^4 fish·g and the boundary point A was varied from 20×10^4 to 160×10^4 fish·g (∞ in x axis means no setting of the carrying capacity). As the effect of the carrying capacity increased, the importance of the number of wild fish and the releasing period increased and that of the releasing site and the number of released fish decreased slightly. Because the importance of the size of fingerlings was hardly affected by the carrying capacity, the size of fingerlings can be regarded as an important item of a releasing program. In addition, there is a tendency that differences in the importances among releasing programs become small as the effect of the carrying capacity increases.

Increase Rate as a Judging Criterion

Of the 243 initial conditions, 20 showed over 2.0 of the increase rate and these conditions showed +1 of quality measure for the releasing site. The quality measures of other releasing programs varied at random. The importance of the suitability of releasing site was also observed by various treatments of the data, for example, by reducing quality measure of only one program.

The mean increase rate of the 243 initial conditions and the coefficient of variation are shown in Fig. 5, along with the changes in the boundary point A, when these conditions were affected by the carrying capacity with $|\overline{AB}|$ of 20×10^4 or 60×10^4 fish·g. When $|\overline{AB}|$ was 20×10^4 fish·g (lower part in Fig. 5), the mean increase rate and coefficient of variation showed the same changes, but with no remarkable tendency. In the case of 60×10^4 (upper part in Fig. 5), the mean decreased as the effect of the carrying capacity increased (boundary point becomes small) but, on the contrary, fluctuation among data on the 243 conditions (coefficient of variation) increased, indicating that difference in the increase rate becomes large which is caused by the com-

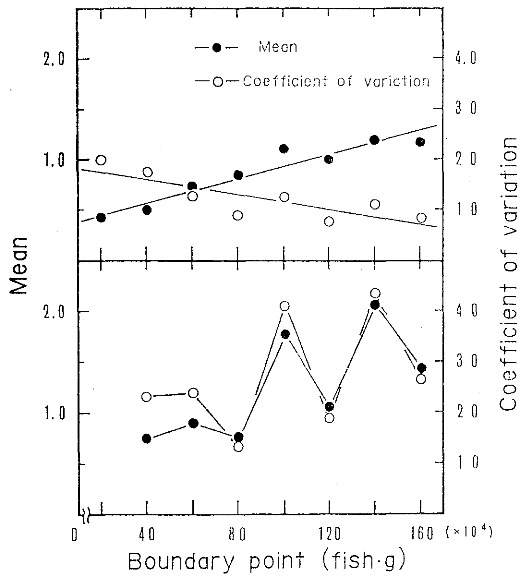

Fig. 5. Mean and coefficient of variation of the increase rate of the 243 initial conditions along with the changes in the boundary point and slope of the carrying capacity function. Upper part: slope is fixed to 60×10^4 fish·g. Lower part: 20×10^4 fish·g.

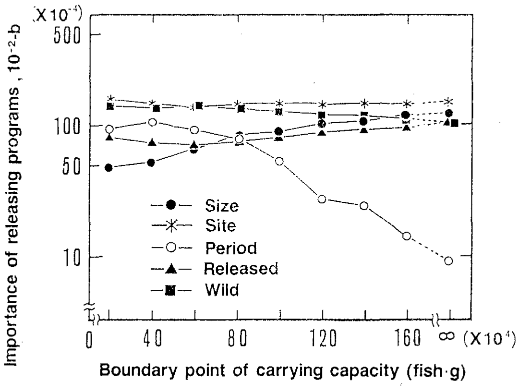

Fig. 6. Changes on importance of items of releasing program along with the boundary point when unit price index of survival is used as a judging criterion. The slope of the carrying capacity function is fixed to 60×10^4 fish·g.

bination of releasing methods.

Unit Price Index of Survival as a Judging Criterion

Fig. 6 shows depiction of the results processed in the same manner as shown in Fig. 4 via Fig. 3, using the unit price index of survival supplied with economic effects (the number of survival in the last day of September/the number of released fish/unit price of fingerlings). The unit price of fingerlings was fixed at 1 yen/mm which is almost general and the same as that of the size of fingerlings (e.g., 30 yen in the case of 30 mm). The ordinate axis (importance of releasing programs) in Fig. 6 was expressed as $10^{-2}-b$, because the regression coefficient b took positive values close to 10^{-2} at the maximum.

When the carrying capacity was not established (∞ in x axis), only the releasing period showed extremely little importance and other programs showed similar importances (in order of the releasing site, size of fingerlings, number of released fish and number of wild fish). As the effect of the carrying capacity increased, the importance of the releasing period increased rapidly and those of the size and number of fish decreased slightly (Fig. 6; $|AB|=60\times10^4$ fish·g).

Discussion

Multiple regression analysis was performed using initial values of five variables on the releasing program as the explanatory variables and one of three judging criteria (biomass, increasing rate and unit price index of survival) as the criterion variables. The standard regression coefficient in the multiple regression formula can be regarded as a relative index which indicates the importance of each releasing program. Also, an all-round evaluation of releasing programs can be performed, by using different judging criteria and establishing the carrying capacity and then detecting direction and degree of changes in the importance.

It is possible to apply such a simulation described in this report to other fish species. In the case of the flatfish, for example, effects of predation by wild flatfish on the releasing programs can be examined. It seemed that the timing of releasing was an important factor (the later is the better) in both cases when predation pressure by wild fish, which is a function of difference in body length between wild and released fishes, was significantly little (ca. 0.05 individual/100 mm body length/five days) and when biomass or increasing rate was used as the judging criterion.

It is difficult to find a conclusive rule regarding the effective releasing program by means of simulation, because interpretation of responses varies depending on the suitability of the original simulation model and the reliability of casual relations inside the system. Since the attempt in this report concerns numerical reproducibility and its profiles on the basis of the most applicable quantitative (mathematically quantificated) information for a model, an output can be evaluated only as a single mode in a single case. In order to value the output results as a universal function, it is essential to: 1) obtain indications about subjects to be examined intensively and directions to be searched out and 2) accelerate studies on inaccurate information and hypothetical components (in the case of unknown factors).

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