Development of stock management evaluation procedure incorporating uncertainty from sampling error (標本誤差による不確実性を考慮した資源管理方策評価方法の開発)[*1]

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Uncertainty is a central assignment of fish stock management. This study developed the stock management evaluation procedure incorporating uncertainty to provide the useful information for the members participating stock management. To evaluate stock management candidates, 30-year population dynamics, including uncertainties, were simulated. Errors in current stock size estimation by bootstrap methods, variability in future recruitment, and changes in future fishing mortalities were incorporated. The evaluation of stock management candidates were conducted through four axes performance indexes. The efficiency of the simulation model was examined through its application to real stock. The walleye pollock Theragra chalcogramma stock and the pointhead flounder Cleisthenes pinetorum stock were selected for simulation model. The ratios of measurement errors in abundance estimates were relatively small in both stock and the ratios were 1% to 59 %. The evaluation of stock management candidates were shown the similar tendency in both stock application. The severe regulation candidates were more effective than loose regulation candidates in the conservation performance. The utilization performance obtained in both stock showed their evaluation were different with differing period length. A quantitative evaluation procedure including the uncertainties from sampling error was developed in this study. This procedure could enrich discussions of the effects of a variety of management actions when stakeholders are considering various requirements of the stock.

KEY WORDS：management procedure, simulation, uncertainty, sampling error, walleye pollock, pointhead flounder.

Chapter 1

General Introduction

Fishery science has an important role to support world food supply. Fish contribute a significant amount of animal protein to the diets of people worldwide[1], and stock management is a science-based method for sustainable use of natural fish stocks[2]. The concept of sustainable development, a typical stock management objective, was first proposed in the early 1930s[3]. The famous maximum sustainable yield (MSY) theory is a basic concept describing sustainable development of fishery, and is based on stock yield and fishing effort (Schaefer[4]).

Studies on MSY-based stock management began decades ago[3,5]. Despite the availability of such management tools, many of the world's fish stocks have been characterized as seriously depleted or in danger of depletion [6-10] with global catches declining since late 1980's [11]. Many of the same stock abundance categorizations have been reported for some Japanese fish stocks[12]. Fish stocks need to be properly managed, if their contribution to the nutritional, economic, and social well-being of the growing world's population is to be sustained [13].

Since the adaptation of the Rio Declaration on Environment and Development in 1992, the concept of sustainable development has become more widely recognized in the field of stock management[14]. The Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries (CCRF) released in 1995 stated that fisheries

benefits should belong to people throughout the world, including both present and future generations, and fisheries should be conducted in a responsible manner[15]. The CCRF was the first document to define formally a precautionary approach to fish stock management and to suggest its application to fisheries.

Moreover, the CCRF referred to a relationship between the precautionary approach and uncertainty, and Article 7.5 of the CCRF includes the statement: "In implementing the precautionary approach, states should take into account, inter alia, uncertainties relating to the size and productivity of the stocks, reference points,…" [16].

Uncertainty is a key element of fish stock management[17], and was defined as "the incompleteness of knowledge about the state or process of nature" [18]. Uncertainties are placed into five error categories: (i) measurement error in observed quantities; (ii) process error in the underlying stochasticity of population dynamics; (iii) model error in the mis-specification of model parameter values; (iv) estimation error resulting from any of the above uncertainties and/or inaccuracy and imprecision in estimated model parameters; and (v) implementation error resulting from variability in the implementation of management policies[19].

Fisheries managers often choose among alternative actions in an effort to achieve the desired social, economic, and biological objectives[17]. In general, managers utilize information about current stock status and potential stock productivity that is provided by scientists. However, scientific information may include many uncertainties, and stock assessment uncertainties lead to risk in decision-making[17].

Since the complete removal uncertainties from scientific information is impossible, managers are required to make decisions in uncertain circumstances. Addition this, government generally has the role of decision maker, the reasons for reaching a decision should be available to the taxpayer. Quantification of the probability of management success and the relative risks between alternative actions is desirable. Such quantifications can enable disclosure to stakeholders and taxpayers how stock management decisions have been conducted face to uncertainties.

Various kinds of stakeholders, such as fishers, consumers, and industry members, may be active participants in stock management. Stakeholders often disagree about the desirable goals of stock management. Building consensus among stakeholders is important for achieving sound stock management because the practice of management plan is conducted by fishers who are included as stakeholders. Furthermore from the viewpoint of concept of stock management as making a decision among various desires, consensus building among stakeholders is an important part of stock management. The quantification of uncertainties about stock status and stock forecasts by scientists can help build consensus among stakeholders. As mentioned above, the consideration of uncertainty has become an important part of the fisheries management decision making process[20].

Computer simulations have been used for considering uncertainties in fish stock management since the 1990s. The Revised Management Procedure (RMP), developed by the Scientific Committee of the International Whaling Commission (IWC)[21], led to the development of a simulation methodology. The energetic work of the IWC has been applied not only to cetaceans but also to fish population management, especially in South Africa [22,23] and Australia [24,25], and to the tuna stocks managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) [26,27]. Most of these studies have used operating models that include various types of uncertainties and simulated fish populations on computers to evaluate management procedure performance, assessment precision, or sensitivity to population parameter estimates. Operating model can be used for developing more robust management procedures. However, it has not been well established and still relying on a trial and error process, especially in the specifications within the simulation models, the evaluation of the simulation results, and the criteria for selection of the most appropriate management action from the various simulation model outputs[28,29].

In spite of the development of the simulation method, uncertainty has not been still well considered in the stock management procedures for a large part of the fisheries. The Japanese Fisheries Agency assesses 42 species and 80 stocks every year[30]. Although 27 of those assessments refer to

the uncertainty of stock management, only 16 use a simulation method. Furthermore, only one of the 16 simulation-modeled stock assessments considers estimation error uncertainty (type iv mentioned above). The other 15 assessments consider only variability in future recruitment, i.e., a process error within population dynamics uncertainty (type ii). Room is still left for improvement in the amount of consideration of uncertainties in the management of Japanese fisheries[30].

Although measurement error uncertainty (type i) is obviously exist in stock assessment, studies on this uncertainty was not found. Stock assessment is based on sample measurements, such as body length, body weight, and aging from commercial landed fish. It is difficult to measure sufficiently large samples because of the limitations in personnel numbers and/or budget. Although some measurements such as the body weight would have large individual variations, the small sample contrasted to the whole catch includes a large sampling error. To collect a random sample from a landed catch, much effort could be invested in sample planning and data manipulation. For example the fish sampling of landed fish was planned by a stratified sampling scheme in many cases; however, such sampling plans can be largely affected by poor or inconsistent landings, short fishing periods, and weather conditions. Furthermore it is difficult to conduct a sampling on target time or amount when daily fish landings varied or externally short fishing period. Thus, estimators from measurement of the samples always face to large sampling error.

For stock management, it is preferable to compare in future stock status from management candidates. Stock forecasts are based not only on the current stock size, but also on a stock-recruitment relationship and/ or a fishing mortality coefficient, and those quantities are affected, directly or indirectly, by sampling error. While there may be several sources of errors in fish stock assessment, only sampling errors have room for improvement in reality. Thus, evaluation of sampling errors would help for considering the uncertainty within stock management.

In general, the process of estimating a fish stock quantity from sampling data is complex. A bootstrap method[31] can be used for such a complex data collecting procedure. This method simply describes a sequence of calculations that incorporates re-sampling idea into the calculation sequence. Using this method, sampling errors in commercial fish landings can be quantified; thereby allowing evaluation of other errors, such as those in catch at age data or those in stock abundance estimates.

Stock management plan is built upon current stock status estimates. The consideration of uncertainty about the estimated current stock size in stock management planning is expected to reduce the risk of making a wrong choice of management actions and to add details to explanations of decision-making process. Simulation models are useful for assessing management actions.

The application of simulation studies to real stocks would reveal the efficiency of the simulation model. As adaptation to real stock, the walleye pollock Theragra chalcogramma stock in the northern waters of the Sea of Japan (WPNJ) and the pointhead flounder Cleisthenes pinetorum stock in the northern Sea of Japan and the Sea of Okhotsk (PFJO) were selected for simulation model. The WPNJ stock is at a low level of abundance and one of the stocks was managed by total allowable catch (TAC) and a detailed monitoring procedure was conducted. On the other hand, the PFJO stock is at a relatively high level of abundance and commercial landings are restricted by fish size. Thus, simulation model efficiency could be tested from several viewpoints using these two differently managed stocks.

In this study, a simulation model that incorporated uncertainty from sampling errors and other types of uncertainties was developed in order to provide useful information for fish stock managers who make a choice among alternative management activities. In chapter 2, the methods of evaluating errors of virtual population analysis (VPA) abundance estimates were discussed. In chapter 3, the evaluation procedure that incorporates uncertainty from sampling error and other type of uncertainties were developed and performance indices were introduced to evaluate the management candidates face to various types of uncertainties. Also, the efficiency of the simulation model was examined through its application to two stocks of different status. In chapter 4, the WPNJ stock was analyzed using

the simulation model and management candidates involving the reduction of fishing pressures were evaluated. In chapter 5, the simulation model was applied to the PFJO stock to assess mesh size related management candidates. Based on the results in those chapters, the general performance of the simulation model and the role of simulation in producing effective scientific advice are discussed in chapter 6.

Chapter 2

The method of quantifying the error of VPA abundance estimates

2.1 Introduction

Fish stock abundances are commonly estimated by many management agencies to provide scientifically-based stock management recommendations[32]. When management decisions are based on quantitative estimates from assessment models, the uncertainty should be quantified[33]. Overestimation of abundance can lead to the risk of stock declines. By contrast, underestimation can lead to loss of potential harvest opportunities. Thus, accurate and precise stock abundance estimates is essential for sound and efficient stock management.

The many methods of stock abundance estimation have been developed. The quantifying error of abundance estimate was established in various methods. For example, the Delury method applies a simple liner regression to the catch per unit effort (CPUE) decrease as the cumulative catch increase and estimate initial stock abundance [34,35]. The error of estimated abundance can be calculated by a general statistics approach [36,37]. The production model estimates model parameters and stock biomass with yield data and CPUE [38,39]. The parameter estimation in the production model used nonlinear least squares or maximum likelihood estimation. Thus the error of estimated stock biomass can obtained by a general statistical approach. VPA[40,41] has been widely applied to estimate the abundance of commercial fish stocks since its development[42]. The methods of quantifying the error of abundance estimates have been studied. However the method of quantifying the error of VPA is more complex than the other two methods because VPA needs more information than the other two methods.

In this chapter shows a method to quantify the error of abundance estimates by VPA.

2.2 The VPA procedure

VPA estimates stock numbers with terminal F, which is the coefficient of fishing mortality at largest age in the latest year, with natural mortality rate M and with catch at age data.

Catch at age calculation

The catch number calculation process is described as follows;

First, getting fish sample from all commercial size categories in an area in some period and measuring biological features such as body length, body weight, age, and so on. Second, catch at age data in a sampling area at the period were calculated as

$$C_{i,k,t,a,j} = P_{i,s,t,a,j} \cdot \frac{Y_{s,t,a,j}}{w_{s,t,a,j}} \qquad (2.1)$$

where $C_{i,s,t,a,j}$ and $P_{i,s,t,a,j}$ are the catch and the proportion of age i fish in all sampled fish respectively, in commercial size category s, in time t, and landed place a in year j.

$Y_{s,t,a,j}$ and $w_{s,t,a,j}$ are the yield in weight and the average weight of sampled fish, respectively in commercial size category s, in time t, landed place a in year j.

Finally, catch at age i for the whole stock is obtained by summing those from each divided catch numbers as;

$$C_{i,j} = \sum_s \sum_t \sum_a C_{i,s,t,a,j} \qquad (2.2)$$

Stock numbers estimation

Stock numbers dynamics are described as

$$N_{i,j} = N_{i+1,j+1} e^{M_i + F_{i,j}} \qquad (2.3)$$

The coefficient of fishing mortality $F_{i,j}$ can be computed as

$$F_{i,j} = -\ln\left(\frac{N_{i,j}}{N_{i+1,j+1}}\right) - M_i \qquad (2.4)$$

In general, one needs to assume that fishing mortality in the oldest age and latest year for estimating stock numbers in analytical solutions. For example, the fishing mortality in the oldest age class was assumed to be equal to in the second oldest age class.

$$F_{I,j} = F_{I-1,j} \qquad (2.5)$$

For example, the fishing mortality in latest year is assumed to the average former years

$$F_{i,J} = \frac{1}{n}\left(F_{i,J-1} + F_{i,J-2} + \cdots + F_{i,J-n}\right) \qquad (2.6)$$

Given the initial value to the fishing morality coefficient in the oldest age in the latest year $F_{I,J}$, stock numbers and the fishing mortality coefficients in all age in all year were calculated. Finally, searching $F_{I,J}$ to satisfy equation (2.5), the final estimators of Ns and Fs were obtained.

2.3 The review of quantifying error of VPA abundance estimates method

Some reports have examined the effect of various errors separately[43,44]. Pope[43] provided a theoretical solution to evaluate the precision of abundance estimates by VPA in a year class as follows

$$var(N_i) = var(C_i)\exp M + (var(C_{i+1})\exp(3M))$$
$$+ \cdots + \left(var(C_i)\left(\frac{\exp(2(t-i)M)(F_t + M)^2}{F_t^2}\right)\right) \qquad (2.7)$$

where Ni is the abundance at age i, C_i is the catch at age i, M is the instantaneous coefficient of natural mortality, C_t is catch at terminal age t, and F_t is the instantaneous coefficient of fishing mortality at terminal age t.

Equation (2.7) assumed that the other parameters of VPA were exact and did not incorporate the variations in the terminal fishing mortality (F_t), while the current VPA method does not fix F_t.

On the other hand, Prager and MacCall[45] evaluated the effects of simultaneous errors in the input parameters and also evaluated the effects of sampling errors on the estimates. They gave analytical solutions using the delta method.

The variance of catch number at age i in year j was calculated as

$$var\left[C_{i,j}\right] = C_j^2 \cdot p_{i,j} \cdot q_{i,j} / n_j \qquad (2.8)$$

where $P_{i,j}$ was the proportion of aged fish belong to age class i. $q = 1 - p$ In this equation, the proportions in the different age classes are distributed multinominally.

The variance of population number estimate provided as

$$var[B(x)] \approx \sum_{k=1}^{r} var[x_k] \cdot (\partial B / \partial x_k)^2$$
$$+ 2\sum_k \sum_{<l} cov[x_k, x_l] \cdot (\partial B / \partial x_k) \cdot (\partial B / \partial x_l) \qquad (2.9)$$

where the function B was the population number estimate and x_k and x_l were usual needed for VPA.

To evaluate the precision of population estimates using the delta method, auxiliary parameters or assumptions about the standard errors of catches and terminal fishing mortality should be incorporated[46].

Numerical simulation provides an alternative approach to evaluate the error of VPA estimates. Some papers have used this method, but these studies were generally aimed at examining the performance of management procedures[25,32] or the variance of recruitment[47] rather than examining the precision of the abundance estimates from VPA.

2.4 The boot strap procedure

The bootstrap method[31] is often applied in statistical fields to quantify uncertainty. In fishery science, the bootstrap procedures were widely used in the genetic sciences[48-50] but few in stock assessment[51-54].

Bootstrap method is a set of procedure with data generate and evaluation. Bootstrap method first generate data called "bootstrap sample" by "resampling" which is the sampling from the original data permitting replications. Normally the sample size of the bootstrap sample is equal to the original sample size.

A general procedure for evaluation of parameter θ is as follows:

1) Generate B independent bootstrap samples $\mathbf{x}_i (i=1,2,\ldots,B)$ each consisting of n data drawn randomly with replication from the original sample;
$$\mathbf{x}_1, \mathbf{x}_2, \ldots, \mathbf{x}_b, \ldots \mathbf{x}_B$$

$$\mathbf{x}_b = \begin{pmatrix} x_{b,1} \\ x_{b,2} \\ \vdots \\ x_{b,n} \end{pmatrix} \qquad (2.10)$$

2) Calculate the bootstrap replicate of the parameter or $\hat{\theta}_b$ statistic for each of the b bootstrap samples, $\mathbf{x}_b$.

$$\hat{\theta}_b = f(\mathbf{x}_b) \qquad (2.11)$$

3) Estimate the interest quantities from B calculated parameter or statistic $\hat{\theta}_b$

For example, the mean of θ the bootstrap replicates of , which is the bootstrap estimate of statistic θ, θ_b is calculated as

$$\overline{\theta}_b = \frac{\sum_{b=1}^{B} \hat{\theta}_b}{B} \qquad (2.12)$$

The bootstrap estimation is useful where the sampled population cannot be adequately expressed by a simple probability function, and especially where the underlying population distribution is unknown.

Various sources of errors are included in VPA, such as errors in fishing mortality, natural mortality, catch statistics and so on. Especially in the catch at age data, which are the most essential catch statistics in VPA, various kinds of sampling errors would be largely included because of the large deviations of body weight and small samples contrasted to the whole catch. These may create large errors in VPA estimates. While there may be several sources of errors, only the sampling errors have a room for improvement in reality. The current study focuses on the sampling error of catch at age data from sampled fish in markets that are fished by commercial fisheries and quantified the influence of sampling error on VPA estimates under the current monitoring procedure. In general, the process of data collection and calculation of catch at age from commercial fisheries is complex and in many cases, the distribution of population is unknown or sample may not be expressed by a simple probability function. Bootstrap method is suitable for quantifying the error of VPA abundance estimates.

2.5 Quantifying error of VPA abundance estimates by boot strap procedure

A non-parametric bootstrap method was applied to all data of measurements (the set of age, weight, and length of the fish) in every fish sample from the commercial landings.
Measurements data is described as

$$\mathbf{F} = \begin{bmatrix} D_{1,1} & D_{1,2} & \cdots & D_{1,\omega} \\ \vdots & D_{q,e} & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ D_{n,1} & \cdots & \cdots & D_{n,\omega} \end{bmatrix} \qquad (2.13)$$

where $D_{q,e}$ is the data of e-th mesurement of q-th fish in the fish sample.

Bootstrap resampling applied to the set of fish measurements and bootstrap sample as:

$$\mathbf{B}_k = \begin{bmatrix} D_{1^*,1} & D_{1^*,2} & \cdots & D_{1^*,\omega} \\ \vdots & D_{q^*,e} & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ D_{n^*,1} & \cdots & \cdots & D_{n^*,\omega} \end{bmatrix} \qquad (2.14)$$

where q^* is a number which is chosen randomly from 1 to n and k is the iteration number ($k = 1, 2, \cdots, K$)

K set of bootstrap samples were produced from each fish sample. K catch at age data sets were obtained from the bootstrap samples as the replication of fisheries' monitoring procedures, which computes the catch number from fish sample measurements.
A total 1000 estimate of stock size at age for all calculate years were calculated by VPA from catch at age data set obtained by the bootstrap procedure. Evaluate the stock size error through applying a statistical method to K stock sizes at age.

Chapter 3
The simulation model

To evaluate variations in future population and fisheries dynamics, population forecast model, which includes errors in stock size estimates, recruitment variability and variability in future fishing mortality was developed.

3.1 Population dynamics

Population dynamics is described as equation (2.3). Equation (2.3) can describe using matrix as

$$\mathbf{N}_{j+1} = \mathbf{P} \cdot \mathbf{S} \cdot \mathbf{N}_j + \mathbf{R}_{j+1} \qquad (3.1)$$

where $\mathbf{N}_j$ is the stock number in year j.

$$\mathbf{N}_j = \begin{bmatrix} N_{1,j} \\ N_{2,j} \\ \vdots \\ N_{I,j} \end{bmatrix} \qquad (3.2)$$

and $N_{i,j}(i=1,2,\cdots,I)$ is the stock number in class i in year j. The succession matrix which shows the probability of fish in class l in a year belongs to class K in the next year; $\mathbf{P}=\{p_{lK}\}$ is described as

$$\mathbf{P} = \begin{bmatrix} P_{1,1} & P_{1,2} & ... & P_{1,I} \\ P_{2,1} & P_{2,2} & ... & ... \\ ... & ... & ... & ... \\ P_{I,1} & ... & ... & P_{I,I} \end{bmatrix} \qquad (3.3)$$

In the age-based model, $P_{i+1,i}=1 (i=1, 2,...,I)$ and the other elements are equal to zero i.e.

$$\mathbf{P} = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ \vdots & 0 & 1 & 0 & \vdots \\ \vdots & \cdots & 0 & \ddots & 0 \\ \vdots & \cdots & \cdots & 0 & 1 \\ 0 & \cdots & \cdots & \cdots & 0 \end{bmatrix} \qquad (3.4)$$

The survival matrix $\mathbf{S}$ is described as

$$\mathbf{S}_j = \begin{bmatrix} S_{1,j} & 0 & ... & 0 \\ 0 & S_{2,j} & ... & ... \\ \vdots & ... & ... & ... \\ 0 & ... & ... & S_{I,j} \end{bmatrix} \qquad (3.5)$$

where $S_{i,j} (i=1,2,.....,I)$ is the survival rates described as

$$S_{i,j} = e^{(-M_i - F_{i,j})}$$

where M_i is the coefficient of natural mortality at age i. $F_{i,j}$ is the coefficient of fishing mortality at age i in year j. The recruitment $\mathbf{R}_j$ is described as

$$\mathbf{R}_j = \begin{bmatrix} R_{1,j} \\ R_{2,j} \\ \vdots \\ R_{I,j} \end{bmatrix} \qquad (3.6)$$

In the age-based model; $R_{1,j}=N_{1,j}$, $R_{i,j}=0$ ($i=2, 3,..., I$) i.e.

$$\mathbf{R}_j = \begin{bmatrix} N_{1,j} \\ 0 \\ \vdots \\ 0 \end{bmatrix} \qquad (3.7)$$

The details of recruitment are mentioned in later chapters.

Abundance estimation procedures

Estimation procedures are different between age-based model (VPA) and length-based model (LPA). VPA estimate procedure has described in chapter 2.

LPA estimates stock numbers and model parameters, which yearly fishing strength and the selectivity of length class fished, with minimizing the residuals sum of squares (RSS) between the observed catch numbers and the estimated catch numbers. The coefficient of fishing mortality at length class i in year j is described as;

$$F_{i,j}=f_j \times s_i \ (j=1, 2,..., J; i=1, 2,...,I) \qquad (3.8)$$

where f_j is the yearly fishing strength and s_i is the selectivity of length class i fish caught. Both f_j and s_i are the parameter of LPA.

The estimated catch number at length class i in year $j \hat{C}_{i,j}$ is computed as;

$$\hat{C}_{i,j} = \hat{N}_{i,j} \frac{F_{i,j}}{\left(F_{i,j} + M_i\right)} \left(1 - e^{(-M_i - F_{i,j})}\right) \qquad (3.9)$$

Parameter estimation is estimated using nonlinear least squares method that minimized the *RSS*.

$$RSS = \sum_{j=1}^{J} \sum_{i=1}^{I} \left(\hat{C}_{i,j} - C_{i,j}\right)^2 \qquad (3.10)$$

As mentioned above the both population estimation procedures, VPA and LPA have the same procedure from data collection to estimate stock number, although final estimation technique is different. The point estimations were calculated from both VPA and LPA from catch numbers. The estimation errors for both VPA and LPA procedures were evaluated by a non-parametric bootstrap method applied to describe in Chapter 2.

3.2 Population forecast model

Stock size for initial value

The bootstrap method was applied to the data for all sampled fish measurements (the set of age, weight, and length of the fish) in every sample. All 1000 set of bootstrap samples were produced from each set of sample in all years, and each bootstrap sample set has the same number of fish measurements as the raw set of sample. One thousand catch at age/length class data sets were obtained from the set of bootstrap samples as the replication of the fisheries' monitoring procedures.

A total 1000 estimates of stock size at class and fishing mortality at class, in all years were calculated by population estimate model from catch at class data set obtained by the bootstrap procedure. These

estimates are used as the initial values, where the population forecast is start at, in the population dynamics and recruitment forecasts.

Population estimates performance

Performance index

In total, 1000 abundances were calculated by estimation procedures (VPA or LPA) from the catch at class data set obtained by the bootstrap procedure.

The relative deviations in the population estimates were calculated as;

$$RD_{i,j,k} = \frac{N^*_{i,j,k} - \hat{N}_{i,j}}{\hat{N}_{i,j}} \quad k=1,...,K \qquad (3.11)$$

where $RD_{i,j,k}$ is the relative deviation of an estimate at class i in year j, which is calculated from an point estimate, $\hat{N}_{i,j}$, and from the k-th bootstrap sample, $N^*_{i,j,k}$. The confidence intervals of the point estimate were computed using Efron's bias-corrected percentiles, which can remove the effect of the bias and skewness caused by the resampling [55-57]. The bias-corrected percentiles were computed as follows:

1. A constant Z_0 is calculated to be the probit transform of Fr:

$$Z_0 = \Phi^{-1}(Fr) \qquad (3.12)$$

where Φ^{-1} is the inverse, standard cumulative normal distribution, and Fr is the ratio for the case that $RD_{c,j,k}$ is negative.

2. The bias-corrected upper and lower limits for $1-a\%$ confidence intervals were calculated as:

$$P_{\text{lower},\alpha} = \Phi(2Z_0 - t_\alpha)$$
$$P_{\text{upper},\alpha} = \Phi(2Z_0 + t_\alpha) \qquad (3.13)$$

where Φ is the cumulative normal distribution function, and t_α is the critical value from the inverse normal curve for $(1-a)\%$ confidence intervals.

3. The upper and lower bounds of $(1-a)\%$ bias-corrected confidence intervals (BCCI) were set as the $P_{upper,\alpha}$ and $P_{lower,\alpha}$ percentile of RDs.

The performance of population estimation procedures were evaluated from 80% BCCI and 50% BCCI.

Magnitude of effect of sampling error on population estimates

The abundance estimates include the process error, caused by the estimation procedure, and the measurement error caused by the estimated catch number from samples. Retrospective analysis is a tool for evaluating the magnitude of model error[58]. The retrospective analysis is the method to evaluate the trends in estimated abundance over time with dropping the recent data sequentially and estimating abundance with left data. A total 1000 retrospective analysis for 5 years were applied to 1000 abundance estimates from catch at class data set obtained by the bootstrap procedure. One-way analysis of variance (ANOVA) was conducted to the output from retrospective analysis for separating the process error and the measurement error. The measurement error is explained as the effect of sampling error on abundance estimates in this study.

Stock numbers and biomass

Stock numbers can be calculated using population dynamics equations (eq. 2.3 or eq. 3.1) from the initial stock values.

The biomass in year j from the kth data set $B_{j,k}$ was calculated as

$$B_{j,k} = \sum_i N_{i,j,k} \cdot w_i \qquad (i=1,2,.....,I) \qquad (3.14)$$

where w_i was the average body weight at class i.

The spawning biomass was calculated as

$$SB_{j,k} = \sum_{i=1}^{I} \left(N_{i,j,k} \cdot mr_i \cdot w_i \right) \qquad (3.15)$$

where $SB_{j,k}$ was the spawning biomass in year j from the k-th data set mr, and w_i are the maturity rate in spawning season and the average body weight respectively at class i.

Recruitment

To simulate recruit variability, the future recruits are estimated by a non-parametric procedures. Kimoto *et al.*[59] proposed a non-parametric stock-recruitment model, which was combination of the modified Marcov Matrix. It is described briefly as;

$$R = \begin{cases} r_1 z & v = 1 \\ (r_2 - r_1)z + r_1 & v = 2 \\ (r_3 - r_2)z + r_2 & v = 3 \\ (R_{max} - r_3)\left(-\dfrac{\ln(z)}{\lambda}\right) & v = 4 \end{cases} \qquad (3.16)$$

where z is a random number from uniform distribution between 0 and 1. r_n is the interval limits of recruitment from recruitment-spawning biomass relationship. R_{max} is the maximum number of recruitment. v is the spawning biomass level from recruitment-spawning biomass relationship. λ is a constant and used 3.16[59]. This method calculates the number of recruitment depending on the level of spawning biomass.

The other approach to calculate the future number of recruitment is using product of spawning biomass and a random chosen number of recruit per spawning biomass (RPS)[12].

The number of recruit in year y from kth data set $R_{y,k}$ is calculated as

$$R_{y,k} = RPS_{j^*,k} \cdot SB_{y,k} \qquad (3.17)$$

where $RPS_{j^*,k}$ was the randomly chosen RPS in year j^* from a set of RPS values calculated from the kth data set. j^* is a randomly chosen year from past years (j=1,2, …, J).

Future fishing mortality

Future fishing mortality and catch at class c was simulated as follows.

The management scenarios were tested as the regulating future fishing mortality in the simulation model. The future fishing mortality coefficient at class i that determines catch at class i is calculated as

$$FF_{i,y,k} = F_{i,j^*,k} \times RR_{i,y} \quad (y=1,2,…,Y) \qquad (3.18)$$

where $RR_{y,j}$ is the ratio of regulation at class i in year y determined from the selected management scenario. Fishing mortality in first forecast year used those in the latest value of initial value because of a time lag between assessment and implementation of regulation.

Fishing mortalities in first forecast year (y=1) were set equal to those in the latest year in the stock assessment (year J: called the current year) because of a time lag between assessment and implementation of regulation [60].

$$FF_{i,y,k} = FF_{i,J,k} \qquad y=1 \qquad (3.19)$$

Catch numbers

The future catch at class i is calculated as

$$C_{i,j,k} = N_{i,j,k} \frac{FF_{i,j,k}}{\left(FF_{i,j,k} + M_i\right)}\left(1 - \exp\left(-FF_{i,j,k} - M_i\right)\right)$$
$$(3.20)$$

where $C_{i,j,k}$ is catch at class i in year j from the k-th data set, and $FF_{i,j,k}$ is the fishing mortality coefficient at class i in year j from the k-th data set.

Management scenarios

Testing management scenarios were expressed as ratio of fishing mortality regulation from the current fishing mortality estimated by the population number estimation procedures. Simulation without suppression of fishing mortality, referred to as current fishing mortality (CFM).

3.3 Performance measurements

Performance measurements are set for evaluating the validity of management procedures. Four main performance measurement indicators were used: conservation erformance, utilization performance, stability, and reliability [61].

Biomass indexes for conservation performance

The biomasses in some period, for example 10, 20, and 30years after, relative to the median of the biomass forecasted by the maintaining current fishing mortality (CFM) runs over the same period were computed as a conservation performance index. These comparisons were classified into five categories as; greater than twice the CFM value; 1.2 - 2 times; 0.8 - 1.2 times; 0.5 - 0.8 times; and less than 0.5 times the median biomass in the CFM run.

The bad performance measure in each simulation run was calculated as the lower 5th percentile of the minimum biomass in the simulation period divided by the median biomass in the current year, expressed as a percentage.

Yield indexes for utilization performance

The cumulative yields from some period, for example 10 years, 20 years and 30 years from each simulation run relative to the median of the cumulative yield in the CFM runs over the same period were computed as an utilization performance index. Yield

comparison with CFM runs was expressed using the same five categories as those described for biomass comparison.

The yields in the certain year relative to the yield of the current year and comparisons expressed using the previously mentioned five categories.

The bad performance measure in each simulation run was the lower 5th percentile of the minimum annual yield in the simulation period divided by the yield in the current year, expressed as a percentage.

Stability performance

The index of the annual changes of yield is drawn as AAV. AAV is defined as the average absolute change in yield divided by the average total yield, expressed as a percentage[24].

$$100 \times \frac{\sum_j \left| Y_j - Y_{j-1} \right|}{\sum_j Y_j} \qquad (3.21)$$

where Y_j is the annual yield in year j.

In fishing ban scenarios, data for the first year to the last year of the full ban, and the next year following the end of the full ban were omitted for the calculation of AAVs to exclude the effects of extreme deviations, resulting from the fishing ban, on the stability performance index.

Reliability performance

While AAV relates to stability overtime within a replicate, reliability relates to inter-replicate variability[61]. Inter-replicate coefficients of variation (CV) of the cumulative yield for some period are used as indexes of reliability performance.

Chapter 4

Application for walleye pollock stock in the northern waters of the Sea of Japan

4.1 Introduction

WPNJ is one of the stocks managed by TAC in Japan. The Hokkaido National Fisheries Research Institute (HNFRI) has provided scientific recommendations for TAC, cooperating with the Hokkaido Fishery Experiment Station (HFES), which belongs to the Hokkaido local government[60]. The data of WPNJ monitoring were collected by the fishery monitoring procedure conducted by HFES with the budget of Japanese Fishery Agency. The data were accumulated over a long period, and monitoring procedures have been also well documented and population have been estimated by using VPA [60]. Until today, only investigated variability in recruitment have been investigated as the uncertainty in the assessment of WPNJ[60]. Errors in population estimates or uncertainty about future fishing mortality have not been considered.

In this chapter, a simulation model, which incorporates errors in population estimates, recruitment variability, and variability in future fishing mortality, was developed for evaluation of WPNJ stock management candidates.

4.2 Materials

The simulation model was used for the WPNJ stock. The peak of the fishing season is in December and January. The spawning season is December to next March[60]. For convenience of data organization and assessment, the fishery year was defined as April to next March. Biological parameters, such as natural mortality at age, average body weight at age, and maturity rate at age were set at the same values used in HNFRI assessment[62], and were shown in Table 4-1.

Table 4-1 Biological parameters of simulation model for walleye pollock in the northern waters of the Sea of Japan.

Age	Natural mortality rate	Average body weight (g) at beginning of age	Spawning season maturity rate
2	0.30	134	0.12
3	0.25	229	0.33
4	0.25	326	0.64
5	0.25	425	0.87
6	0.25	485	0.96
7	0.25	545	0.99
8	0.25	570	1.00
9	0.25	578	1.00
10^+	0.25	688	1.00

4.3 Data

Catch at age data were collected by the fishery monitoring procedure conducted by Hokkaido Fishery Experiment Station (HFES). Catch at age data from 1991 to 2004 monitored by HFES were used. The WPNJ fishery consists of three fishery categories: (i) south coastal fishery (SC); (ii) mid-coastal fishery (MC); and (iii) trawl fishery (TR). The TR mainly aimed at younger age-classes. The older age-classes were fished by SC and MC using gill nets and longlines (Fig. 4-1).

Catch at age was estimated through the monitoring procedure based on the stratified sampling of fisheries. The three fisheries were regarded as the stratums. The times and locations of sampling were empirically selected to represent the stock.

A fish sample for aging (CFS) was obtained from commercially landed fish. The number of fish in a CFS was approximately 100, and CFSs were collected from all commercial size categories in a sampling port for each of the three stratums, every year. The number of commercial size categories and the number of sampling ports varied widely because of the differences in commercial size categories between the sampling ports and CFS data that resulted from events such as poor landings, weather conditions, and limitations in personnel numbers, and/or budget (Table 4-2). The missing samples were empirically extrapolated by the similar samples.

In 2004, for example, 2844 fish were aged and the weight-based sampling ratio was 0.004%.

4.4 Methods

Simulation

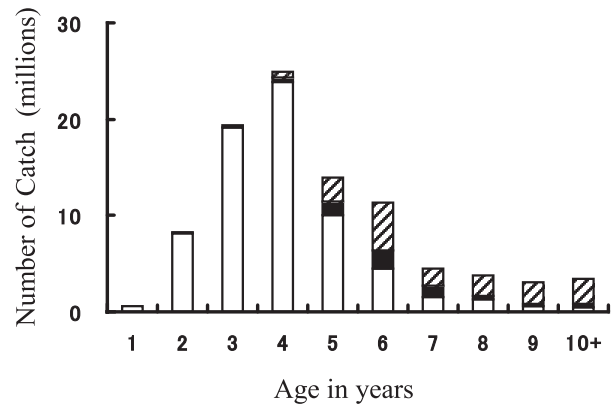To evaluate variations in future population and fisheries dynamics, 1000 population dynamics series

Fig.4-1 Catch at age in 2004 from the south coastal fishery (shaded box), mid-coastal fishery (■) and trawl fishery(□) for walleye pollock in northern waters of the Sea of Japan.

were forecasted, with 1000 sets of initial stock number at age, numbers of recruits per spawning biomass (RPS), and fishing mortality rates. Age at recruitment, i.e., youngest age in the calculation, was defined as age 2, because ages 0 and 1 were rarely caught. Age groups ?10 were pooled and referred to as 10+. Future population was forecasted for 30 years (2005 to 2034).

Stock size for initial value

The stock size at age of the WPNJ stock from 1991 to 2004 was estimated using VPA. Estimation errors were evaluated by a non-parametric bootstrap procedure.

Base case forecasting model

Stock numbers and biomass

Stock numbers > age 3 class was calculated as equation (3.1) in chapter 3.

The number of fish at 10^+ was calculated as

$$N_{10^+,j,k} = N_{10^+,j-1,k}\, e^{\left(-M_{10^+} - FF_{10^+,j-1,k}\right)} + N_{10,j,k} \quad (4.1)$$

where $N_{i,j,k}$ was the number of fish at age i in year j from the kth data set, M_i was the natural mortality coefficient at age i, and $FF_{i,j,k}$ was the fishing mortality coefficient at age i in year j from the kth data set. The biomass was calculated by equation (3.14) The spawning biomass was calculated as

$$SB_{j,k} = \sum_{i=2}^{10^+} (N_{i,j+1,k} \cdot mr_{i-1} \cdot w_i) \quad (4.2)$$

Table 4-2 Details of the sampling procedure for calculate the catch at age of walleye pollock in the northern waters of the Sea of Japan.

Fishery	SC			MC			TR		
Year	Sampling[*1]	Categories[*2]	Ports[*3]	Sampling	Categories	Ports	Sampling	Categories	Ports
1991	5	2	3	1 or 2	1 or 2	3	10	1	1
1992	5	2	3	2	2	2	8	1	1
1993	5	2	3	1	2	2	6	1	1
1994	4	2	3	1	2	2	5	1	1
1995	5	2	3	2	2	2	5	1	1
1996	5	2	3	1 or 2	2	2	7	1or 2	1
1997	4 or 5	2	3	2 or 3	2	2	5	1 or 2	1
1998	5 or 6	2	3	3	1 or 2	2	4	1	1
1999	5 or 6	2	3	1	2	2	5	1	1
2000	5 or 6	2	3	2	1 or 2	2	7	1	1
2001	3 or 5	1 or 2	3	3	2	1	3 or 6	1	2
2002	3 or 5	2	3	2	2	1	5 or 4	1 or 3	2
2003	4 or 5	2 or 3	3	3	2	1	4	1 or 3	2
2004	3 or 5	2 or 3	3	4	2	1	4	1	1

*1: Frequency of the sampling (times per year).

*2: The number of commercial size categories.

*3: The number of sampling ports.

SC, south coastal fishery; MC, mid-coastal fishery; TR, trawl fishery.

where $SB_{j,k}$ was the spawning biomass in year j from the kth data set, mr_i was the maturity rate in spawning season at age i, and w_i was the average body weight at beginning of age i. Since the spawning season is at the end of study year, the number of spawning individuals was approximated by VPA as the number of individuals in the next age class at the beginning of the next year.

Recruitment

Since a clear relationship between spawning stock size and recruitment has not been observed in the WPNJ stock [60], number of recruitment was the product of a randomly selected RPS and a spawning stock biomass forecast.

RPS was calculated as

$$RPS_{j,k} = \frac{N_{2,j+2,k}}{SB_{j-1,k}} \quad (j=1991\ldots 2002) \qquad (4.3)$$

Twelve RPS values were calculated from a set of 1991 to 2002 number of fish at age. Number of recruitment was determined by equation (3.17).

Management scenarios

Twenty-two management scenarios in three categories of management scenarios under consideration were tested. Category 1 scenarios included regulations that suppressed fishing mortality for the whole fishery over all years. Category 2 scenarios regulated the fisheries separately, while category 3 scenarios banned fishing in earlier years and restarted fishing, with regulations, in the

Table 4-3 Management scenarios for walleye pollock in the northern waters of the Sea of Japan

Management scenario	Regulation of trawl fishery	Regulation of coastal fishery
Category 1-1	90%	90%
1-2	80%	80%
1-3	70%	70%
1-4	60%	60%
1-5	50%	50%
1-6	40%	40%
1-7	30%	30%
1-8	20%	20%
Category 2-1	100%	80%
2-2	80%	100%
2-3	80%	60%
2-4	60%	80%
2-5	70%	50%
2-6	50%	70%
Category 3-1	100%	Ban 5 yrs-100%
3-2	Ban 5yrs-100%	100%
3-3	Ban 3 yrs-100%	Ban 3 yrs-100%
3-4	Ban 5 yrs-100%	Ban 5 yrs-100%
3-5	Ban 10yrs-100%	Ban 10 yrs-100%
3-6	Ban 10 yrs-80%	Ban 10 yrs-80%
3-7	Ban 10 yrs-60%	Ban 10 yrs-60%
3-8	Ban 10 yrs-40%	Ban 10 yrs-40%

remaining years. Within each category, larger scenario numbers indicate relatively more severe regulation. Management scenario details are shown in Table 4-3.

Future Fishing Mortality and catch at age

The future fishing mortality and catch at age was simulated as follows:

Relative performances of each fishery to the harvest were calculated. The ratio of the trawl fishery to the whole fishery at age i, RT_i was calculated as

$$RT_i = \frac{\sum_{j=1991}^{2004} TC_{i,j}}{\left(\sum_{j=1991}^{2004} TC_{i,j} + \sum_{j=1991}^{2004} CC_{i,j} \right)} \qquad (4.4)$$

where $TC_{i,j}$ and $CC_{i,j}$ were the catch at age i in year j in the trawl fishery and in the coastal fishery, respectively.

The ratio of the coastal fishery to the whole fishery at age i, RC_i was calculated as

$$RC_i = 1 - RT_i \qquad (4.5)$$

The ratio of regulation of fishing mortality coefficient for the combined fisheries at age i in year j $RR_{i,j}$ was calculated as

$$RR_i = RT_i \cdot \alpha + RC_i \cdot \beta \qquad (4.6)$$

where α is the percentage of current fishing mortality for the trawl fishery and β the percentage in the coastal fishery were selected according to the management scenario(Table 4-3).

The fishing mortality coefficient at age and catch at age was calculated by equation (3.18), (3.19), and (3.20).

Performance measurements

The validity of management procedures were evaluated by the performance measurements described in chapter 3.

Additional analysis

Variation of recruitment assessment

The RPS from 1991 to 2002 were used for base case simulations in eq. (3.17); however, RPSs from 1981 to 2002 were also available from HNFRI assessments[60]. Most of the RPSs during 1991 to 2002 were in the lower half of the RPSs from 1981-2002 (Fig. 4-2). To evaluate the effects of RPS period choice, three other RPS period options were tested.
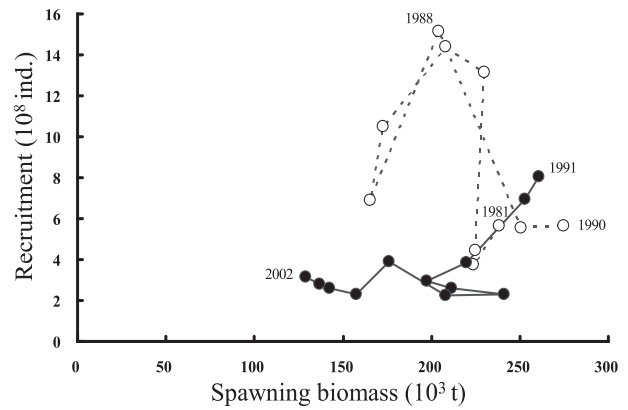

Fig.4-2 Relationships between recruitment and spawning biomass of the walleye pollock in the northern waters of the Sea of Japan. Recent values (solid lines, ●), former values (broken line, ○).

The $RPS_{j*,k}$ in eq. (3.17) for the four RPS period options were

Recruitment base case: $RPS_{j*,k}$ randomly chosen from 1991 to 2002.

Recruitment option 1:

$RPS_{j*,k}$ randomly chosen from 1981 to 2002.

Recruitment option 2:

$RPS_{j*,k}$ randomly chosen from 1991 to 2002 for the first five years and from 1981 to 2002 for the 6th and following years.

Recruitment option 3:

$RPS_{j*,k}$ randomly chosen from 1991 to 2002 for the first ten years and from 1981 to 2002 for the 11th and following years.

RPSs from 1991 to 2002 were calculated from the kth data set of stock number at age, as used in the base case. RPSs from 1981 to 1990 were calculated from a set of point estimators of stock number at age. The same HNFRI RPS data set was used in all simulation iterations. A total of 92 scenarios (4 recruitment options and 23 management scenarios) were tested in the forecasting model.

Effects of simulation fluctuations

To evaluate the effects of fluctuations in the simulation model, modified base case trials were evaluated. The modified base cases were based on management scenario 1-5 with three fluctuation settings as follows and the outputs were compared to that of the base case trials (FULL).

(1) Variability of RPS (AR)

To exclude RPS variability, $RPS*_k$ in eq. (3.17) was fixed at the 1991 to 2004 average in kth data set as

$$RPS_{j^*,k} = \frac{\sum_{1993}^{2004} N_{2,j,k}}{\sum_{1990}^{2001} SB_{j,k}} \qquad (4.7)$$

(2) Fishing mortality (AF)

To exclude fishing mortality fluctuations, F in eq. (3.18) was fixed at the 1991 to 2004 average as

$$F_{i,j^*,k} = \frac{1}{14}\sum_{1991}^{2004} F_{i,j,k} \qquad (4.8)$$

(3) Population estimation (PE)

Point estimators of stock size at age were used instead of the 1000 sets of stock size at age data produced by the bootstrap procedure.

4.5 Results

Error in stock size estimation

The CVs of catch at age and abundance estimates by age are shown in Table 4-4. The CVs in the abundance estimates in the latest year and the oldest age-class were high, while the CVs of catch were high in the younger ages (ages 1 and 2) and older ages (ages 9 and 10+).

Error in catch at age

The frequency distributions of catch estimated by the bootstrap procedure from the data in 2004 are shown in Fig. 4-3. The major ages were 3-5 (the frequencies of each age were 0.21, 0.27, and 0.15, respectively). The distributions of catch from the bootstrap procedure were asymmetric. Fig. 4-4 shows the CV of the catch at age in 2004 using the bootstrap method. The CV ranged from 6.8% (age 4) to 18.9% (age 1). The CV of age 1 was much larger than those of other ages because fish at age 1 were rarely caught by these fisheries (Fig. 4-1).The CVs of the catch at age in the three fishing divisions are shown in Fig. 4-5. The CVs of the major age-classes were low. However, minor age-classes had relatively high CVs.

Error in abundance estimates

The BCCI of the abundance estimates using the bootstrap procedure in 2004 is shown in Fig. 4-6. The distributions became narrower with age. This tendency was similar to that of the CV of the catch at age (Fig. 4-4). Fig.4-7 shows the BCCI in the abundance estimates for the 1991 cohort. The variances were smaller, as cumulative calculations were made from age 10+ to age 1. Fig.4-8 shows the process error and measurement

Table 4-4 The coefficient of variations (%) of the catch and abundance estimates of the walleye pollock in the northern waters of the Sea of Japan evaluated from the bootstrap procedure.

Cath at age — year

age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	790	103	-	-	-	-	-	37	-	3	33	7	9	19
2	40	28	98	15	61	18	26	9	102	2	10	20	6	9
3	4	10	16	11	14	12	9	10	40	12	6	9	5	9
4	7	4	11	10	7	7	9	15	14	9	10	6	9	7
5	7	8	6	7	12	6	8	9	14	11	13	9	7	9
6	7	8	10	6	7	11	8	6	15	11	12	10	9	9
7	11	12	10	9	5	18	11	8	14	10	10	12	9	13
8	19	13	14	11	8	23	15	11	10	11	6	11	9	14
9	22	24	13	15	19	27	23	14	7	15	6	10	10	15
10+	24	15	18	16	15	9	26	17	11	15	6	11	9	11

Population at age — year

age	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	5	3	3	4	4	5	6	6	4	**7**	7	**9**	9	**20**
2	4	5	3	3	4	4	5	6	6	**4**	7	7	**9**	**9**
3	2	4	5	3	4	4	4	5	6	6	4	7	**7**	**9**
4	4	3	5	5	3	4	4	5	6	6	6	5	**9**	**7**
5	5	5	4	5	6	4	4	5	5	6	7	7	**8**	**10**
6	5	6	6	6	**7**	6	4	4	5	5	7	8	**10**	**10**
7	7	8	8	8	**8**	9	7	5	6	5	6	8	**10**	**14**
8	13	9	10	10	**12**	13	10	9	6	6	6	6	**10**	**15**
9	15	16	11	11	16	24	15	10	**12**	7	**8**	7	8	**16**
10+	33	29	23	22	21	36	32	22	18	19	12	14	14	**15**

Bold indicates relatively higher CVs that were obtained from both catch and abundance in each year
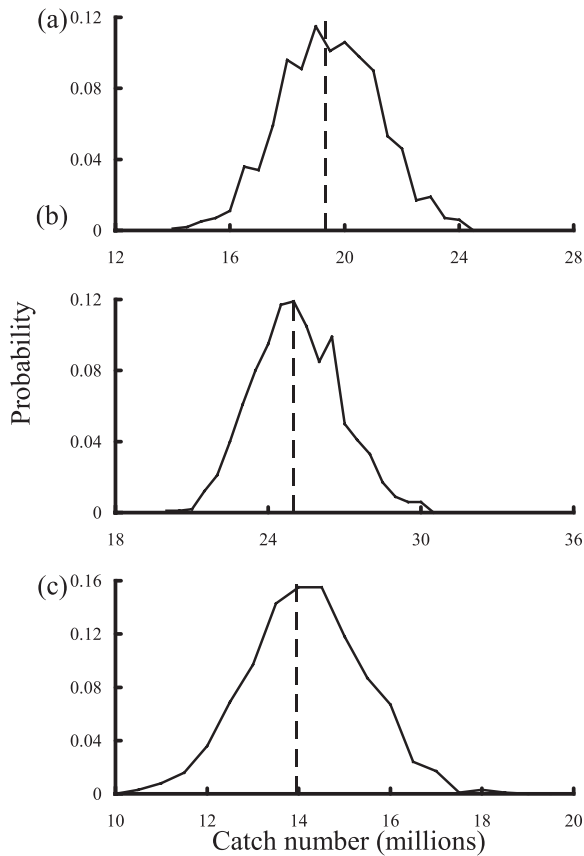
Fig.4-3 Frequency distributions of catch of the walleye pollock in the northern waters of the Sea of Japan in 2004 for (a) age 3, (b) age 4, and (c) age 5, obtained using the bootstrap procedure. Vertical broken lines show the point estimates of catch at age.
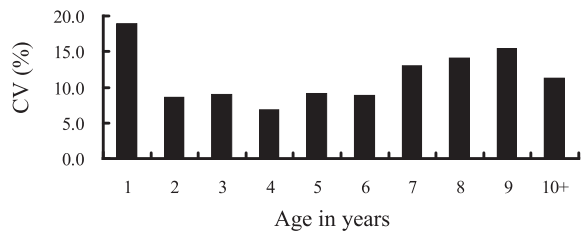

Fig.4-4 Coefficients of variation (CV %) for catch of the walleye pollock in the northern waters of the Sea of Japan in 2004 estimated using the bootstrap procedure.

error in abundance estimates in 1999. The ratios of measurement errors in abundance estimates were greater as age. The ratios were 2% to 59 %.

Simulation: Base case trial

Trends

Biomass abundances forecasted for each management scenario are shown in Fig. 4-9. The CFM run showed an abundance decrease. Category 1 management scenarios 1-6, 1-7, and 1-8 showed increases while scenario 1-5 showed stable abundances. Scenarios 1-1, 1-2, 1-3, and
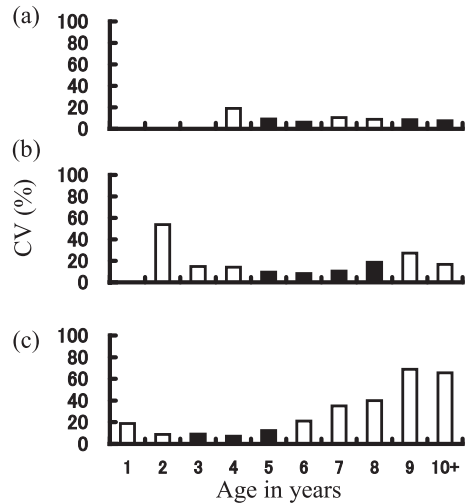

Fig.4-5 Coefficients of variation (CV%) for catch of the walleye pollock in the northern waters of the Sea of Japan by fishery in 2004 for (a) south coastal fishery, (b) mid coastal fishery, and (c) trawl fishery, estimated using the bootstrap procedure(■, □), showing major age-class target by each fishery(■).
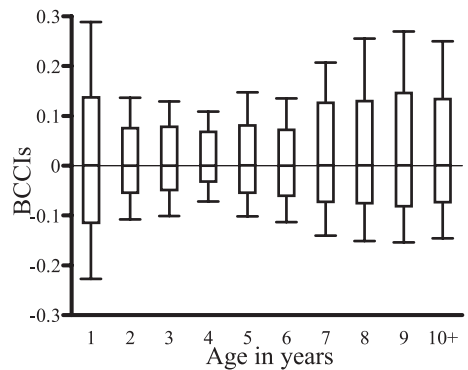

Fig.4-6 Bias-corrected confidence intervals (BCCIs) for the 2004 estimated abundance of the walleye pollock in the northern waters of the Sea of Japan. Boxes indicate the 50 % BCCI and vertical lines with bars indicate 80 % BCCI.
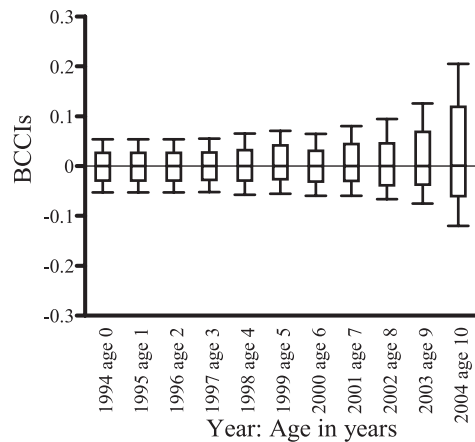

Fig.4-7 Bias-corrected confidence intervals (BCCIs) for the 2004 estimated abundance of the walleye pollock in the northern waters of the Sea of Japan. Boxes indicate the 50 % BCCI and vertical lines with bars indicate 80 % BCCI.

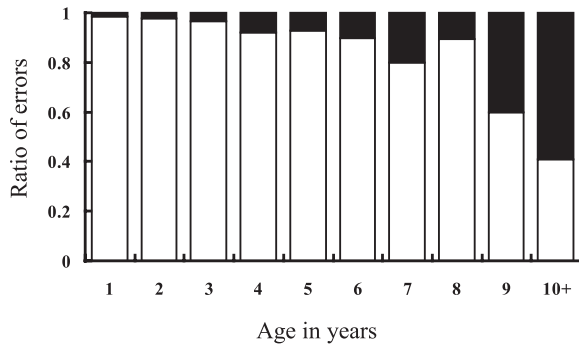1-4 showed decreases in forecasted biomass levels. All

Fig.4-8 The ratio of error on abundance estimates in 1999 by retrospective analysis for the process error (□) and the measurement error (■) of the walleye pollock in the northern waters of the Sea of Japan.

management scenarios in category 2 showed decreases while in category 3, all scenarios showed increases within the regulatory ban period, except for scenario 3-1 in which there was no ban in the trawl fishery and only a five-year ban in the coastal fishery.

Forecasts of yield for each management scenario are shown in Fig. 4-10. The yields in 2004 and 2005 were the same in all scenarios because of the time lag between stock assessment and implementation of regulations. In category 3 scenarios, some years beginning in 2006 showed zero or small yields, corresponding with the fishing ban period used in each scenario. During, the remaining years in the category 3 scenarios, and in the category 1 and 2 scenarios, the yield trends were similar to those observed in the biomass forecasts.

Biomass

The biomasses forecasts at 2014, 2024, and 2034 for each management scenario relative to the median of the biomass forecasted by the CFM run are shown in Fig. 4-11. The medians of all management scenarios compared with the CFM run were one (1) or greater. By 2014, the distribution of outputs shifted to larger biomass values as the amount of regulation alteration increased. In this distribution shift, the medians increased with the increases in regulations within the same category. Moreover, the outputs with larger relative biomass levels (more than two times than the median of the CFM biomass) increased and those with relatively similar biomass levels (0.8-1.2 times the CFM biomass) decreased with changes in the amount of regulation. Similar results

were observed at 2024 and 2034, but biomass levels relatively larger than in 2014 were forecast. Within scenarios, the distribution of outputs shifted to larger biomass levels as time progressed. The distributions of outputs in scenarios 3-5, 3-6, 3-7, and 3-8 produced relatively large biomass values at all time points.

The lower 5th percentile of the minimum biomass forecasted in each simulation scenario was divided by the 2004 median of biomass and expressed as a percentage (Table 4-5). In each category, the relative output minimums increased with the amount of regulation change, except in the change from scenario 3-2 to 3-3. Minimum biomass forecasts for each management scenario were larger than the output forecast for the CFM run.

Yield

Cumulative yields forecasted from 2005 to 2014, to 2024, and to 2034 for each management scenario relative to the median of the cumulative yield in the CFM run are shown in Fig.4-12. From 2005 to 2014, median outputs for all management scenarios relative to the CFM median were one (1) or less. However, from 2005 to 2024 and to 2034, most median outputs in each management scenario relative to the CFM value were one (1) or more. From 2005 to 2014, the distributions of outputs shifted to smaller cumulative yields as the amount of regulation change increased. From 2005 to 2024, the distributions of outputs for each management scenario did not show clear responses to increasing changes in the regulations. However, from 2005 to 2034, the median outputs for each management scenario became larger as the amount of regulation change increased. From 2005 to 2034, the distribution of outputs sifted to larger cumulative yields mostly corresponding to increases in the amount of regulation change. The outputs for scenario 1-7 showed the largest values in category 1 while the outputs for scenario 3-6 were the largest among the category 3 scenarios. Within scenarios, the distribution of outputs shifted toward larger cumulative yields as time progressed.

The yields forecasted at 2009, 2011, and 2016 for each management scenario relative to the yield in 2004 are shown in Fig.4-13. These data show the results after 3, 5, and 10 years of regulation change. The outputs in the first year or first few years after a fishing ban ended, such as scenario 3-3 at 2009, scenario 3-1, 3-2, and 3-4 at
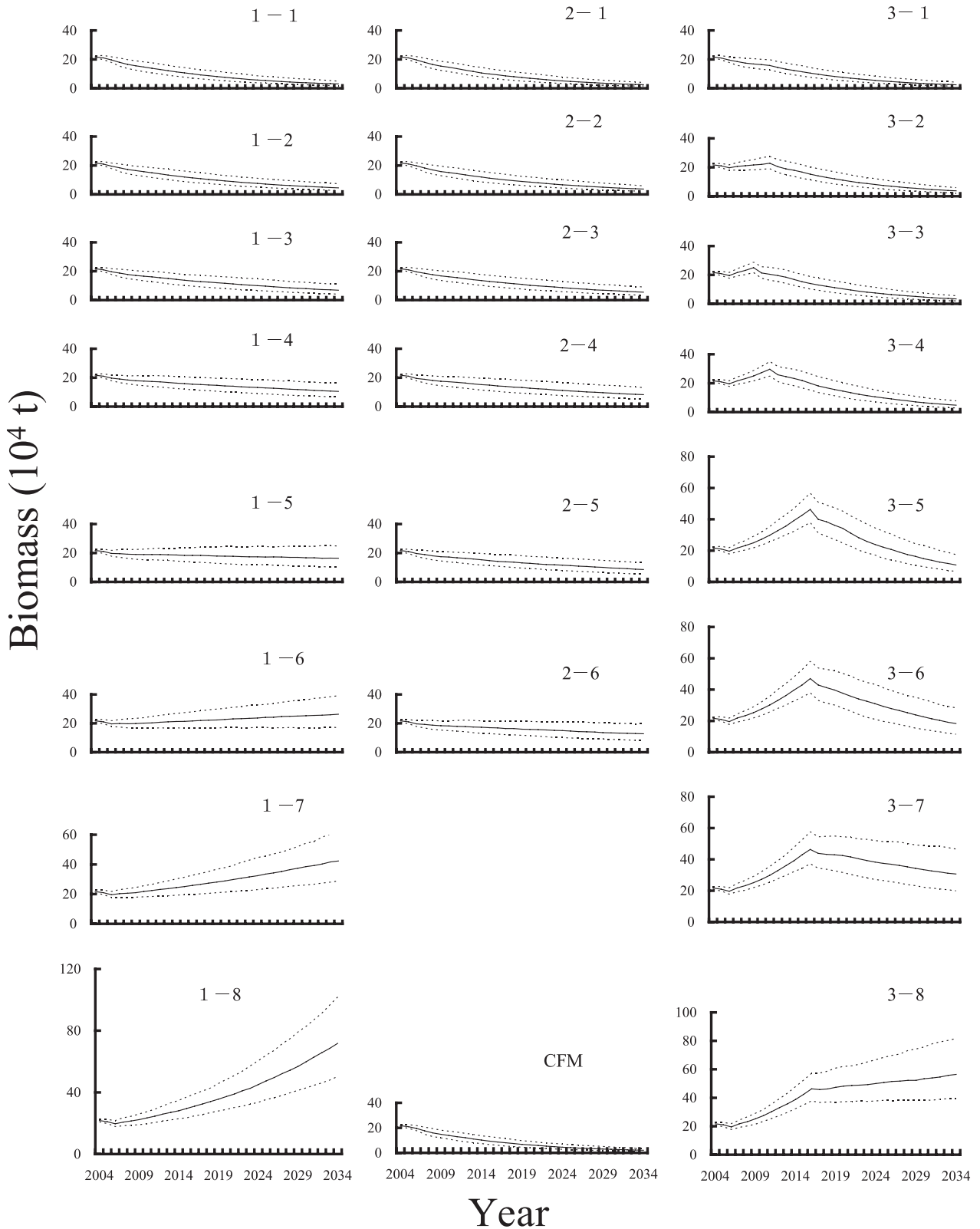
Fig.4-9 Forecasted biomass trajectories of the walleye pollock in the northern waters of the Sea of Japan for each of the various management scenarios. Median of forcast biomass (solid lines), tenth and ninetieth percentiles (broken lines).

2011, or scenario 3-5 to 3-8 at 2016, produced relatively large yields. At 2016, the outputs of scenario 3-5 produced the largest yield. The outputs of scenarios 3-6 to 3-8 produced smaller yields than scenario 3-5 because
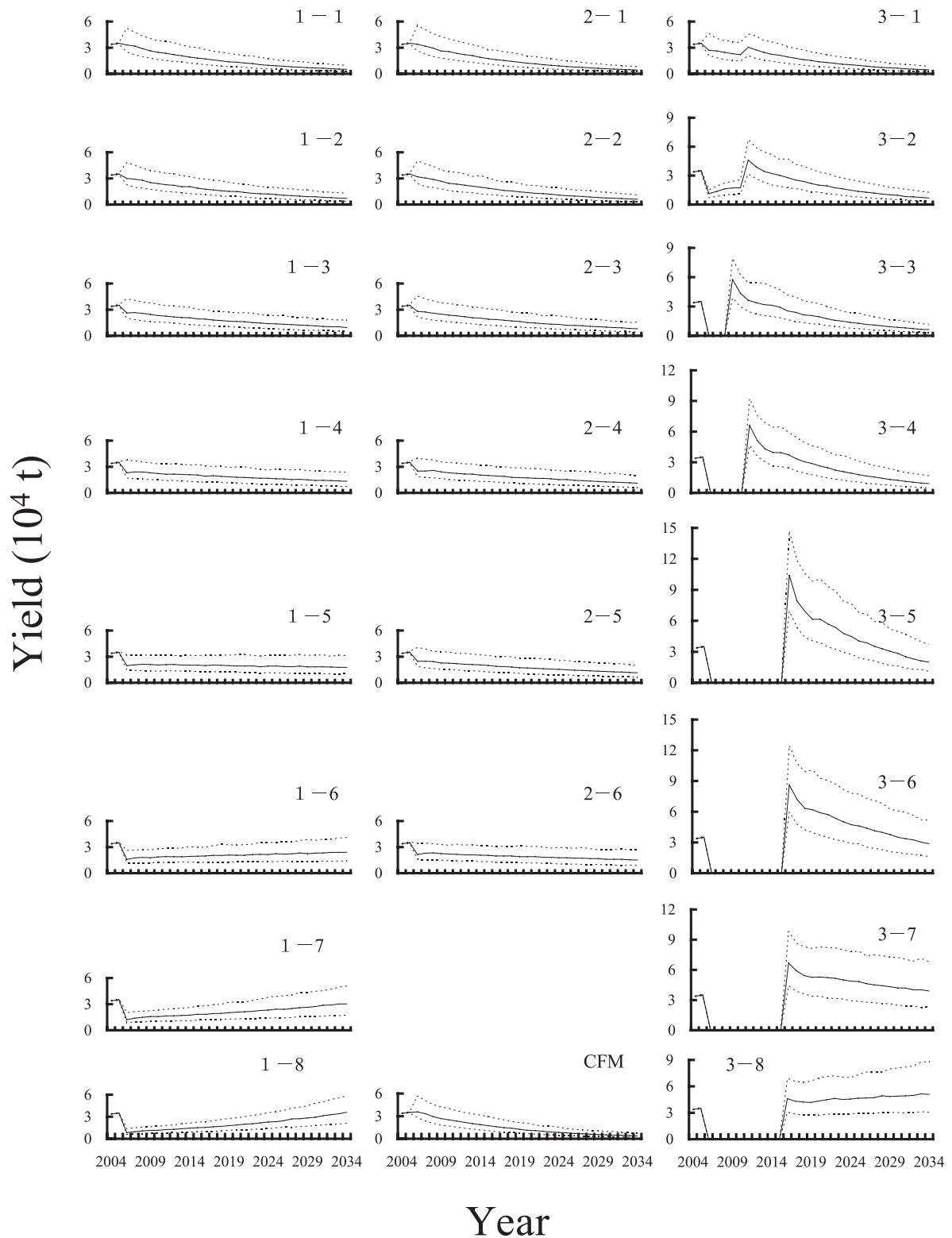
Fig.4-10 Forecasted yield trajectories of the walleye pollock in the northern waters of the Sea of Japan for each of the various management scenarios. Median of forcast biomass (solid lines), tenth and ninetieth percentiles (broken lines).

scenario 3-5 had no fishery regulation after the end of the 10-year ban. In scenarios 3-6 to 3-8 some regulations were added following the fishery ban period.

The minimum yield forecasts produced in each scenario as a percentage of the 2004 yield are shown in Table 4-5. In categories 1 and 2, the forecasted minimum yields
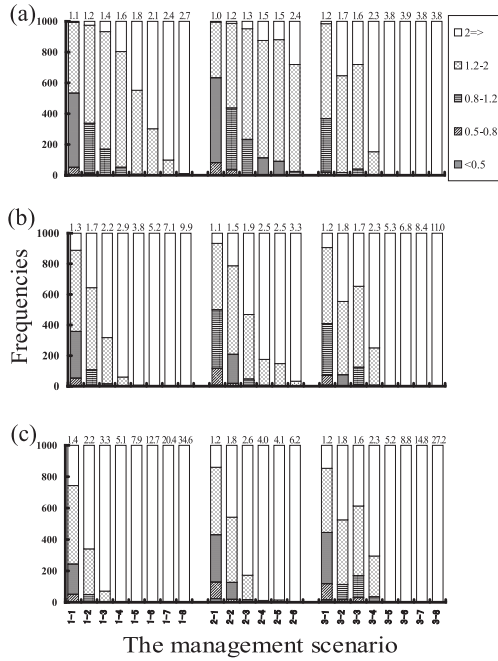
Fig.4-11 Forecasted biomass of the walleye pollock in the northern waters of the Sea of Japan in (a) 2014, (b) 2024, and (c) 2034 relative to the median of the biomass from the no regulation run. Numbers above each column are the median of outputs for each of management scenarios.
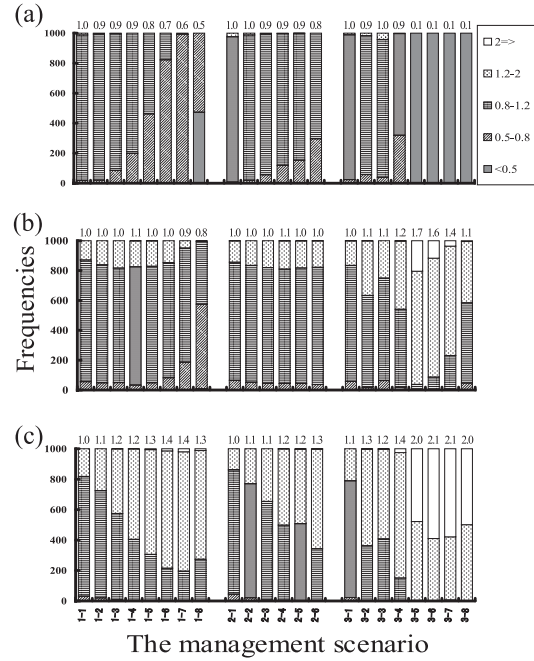

Fig.4-12 Forecasted cumulative yield of the walleye pollock in the northern waters of the Sea of Japan in (a) 2005 ? 2014, (b) 2005?2024, and (c) 2005?2034 relative to the median of cumulative yield from the CFM run. Numbers above each column are the median of outputs for each of management scenarios.

Table 4-5 Minimum biomass and yield in each scenario of walleye pollock management in the northern waters of the Sea of Japan

Management	Lower 5th percentile	
Scenario	Minimum biomass[a]	Minimum yield[b]
1-1	7.0	6.3
1-2	10.5	8.3
1-3	16.5	11.4
1-4	25.9	15.9
1-5	40.1	20.8
1-6	60.3	25.3
1-7	72.6	22.3
1-8	79.1	15.0
2-1	5.6	4.9
2-2	8.6	7.2
2-3	13.5	10.5
2-4	20.8	13.8
2-5	21.1	14.0
2-6	31.9	18.3
3-1	5.6	5.6
3-2	8.8	8.7
3-3	7.7	0
3-4	11.4	0
3-5	26.0	0
3-6	44.8	0
3-7	76.4	0
3-8	79.4	0
CFM[*]	4.4	4.5

[a]Lower 5th percentile of the minimum biomass in the simulation period divided by the 2004 median biomass, expressed as a percentage.[b]Lower 5th percentile of the minimum annual yield in the simulation period divided by the 2004 yield, expressed as a percentage.

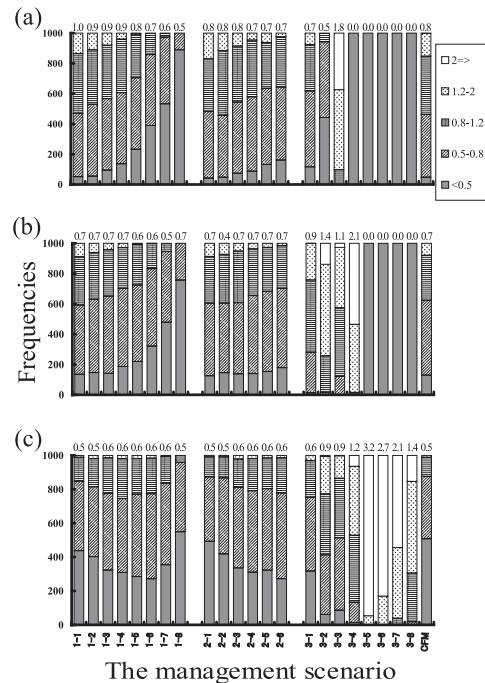* CFM: Current fishing mortality run.

Fig.4-13 Forecasted yield of the walleye pollock in the northern waters of the Sea of Japan in (a) 2009, (b) 2011, and (c) 2016 relative to the yield in 2004.
Numbers above each column are medians of out puts for each of management scenarios.

Table 4-6 Coefficients of variations (%) for cumulative yield of walleye pollock in the northern waters of the Sea of Japan, by management scenario and period.

Management scenario	From 2005 to 2014	From 2005 to 2024	From 2005 to 2034
1-1	9.4	12.7	15.0
1-2	9.4	12.5	15.0
1-3	9.6	13.1	16.0
1-4	9.1	12.7	15.9
1-5	9.8	13.6	17.4
1-6	10.0	13.7	17.5
1-7	9.9	13.8	18.0
1-8	9.6	13.6	17.7
2-1	9.7	12.7	14.7
2-2	9.6	13.0	15.3
2-3	9.8	13.0	15.8
2-4	9.4	13.1	16.6
2-5	9.7	13.2	16.1
2-6	9.3	12.9	16.2
3-1	9.9	12.9	14.8
3-2	10.8	13.8	16.0
3-3	11.8	13.9	16.1
3-4	13.1	14.8	16.9
3-5	1.7	16.8	19.3
3-6	1.7	17.3	20.0
3-7	1.7	17.7	20.3
3-8	1.7	17.7	20.3
CFM*	9.4	12.8	14.9

*CFM: Current fishing mortality run

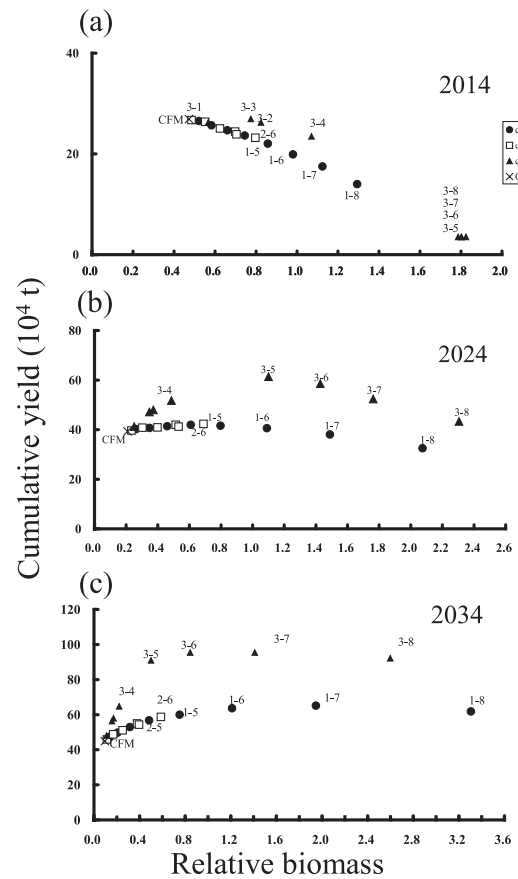
Fig.4-14 Relationships between cumulative yields and biomasses of the walleye pollock in the northern waters of the Sea of Japan in a) 2014, (b) 2024, and (c) 2034 for category 1 (●) category 2 (□) category 3 (▲) and CFM(×).
The biomasses are shown as the relative values, divided by the median of biomass in 2004.

became larger as the amount of regulation increased, except in scenarios 1-6 to 1-7 and 1-8. All indexes of minimum yield in categories 1 and 2 were greater than index for the CFM run. As full fishing ban regulations were implemented in category 3, the minimum yields were zero.

The relationships between biomass and cumulative yield over three forecast periods for each management scenario are shown in Fig.4-14. Clear trade-offs between biomass and yield were seen in the scenarios at 2014, but no clear trade-off was observed at 2024 and 2034, as the yields tended to remain stable or increase with increasing biomass.

AAVs were used as a stability performance measurement. Category 3 management scenarios showed high AAV values, averaging between 36.4 and 49.8 and standard deviations ranged from 6.0 to 7.4. No clear difference was seen in the AAV values among the scenarios in categories 1 and 2, which averaged between 33.2 and 35.5 with standard deviations ranging from 4.8 to 5.9. The AAV average in the CFM run was 35.3 ± 5.9.

Measurement indicators of performance reliability, the inter-replicate CVs of cumulative yields, for the periods from 2005 to 2014, to 2024, and to 2034, are shown in Table 4-6. Within each scenario, the CVs became larger as period duration increased. However, within the same period, the CVs did not show clear trends or clear differences among scenarios. CVs for scenarios 3-5, 3-6, 3-7, and 3-8 for 2005 to 2014 were small because the 10-year fishing bans were simulated in those scenarios.

Effects of recruitment assumptions

Generally, future trends in biomass abundance are affected by the recruitment assumptions. For example, Fig.4-15 shows the biomass trends for scenarios 1-5 and 3-5 using four recruitment assumptions. Recruitment options 1 through 3 forecasted increasing or increasing then stable biomass trends in both scenarios, while the
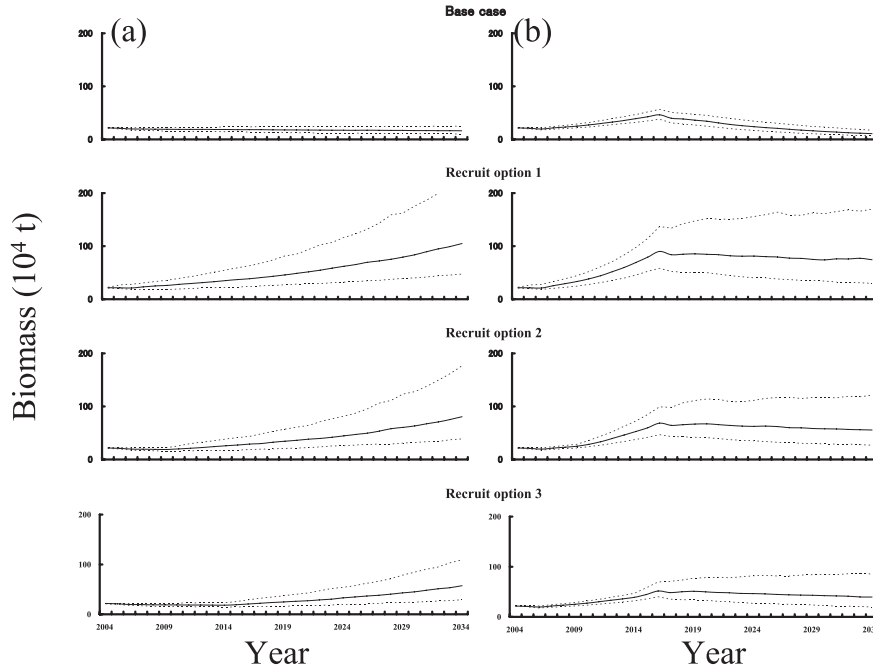
Fig.4-15 Comparison of biomass trajectories of the walleye pollock in the northern waters of the Sea of Japan for each of recruitment assumptions for management scenarios (a)1-5 and (b) 3-5. Median of forcast biomass (solid lines), tenth and ninetieth percentiles (broken lines).
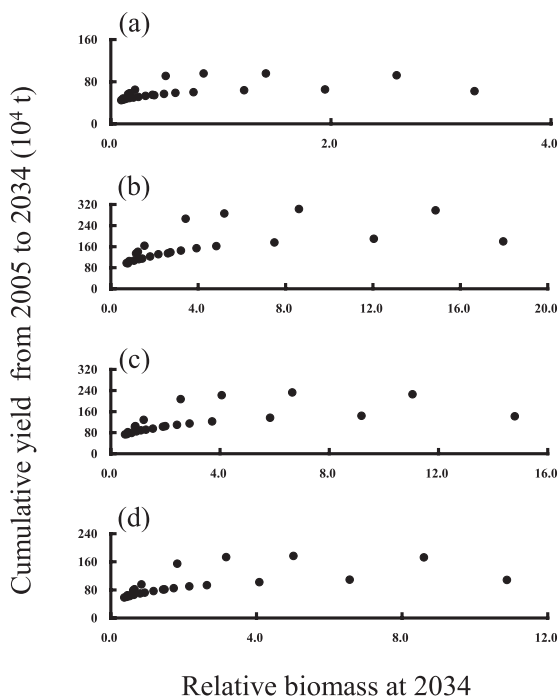
Fig.4-16 Comparison of the relationships between cumulative yield form 2005 to 2034 and biomass at 2034 of the walleye pollock in the northern waters of the Sea of Japan for (a) base case, and recruitment opions (b) 1, (c) 2 and (d) 3. The biomasses are shown as the relative values, divided by the median of biomass in 2004.
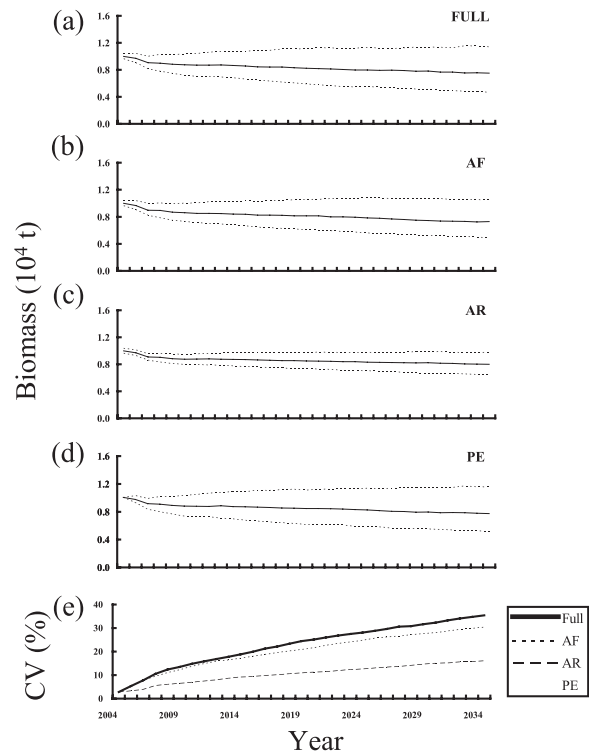
Fig.4-17 The differences of (a-d) biomass trajectories of the walleye pollock in the northern waters of the Sea of Japan among settings of fluctuations for management scenario 1-5. (e) Coefficient of variations of biomasses for each trial.

base case option showed stable or decreasing biomass forecasts.

The relationships between biomass in 2034 and the cumulative yield from 2005 to 2034 calculated for the

four recruitment assumptions are shown in Fig.4-16. Each recruitment assumption produced a similar initial increase in cumulative yield followed by a relatively stable yield at increased biomass levels. Each option produced different absolute cumulative yield values at higher biomass levels.

Effects of fluctuations in the simulation

Management scenario 1-5 was used in this assessment because the base case results from this scenario were moderate (Fig.4-9). Fig.4-17 shows the 2005 to 2034 trends for the base case (FULL) and the three fluctuation options, along with the CVs for each case. The trends were similar, but the CV in the AR trial was smaller than that in the other three trials. At 2034, the CVs for the AR, AF, and PE trials relative to the CV for FULL were 46%, 86%, and 92%, respectively.

4.6 Discussion

Error of abundance estimate

This study using a bootstrap procedure indicates that the CVs of the VPA estimates were high in the latest year and in the oldest age class. The CVs of abundance were smaller, as cumulative calculations were made from recent years to former years in the same cohort.

Although catch at age includes errors, the CVs of the abundance estimate become smaller as the errors accumulate in the result of the VPA calculation (Table 4-4). The CVs become smaller as errors accumulate, because in the VPA calculation, the catch at age accumulates from recent years to former years along a cohort. The catch at age error is thought to be caused by errors in aging or catch miss report[32,45]. Then, errors in catch at age in the same cohort are independent. According to the central limit theorem, the CVs should become smaller as errors accumulate.

Therefore, the effect of the sampling error becomes smaller when the catch at age used for abundance estimates has accumulated for a few years. The sampling error directly affects the abundance estimates in the latest year and oldest age classes as a result.

The bootstrap method was applied to evaluate the precision of the catch at age and population estimates. The delta method is an alternative approach to evaluate the precision of the catch at age and population estimates. However, solutions using the delta method tend to be complex[63]. Especially in complex situations, such as our calculation of catch at age (Table 4-2), procedures using the delta method are difficult to develop. Moreover, to evaluate the precision of population estimates using the delta method, auxiliary parameters or assumptions about the standard errors of catches and terminal fishing mortality should be incorporated[46].

However, the bootstrap procedure can be developed simply by describing the sequence of calculations and incorporating the resampling idea into the calculation sequence. One can directly assess error in the VPA estimates without auxiliary assumptions or additional information. This is why the bootstrap procedure was selected.

Another theoretical solution to evaluate the precision of abundance estimates in a year class was provided by Pope[43]. Equation (2.7) assumed that the other parameters of VPA were exact and did not incorporate the variations in the terminal fishing mortality (F_t), while the current VPA method does not fix F_t.

The average coefficient of variance on the estimated abundance by using the results of this study and equation (2.7) were 8.59 and 5.31, respectively, which suggest that equation (2.7) underestimated the coefficient of variation, especially in recent years. These results suggest that the bootstrap procedure is more valid than equation (2.7) in the evaluation of the precision of abundance estimates in the current VPA procedures.

Fig.4-5 shows that the minor age-classes have relatively high CVs of catch at age. However, these variations do not substantially affect the abundance estimates because these minor age-classes only comprise a minor contribution to the whole catch at age (Fig.4-1). Although the sampling ratio was less than 0.01% of weight in this monitoring program, the CVs of catch at age were almost 20% in most cases (Table 4-4). High CVs of catch at age were found in the youngest and second-youngest age classes. These younger age classes were rarely landed in the fisheries. To improve the monitoring procedures in such cases, it is preferable to put greater effort into reducing the sampling error in the minor age-classes rather than the major age-classes. The CVs of estimated abundance using VPA with catch at age data calculated using the bootstrap procedure are shown in Table 4-4. The CVs of the latest year and oldest age classes were high. The estimated abundances in the latest year and oldest age classes had greater CVs than

their CVs of catch. It seems that increased errors in the latest year and oldest age classes result from the VPA assumptions (eqns 2.5 and 2.6). Further, the estimated abundances in these classes were computed directly from the catch data and sampling error directly affects the abundance estimates.

Examination of the 1994 cohort showed that the BCCIs were smaller as backward calculations were made (Fig.4-7). Similar results for other cohorts can be seen in Table 4-3. The large CVs of catches in former years do not affect abundance estimates. The effect of sampling error becomes smaller when the catch at age information for abundance estimation has accumulated for a few years.

The retrospective analysis showed that the measurement errors caused by the sampling error were smaller than the process errors in the all ages except the oldest age (Fig.4-8). The abundances estimated in younger age had smaller measurement error than in older age estimates. The abundances estimated in younger age were stabilized by data accumulation following years. Therefore the process error was large in the younger age class. The ratio of measurement error was 2 to 59 %. The effect of sampling error in abundance estimate was limited.

Simulation result

Conservation performance

The explicit decrease in biomass forecasted by the CFM run and the trends forecasted by the management category 3 runs, which showed temporary increases followed by decreases when fishing mortality returned to current levels, suggests that current fishing mortality levels exceed the level needed to maintain a sustainable biomass.

Two types of indices for conservation performance were introduced. The first index was based on the lower fifth percentile of minimum biomass observed in the simulation period, and the second was the output for each management scenario relative to the output of the CFM run. Both indices showed that any regulation change would be more conserving of the stock than the CFM. The minimum biomasses in all management scenarios were larger than that in the CFM run, and would reduce the risk of population collapse. Moreover, future biomass levels following changes to the regulations were expected to be larger than those in the CFM run.

Furthermore, the more severe the regulation change showed the greater the conservation of the stock. The more severe management scenarios in our study had larger minimum biomass levels in the simulation period (Table 4-5). Also, the distribution of biomass in each of the management scenarios shifted to larger biomass as the amount of regulation change increased (Fig. 4-11). According to these shifts, changing the regulation of the fishery would decrease the risk of population collapse.

Even relatively small regulation changes, as in scenarios 2-1 and 3-1, resulted in greater stock conservation than the CFM run, but the risk of future population decline remained (Fig.4-9). In these scenarios, some outputs were 0.5?0.8 of CFM at all time points and increased as time progressed (Fig.4-11). The probability that the biomass would be less than half of the median biomass in the CFM, increased in both scenarios, as time progressed. Both of these management scenarios only regulated the coastal fishery. The catch at age in the coastal fishery exceeded the trawl fishery only in age class 8 and older, a group with a relatively small biomass. Under such minor regulation change, although the future biomasses increased slightly more than that in the CFM run, variation in the biomass levels increased as time progressed. Thus, there was a risk of a population decrease than CFM and that risk increased with time. Other scenarios rarely showed a biomass smaller than the median biomass of the CFM run. More severe regulation than that in scenario 2-1 is desirable to avoid a critical decrease in biomass despite of regulation.

From the stock conservation viewpoint, any of the regulation changes considered here would conserve more WPNJ than the CFM approach, and the more severe regulations would provide greater stock conservation. Although the minor regulation changes were more stock conservative than CFM on average, there remained a risk of population decline.

Utilization performance

Cumulative yields forecasted in 2005-2014, 2005-2024 and 2005-2034 for each management scenario were used to evaluate utilization performance and are expressed in Fig.4-12. The evaluation showed that this index differed with differing period lengths. Simulation output indicated that lower cumulative yields occurred in the shorter periods with larger cumulative yields in the longer periods. Furthermore, in the shorter period, the more

severe regulations did not utilize as much of the WPNJ stock as yield. However, over longer periods, stock yield was more greatly utilized in the more severe regulation scenarios. Thus, the effect of regulation change on stock utilization was not observed in the short term but was obvious over the long term.

The yield forecasts relative to the current yield provide useful information for fishers on the amount of yield following regulation changes. Fig.4-13 shows the results after 3, 5 and 10 years of regulation change. Within the category 3 scenarios, the first year or years after a fishing ban had large yields. Fig.4-13 also showed the relatively low output of the CFM run. It tells the forecasted future utilization if the current fishery continues as it is, and activates the discussion of additional regulation.

The lower fifth percentile minimum yields throughout the simulation period (Table 4-5) can be interpreted as a guaranteed catch with 95% confidence[61]. The suggestion of a guaranteed yield may be helpful when attempting to reach consensus among stakeholders.

Trade-off between conservation and utilization

An ideal management procedure should have good stock conservation and stock utilization performances. However, this study indicates a trade-off between conservation and utilization. The forecasts of yield shown in Fig.4-14 may be useful when discussing this trade-off. Fig.4-14 can be used to exclude extreme candidates. However, evaluations of this index differ depending on the time. Showing more than one timeframe in an evaluation enables multilateral discussion.

Stability performance

The AAVs of the management scenarios were used to evaluate stability performance. The AAVs of the category 3 management scenarios were higher than the AAVs of categories 1 and 2 because of the rapid decrease in yield after fishery ban implementation (Fig.4-10). Scenarios 3-7 and 3-8 showed relatively low AAV because of relatively flattened yield trends after a 10-year ban (Fig.4-10). Most management scenarios showed lower AAVs than the CFM run indicating that those management scenarios resulted in more stable performances than the CFM run.

Reliability performance

The inter-replicate CVs of the cumulative yield shown in Table 4- 6 may be used to evaluate reliability

performance. After 30 years, the maximum variation in the index was 20.3% in scenario 3-8. Overall, the variation in the cumulative yield CVs was relatively small and there were small differences among all scenarios. These small differences suggest that the results of each simulation run may be regarded as equally reliable.

Recruitment

Estimation method

The randomly sampled RPS used in the future recruit calculation correspond to a process error involving population dynamics uncertainty (type ii). An alternative method of accounting for such stock-recruitment uncertainty would be to use a formalized relationship, for example, a Ricker's function[64]. However, using an inappropriate function could introduce other process errors, including some bias or inaccurate trends. Therefore, randomly chosen RPS values, instead of using a theoretical function, was selected in this study.

Effects of recruitment assumptions

The future biomass forecasts were strongly affected by assumptions about recruitment (Fig.4-15). However, it is impossible to know which assumption is the nearest to reality. Therefore, there is no way to accurately predict future absolute biomass levels. Fortunately, the relationship between biomass and cumulative yield did not change markedly among the four recruitment assumptions used in the simulations (Fig.4-16). Thus, management scenario evaluation, at least the overall ranking of management candidates, would not be affected by recruitment assumptions; however, the absolute value of the biomass levels may be strongly affected.

Effects of fluctuations in simulation

The AR trial had a smaller biomass CV than the other simulation fluctuation trials (Fig.4-17). These data suggest that using average recruitment instead of stochastic variations in recruitment may lead to underestimating future variations, resulting in misinterpretation of the management procedure evaluation results.

At 2034, the ratios of CV for AR, AF and PE trials to the CV for FULL were 46, 86 and 92%, respectively. Thus, the uncertainty caused by recruitment variation most greatly affected the population forecasts in this simulation. Improved understanding of recruitment variation is essential for evaluation of management candidates.

Chapter 5

Application for pointhead flounder stock in the northern Sea of Japan and the Sea of Okhotsk stock

5.1 Introduction

The pointhead flounder stock in the northern Sea of Japan and the Sea of Okhotsk (PFJO) is an important stock for both coastal gill net and offshore trawl fisheries[65]. HFES annually assesses the PFJO stock and provides scientific advice to the Hokkaido local government[65, 66]. PFJO stock fishery yields after 1986 fluctuated from 2055 to 3361 tons and 2444 tons in 2004[66]. A limitation on landed fish size is the main stock management approach used in PFJO fishery, and because of a stock management agreement signed among fisheries associations in 1994, the two fisheries limit their landings to fish >180 mm in total length[66]. To meet stock management needs and avoid low unit prices when capturing small fish, the mesh size was increased in gill net fishery[65].

LPA approaches have been developed since the late 1970's[67-73]. LPA provide estimates of stock numbers at length without the need to convert age data to length data. A length limitation managed fishery, such as that for the PFJO stock, requires estimates of biomass and/or stock numbers at length. LPA is an appropriate assessment method for stocks that have adopted or considered a length limitation regulation because of its expected precision without the conversion from age data to length data[69]. PFJO was tried to assess by LPA[65]. Furthermore the mesh selectivity of gill nets used in the PFJO fishery has been estimated[74]. For those reasons, the PFJO stock was deemed suitable for evaluating management effect in this study.

5.2 Materials

The simulation model was used for the PFJO stock. The coastal gill net PFJO fishery operates each year from April to July and contributes about 38% of the annual PFJO yield and the trawl fishery operates each year from September to April and contributes about 55% to the annual PFJO yield[65]. For convenience of data organization and assessment, the fishery year was defined as August to the next July[65]. The biological parameters used in this study, such as natural mortality rate at length, average body weight at length, and maturity rate at length, were set at the same values as that used in HEFS assessments[65, 75, 76] and are shown in Table 5-1.

Table 5-1 Biological parameters of simulation model for pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk.

Size(mm)	Natural mortality rate	Average body weight (g) at beginning of age	Spawning season maturity rate
180-200	0.25	58	0.12
200-220	0.25	81	0.37
220-240	0.25	109	0.72
240-260	0.25	143	0.92
260-280	0.25	184	0.98
280+	0.25	259	1.00

5.3 Data

Catches from 1985 to 2004 were classified into 6 length classes from 200mm to 280mm with an interval of 20mm, the data smaller 200mm were polled as−200mm length class, and the data over 280mm and larger were polled as 280+ length class. The length classes were assigned numbers from the smallest size class (length class 1) to the largest (length class 6). Catches in each length class were estimated using data collected by HEFS monitoring procedure with the budget of Japanese Fishery Agency. The procedure was based on stratified sampling of the two main fisheries, and the two fisheries were regarded as two strata. The times and locations of the sampling were empirically selected by HEFS to represent the stock. The fish samples were obtained once or twice each year in each fishery. Any sample periods or locations that were not sampled were empirically extrapolated from similar samples.

5.4 Methods

Simulation

To evaluate variations in future population and fisheries dynamics, 1000 population forecast iterations, with 1000 sets of initial stock numbers at length, numbers of recruits and spawning biomass plots, and fishing mortality rates, were performed. The future population was forecasted for 30 years (2005−2034).

Stock size for initial value

The PFJO stock size at length from 1985 to 2004 was estimated using LPA. One thousand catch at

length data set were produced using a non-parametric bootstrap procedure described in chapter 2. One thousand estimates of stock numbers at length and 1000 fishing mortality at length, from 1985 to 2004, were produced from replication of the LPA with one thousand catches at length. These estimates were the initial values in the population dynamics and recruitment forecasts.

The LPA performances were evaluated by the same criteria used in chapter 3.

The definition of recruitment

The LPA model does not require age data. Therefore, information on yearly recruits is not derived from a LPA assessment. However, the relationship between spawning biomass and recruitment is needed to estimate the number of future recruits. To fill this need, the numbers of recruits per year were estimated as follows. Because of the rare occurrence of age 0 and age 1 PFJO in the fisheries, recruitment was defined as the stock number at age 2. The smaller length classes were considered for yearly recruitments number estimation. The smaller 4 length classes were defined from 100mm to 180mm with an interval of 20mm and were assigned numbers from 100mm to 120 mm size class (length class S1) to 160mm to 180mm size class (length class S4). Therefore in recruitment estimation, total 10 length classes (S1–S4 and 1–6) were considered.

Here, the probability of age 2 fish in length class l was estimated as

$$SP_l = \int_{ll}^{ul} \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-el)^2}{2\sigma^2}} dx$$

$(l=$ S1, S2, .., S4, 1, 2, $\cdots$, 6)   (5.1)

where el is the estimated length at age 2 and σ is the standard deviation at age two derived from PFJO growth curve estimated by Itaya and Fujioka[76] ll and ul are lower size and upper size in length class l respectively. At length class –200mm (length class 1), ll was 180mm and at length class 280+mm (length class 6), ul was 300mm were set. The probability of age 2 fish in a year recruit to fishery in each size classes in the same year (after zero years) $RP_{l,0}$ was obtained as SP_l in length class 1 to 6.

$$RP_{l,0}=SP_l \ (l=1, 2, 3, \cdots, 6)$$ (5.2)

The age 2 fish in smaller size class than 180mm should be considered because they recruit to fishery in the following years.

The probability of age 2 fish belong to length class l in after n years
$RP_{l,n}$ was calculated as;

$$RP_{l,n} = \sum_{\kappa=S1}^{S4} RP_{\kappa,n-1} P_{\kappa,l} \ (l=1,2,3,...,6)$$ (5.3)

where $P_{k,j}$ is the probability that a fish, which belongs to the length class K in a year, belongs to length class l in the next year (Table 5–2).

The probability of age 2 fish recruit in each length classes computed for five years because that the five years calculation can cover 99.9 % probabilities of the age 2 fish dynamics.

Table 5–2 The forward length transition probability of pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk.

Length class in year j	Length transition probability in in year j+l									
	100-120	120-140	140-160	160-180	180-200	200-220	220-240	240-260	260-280	280+
100-120	0.00	0.03	0.23	0.45	0.25	0.04	0.00	0.00	0.00	0.00
120-140	0.00	0.00	0.07	0.31	0.42	0.18	0.02	0.00	0.00	0.00
140-160	0.00	0.00	0.01	0.12	0.37	0.36	0.12	0.01	0.00	0.00
160-180	0.00	0.00	0.00	0.03	0.19	0.40	0.30	0.08	0.01	0.00
180-200	0.00	0.00	0.00	0.00	0.07	0.25	0.39	0.23	0.05	0.00
200-220	0.00	0.00	0.00	0.00	0.00	0.12	0.31	0.37	0.17	0.03
220-240	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.35	0.32	0.14
240-260	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.36	0.37
260-280	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.37	0.63
280+	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00

The first appear in fishery age 2 fish in each length class (length class 1 to length class 6) were calculated as;

$$NR_{l,j} = \sum_{n=0}^{5} R_{j-n} Rp_{l,n} e^{(-n \cdot M)} \qquad (5.4)$$

where R_j was the number of age 2 fish in year j, defined as recruitment. M is natural mortality rate.

The first appeared stock number in each length class in year j $\dot{N}_{l,j}$ is defined as

$$\dot{N}_{l,j} = N_{l,j} - \sum_{\kappa=1}^{l} P_{\kappa,l} N_{\kappa,j-1} \qquad (5.5)$$

where $N_{l,j}$ is the stock number in the length class l in year j as estimated by LPA.

The recruitments in years R_j were then estimated using a nonlinear least squares approach that minimizes the RSS.

$$RSS = \sum (NR_j - \dot{N}_{1,j})^2 \qquad (5.6)$$

Base case forecasting model

Stock numbers and biomass

Stock numbers and biomass were calculated by equation (3.1) and by equation (3.14), respectively.

The spawning biomass

The spawning biomass was then calculated as

$$SB_{j,k} = \sum_{l=1}^{6} \left(N_{l,j,k} \cdot mr_l \cdot w_l \right) \qquad (5.7)$$

where $SB_{j,k}$ was the spawning biomass in year j from the kth data set, mr_l was the maturity rate at mid-length of length class l, and w_l was the average body weight at mid-length of length class l. Since the PFJO spawning season is at the end of the study year, the number of spawning individuals was the number of individuals at the beginning of the next year as estimated by LPA.

Recruitment

A clear relationship between spawning stock size and recruitment has not been reported for the PFJO stock[65]. Furthermore, the estimated recruitment in this study did not show a clear relationship between spawning stock size and recruitment. Thus, A non-parametric stock-recruitment model[59] was used to estimate future recruitment as described in equation (3.16).

Management scenarios

The regulation limiting landed fish size is a key aspect of management in PFJO fishery. To that end, the gill net fishery has increased the mesh size

to avoid small fish fishing. This study focuses on assessing further regulations that would raise landed fish size.

The mesh selectivity of gill nets in the PFJO fishery was studied by Wakayama *et al*[74]. A mesh opening of 115 mm is the current mesh size for the PFJO gill net fishery and has been termed current mesh in this study. To evaluate changes to gill net mesh size, 4 additional sizes were considered. Along with the current mesh, mesh openings of 106mm, 121mm, 127mm, and 136mm were tested; referred to as mesh 1, mesh 2, mesh 3, and mesh 4, respectively (Table 5-3). Seven management scenarios were tested in the simulation model. Scenarios 1 to 4 regulated the coastal gill net fishery only, using meshes 1 to 4 individually over the full simulation period (Table 5-3). Scenarios 5 to 7 individually applied meshes 2 to 4 to the coastal fishery for the full simulation period, and an equivalent adjustment, described below, was added to the trawl fishery for the full simulation period (Table 5-3). Simulations without suppression of fishing mortality(CFM) were also performed.

Table 5-3 Management scenarios for pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk.

Management scenario	Regulation of trawl fishery	Regulation of coastal fishery
1	Non	Mesh 1 (106 mm)
2	Non	Mesh 2 (121 mm)
3	Non	Mesh 3 (127 mm)
4	Non	Mesh 4 (136 mm)
5	Equivalent to Mesh 2	Mesh 2
6	Equivalent to Mesh 3	Mesh 3
7	Equivalent to Mesh 4	Mesh 4

Future fishing mortality and catch numbers at length class

To formalize the management scenarios, the relative efficiencies of each tested mesh size were calculated.

$$RE_{l,m} = \frac{SE_{l,m}}{SE_{l,c}} \qquad (5.8)$$

where $RE_{l,m}$ is relative efficiency of mesh size m to the current mesh at mid-length of length class l. $SE_{l,m}$ is the selectivity of mesh size m at mid-length of length class l as estimated by the master curve for mesh selectivity in PFJO gill net and $SE_{l,c}$ is the selectivity of the current mesh at mid-length of length class l[74].

To formalize the management scenarios for coastal

fishery, the relative efficiency of the proposed mesh size m to the current mesh was used. However, this data could not be applied to trawl fishery because of the difficulty of regulation by fish length in the trawl fishery. To formalize the management scenarios for trawl fishery, average capture efficiency over various fish length classes were needed. Thus, the average length components of whole PFJO fishery were needed. The average length component LC_l was calculated as

$$LC_l = \frac{\sum_j C_{l,j}}{\sum_{l,j} C_{l,j}} \qquad (5.9)$$

where $C_{l,j}$ is the point estimate of the number caught in length class l in year j.

The average efficiency over length for each tested mesh size was then calculated as

$$ARE_{m,l} = \sum_l RE_{m,l} \cdot LC_l \qquad (5.10)$$

Furthermore, the relative performance of each fishery to the total harvest by length class was needed to simulate the management scenarios. The ratio of the trawl fishery to the whole fishery at length class l RT_l was calculated as

$$RT_l = \frac{\sum_{j=1994}^{2004} TC_{l,j}}{\left(\sum_{j=1994}^{2004} TC_{l,j} + \sum_{j=1994}^{2004} CC_{l,j} \right)} \qquad (5.11)$$

where $TC_{l,j}$ and $CC_{l,j}$ were the catch at length class l in year j in the trawl fishery, and in coastal gill net fishery, respectively. After 1994, the landed fish were restricted to a total length of >180mm; thus, the 1994 to 2004 data were used in this calculation. The ratio of the coastal gill net fishery to the whole fishery at length class l RC_l was then calculated as;

$$RC_l = 1 - RT_l \qquad (5.12)$$

Finally, the regulation rate for the whole fishery for each of the 7 scenarios were calculated as

$$RR_l = \begin{cases} RC_l \cdot RE_{m,l} + RT_l & \text{(scenario 1 to 4)} \\ RC_l \cdot RE_{m,l} + RT_l \cdot ARE_{l,m} & \text{(scenario 5 to 7)} \end{cases}$$

$$(5.13)$$

The future fishing mortality and catch numbers at length class were calculated by equation (3.18), (3.19), and (3.20).

Performance measurements

Performance measurements were set for evaluating the management procedures as described in chapter 3.

Additional analysis

Effects of simulation fluctuations

To evaluate the effects of fluctuations in the simulation model, modified base case trials were run for management scenario 5 with three fluctuation settings. Outputs from base case trials were compared to outputs from each of the following three fluctuation options.

(1) Variability of recruit (AR)

To exclude recruit variability, using average number of recruit in each SB level.

The future recruitment estimation method used in the base case trial divided SB into 4 levels and estimate future recruitment in stochastic procedure. In AR trial, the average numbers of recruitment for 4 SB levels calculated from k-th data set and used in the AR trial instead of estimated number of recruitments stochastically in the base case trial.

(2) Fishing mortality (AF)

To exclude fishing mortality fluctuations, F in eq. (3.18) was fixed at the 1994 to 2004 average as

$$F_{i,j^*,k} = \frac{1}{11} \sum_{1994}^{2004} F_{i,j,k} \qquad (5.14)$$

(3) Population estimation (PE)

Point estimates of stock number at length were used instead of the 1000 sets of stock numbers at length data   produced by the bootstrap procedure.

5.5 Results

Error in stock size estimation

The CVs of catch at length and abundance estimates by length were shown in Table 5-4. The CVs in the abundance estimates in the latest year were high.

Error in abundance estimates

The BCCI of the abundance estimates using the bootstrap procedure in 2004 is shown in Fig.5-1. The distributions became narrower with length. Fig.5-2 shows the process error and measurement error in abundance estimates in 1999. The ratios of measurement errors in abundance estimates were greater as length except for largest size class. The ratios were 1% to 29%.

Table 5-4 The coefficient of variations (%) of the catch and abundance estimates of the walleye pollock in the northern waters of the Sea of Japan evaluated from the bootstrap procedure.

Length(mm)	year																			
	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Catch																				
-200	24.0	11.5	10.1	9.3	5.1	13.7	13.5	15.9	14.2	10.7	9.9	10.7	12.8	28.0	81.9	98.6	-	49.1	49.1	-
200-220	8.3	6.2	6.2	10.0	11.5	9.1	6.6	4.7	3.7	3.3	4.4	5.1	7.3	15.8	18.3	15.5	39.4	8.7	23.4	33.3
220-240	6.7	6.3	7.6	8.8	20.4	11.3	9.4	7.1	7.1	6.4	5.8	6.5	8.8	7.3	8.4	11.7	8.8	12.4	10.2	13.0
240-260	9.0	11.5	6.4	10.0	12.6	17.3	10.8	8.0	6.9	5.6	8.5	6.4	5.2	7.7	10.7	4.8	6.5	8.2	5.6	7.8
260-280	14.3	15.0	14.2	10.5	11.6	11.0	7.8	8.3	9.1	7.5	9.1	9.0	6.6	5.1	11.4	7.0	6.9	8.5	9.3	7.7
280+	12.3 28	13.9	15.1	22.8	25.3	20.2	22.1	19.1	9.5	11.3	10.9	7.0	9.3	6.9	8.9	5.3	9.0	6.4	5.4	8.4
abundance																				
-200	4.2	4.1	4.2	4.2	4.2	4.3	4.2	4.2	4.4	4.6	5.2	5.0	4.9	5.2	5.1	5.3	6.1	6.1	8.9	-
200-220	4.4	4.1	4.2	4.4	4.2	4.3	4.2	4.1	4.3	4.4	4.8	5.1	4.6	5.2	5.0	5.1	5.6	6.1	6.6	35.5
220-240	4.6	4.1	4.4	4.6	4.4	4.5	4.4	4.2	4.2	4.5	4.8	5.5	5.3	5.1	5.3	5.2	5.4	6.3	6.2	14.3
240-260	4.7	4.4	4.5	4.7	4.4	4.5	4.6	4.4	4.3	4.5	4.5	5.1	6.4	5.2	6.5	5.5	5.2	6.3	7.0	8.8
260-280	5.1	4.9	4.9	4.9	4.6	4.5	4.4	4.3	4.3	4.5	4.3	4.3	4.8	4.4	5.7	5.7	6.1	7.5	8.3	11.0
280+	5.2	5.1	5.0	5.0	4.7	4.5	4.4	4.3	4.4	4.6	4.3	4.4	4.8	4.5	5.8	5.9	6.5	8.5	10.5	13.5

Bold indicates relatively higher CVs of tained from both catch and abundance in each year.
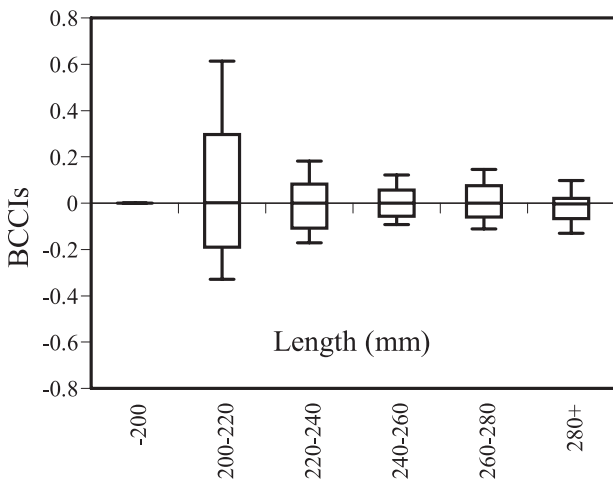
Fig.5-1 Bias-corrected confidence intervals (BCCIs) for 2004 abundance of pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk.
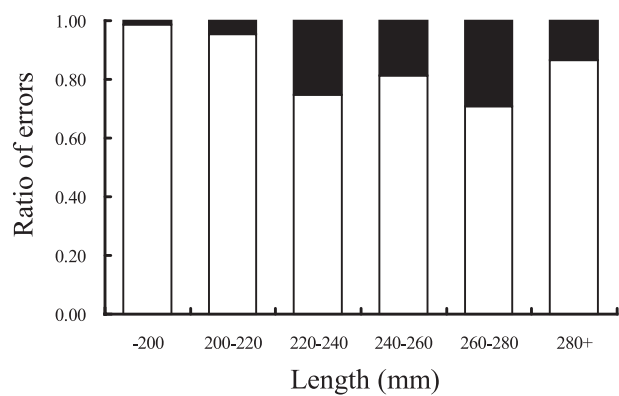

Fig.5-2 The ratio of error on abundance estimates in 1999 by retrospective analysis for the process error (□) and the measurement error (■) of the pointhead flounder in the northern Sea of Japan and the Sea of Okhotsk.

Simulation: Base case trial

Trends

Biomass abundances forecasted for each management scenario were shown in Fig.5-3.

The CFM run showed a flat biomass trajectory after three years decline in the median of the outputs and in the range between the tenth and ninetieth percentiles of the outputs, which indicates that the 80% confidence interval of the simulation outputs enlarged three times as 80% confidence interval at 2004 in first three years and showed a flat trajectory in following years. Scenarios 1, 2 showed the same trend as the CFM run (Fig.5-3). However, scenarios 3, 4, 5, 6, and 7 showed slightly smaller biomass decrease than the other three scenarios. Forecasts of yield for each management scenario are shown in Fig.5-4. The yield trends were slight decrease as similar to those observed in the biomass forecasts (Fig.5-3) but small decreases and

increases were observed.

Biomass

The biomasses forecasts at 2014, 2024, and 2034 for each management scenario relative to the median of the biomass forecasted by the CFM run are shown in Fig.5-5. The medians of all management scenarios were equivalent to or greater than the CFM run. By 2014, the frequency distribution of outputs slightly shifted to larger biomass values in concert with the increase in the amount of regulation alteration from scenario 1 to 4 and from scenario 5 to 7. In this distribution shift, the medians also increased with the increases in regulations. Moreover, the outputs with relative larger biomass levels (>1.2 times the CFM biomass median) increased and those with relatively smaller biomass levels (< 0.5 times the CFM biomass median) decreased with changes in the amount of regulation. Similar results were observed at 2024 and 2034. The difference as time progress within the same
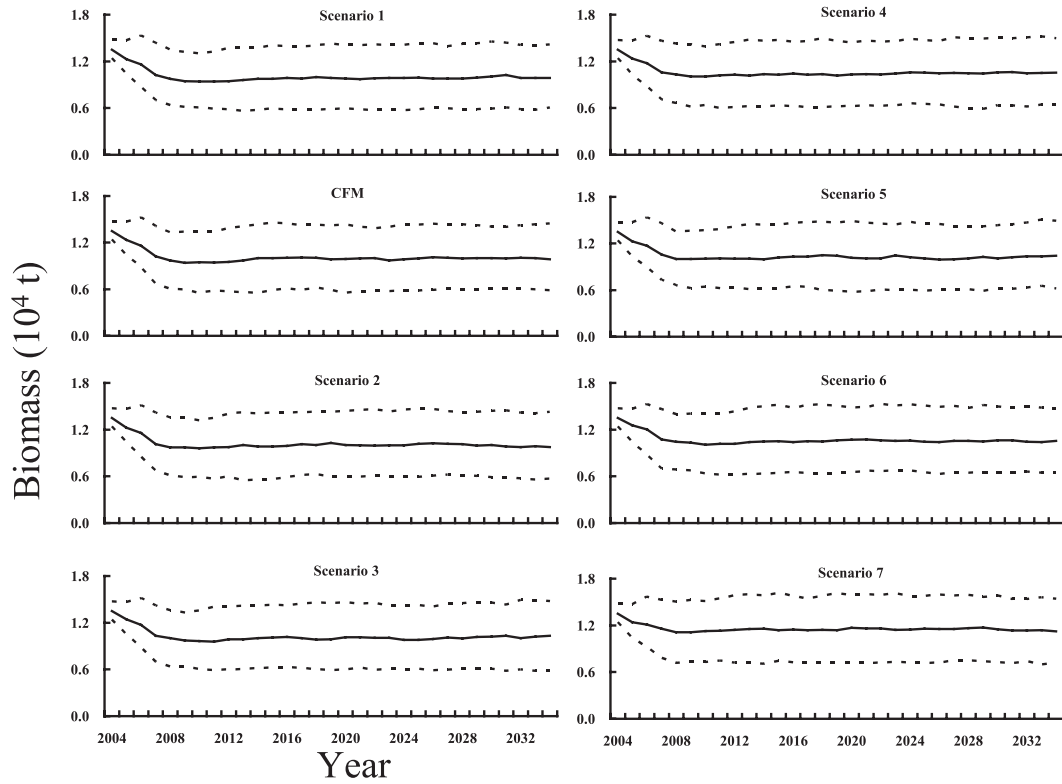
Biomass (10^4 t)

Fig.5-3 Forecasted biomass trajectories of pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk for each of the various management scenarios. Median forcast biomass (solid line), tenth and ninetieth percentiles (broken lines).
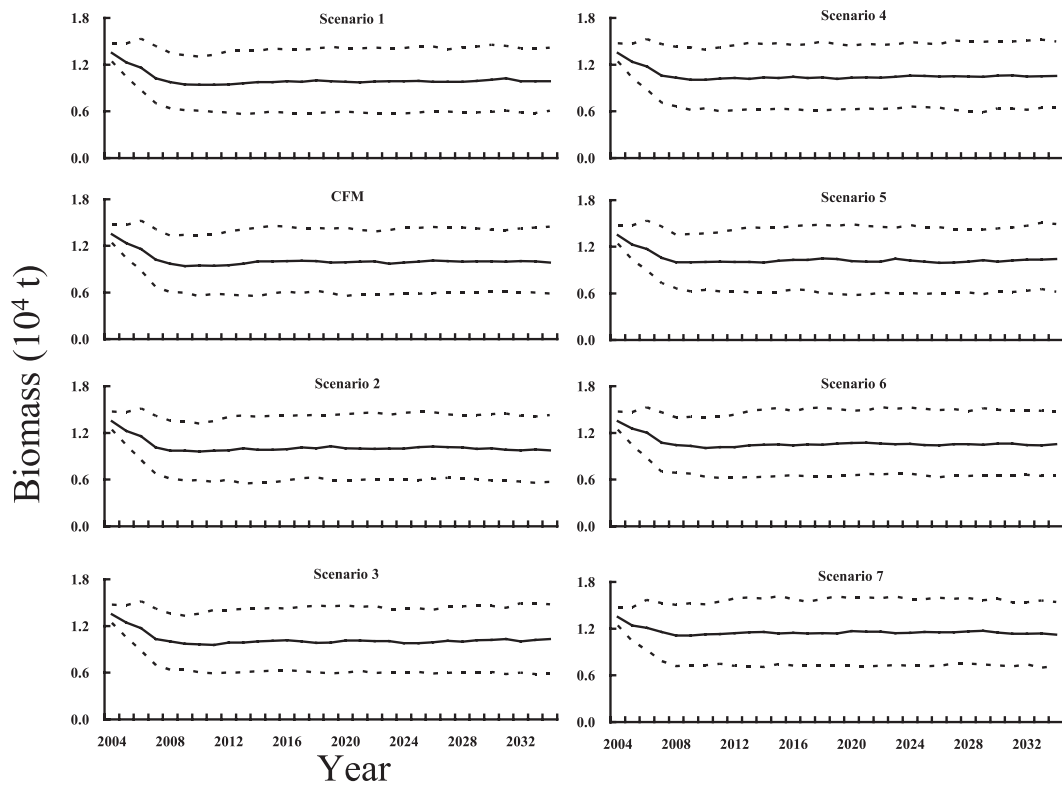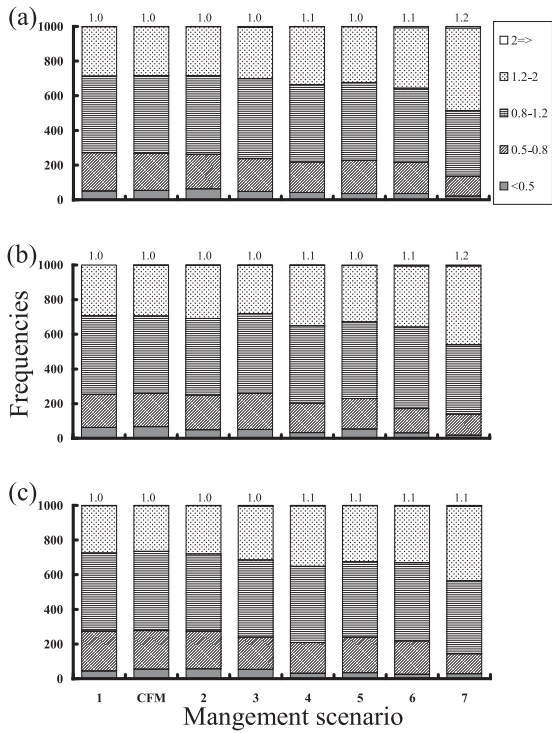
Biomass (10^4 t)

Fig.5-4 Forecasted yield trajectories of Pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk for each of the various management scenarios. Median forcast biomass (solid line), tenth and ninetieth percentiles (broken lines).

Fig.5-5 Forecasted biomass of pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk in (a) 2014, (b) 2024, and (c) 2034 relative to the median of the biomass from the CFM run. The numbers shown in each column were the median of outputs for each of management scenarios.

Table 5-5 Minimum biomass and yield in each scenario of pointhead flounder management in the northern waters of the Sea of Japan and the Sea of Okhotsk.

Management	Lower 5th percentile	
Scenario	Minimum biomass[a]	Minimum yield[b]
1	15.0	13.8
CFM[*]	15.0	13.6
2	14.2	14.0
3	15.6	14.7
4	16.1	15.0
5	15.3	14.4
6	18.3	15.9
7	22.9	15.1

[a] Lower 5th percentile of the minimum biomass in the simulation period divided by the 2004 median biomass, expressed as a percentage.

[b] Lower 5th percentile of the minimum annual yield in the simulation period divided by the 2004 yield, expressed as a percentage.

* CFM: Current fishing mortality run.

scenario were not found.

The lower 5th percentile of the minimum biomass forecasted in each simulation scenario was divided by the 2004 median of biomass and expressed as a percentage (Table 5-5). Those data show that the

Fig.5-6 Forecasted cumulative yield of Pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk in (a) 2005 - 2014, (b) 2005- 2024, and (c) 2005- 2034 relative to the median of cumulative yield from the CFM run.
The numbers shown in each column were the median of outputs for each of management scenarios.

relative output minima increased with the amount of regulation change.

Yield

Cumulative yields forecasted for the periods 2005–2014, 2005–2024, and 2005–2034 for each management scenario relative to the median of the cumulative yield in the CFM run are shown in Fig.5-6. The median outputs for all management scenarios were equal to, or smaller than, the CFM median. From 2005 to 2014, the distributions of outputs shifted to smaller cumulative yields as the amount of regulation change increased, except in scenario 1 with a smaller mesh size. Similar results were observed from 2005 to 2024 and from 2005 to 2034. Within all scenarios, the differences as time progressed were not found (Fig.5-6).

The minimum yield forecasts produced in each scenario, as a percentage of the 2004 yield, are shown in Table 5- 5. With the exception of scenario 1 and scenario 7, the forecasted minimum yields became
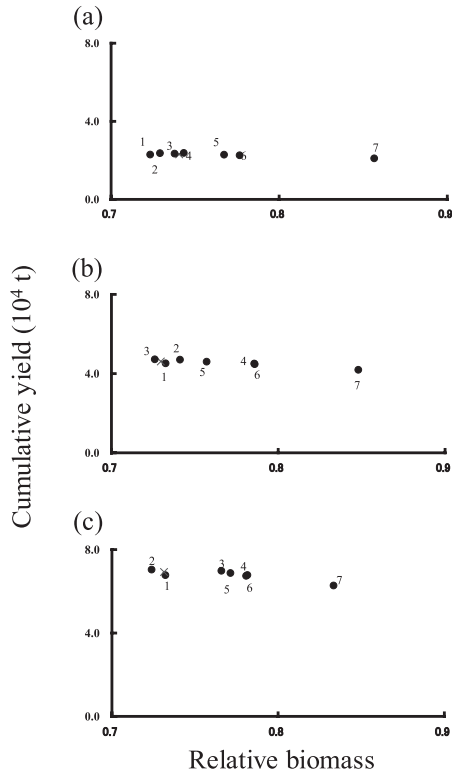
Fig.5-7 Relationships between cumulative yields and biomasses of pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk in (a) 2014, (b) 2024 and (c) 2034. The biomasses are shown as the relative value; divided by the median of biomass in 2004.

Table 5-6 Coefficient of variation for cumulative yield for pointhead flounder in the northern waters of the Sea of Japan and the Sea of Okhotsk, by management scenario and period.

management scenario	10 years	20 years	30 years
1	15.3	10.4	8.6
CFM	15.8	10.8	8.8
2	15.3	10.9	8.7
3	14.9	10.4	8.7
4	15.7	11.3	9.0
5	15.4	11.1	9.0
6	16.0	11.2	9.0
7	16.9	12.3	9.7

larger as the amount of regulation increased. All of the scenarios' indices of minimum yield were greater than the index for the CFM run.

The relationships between biomass and cumulative yield over three forecast periods for each management scenario are shown in Fig.5-7. This Figure suggests the presence of trade-offs between biomass and yield
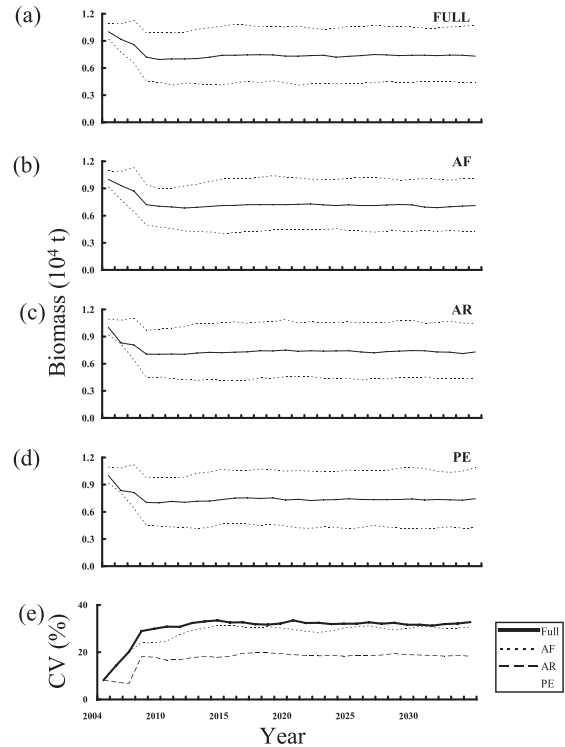
Fig.5-8 The differences of biomass trajectories of pointhead flounder in the northern waters of the Sea of Japan(a-d) and the Sea of Okhotsk among settings of fluctuations for management scenario 5. (e)Coefficient of variations of biomass for each trial.

in the scenarios at all time period.

AAV values were used as a stability performance measurement. No clear differences were observed in the AAV values for the various scenarios. Among the scenarios, the average AAV values ranged between 58.7 and 59.6 with standard deviations ranging from 8.6 to 9.2. The average AAV in the CFM run was 59.4 ± 9.1.

As measurement indicators of performance reliability, inter-replicate coefficients of variation (CVs) of the cumulative yields for the periods 2005-2014, 2005-2024, and 2005-2034, were determined (Table 5-6). Within each scenario, the CVs became smaller as period length increased.
However, within the same period, the CVs increased as the amount of regulation increased.

Effects of fluctuations in the simulation

Management scenario 5 was selected for use in this assessment because its base case results reflected a moderate amount of regulation change (Table 5-3). Fig.5-8 shows the 2005-2034 trends for the base case (FULL) and the three fluctuation options, along with

the CVs for each trial. The trends were similar, but the CV in the AR trial was smaller than that in the other three trials. At 2034, the CVs using AF, AR, and PE fluctuation trials relative to the CV for the base case were 93%, 55%, and 99%, respectively.

5.6 Discussion

Conservation performance

The stable biomass trend after decline in first three years forecasted by the CFM run suggests that the current fishing mortality scenario is adequate to maintain a sustainable biomass in the PFJO stock. Scenario 1, using a smaller gill net mesh size than CFM represented a reduced amount of regulation from that in the current fishery, and the conservation performance of scenario 1 was equivalent to that in the CFM. It indicates that former mesh size increased to the current mesh size have a restricted effect to maintain a sustainable biomass in the PFJO stock. Two indices showed that any increase in mesh size regulation would conserve more of the PFJO stock than the CFM. First, the minimum biomass resulting from scenarios 2 to 4and scenarios 5 to 7 were larger than that in the CFM run, and would indicate a reduction in the risk of population collapse. Second, the future biomass levels achieved following additional mesh size regulation would be expected to be larger than those in the CFM run. Furthermore, the scenarios showed that the more severe the mesh size change, the greater the conservation of the stock. More severe management scenarios also produced larger minimum biomass levels in the simulation period (Table 5-5). Also, the distribution of the biomass within each of the management scenarios shifted to a larger biomass as the amount of regulation change increased (Fig.5-5). Based on these results, increasing the regulation of the fishery would decrease the risk of population collapse.

Scenarios 2 to 4 only regulated the coastal gill net fishery. Even relatively small regulation changes, as in scenarios 2 to 4, resulted in greater stock conservation than the CFM run, but these were relatively small differences compared with CFM run (Table 5-5, Fig.5-5). However, the scenarios 5 to 7 in which the same strength of regulation was applied to the trawl fishery as that used in the coastal gill net fishery, showed more effective results than those shown by scenarios 2 to 4 (Table 5-5, Fig.5-5). These results suggest that regulating both fishery types would lead to a greater conservation of the stock and lesser risk of population collapse. However, some simulation outputs were less than 0.5 of the median biomass in the CFM run at all time points suggesting that a risk of management failure remains, even under relatively severe management scenarios (Fig.5-5). Nevertheless, the risk of management failure decreased as the amount of regulation alteration increased. From a stock conservation viewpoint, any increase in mesh size with or without a similar trawl fishery restriction would conserve the PFJO stock more than the CFM approach. Furthermore, more severe regulation changes would provide greater stock conservation. Although the risk of management failure decreased as the severity of the regulation alteration increased, there was still risk of stock failure, even at the most severe management scenario tested.

Utilization performance

Cumulative yields forecasted for the periods 2005-2014, 2005-2024, and 2005-2034 for each management scenario were used to evaluate utilization performance (Fig.5-6). The evaluation showed that the yield differed with different period length. Simulation outputs indicated that lower cumulative yields occurred in short periods while larger cumulative yields were forecasted over long periods. The more severe regulations did not use as much of the total PFJO stock as yield. In scenario 1, the simulation output showed a similar to CFM for the period 2005-2014, however the lesser use for the period 2005-2034. Therefore in the short period, the smaller mesh size than the current fishery can obtain equivalent in yield but smaller yield occurred in the long period. Furthermore in scenario 7, a simulation output was inferior to other scenarios observed in short period and the same simulation out put observed in long period but the differences from other scenarios became smaller. Thus, the effects of regulation change on stock utilization may not be observed over the short term, but they become obvious over the long term.

The lower 5th percentile of the minimum yields throughout the simulation period in scenario 7 was the smaller than scenario 6 out put despite of minimum yields became larger as the amount of regulation

increased (Table 5–5). Scenario 7 represented the most severe regulation change in this study, and the results show that a severe regulation can prevent more utilization, despite of potential harvest remained.

Stability performance

The AAVs of the management scenarios were used to evaluate stability performance and showed little variation. The management scenarios considered in this study were based on changing gill net mesh size and, in some scenarios, altering the trawl fishery to a similar extent. The management scenarios in this study were considered relatively loose forms of regulation compared to a fishing ban regulation or a reduction in the number of the fishing fleets. The use of relatively loose regulation changes in these simulations may be the cause of the similarities in AAV values among the scenarios.

Reliability performance

The inter-replicate CVs of the cumulative yields were used to evaluate the differences in performance reliability (Table 5–6). After 30 years, the maximum variation in the index was 9.7% in scenario7. Overall, the variation in the cumulative yield CVs was relatively small and there were small differences among all scenarios. These small differences suggest that the results of each simulation run may be regarded as equally reliable.

Effects of fluctuations in simulation

The AR trial had a smaller biomass CV than the other simulation fluctuation trials (Fig.5–8). These data suggest that using average recruitment instead of stochastic variations in recruitment may lead to underestimating future variations, resulting in misinterpretation of the management procedure evaluation results. At 2034, the CVs using AF, AR, and PE fluctuation trials relative to the CV for the base case were 93%, 55%, and 99%, respectively. Thus, the uncertainty caused by recruitment variation most greatly affected the population forecasts in this simulation. Improved understanding of recruitment variation is essential for evaluation of management candidates.

Chapter 6
General discussion

It is widely recognized that there are various kinds of demand for fishery stock. Building consensus among stakeholders is the essence of fishery stock management. One role of the fishery scientist is to offer scientifically based information on the stock of interest. Furthermore, uncertainty is unavoidable in stock management. To conduct fishery stock management, a wide range of uncertainties should be considered. A simulation model that incorporated uncertainty from sampling errors and other types of uncertainties was developed in this study and provided useful information for fishery stock managements.

Uncertainties have been placed into five error categories: (i) measurement error in observed quantities; (ii) process error in the underlying stochasticity of population dynamics; (iii) model error in the mis-specification of model parameter values; (iv) estimation error resulting from any of the above uncertainties and/or inaccuracy and imprecision in estimated model parameters; and (v) implementation error resulting from variability in the implementation of management policies[19].

This study considered errors in stock sizes estimated from catch-at-age data (WPNJ) or catch at length data (PFJO) by bootstrapping. The stock size estimation errors were investigated in relation to measurement error (type i) and estimation error uncertainties (type iv).

The randomly sampled RPS used in future recruit calculation in chapter 4 or the stochastic estimation in chapter 5 correspond to a process error involving population dynamics uncertainty (type ii). The RPS and the probabilities used in the stochastic approach used in this study were calculated from a bootstrapped 1000 stock number data set, a process which takes the measurement error (type i), process error in the population dynamics (type ii), and estimation error (type iv) into consideration.

On the other hand, uncertainties related to implementation error (type v) were not incorporate in this study. However, this study would be reducing this type of uncertainties. The consensus among stakeholders is important for implementation of stock

management because the demands for fishery stock are varied among stakeholders. This study provides a variety of evaluations, and such evaluations would help building consensus among stakeholders. Therefore this study would be reducing the implementation uncertainties.

Also model error uncertainties (type iii) were not investigated in this study, but could be considered using sensitivity analysis. However, it was noted that some parameter errors, such as the specification of a natural mortality rate, did not affect the observed biomass and yield trends. Thus, simulation modeling in this study took into consideration several important and wide-ranging uncertainty types and should provide an appropriate level of understanding of the uncertainties involved in stock management.

Cooke[61] proposed four main axes of performance measurements to evaluate the validity of management procedures. The performance measurements used in this study corresponded closely to those four axes. Conservation performance indices are essential for evaluation of stock management candidates and can indicate the probability of sustainable stock utilization, without stock collapse, under some management candidate. As far as conservation performance, the severe regulation candidates were more effective than loose regulation candidates. In chapter 4, the scenario 3-1, relatively loose regulation, showed the probability of biomass decrease than biomass forecasted by no regulation scenario and became the same level were about 11 % and about 33 %, relatively in after 30 years. The comparing medians of outputs, it would be similar to the result from a deterministic method instead of simulation method, showed that the scenario brought 1.2 times biomass as forecasted by no regulation scenario. This deterministic information cannot give the subsist risk in management candidates but simulation results can give the risk in a quantitative way.

The utilization performance indices showed harvest levels from a stock using a particular management candidate. The utilization performance obtained in both chapter 4 and chapter 5 showed their evaluation were different with differing period length. Generally, there are different needs for amounts and timing of harvests requested by stakeholders. Some people may want

short-term benefits, while others may be interested in harvests over longer periods. The differences of this index among period length indicate that various pieces of information should be provided when attempting to obtain consensus among stakeholders on utilization of a stock.

The stability performance index indicates variation in annual harvest. In chapter 5, changing gill net size strategy showed the small difference among scenarios. However in chapter 4, although small differences among scenarios under the constant suppressing fishing mortality over period scenarios, the large variation were showed under fishing ban scenarios despite of excluding the effect of extreme deviations, resulting from the fishing ban. The rapid increase stock biomass with fishing ban and rapid decrease by strong fishing pressure brought higher AAVs. This type of variation can result in difficulties when planning business schedules, plant and equipment investments, and employment needs. For the consumer, it leads to price variation, and may destabilize the food supply. Thus, stability performance is important to most stakeholders and the external sever regulation like a fishing ban strategy is not preferable for stability performance.

The reliability performance indices show the reliability of the simulation outputs. In chapter 4 and chapter 5, the small differences observed among scenarios and periods suggested that each simulation run was equally reliable. Such calculates would be useful to managers when selecting among several management action candidates.

In chapter 4, three recruitment assumptions were tested and future biomass forecasts were found to be strongly affected by assumptions about recruitment. However, it was impossible to determine which assumption is the nearest to reality since there is no way to accurately predict future biomass levels. However, it was found that the overall ranking of management candidates was not markedly affected by recruitment assumptions, even though the absolute value of the biomass levels were strongly affected by recruitment assumptions. Therefore, the discussion for management can start without arguments of recruit assumption. Scientists should consider reasonable recruitment assumption and provide information on

how the evaluation of management candidates is affected by the assumptions.

The effects of fluctuations were evaluated in chapters 4 and 5. In both chapters, the uncertainty caused by recruitment variation most greatly affected the population forecasts rather than the uncertainty caused by sampling error. On the other hand, the effect of sampling error was observed definitely in stock size estimation by VPA and by LPA. Reducing sampling error improves stock size estimation precision. However when forecasting future population dynamics based on stock size estimation, future variations were affected largely recruitment variation rather than sampling error was quantified by this simulation study.

It is widely said that improving stock size estimation precision is essential for sound stock management. However this study quantified various uncertainties including stock management showed that improving stock size estimation precision is not directly connected to ensure sound management. At least, the two stock examined in this study were assessed sufficient precision in stock size estimation for forecasting future population dynamics. Improving recruitment variation is effective on stock management rather than improving stock size estimation precision. However assessment information for different stocks varies in their quality and quantity. Therefore, revealing the relative effects of different fluctuations through simulation should improve the evaluation of management candidates.

This study showed that various indices can be useful for evaluating different management scenarios. The trade off between the conservation and utilization were showed. The evaluation of management scenarios differed depending on the index selected and the period considered. Furthermore, there are various aspects of stock management that depend on how people derive benefits from the stock. Hilborn et al.[17] pointed out that stock managers should play a moderate role because there is no single user voice. Hilborn and Walters[38] defined the role of the scientist in stock management as helping managers to make choices about dynamic fishery systems in the face of uncertainty. It is impossible to remove uncertainties in stock management completely, and inaccurate forecasting of the future status of stocks is unavoidable.

An important duty of fishery scientists is to provide an estimate of the possible stock status based on the available scientific data, rather than trying to forecast a 'best estimate'. This study provides a method to evaluate management procedures from various viewpoints and provides the limitations of the results. Furthermore, even people out of a scientific specialty may have been concerned or easily understand about the influence of the sampling error on the estimation of interest quantity because that they know a direct observation is difficult for under sea living fishery stock. A quantitative evaluation procedure including the uncertainties from sampling error was developed in this study. This procedure could enrich discussions of the effects of a variety of management actions when stakeholders are considering various requirements of the stock.

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