A Policy Assessment under Uncertainty of Fishery Management and Marine Ecosystem: Japanese Clam Fishery Collapse

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Abstract: *This study develops an assessment model to elucidate ecological and socio-economic issues in terms of vulnerability of less-competitive fisheries. As needed to make an arrangement of ecological-economic policy instruments for fisheries, resource stocks information of low-trophic fish species, which are more unobtainable for small-scale fisheries compared to large-scale fisheries, latent fishery productivity, and fishery behavior subject to the whole economy are stochastically estimated by use of the extended Kalman filter. The assessment is derived from the identified simple predator-prey bioeconomic model combined with a general equilibrium model. The results show, as the causes of fishery collapse, the growth accounting of a Japanese clam fishery elucidates that the fishery is an industry of excessive inputs of production factors and declining technological levels over time. Furthermore, the releases of clam seedlings containing predators and rapid increase of imported clam commodity, which are contemporaneous occurrence, are crucial factors in the drastic clam stock reduction and withdrawal from clam fishing.*

1 Introduction

The unending world crisis of aquatic resource and fishery collapse are a major concern of resource economists due to difficult sustainable usage (Clark, 2006; Worm et al., 2006). Therefore, on the basis of conventional deterministic bioeconomic model (e.g., Gordon, 1954; Schaefer, 1957), previous studies have estimated fish production functions for the fish stock assessment.

The majority of the studies tend to focus on a more competitive fishery of a higher value-added fish resource management (e.g., flatfish, halibut, salmon, tuna placed at a high-trophic level of organism in an aquatic food chain) and a heavy investment to fishing equipments (e.g., long lines, trawl fishery, fish sonar). In this kind of fish resource management in large-scale fisheries, there will be a comparatively high incentive to regulate the fishing and then to survey the fish stock abundance. Thus, the observation data as needed to estimate the production function, i.e., the fish stock, are easily obtainable. Additionally, the studies have addressed the fisheries collapse as a single fishery industry problem and then segmentalize factors input for fish production, e.g., the number of vessels, fishing hours. The framework is evidently reasonable to establish causal connections between the fish resource depletion and the mechanized vessels, and on that basis to achieve a more efficient fishing.

However, what are small-scale fisheries? It would appear that the small-scale fisheries have a less incentive to survey the abundance of fish species being in a low-trophic level because they prefer not to catch these low-value-added fish. Therefore, it is increasingly-difficult to obtain the stock data of low-trophic species. However, the low-trophic level species, e.g., plankton feeders of anchovy and clam, which are more than 30% of global fisheries production, have large impacts on other aquatic species depending on the food web (Smith et al., 2011). As for the significance of multispecies in fisheries, Flåten (1989) theoretically demonstrated that a low valued fish species should be harvested at a loss in the fishing strategy between two species.

Additionally, the small-scale fisheries, which have been not really investigated, should be valued more in the context of technology, biology, socio-economy, and institution (Guyader et al., 2013). However, the vulnerability of small-scale fisheries to a larger policy measure such as trading policies has not been taken into consideration. For example, clam fisheries require little large capital and just use a small boat and equipments for clam catch. Since the late 1980s, Japan relies on the imported clams, and the 2006 domestic clam catches reduce by 1/4 of the peak catches. This leads to an increases in domestic unit supply price and a decrease in import unit price (Figs. 1 and 2: Data from Trade Statistics of Japan).

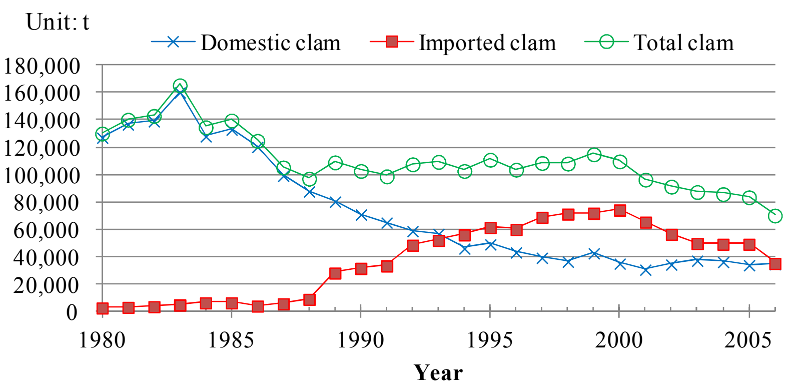


Fig. 1. Components of clam commodity supply in Japan

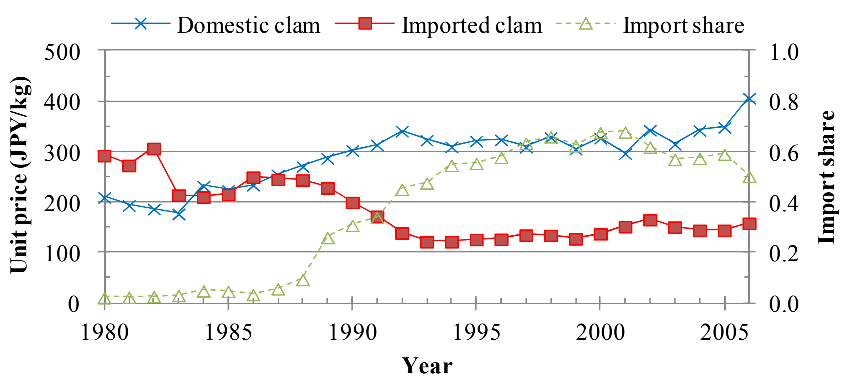


Fig. 2. Unit supply price of clam commodity in Japan

For the sustainable development of small-scale fisheries exposed to ecological and global economic perspectives mentioned above, we should consider an interaction problem between the small-scale fisheries and the whole economy, i.e., the general equilibrium approach. Therefore, a stock estimation method, which describes the fisheries impact from the whole economy and serves to a substitute for fish stock assessment with vessel survey, should be developed.

Furthermore, in the researches mentioned above, what we require considerable attention is to exclude other reasons of fishery collapse attributing to the market economy and aquatic ecosystem of ecological food chains. In addition, some researches enhance the applicability of either input-output (I-O) tables or social accounting matrix (SAM) to evaluate the impact of fishery policy on socio-economy and efficiency of labour inputs in the fishery (Heen and Flåten, 2007; Arita et al., 2013). The method is to combine bioeconomic models with I-O tables. However, the models assume constant input coefficients to exclude the substitutability of production factors and mobile labour among industries therefore, it may be insufficient to evaluate the effects of policies which encourages the fishery improves the labor productivity and economic growth associated with trading.

From these perspectives, a research question is how to quantify the fisheries production factors endogenously as the substitution problems among multi-industries and multi-regions, whose solution will illuminate insight in the economic measures to revitalize the fisheries in the socioeconomic dimension. However, there is still an open question how the economy market and ecosystem interact in the long-term period, and then how that influences on the fishery development and collapse. To address this issue, we will need a comprehensive approach that a marine ecosystem model for multi-species is combined with a general equilibrium model.

However, a further overriding problems is to estimate the time effect in a production function, which shows a latent characteristic of fishing technological productivity and leads to deeply understand how the fisheries have managed their fishing or else why the fishery collapses. Wolff et al. (2013) defined the production function including an experience effect in terms of skippers' learning- by-doing to estimate it as a time-varying technical efficiency.

In the technological productivity in fisheries, total factor productivity (TFP), which has a potential to explain the fisheries development and collapse, has been preferred to estimate by regression analysis (Squires, 1992, 1994; Jin et al., 2002; Hannesson, 2007; Hannesson et al., 2010). The TFP is an unobserved factor and is given as a variation of the productivity. However, when we look at not the fishery but a broader manufacture industry and national, it is believed that the TFP includes a time dependent technological change, which is estimated as well as productivity inefficiency by use of a stochastic frontier production function (Aigner et al., 1977; Meeusen and van den Broeck, 1977; Battese and Coelli, 1995). Little fishery researches have been performed to estimate the long-term trend of technological changes.

On the basis of these considerations, the purpose of this study is to develop a methodology which illuminates insights in how to make an arrangement so that the economically less competitive fisheries for low–trophic aquatic species can conserve the species while the fisheries perform sustainable development. Thus, this study applies the data assimilation to estimations of the unobserved fish resource stocks, technological change over time, and fisheries growth in the whole economy dimension. This study assumes a representative fish catchability and fish stock in a whole fishing ground, which is combined with a macroscopic model describing the regional economy. This approach is different from the conventional works to estimate spatial distributions of catch per unit effort based on the fishery science (Vincent et al., 2007; Vølstada et al., 2014), which requires more detail information for fishing (e.g., vessels, fishing equipments) and for biology (e.g., population by age which is used in the vertical population analysis; Gulland, 1965; ICES, 2012). This is because the study deals with unobtainable situations of stock assessment by detailed scientific marine survey of multispecies.

Furthermore, the data assimilation method, which considers the uncertainty of observation data and model system, will open the door to the growth accounting which elucidates the real-world collapse of fisheries even though the actual data of fish stocks is unobtainable. The studies relevant to bioeconomic model parameter estimations have been performed by use of the variational method (Lowson et al., 1995; Ussif et al., 2002) and the sequential method (Peter and Johns, 1985; Peterman et al., 2000; Kvamsdal et al., 2012). However, the studies limit to a single industry problem with fish stock observations. Therefore, the studies don't provide the findings how the fisheries develop or collapse subject to the global economic fluctuations.

In this study, the bioeconomic model with a simplified predator-prey ecosystem is incorporated into a two-country model with two industries. Applying the extended Kalman filter, which is one of the data assimilations, to the dynamics of the bioeconomic model part, the parameters of the natural growth rate of a fish, the predation, and the efficiency of fishing and trading of fish commodities are estimated. Furthermore, this study adds to extracts a long-term trend of fishing productivity from the TFP. The identified model estimates the growth accounting, by use of which causes of the fishery collapse is investigated. This study focuses on a Japanese clam fishery depression to elucidate the causes under uncertainty of economic ecosystems.

This paper is organized as follows. Section 2 defines the production function and explains how a two-country model and a bioeconomic model are integrated into the data assimilation scheme. Section 3 describes a collapse case of Japanese clam fishery. We add to explain the collection method of data necessary for the model estimations. Section 4 shows the practical procedure for parameter estimations and the estimation results. Section 5 shows the analytical results of the fish stock estimates, whole economy impacts, and growth accounting. The reasons of the clam fishery collapse are then elucidated from ecological and socio-economic point of views. Section 6 refers to the validity of the proposed method and future prospects.

2 Methods

To evaluate the fisheries development in the general equilibrium and in the absence of fish resource stock observations, we go through the following two procedures. The production function and fish resource stock were estimated by the extended Kalman filter. The long-term trend of technological change is defined in the production function. We then describe the calculation method for growth accounting by use of the resultant fish stock estimates and model parameters.

2.1 The data assimilation

A general equilibrium of economy market involving the fisheries is formulated as a nonlinear programming. The dynamics of fish resource stock contains the amount of fisheries production, inputs such as the labour, capitals, and intermediate goods, which are given as solutions of the general equilibrium model. To estimate a fish stock in that analytical condition, the fish stock must be defined as a system state variable in the data assimilation scheme. As a result, the following stochastic state-space system is introduced.

$$d\boldsymbol{x}_t / dt = \boldsymbol{f}(\boldsymbol{x}_t, t) + \boldsymbol{G}(t)\,\boldsymbol{\omega}_t \qquad (1)$$

$$\boldsymbol{y}_t = \boldsymbol{h}(\boldsymbol{x}_t, t) + \boldsymbol{v}_t \qquad (2)$$

where $\boldsymbol{x}_t$ is a system state vector, t is a time, $\boldsymbol{f}$ denotes a vector of system's dynamics without error sources, $\boldsymbol{G}$ is $\partial \boldsymbol{f} / \partial \boldsymbol{x}$, $\boldsymbol{\omega} \sim \boldsymbol{N}(0, \boldsymbol{R}_t)$ is a white Gaussian vector with zero mean and covariance matrix $\boldsymbol{R}$, $\boldsymbol{y}$ is an observation vector, $\boldsymbol{h}$ is a vector of observation function without error sources, and $\boldsymbol{v} \sim \boldsymbol{N}(0, \boldsymbol{Q}_t)$ is a white Gaussian vector with zero mean and covariance matrix $\boldsymbol{Q}$.

Eq. (1) describes the dynamics of fish resource stock of the region k, XM_k. The bioeconomic model consists of a stock increase associated with the natural growth of the fish F_k and the fish seedlings GX_k, and a stock reduction associated with the fish catches $Z_{k,1}$ and the prey of predators H_k. The deterministic stock dynamics for the low-trophic species of Eq. (1) can be written as Eq. (3).

$$f_k = F_k(XM_k) - Z_{k,1}(XM_k) + GX_k(XM_k) - H_k(XM_k) \qquad (3)$$

Assume that the predator mixed in the seedling bags of the low-trophic species is released. The predators stock and biology is unknown. Thus, to simplify the dynamics of predator (to reduce the number of model parameters), we assume that the predator stock SS is proportional to the amount of the released seedlings, SE.

$$SS_k\big|_t = \sum_{T=1}^{t} p_{mk}\, SE\big|_T \qquad (4)$$

where p_{mk} is the percentage of the predator mixed in the seedling bags.

In the general equilibrium problem for two regions, two industries, and two species (a prey and a predator), a state vector consists of the model parameters and the fish stocks is defined as

$$\boldsymbol{x} = (XM_k, SS_k, K_e, \; V_{xs}, p_{mk}, kq_{k1}, kf_{k1})^T \qquad (5)$$

where K_e is the carrying capacity of the fish, V_{xs} is the capture rate by the predator. Other model parameters of kq, kf represent the time dependence of the technological change of fish catchability and trading, respectively. The dynamics of the model parameters is given as $f_i = 0$. Kiyama (2013) presents the formulation details associated with the bioeconomic model and general equilibrium model. Next, we assume that the observation equation (2) has observation variables of the value of fish production PV and fish catches Z by region. The observation vector is defined as follows.

$$\boldsymbol{y} = \left(PV_{k,1}^{(obs)}, Z_{k,1}^{(obs)} \right)^T \qquad (6)$$

The extended Kalman filter is applied to this state-space system to estimate the fish resource stock and the model parameters, where the numerical solution is from an iterate approach (Jazwinski, 1970) as listed in Fig. 3.

Step 1 Consider the last filtered state estimate in a time step k, $\hat{\boldsymbol{x}}(k|k)$.

Step2 Predict the system's state at the next time step $k+1$, $\hat{\boldsymbol{x}}(k+1|k) = \hat{\boldsymbol{x}}(k|k) + \int_k^{k+1} \boldsymbol{f}\left(\hat{\boldsymbol{x}}(t|k), t\right) dt$.

Step3 Compute the predicted error covariance,

$$\boldsymbol{P}(k+1|k) = \boldsymbol{\Phi}(k+1, k; \hat{\boldsymbol{x}}(k|k)) \boldsymbol{P}(k|k) \boldsymbol{\Phi}^T (k+1, k; \hat{\boldsymbol{x}}(k|k)) + \boldsymbol{Q}(k+1),$$

$$\boldsymbol{\Phi}(k+1, k; \hat{\boldsymbol{x}}(k|k)) = \boldsymbol{I} + \Delta\, \boldsymbol{G}(\hat{\boldsymbol{x}}(k|k)),\ \Delta : \text{Time interval.}$$

Step4 Store $\hat{\boldsymbol{x}}(k+1|k)$ as an iterator $\boldsymbol{\eta}_1$ and begin the iteration.

Step 5 Update the iterator $\boldsymbol{\eta}_i$ by the gain filter $\boldsymbol{K}$.

$$\boldsymbol{\eta}_{i+1} = \hat{\boldsymbol{x}}(k+1|k) + \boldsymbol{K}(k+1; \boldsymbol{\eta}_i)\ [\boldsymbol{y}(k+1) - \boldsymbol{h}(\boldsymbol{\eta}_i, k+1) - \boldsymbol{M}(k+1; \boldsymbol{\eta}_i)],$$

$$\boldsymbol{K}(k+1; \boldsymbol{\eta}_i) = \boldsymbol{P}(k+1|k) \boldsymbol{M}^T (k+1; \boldsymbol{\eta}_i) \left[\boldsymbol{M}(k+1; \boldsymbol{\eta}_i) \boldsymbol{P}(k+1|k) \boldsymbol{M}^T (k+1; \boldsymbol{\eta}_i) + \boldsymbol{R}(k+1)\right]^{-1},$$

$$\boldsymbol{M}(k+1; \boldsymbol{\eta}_i) = \partial \boldsymbol{h}(\boldsymbol{\eta}_i, k+1) / \partial \boldsymbol{\eta}$$

Step6 The iteration terminates with no significant difference between consecutive iterates. Otherwise, return to step5. The last iterator becomes the system estimate at the next time step $k+1$, $\hat{\boldsymbol{x}}(k+1|k+1) = \boldsymbol{\eta}_{i+1}$.

Step7 Compute the new error covariance.

$$\boldsymbol{P}(k+1|k+1) = [\boldsymbol{I} - \boldsymbol{K}(k+1; \boldsymbol{\eta}_l) \boldsymbol{M}(k+1; \boldsymbol{\eta}_l)]\ \boldsymbol{P}(k+1|k) [\boldsymbol{I} - \boldsymbol{K}(k+1; \boldsymbol{\eta}_l) \boldsymbol{M}(k+1; \boldsymbol{\eta}_l)]^T + \boldsymbol{K}(k+1; \boldsymbol{\eta}_l) \boldsymbol{R}(k+1) \boldsymbol{K}(k+1; \boldsymbol{\eta}_l)^T$$

Fig. 3. Calculation procedure of the extended Kalman filter

2.2 Production function in fisheries

This study takes measures that the fisheries production function includes time dependent part explicitly and can be stochastically determined in accordance with the extended Kalman filter. Therefore, it can be said that this estimation method of the production function has both sides of the stochastic frontier analysis and the conventional regression analysis. The former stochastically considers the technical improvement over time and technical inefficiency, in which a translog production function containing the time part explicitly is estimated by use of panel data. However, chief studies focus on not the fishery but the manufacture industries so far (e.g., Battese and Coelli, 1995). The latter method generally excludes the term of time but is preferred to use for the growth accounting (e.g., Hannesson et al., 2010). Then, all fishery data of the fishing effort and fish stock from the separate statistics are prepared for the growth accounting. They apply the regression analysis to estimate the production function.

Additionally, Wolff et al. (2013) uses the panel data to estimate a non-translog fishery production, which has not a variable of time but an explanatory variable related to a skipper learning-by-doing describing time dependent technological change. However, the result shows that the time effect of skipper's learning-by-doing is insignificant.

Different from the previous studies, this study attempts to estimate the time dependent production function with the variable of time and unobserved fish stocks at the same time. Assuming constant returns to scale output in open access fisheries, this study extends the Schaefer production function to describe the technical change over time as follows.

$$Y_k = q_0 A_k(t)\{E_k\}^{\beta_k}\{K_k\}^{(1-\beta_k)} XM_k \qquad (7)$$

where Y is the fish yield, q_0 is a constant parameter of technology level in the reference year (t = 1), E is the labour, K is the capital, and β is the Cobb–Douglas power of labour. The technological change rate over time, which is a long-term constant change of technological change inherent in a certain fishery, is denoted as $A(t)$.

$$A_k(t) = t^{-k_{qk}}, \quad t \geq 1 \qquad (8)$$

where the parameter k_{qk} represents the rate of change in technological level. Technological progress is described as a negative value of the parameter (k_{qk} < 0). A positive value of the parameter represents a decrease in productivity. In the more general description, Equation (7) can be rewritten with the fish catches Z_k in place of the Yield Y_k when the input of intermediate goods is taken into consideration, i.e., $Y_k = ax_{ki,j} \times Z_k$, where $ax_{ki,j}$ is the coefficient of intermediate input.

Furthermore, the observation equation (2) associated with the fish catches can be written as a sum of the deterministic fish catches from Eq. (7) and the observation error.

$$Z_k^{(obs)} = ax_{k\,i,j}^{\ -1} q_0 A_k(t)\{E_k\}^{\beta_k}\{K_k\}^{(1-\beta_k)} XM_k + \nu_k = h_k(t) + \nu_k \qquad (9)$$

where $h(t)$ is the production function at a time t, and ν is the error term of a white Gaussian vector with zero mean and a covariance matrix.

Fig. 4 represents a technological change in the time period $t_1 - t_2$ when the parameter kq has a negative value.

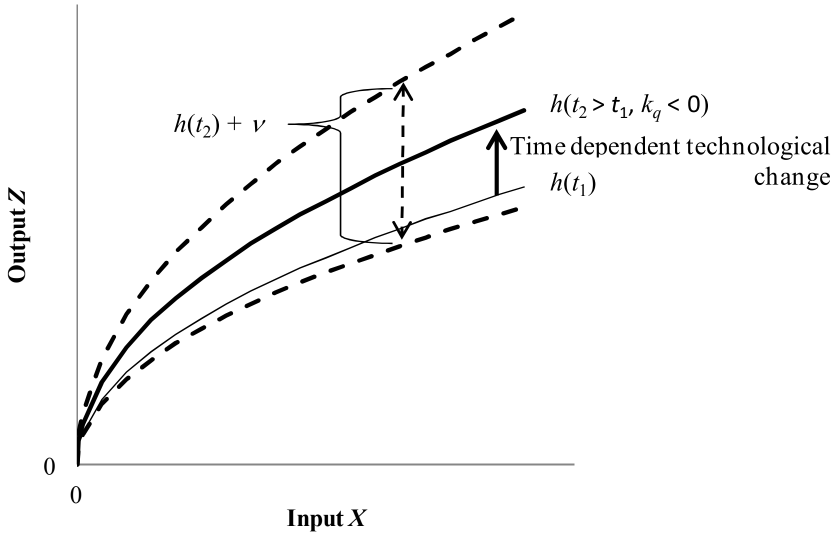


Fig. 4. Technological change from production functions at times t1 and t2

2.3 Growth accounting

Growth accounting requirements are the data of fish catches, fish stocks, fishing efforts, i.e., factor inputs necessary for fish production. To assess the fisheries development, previous studies perform the growth accounting and estimate a change in total factor productivity (TFP) or the Solow residual (Squires, 1992 and 1994; Jin et al., 2002; Hannesson, 2007; Hannesson et al., 2010), where the TFP is generally assumed to be unobserved. By use of the harvest function of $Y = q_0 A_c \; E^{\beta} K^{(1-\beta)} XM$ (Clark, 1976), the change in TFP (A_c) is calculated from given values of the output and inputs as follows.

$$\frac{\dot{A}_c}{A_c} = \frac{\dot{Y}}{Y} - \beta\frac{\dot{E}}{E} - (1-\beta)\frac{\dot{K}}{K} - \frac{\dot{XM}}{XM} \qquad (10)$$

However, this study attempts to estimate a trend of long-term technological change during the analytical period as $A(t)$. Thus, it is assumed that the TFP (A_c) consists of a consistent long-term technological change $A(t)$ and the rest of TFP (B), where $A_c = A(t) \times B$. The unobserved variable of B explains the contribution of a short-term variation associated with fishing productivity. As a result, the change in TFP can be written as follows.

$$\frac{\dot{A}_c}{A_c} = \frac{\dot{A}(t)}{A(t)} + \frac{\dot{B}}{B} \qquad (11)$$

Eq. (11) explains that the change in TFP is defined as a sum of the change in long-term TFP trend and the change in the short-term variation. Tornqvist approximation of Eq. (10) is written as follows.

$$\ln\left\{\frac{A_c(t_2)}{A_c(t_1)}\right\} = \ln\left\{\frac{A(t_2)}{A(t_1)}\right\} + \ln\left\{\frac{B(t_2)}{B(t_1)}\right\} = \ln\left(\frac{Y(t_2)}{Y(t_1)}\right) - \beta\ln\left\{\frac{E(t_2)}{E(t_1)}\right\} - (1-\beta)\ln\left\{\frac{K(t_2)}{K(t_1)}\right\} - \ln\left\{\frac{XM(t_2)}{XM(t_1)}\right\} \qquad (12)$$

Substituting the observation values of Y, E, K, and the estimates of XM and $A\ (t)$ by the extended Kalman filter into Eq. (12), we calculate the growth accounting of fisheries.

2.4 Bioeconomic model

The bioeconomic model for fish species dynamics is formulated as Eq. (3). The multi–species bioeconomic model has been developed (i.e., the Lotka–Volterra model by Clark, 1976; Hannesson, 1983; the Gause model by Flåten, 1991; the Michaelis−Menten type by Arditi and Ginzburg, 1989; Hsu et al. 2001). This study applies the Michaelis−Menten type function. Considering no data about the predator's biology, the predator's stock dynamics is simplified to reduce model parameters for the parameter estimation. Thus, the accumulated predator's weight is assumed to be equivalent to the weight of the predator mixed in the seedling bags. The formulation is written as follows.

Natural growth of prey $$F_k = \left\{ -\left(\bar{b} - \bar{c}Ke\right)Ke + \bar{b}\frac{XM_k}{A_k} - \bar{c}\left(\frac{XM_k}{A_k}\right)^2 \right\} A_k \tag{13}$$

Prey in the seedling $$GX_k = \left(1 - p_{mk}\right) SE_k \tag{14}$$

Reduction of prey by feeding damage $$H_k = V_{xs\,k} \frac{XM_k}{K_{xs\,k} + XM_k} SS_k \tag{15}$$

where $\bar{b}$ and $\bar{c}$ are the parameters, Ke is the carrying capacity, A_k is a fishing area, p_{mk} is a percentage of predators mixed in the seedlings, SE_k is the amount of seedlings released, V_{xs} is the capture rate, and K_{xs} is the half saturation constant.

2.5 CGE model

This study prepares a two–region model, which describes the interaction between a target region (industry) and the other region (industry). Thus, the model consists of two regions denoted by k = 1, 2, and two industries of the target fishery (j = 1) and rest of the industry (j = 2). Fig. 5 illustrates the schematic diagram of the CGE model with the nested structure of the fishery production. Kiyama (2013) refers to details of the model formulation and parameter determination.

Fish catches as home product outputs are formulated by the production function (7), and the corresponding output is defined as $Z_{k,1}^{(1)}$. In the general equilibrium, the fish catches must be the same as the fish catches for the trading strategy to maximize producer's profits. Therefore, applying the Armington assumption, the fish catches are transformed to domestic goods $D_{k,1}$ and exported goods to maximize the profit in the trading market. As a result, the following relation between the domestic goods and the catches $Z_{k,1}^{(2)}$ is given.

$$Z_{k,1}^{(2)} = D_{k,1}\left(\frac{p_{d\,k,1}}{\delta d_{k,1}\,\vartheta_{k,1}{}^{\phi_{k,1}}\,p_{z\,k,1}}\right)^{\frac{1}{1-\phi_{k,1}}} \tag{16}$$

where $\phi_{k,1}$ is the coefficient of elasticity of transformation, $\delta d_{k,1}$ denotes a share parameter of domestic goods, $\theta_{k,1}$ represents a scale parameter, p_d is a domestic price, and p_z is a producer's fish price. The scale parameter is assumed to be time dependent and is estimated by the extended Kalman filter. The notation t means years elapsed from a reference year.

$$\vartheta_{k,1}(t) = \vartheta_{0k,1} t^{-kf_{k,1}} \qquad t \geq 1 \qquad (17)$$

where $\theta_{0k,1}$ is the initial year value of $\theta_{k,1}$, and $kf_{k,1}$ is a parameter of the rate of change in the transformation between the domestic supply and exports. Finally, the general equilibrium solution satisfies the following relation.

$$Z_{k,1}^{(1)} = Z_{k,1}^{(2)} \qquad (18)$$

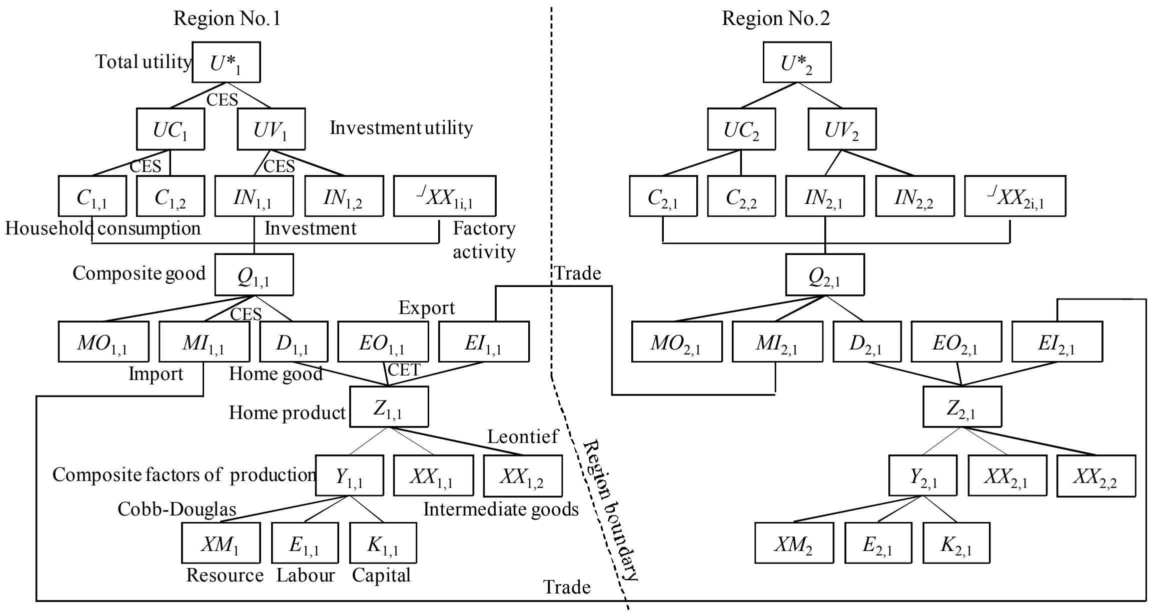


Fig. 5. Two–region model structure in the industry j = 1

3 The Data

This study focuses on clam fisheries in Maizuru Bay, Kyoto prefecture, Japan. The data given from annual fisheries statistics are clam catches, price, weight of clam seedlings for Maizuru city in Kyoto prefecture and the rest of Kyoto prefecture. Additionally, the prefectural input-output tables and municipal economic accounts estimates provide wage, and sectoral labour and capital.

3.1 Clam catches

This study considers interannual clam catches in 1980–2006 as shown in Fig.6. In the 1980s, the Maizuru Clam Fishery recorded catches of around 200 tons, which implies that this fishery plays a chief role of clam fishing in Kyoto prefecture. In the subsequent period, however, three phases of catch decrease are observed. The first decrease occurred in 1993, and the second in 1998 (a sharp decline to 38 tons). Subsequent catches remained at the same level until 2002. From 2003 to 2006, however, the catch decreased again by a few tons.

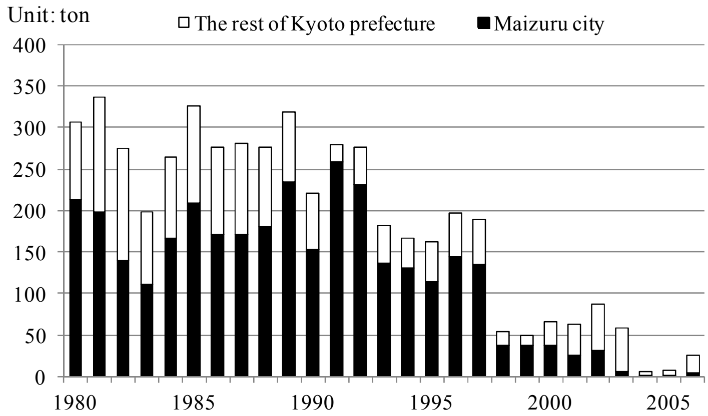


Fig. 6. Clam catches in Kyoto prefecture: 1980–2006

In 2000, the Kyoto Prefectural Agriculture, Forestry and Fisheries Technology Center reported that many of the dead clams exhibited no seashell damage, probably because clams are the natural prey of starfish (*Astropecten polyacanthus*). In addition, a 2010 report concluded that the causes of clam resource depletion are not relatively well known, however the following observations are noteworthy. Immediately after releasing clam seedlings from other regions were released in 1995–1997, the clam catch declined sharply. In fact, the released population of clam seedlings seems to be 3,100,000 in 1995, 6,300,000 in 1996, and 2,500,000 in 1997. The seedling size is about 1–2cm. Generally, it is recognized that the seedling release from other regions heightens the risk of clam death from a parasitic infection (*Perkinsus protozoan*) and a predator (*Euspirafortunei*) infusion. However, there has been no further evidence on decreasing clam fisheries activity so far. This study assumes that the released clam seedlings grow to a 3cm-long in major length and 20g by weight one year later and are harvested.

3.2 Labour and capital

The data of labour, capital, and fish catches were collected from regional input-output tables based on 1995 valuations. Kyoto prefecture, tabulated into 92 sectors, was divided into two regions: Maizuru city and the rest of Kyoto prefecture. Each region was further divided into two sectors: the clam fisheries and other industries. The regional value of production was considered on a pro-rata basis. The regional labour and capital inputs of clam fisheries were estimated from the production value divided by the annual sales value. Accommodating regional supply-demand imbalances by inter-regional trade data, we completed regional social accounting matrix (RSAM). Table 1 is the 1980 RSAM. However, for this empirical study, all quantities of RSAM are normalized by the 1980 regional unit price of the clam commodity (224JPY/Clam-kg). The details are given by Kiyama (2012).

Table 1. Regional social accounting matrix in 1980

(a) Maizuru City

Unit: Million JPY

			Expenditures								
			Factory activity		Factors of Production		Final consumption	Investment	Export		Total
			Clam fishery	Others	Labour	Capital			Rest of the world	Kyoto	
Receipts	Factory activity	Clam	0	9			6	0	33	12	60
		Others	24	188,344			186,231	56,559	146,112	19,461	596,729
	Factors of production	Labour	18	217,936							217,954
		Capital	6	45,102							45,108
	Final consumption				217,954	45,108					263,062
	Investment						76,825		-838	-19,428	56,559
	Import	Rest of the world	12	145,295							145,307
		Kyoto	0	44							44
	Total		60	596,729	217,954	45,108	263,062	56,559	145,307	44	

(b) The rest of Kyoto Prefecture

Unit: Million JPY

			Expenditures								
			Factory activity		Factors of Production		Final consumption	Investment	Export		Total
			Clam fishery	Others	Labour	Capital			Rest of the world	Kyoto	
Receipts	Factory activity	Clam	0	149			156	0	14	0	320
		Others	10	4,322,650			4,637,268	1,408,344	3,627,688	44	13,996,005
	Factors of production	Labour	8	5,001,990							5,001,998
		Capital	3	1,033,812							1,033,815
	Final consumption				5,001,998	1,033,815					6,035,813
	Investment						1,398,388		-9,472	19,428	1,408,344
	Import	Rest of the world	287	3,617,943							3,618,230
		Kyoto	12	19,461							19,472
	Total		320	13,996,005	5,001,998	1,033,815	6,035,813	1,408,344	3,618,230	19,472	

3.3 Fish stocks

The fish stock is usually estimated by use of a certain stock assessment model. For example, the International Council for the Exploration of the Sea (ICES) applies the VPA model to estimate the index of abundance related to the fish population by age caught per tow given from a periodic vessel research survey (Gudmundsson, 1995; ICES, 2012). However, annual clam stocks are not known in the target fisheries because no previous survey of clam stocks has been undertaken. Furthermore, an estimation of aquatic resources involves a great degree of uncertainty of habitat environment. Therefore, taking account of the uncertainty by the data assimilation, the clam stocks are estimated. In the data assimilation, the clam catches and values of production are used as the observation data of the annual fisheries statistics of the Ministry of Agriculture, Forestry and Fisheries of Japan.

The predators stocks are more unclear. According to an interview to three clam fishermen in Maizuru on March, 2012, they recognize a recent increase of starfish and bladder moon shell, which are predator of the clam. Therefore, this study assumes that the predator increases after the clam seedling release and is an aggregate of multispecies with no data of the biology.

4 Parameter Identification

4.1 Observation function

The model parameters in the state variables vector of Eq. (5) are estimated by the extended Kalman filter. To consider both the fishing and trading of fish product, which influence on the fisheries productivity in the general equilibrium, the observation function vector of Eq. (6) is assumed as the mixed forms of $Z_{k,1}^{(1)}$ and $Z_{k,1}^{(2)}$.

$$\boldsymbol{h} = \left(p_{z1,1}\left(Z_{1,1}^{(2)} \right) Z_{1,1}^{(1)},\, p_{z2,1}\left(Z_{2,1}^{(2)} \right) Z_{2,1}^{(1)},\, Z_{1,1}^{*},\, Z_{2,1}^{*} \right)^{T} \quad (19)$$

$$Z_{k,1}^{*} = \alpha Z_{k,1}^{(1)} + (1-\alpha) Z_{k,1}^{(2)} = Z_{k,1},\; 0 \le \alpha \le 1 \quad (20)$$

where $Z^{*}_{k,1}$ is the extended catches with a weighting factor α.

4.2 Initial value

The parameter identification problem requires the initial values of model parameters. Thus, we determined the initial values of bioeconomic model parameters and initial clam stocks by the multiplier method without use of the CGE model (with observations of labour and capital), where a residual sum of squares between the estimates from Eq. (3) and the 1980–2006 observations of clam catches was minimized. Aside from this, we determined the two-country model parameters so that the equilibrium condition in the 1980 regional social accounting matrix can be satisfied (Kiyama, 2012). The initial state estimate error was assumed to be 10% at a maximum. Finally, the initial values of the state estimate and the covariance were obtained as listed in Table 2. The covariance matrix of system noise $\boldsymbol{R}$ was assumed to be one hundredth of the matrix $\boldsymbol{P}$. Table 3 shows the initial observations y and their covariance matrix $\boldsymbol{Q}$, where observation errors were assumed as 3% for Maizuru city (k = 1), and 5% for the rest of Kyoto prefecture (k = 2).

Table 2. Initial state variable and covariance

State variable	Unit	$\boldsymbol{x}(1\|1)$	$\boldsymbol{P}(1\|1)$
XM_1	t	771.6	5953.7
XM_2	t	15432	23815
SS_1	t	0	0.4402
Ke	kt/km^2	19.67	0.24
Vxs	y^{-1}	40.46	16.37
p_{m1}	-	0.107	0.000115
kq_{11}	-	0.3	0.0009
kq_{21}	-	0.3	0.0009
kf_{11}	-	-0.02	0.000004
kf_{21}	-	-0.02	0.000004

Table 3. Initial observation value and covariance

Observation variable	Unit	$\boldsymbol{y}$	$\boldsymbol{Q}$
PV_{11}	Million JPN	43.83	1.728
PV_{21}	Million JPN	30.17	2.276
Z_{11}	t	199	35.6
Z_{21}	t	137	46.9

4.3 Parameter estimates

Estimates of all parameters converge to certain values as the filtering progresses (see the estimates in 2000□2005, Fig. 7). From the shadowed area in Fig. 7 and the comparison of covariance between P(1|1) (Table 1) and P(27|27) (Table 3), that the covariance of model parameters decreases as the filtering step goes on. Therefore, it can be said that the parameters were reasonably estimated. By use of the final parameter estimates in Table 4, we estimate the clam stocks and perform the growth accounting of the clam fisheries. The estimates explains a fall of the long-term technological level (kq_{11} = 0.103) and a 10.6% incorporation of predator in the clam seedling bags (p_{m1} = 0.106).

Table 4. Final state variable and covariance

State variable	Unit	$\boldsymbol{x}$(27|27)	$\boldsymbol{P}$(27|27)
XM_1	t	353.1	470.5
XM_2	t	15618	18821
SS_1	t	25.1	3.3
Ke	kt/km^2	20.31	0.03
Vxs	y^{-1}	38.96	8.00
p_{m1}	-	0.106	0.00006
kq_{11}	-	0.103	0.00009
kq_{21}	-	0.143	0.00003
kf_{11}	-	-0.036	0.0000038
kf_{21}	-	-0.024	0.0000040

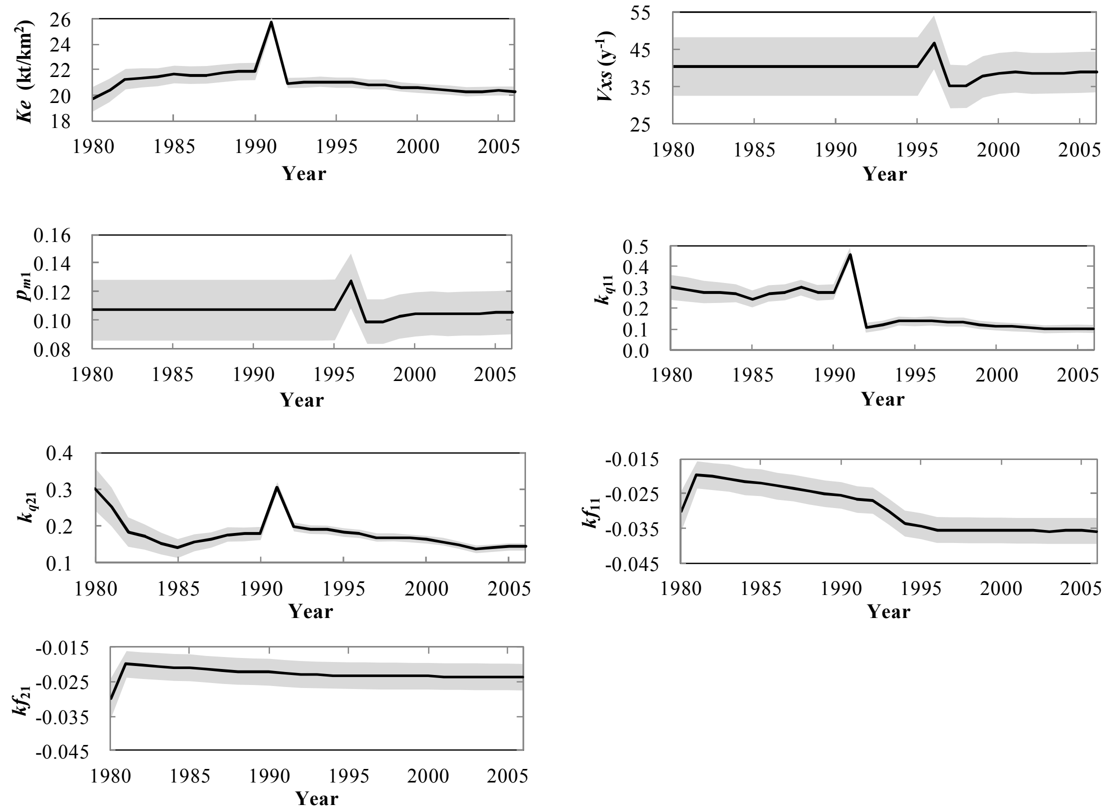


Fig. 7. Transition of parameter estimates

Note: Shadowed area is 95% confidence intervals.

5 Results

5.1 Clam stocks

Fig. 8 shows the prediction of clam stock, clam catches, predator stock, and the observation of clam catches in 1980–2006. Decompose the whole analytical period into four periods. Period I is a stable term that the fishery achieved a sufficient clam catches at around 200 tons (1980–1991). Period II is the term that the catches began to decrease over time (1991–1995). Period III includes the term that the fishery released the clam seedling as a measure for the sake of a recovery of the clam stock (1995–2000). Period IV describes that the catches decreased drastically (2000–2005).

We can see that the clam stock with a gradual downward trend is predicted during the periods I and II. In the subsequent period III, a temporal recovery is predicted because of both the seedling release and a small catch in the previous period II. In the period IV, feeding of the clam by the predator is dominant and the clam stock decreases by 39% of the 1980 stock.

However, there is some question as to too small catches. In fact, the 2006 clam catches is one hundredth of the peak value of clam catches, even though the stock decreases by about half. To answer this question, we further investigate other factors as ecological and general equilibrium effects.

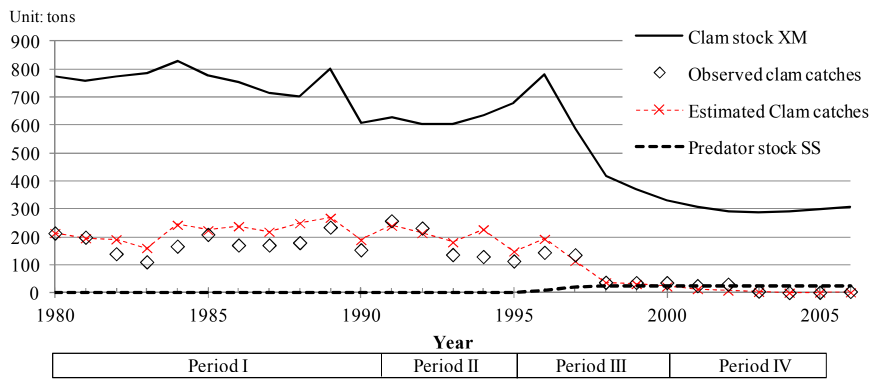


Fig. 8. Estimated clam stock, predator stock and clam catches

5.2 Predation

As an ecosystem-based assessment for the clam resource management, this model predicts a more detail mechanism of the clam resource depletion. Fig. 9 illustrates that the clam stock reduction rate by the feeding damage exceeds the stock reduction rate by the catch (fishing) since 1997. As a result, the natural growth rate of the clam decreases to be balanced with the clam reduction rate by the feeding damage. As a result, the recent amount of clam catches approaches asymptotically to zero. From this fact, it follows that a recovery of the clam stock will not be expected if some kind of ecological measure is taken.

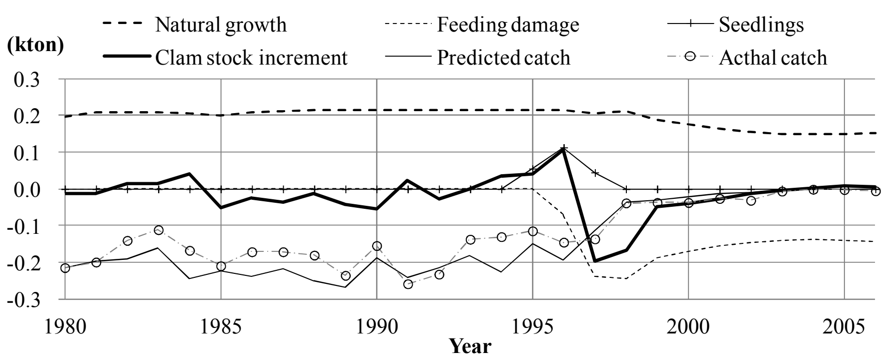


Fig. 9. Clam stock increment and its decomposition

5.3 Fishery in the whole economy

From a whole economy point of view, we investigate a temporal economic change of the Maizuru Clam Fisheries based on predictions of the identified CGE-ecosystem model. In the monetary balance between the clam catches and the amounts of supply destinations, the fisheries export a large part of the caught clam during the whole analytical period as shown by the sum of exports to the rest of Kyoto prefecture (ROK) and the rest of world (ROW) in Fig. 10. The ROW means foreign countries and Japan except Kyoto prefecture.

On the other hand, the supply of clam commodity in Maizuru highly depends on the import from the rest of world (Fig. 11). Additionally, the domestic supply of clams caught in Maizuru has a constant share in 1980–1995. However, the subsequent periods shows that the domestic supply gradually disappears while a supply share of the import from the ROW is close to 100%.

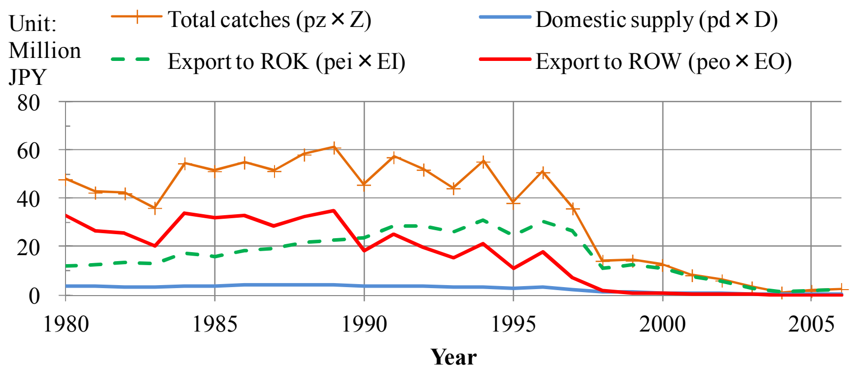


Fig. 10. Composition of clam commodity produced in Maizuru City
Notes: ROK is the rest of Kyoto prefecture. ROW is the rest of world.

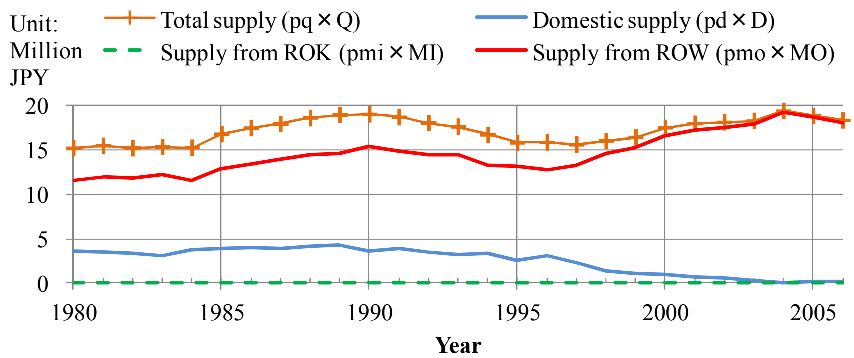


Fig. 11. Composition of clam commodity supplied in Maizuru City

This recent import dominance can be explained from a temporal change of the unit price of clam commodities. However, it should be noted that the price estimates from the CGE model describes relative change and therefore this paper assumes that all prices are initially set as the same value. In 1980s of plenty of domestic clam catches, the domestic production price is relatively lower than the import price from the ROW. However, the magnitude relation between these prices goes across since 1995. Especially, the model estimates a drastic increase in the domestic production price in 1997–2006, which corresponds to the periods not only of an accelerating increase of imported clam (Fig. 11) but also of a rapid decrease of clam stocks after the 1995–1997 clam seedling release. Since the import begins rising to supply the clam commodity in Japan (Fig. 1) before or after 1990, it can be said that the model reasonably predicts the transition of trading in the clam commodities. From the above discussions, the Maizuru Clam Fisheries is strongly subjected to the emergence of a low-price import clam as a trading policy (Fig. 12) as well as the predation of clam associated with the seedling releases as an ecological measure.

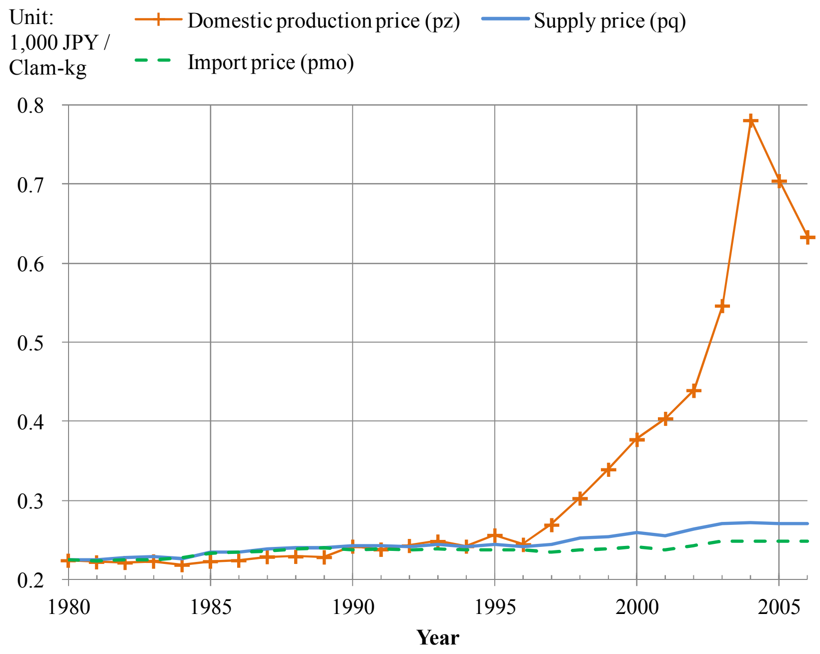


Fig. 12. Unit prices of clams

5.3 Growth accounting

The data for growth accounting are listed in Table 5, where the clam catches, labour, and capital are given from the statistics, and the clam stock is from the model identified by the extended Kalman filter (EKF model). The cost shares between the labour and capital are calculated by using the observed wage and capital rent.

To take account of the model dependency of growth accounting estimates, this study compares the conventional method with the method of the EKF model. The conventional method estimates the production function of Eq. (7) with the data of Table 5, by a regression analysis (RE). A good estimation is confirmed from test statistics as shown in Table 6. The initial technological level q_0 and the elasticity β are significant at the 1% level. However, the parameter describing a long-term trend of technological change kq has a relatively small t–value.

By the way, the EKF model parameter is q_0 = 0.0060, k_q = 0.1031, and β = 0.5. The difference of parameter estimates between two methods is thought to be due to the assumed model, i.e., whether the production function has been estimated in the dynamic general equilibrium or not. However, the relative error of parameter estimates is 25% at a maximum. Therefore, it can be said that the parameter estimates from these two methods is more or less the same and then the difference of estimates is insignificant in the interpretation of growth accounting.

Before discussion of the growth accounting, however, we investigate the predictability of the two models since the TFP (the Solow residual) is highly influenced. The fishery production function of Eq. (7) with parameter estimates determined from both the regression analysis (RE) and the extended Kalman filter (EKF) provides reasonable prediction in the catches in Fig. 13. This fact can also be confirmed from the correlation relation as shown in Fig. 14. However, the EKF model tends to overestimation and therefore the RE model seems to be more suitable for replication of the observations. Thus, we investigate the influence on the interpretation of the fishery development from the comparison of the RE model with the EKF model.

Table 5. Data for growth accounting

Year	Time step number t	Catches (tons) Z	Labour L	Capital K	Clam stock (tons) XM	Cost shares Labour S_L	Cost shares Capital S_K
1980	1	214	81.3	26.1	772	0.757	0.243
1981	2	199	75.2	25.5	758	0.754	0.246
1982	3	140	78.6	26.2	773	0.757	0.243
1983	4	111	68.0	22.3	787	0.767	0.233
1984	5	167	99.1	33.5	829	0.762	0.238
1985	6	209	94.3	33.7	777	0.733	0.267
1986	7	171	86.9	37.5	752	0.698	0.302
1987	8	171	91.8	36.6	715	0.710	0.290
1988	9	180	104.7	42.9	702	0.704	0.296
1989	10	235	124.9	49.2	800	0.703	0.297
1990	11	154	84.4	37.9	606	0.688	0.312
1991	12	258	109.8	46.6	629	0.700	0.300
1992	13	232	162.1	43.4	603	0.792	0.208
1993	14	137	92.5	37.0	602	0.716	0.284
1994	15	130	75.3	44.6	636	0.634	0.366
1995	16	114	56.9	27.8	677	0.677	0.323
1996	17	145	69.9	33.6	783	0.687	0.313
1997	18	136	81.0	28.9	586	0.750	0.250
1998	19	38	31.3	14.4	419	0.703	0.297
1999	20	37	26.7	14.8	370	0.655	0.345
2000	21	37	25.8	13.0	331	0.663	0.337
2001	22	26	18.2	8.9	305	0.684	0.316
2002	23	31	16.3	6.3	293	0.724	0.276
2003	24	6	7.2	2.7	288	0.722	0.278
2004	25	1	1.6	0.7	291	0.691	0.309
2005	26	2	1.9	1.1	299	0.622	0.378
2006	27	5	3.0	1.8	305	0.621	0.379

Table 6. Result of estimated nonlinear regression model

Variables	Estimate	Standard error	t−value	Pr(>|t|)
q_0	0.0045 **	0.00122	3.71	0.00109
k_q	0.0843	0.05016	1.68	0.1059
β	0.6271 **	0.21465	2.921	0.00748
No. of obseervations	27			
Durbin−Watson statistic	1.5800			
R^2	0.9127			

Notes: **Significant at the 1% level; Pr is a significant probability relevant to the *t*-value.

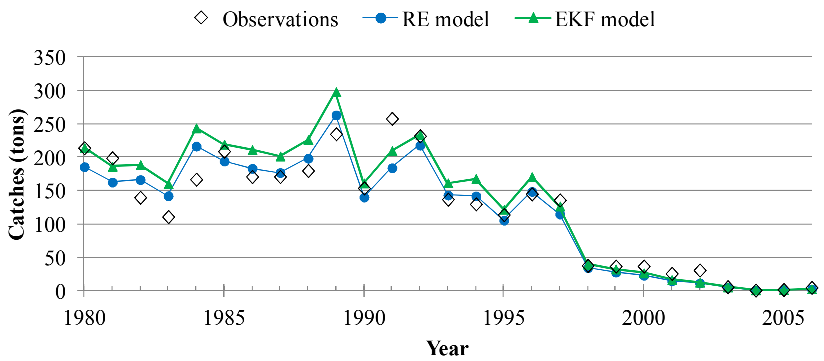


Fig. 13. Comparison of catches predicted from regression model and EKF model

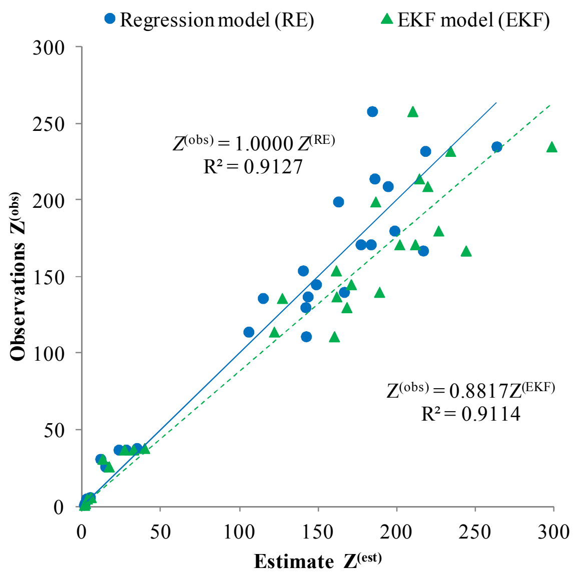
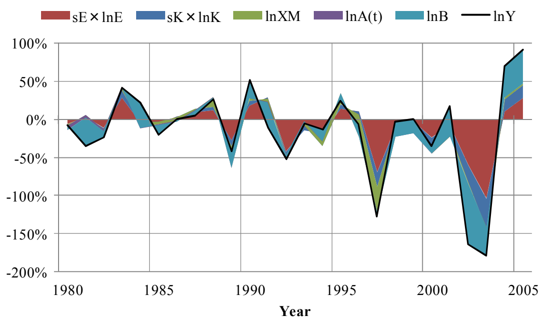


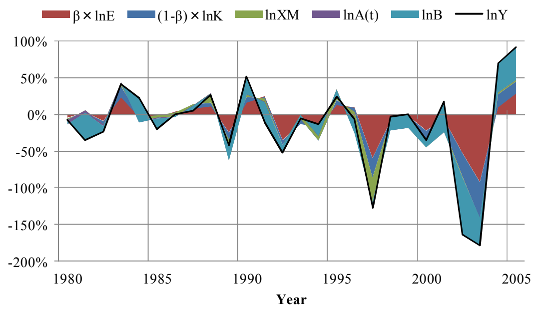
Fig. 14. Correlation between observations and estimations in the clam catches

The fisheries growth rate and its decomposed factors (the labour, capital, clam stock, and TFP) are shown in Fig. 16, where the TFP consists of the long-term trend A and the rest of TFP B (see Eq. (10)). Two cases are assumed in the Tornqvist approximation. One is that the cost shares in place of the elasticity in Eq. (12) are used in the approximation (Hulten, 1986). The other is that the elasticities estimated from the RE model and the EKF model are used. From both the comparison between Figs. 15(a) and (b), and the comparison between Figs. 15(c) and (d), it is found that factors contribution to the economic growth is almost the same between the cost shares or the elasticity. Furthermore, for example, from the comparison between Figs. 15(a) and (c), it is found that the appearance of factors contribution is similar between the RE model and the EKF model. Therefore, it can be said that the EKF method provides robust estimates.

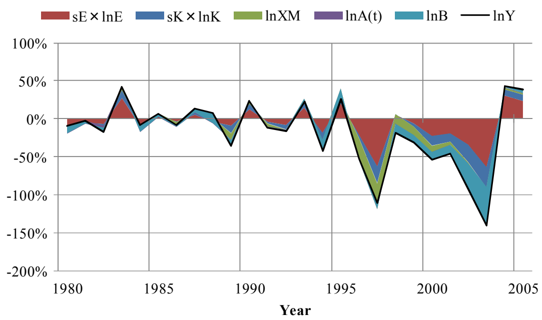
These interannual growth accountings show a significant decrease in the rate of fishing efforts (the labour and capital) with considerable decrease in clam catches in 1991–1992, 1996–1997, and 2002–2003 (see the red and blue areas in Fig. 15). In addition, falling clam stocks largely contributed to decreasing clam catches in 1996–1997 (see the green area in Fig. 15). The long-term trend of TFP, $A(t)$, explains a considerably lower proportion of the growth rate compared to the rest of TFP, B.



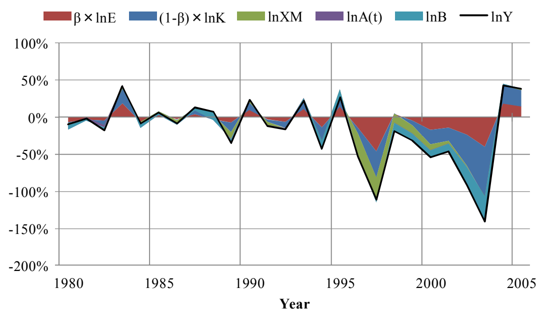
(a) RE model with cost shares sE and sK



(b) RE model with elasticity β



(c) EKF model with cost shares sE and sK



(d) EKF model with elasticity β

Fig. 15. Comparison of factors contribution in fishery growth rate

Average Tornqvist indices for the four periods I, II, III and IV are calculated from Eq. (12). Tables 7 (a)–(c) shows the results from different three calculation methods, i.e., two calculations by use of the cost shares and the elasticity in the RE model, and a calculation by use of the elasticity in the EKF model. From the comparison of Tables 7(a), (b) and (c), it is found that the Tornqvist indices are almost the same and we can have a unique explanation why the fishery continues a very small catches. In what follow, we discuss the reason of continuing small fishery activities by use of Table 7(c).

From 1980 to 1991, fisheries caught a large amount of clams, and the output increased by 1.7% per year, but clam stocks decreases by 1.9% per year. TFP and its long-term trend A decreased annually by 0.4% and 2.3%, respectively. In the subsequent four-year period, 1991–1995, output decreased by 20.4% per year, which is 5.7% more than the input reduction rate, and clam stocks increased by 1.8% per year. The change in TFP explains the maximum decrease, 7.6% per year. Both output and input further decreased during 1995–2000 by 22.5% and 15.5% per year, respectively, and the clam stock decreased significantly by 14.3% per year. The TFP change reversed to a 7.3% increase per year. Both output and input showed the maximum rate of decrease per year during the 2000–2005 periods: 58.4% and 50.2%, respectively. Meanwhile, the rate of decrease in the clam stock diminished to 2.1% per year, and TFP decreased by 6.1% per year, with a long-term trend of 0.4%.

Table 7. Factors growth rate and contribution ratio

(a) Calculation with cost shares in regression model

Period	Year	Output (O)	Input ($I = L + K$)	O - I	Labor (L)	Capital (K)	Fish stock (XM)	TFP (Ac = O - I - XM)	Trend of technological change (A)	B (TFP - A)
I	1980 -	0.017	0.034	-0.017	0.020	0.014	-0.019	0.001	-0.019	0.020
	1991	100	201	-101	117	84	-109	8	-112	120
II	1991 -	-0.204	-0.153	-0.051	-0.113	-0.040	0.018	-0.069	-0.006	-0.063
	1995	100	75	25	55	20	-9	34	3	31
III	1995 -	-0.225	-0.156	-0.069	-0.106	-0.050	-0.143	0.074	-0.005	0.078
	2000	100	69	31	47	22	63	-33	2	-35
IV	2000 -	-0.584	-0.507	-0.077	-0.335	-0.172	-0.021	-0.056	-0.004	-0.053
	2005	100	87	13	57	29	4	10	1	9

(b) Calculation with elasticities from regression model

Period	Year	Output (O)	Input ($I = L + K$)	O - I	Labor (L)	Capital (K)	Fish stock (XM)	TFP (Ac = O - I - XM)	Trend of technological change (A)	B (TFP - A)
I	1980 -	0.017	0.037	-0.020	0.017	0.020	-0.019	-0.001	-0.019	0.018
	1991	100	217	-117	101	116	-109	-8	-112	104
II	1991 -	-0.204	-0.151	-0.053	-0.103	-0.048	0.018	-0.071	-0.006	-0.065
	1995	100	75	25	51	24	-9	34	3	31
III	1995 -	-0.225	-0.156	-0.069	-0.099	-0.057	-0.143	0.074	-0.005	0.078
	2000	100	69	31	44	25	64	-33	2	-35
IV	2000 -	-0.584	-0.506	-0.077	-0.325	-0.181	-0.021	-0.057	-0.004	-0.053
	2005	100	87	13	56	31	4	9	1	8

(c) Calculation with elasticities identified by the EKF model

Period	Year	Output (O)	Input ($I = L + K$)	O - I	Labor (L)	Capital (K)	Fish stock (XM)	TFP (Ac = O - I - XM)	Trend of technological change (A)	B (TFP - A)
I	1980 -	0.017	0.040	-0.023	0.014	0.026	-0.019	-0.004	-0.023	0.019
	1991	100	236	-136	80	155	-109	-27	-137	110
II	1991 -	-0.204	-0.147	-0.057	-0.082	-0.065	0.018	-0.076	-0.007	-0.068
	1995	100	72	28	40	32	-9	37	4	33
III	1995 -	-0.225	-0.155	-0.070	-0.079	-0.076	-0.143	0.073	-0.006	0.078
	2000	100	69	31	35	34	64	-33	3	-36
IV	2000 -	-0.584	-0.502	-0.081	-0.259	-0.243	-0.021	-0.061	-0.004	-0.056
	2005	100	86	14	44	42	4	10	1	9

Note: Upper value is calculated from Eq. (12). Lower is a percentage of factors contribution to the output.

From 1980 to 1991, fisheries caught a large amount of clams, and the output increased by 1.7% per year, but clam stocks decreases by 1.9% per year. TFP and its long-term trend A decreased annually by 0.4% and 2.3%, respectively. In the subsequent four-year period, 1991–1995, output decreased by 20.4% per year, which is 5.7% more than the input reduction rate, and clam stocks increased by 1.8% per year. The change in TFP explains the maximum decrease, 7.6% per year. Both output and input further decreased during 1995–2000 by 22.5% and 15.5% per year, respectively, and the clam stock decreased significantly by 14.3% per year. The TFP change reversed to a 7.3% increase per year. Both output and input showed the maximum rate of decrease per year during the 2000–2005 periods: 58.4% and 50.2%, respectively. Meanwhile, the rate of decrease in the clam stock diminished to 2.1% per year, and TFP decreased by 6.1% per year, with a long-term trend of 0.4%.

From this result, it is found that the output decrease can be explained by two contribution patterns of labour, capital, clam stocks, and TFP. One is a high contribution ratio of labour and capital inputs. In fact, the contribution ratios of these inputs were calculated as 72% and 86% for 1991–1995 and 2000–2005, respectively. Additionally, growth accounting reveals excessive inputs of labour and capital even in the stable fishing conditions of 1980–1991 (the contribution ratio of 236%). This means that the clam fishery potentially carries a burden associated with inputs of production factors. The other is a high contribution ratio of clam stocks. During the 1995–2000 period, the contribution ratio of clam stock reached 64%. This period coincides with the clam stock reduction from feeding damage after seedling release. Growth accounting sheds light on the factors that decrease clam catches. Thus, clam fishing in Maizuru Bay is a potentially excess-input industry, and on that basis, an improper seedling release for the clam stock management leads to the resource depletion and an additional remove from the clam fishing.

6 Conclusion

This paper demonstrates the possibility of concurrent estimation of a low-trophic species stocks and technological change trend for less-competitive fisheries by application of the extended Kalman filter. Additionally, combining the predator-prey bioeconomic model with the CGE model enables to describe the relationship between small-scale fisheries and global economy. An empirical study elucidated the causes of the Japanese clam fishery as comprehensive issues, such as the improper ecological measure, market-dominant import clam, recessive technological level over time and latent excessive input industry. As a result, the fishery continues to withdraw from clam fishing without a recovery of the clam resource stocks. This fact sheds light on a hard problem to perform fishery assessment due to the uncertainty of economy and ecosystems and lack of stock surveys or observations.

However, this developed method is just applied to one empirical study. Therefore, more empirical analyses are needed to verify this methods applicability. At the same time, it is necessary to examine whether this model maintains consistency with the conventional stock assessment model such as VPA, otherwise how this model should be arranged to achieve compliance with the conventional method.

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