Bull. Fish. Sci. Hokkaido Univ.
62(3), 75-82, 2012.

Fishery Income Fluctuation with Changing Social Situation and Selecting Fishing Ground, in the Japanese Coastal Squid Jigging Fishery (1975–2008)

Osamu TAMARU[1)], Kazushi MIYASHITA[2)], Nobuo KIMURA[3)], Yasuzumi FUJIMORI[4)], Hideo TAKAHARA[1)] and Teisuke MIURA[5)]

(Received 31 August 2012, Accepted 11 September 2012)

Abstract

In recent years in Japan, falling fish prices and rising fuel costs have worsened the economic conditions for many fisheries-dependent households. Many fishermen select the fishing ground in which they anticipate they can maximize their total catch, even when such grounds are far from their home harbor. As a result, fishermen have the potential to select a fishing ground in which they do not maximize their income. Especially the Japanese coastal squid jigging fishermen need to develop energy-saving squid jigging fishery practices, because of the high fuel consumption in comparison to other fisheries. By using the Management Simulation Method, we show that income fluctuations are caused by various factors. We used social factors and fishing ground factors in this simulation. According to the simulation results, small changes in social and fishing ground situations can result in changes in selection of the optimal fishing grounds. We conclude that the selection of fishing grounds by fishermen based only on their own knowledge and/or intuition might not result in choices that maximize their income, and it is necessary to develop objective methods to choose the fishing ground in which they can maximize their income.

Key words : Squid jigging fishery, Income fluctuation, Selecting fishing ground, Social situation

Introduction

In recent years in Japan, falling fish prices and rising fuel costs have worsened the conditions for many fisheries-dependent households. It was indicated that there are two reasons that managements of fisheries households were not affected by the past two oil crisis. The first reason is that many fisheries households had resources to spare. The second reason is that fish prices were comparatively high (Baba, 2008a-c). But now in Japan, many fisheries households do not have spare resources. So, we think that it is necessary to examine the changes in social factors and to enable an optimal choice in each situation.

However, without extensive data to predict fuel cost, fish price, making a selection of fishing ground and fish stock is very difficult with a goal for optimizing economic return. So fishermen have operated their fisheries based on their own knowledge and / or intuition, without a scientific basis to model economic return.

In addition, people make a choice which they think is optimal, and they only make a risky choice when they are in a bad situation (Kahneman and Lovallo, 1993 ; Tversky and Kahneman, 1992 ; Kikuzawa, 2006 ; Furuyama, 2008). In addition, people do not make an optimal choice as only high expected value, but as considering many factor such as St. Petersburg's paradox, M. Allais's paradox, bias of certainty, loss aversion, aversion of ambiguity, framing effects and status quo effects (Fukuda, 2003). These indications mean many Japanese coastal squid jigging fisheries-dependent households, in economic hardship, might make a risky choice at their own fisheries management.

Japan had gone through the second oil crisis in 1970s, the bubble economy (favorable business condition) in later 1980s, following the collapse of the bubble economy, and the deflation era in early 1990s and the third oil crisis in recent years. In addition, squid prices have decreased with deflation, and many Japanese squid jigging fisheries households are in financial crisis now. So, we think it is important to increase fishery income by examining measures to optimize choice design based on fluctuation of fuel cost, fish price, selection of fishing ground and so on.

Fishery income consists of sale of catch and cost of operating. Thus, if squid jigging fishermen want to increase their income, it is necessary to increase sales and/or decrease cost. The sale of catch is made up of catch and price of squid, so we should know that relationship between catch and price of squid.

Surveying real income in all social situations and operating

1) *National Research Institute of Fisheries Engineering, Fisheries Research Agency*
2) *Laboratory of Marine Ecosystem Change Analysis, Field Science Center for Northern Biosphere, Hokkaido University*
3) *Laboratory of Marine Industorial Science and Technology, Graduate School of Fisheries Science, Hokkaido University*
4) *Laboratory of Marine Bioresource and Environment Sensing, Graduate School of Fisheries Science, Hokkaido University*
5) *Hokkaido Industrial Technology Center*

conditions is not feasible because conditions of fisheries operations change from hour to hour and social situations also change. Therefore, in this study, we pay attention to a method of simulation in which we can set situations and conditions with ease.

In fisheries science, simulation methods are in use for clarifying the marine ecosystem (Suzuki et al., 1979 ; Kishi, 2008), managing fish resources (Kato and Matsumiya, 1993 ; Katsukawa, 2004, 2007 ; Hiramatsu, 2004, Wakayama et al., 2006 ; Wakayama, 2008), modeling net motion in sea water (Takagi et al., 2002, 2004 ; Kudo, 2004), modeling fish schooling behavior (Suzuki, 2006) and trying to select fishing grounds (Tameishi, 1999 ; Hara et al., 2009 ; Yoshinaga et al., 2004). However, until now, there is no study clarifying fluctuations of squid jigging fishery income and environmental damage caused by changing of social situations and fishery operating conditions.

So, the objective of this study is clarifying fluctuations of Japanese squid jigging fishery income in relation to changing social situations and operating conditions, by using the fishery income simulation model from departure from port to return to the port.

Materials and methods

Classifying the social situations

We classified the yearly social situations using the criteria 1) average price of the type A oil, 2) average price of the fresh squid, 3) average employment cost and 4) total catch of fresh squid.

We extracted the yearly average nominal prices of the type A oil from the homepage of the Bank of Japan, and estimated the yearly average real prices by compensating with the consumer price index. We extracted the yearly average nominal prices for fresh squid from the Annual Statistics of Fishery and Fish Culture by Ministry of Agriculture, Forestry and Fisheries, and estimated the yearly average real prices of the fresh squid by compensating with the consumer price index. The yearly average employment nominal costs of the coastal squid jigging fishery were picked up from the homepage of the National Fishermen Recruit and Training Center, and yearly average employment real costs were estimated by using wage rate index of agricultural seasonal laborers.

After we obtained all parameters, we classified the social situations by using hierarchical cluster analysis whose parameters 1)-4) of yearly average real price of the type A oil, yearly average real price of the fresh squid, yearly average real employment cost and yearly total catch of fresh squid. In this analysis, Euclidean distance was used as distance. We classified 5 clusters by using the group average method. After we identified 5 types of social situation, we quantified the characteristics of each cluster using principal component analysis based on parameters of yearly average real price of the type A oil, average real price of the fresh squid, average real employment cost and total catch of fresh squid.

Finally, we compared yearly average real price of the fresh squid to yearly total catch of fresh squid for clarifying relationship between price and catch of fresh squid.

Construction of the fishery income simulation model

We constructed a fishery operating simulation model for estimating fishery income in each operation. Steps of the procedure were as follows :

The fuel consumption in liters per km of Hamade-Maru moving at 10 knots, regular vessel speed from the harbor to the fishing ground, was 4.71 l/km (measured value). The fuel consumption (F_m in liters) when Hamade-Maru moves d km can be expressed as a function of the distance (d in km)

$$F_m = 4.71 \times d \tag{1}$$

During squid jigging operations of Hamade-Maru, fish lamps whose wattage is 180 kW are powered by auxiliary engines. The fuel consumption at squid jigging operation (F_o in liters) can be expressed as a function of the operating time (T_o in min) and the fuel consumption rate (P_o in l/min), where P_o was 0.80 in l/min (measured value).

$$F_o = T_o \times P_o \tag{2}$$

When fishermen select other fishing grounds n times, the total fuel consumption through all processes (F in liters) is

$$F = \sum_{k=1}^{n+1} F_{mk} + \sum_{k=1}^{n} F_{ok} \tag{3}$$

where F_{mk} means the fuel consumption for the k moving process, and F_{ok} means the fuel consumption for the k squid jigging operation.

In this study, the cost of the coastal squid jigging fishery was constructed of the fuel cost, the employment cost and the cost of the foam polystyrene cases used to box fresh squid with ice. The total fuel cost through all processes (Q in JPY) can be expressed as a function of the total fuel consumption through all processes (F in liters) and the fuel rate of type A oil (R in JPY/kg).

$$Q = F \times R \tag{4}$$

The cost of the foam polystyrene cases to box fresh squids with ice (W in JPY) can be expressed as a function of the amount of catch (C in case), the unit price of a foam polystyrene case (y in JPY/case), the unit price of ice (i in JPY/kg), and the total amount of ice (j in kg).

$$W = C \times y \times i \times j \tag{5}$$

The sales of catch (Y in JPY) can be expressed as a function of the amount of catch (C in case), and the unit price of fresh squid (r in JPY/case).

$$Y = C \times r \tag{6}$$

So, the fishery income in one operation (O in JPY) is

$$O = Y - Q - M - W \quad (7)$$

where M is the employment cost in JPY/day.

Results

Transition of the parameters

The real price of type A oil continued at a high level in the second oil crisis (1979–1988) and the third oil crisis (2004–2008) (Fig. 1). The real price of fresh squid continued at a high level in the 1970s–1980s, and changed to a low level (1/3 of the high level) in 1990s–2006 (Fig. 2). The employment cost has continued to increase every year, and the employment cost in recent years is 1.25 times more than the employment cost in the second oil crisis (Fig. 3). The catch of fresh squid continued at a low level until 1990, and has increased at a faster rate after 1990 (Fig. 4).

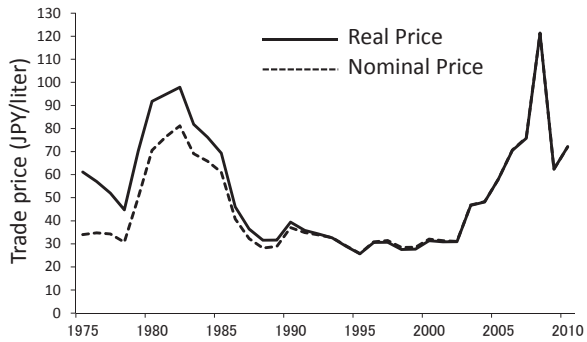

Fig. 1. Secular change of type A oil price.

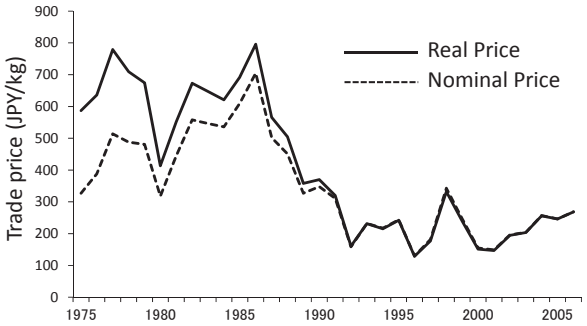

Fig. 2. Secular change of fresh squid trade price.

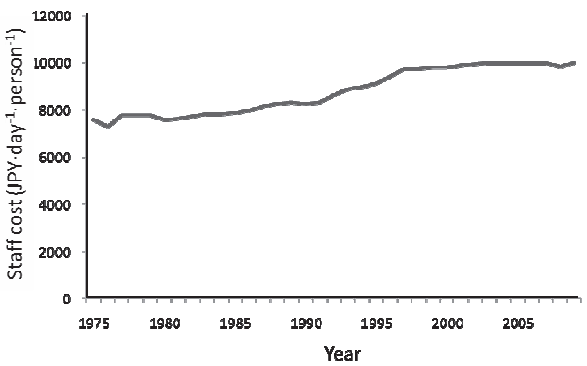

Fig. 3. Secular change of crew's staff cost.

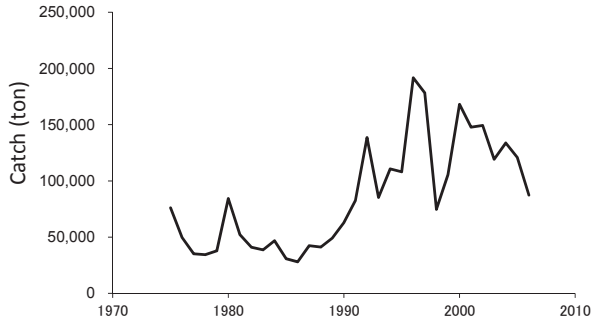

Fig. 4. Secular change of catch of fresh squid.

Classification by social situations

Fig. 5 shows the results of hierarchical cluster analysis using parameters are yearly 1) average real price of the type A oil, 2) average real price of the fresh squid, 3) average real employment cost and 4) total catch of fresh squid. The Y-axis means the indicator of similarity. We determined the similarity is 1.5, and classified 5 clusters. The first cluster contained 1975–1979 and 1983–1986 (before and after the second oil crisis), the second cluster contained 1980–1982 (second oil crisis), the third cluster contained 1987–1991 (bubble economy), the fourth cluster contained 1992–2002 (following the collapse of the bubble economy, and deflation era) and the fifth cluster contained 2003–2008 (third oil crisis).

Fig. 6 shows the results of principal component analysis whose parameters are yearly 1) average real price of the type A oil, 2) average real price of the fresh squid, 3) average real employment cost and 4) total catch of fresh squid. The first principal component is (unit price of fresh squid × 0.649) + (unit price of type A oil × 0.431) – (employment cost × 0.627). So, forward direction of X-axis indicates increasing unit price of fresh squid and decreasing employment cost. The second principal component is (unit price of type A oil × 0.897) + (employment cost × 0.378) – (unit price of fresh squid × 0.230). So, forward direction of Y-axis indicates increasing unit price of type A oil.

The first cluster contained 1975–1979 and 1983–1986, the second cluster contained 1980–1982, the third cluster con-

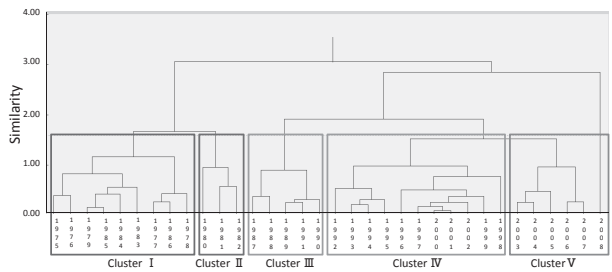

Fig. 5. Result of cluster analysis of income determination parameters.

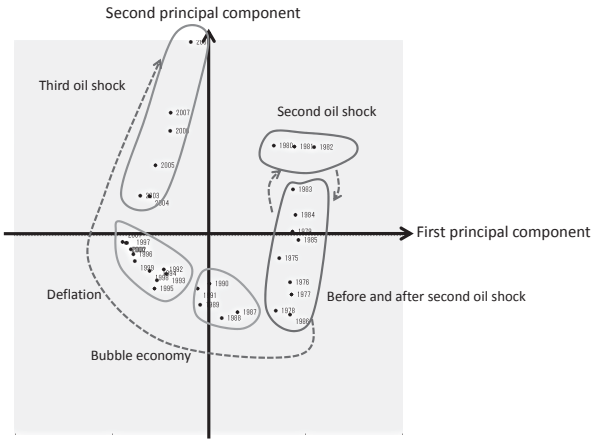

Fig. 6. Result of principal component analysis of income determination parameters.

tained 1987–1991, the fourth cluster contained 1992–2002 and the fifth cluster contained 2003–2008.

Relationship between catch and price of squid

The unit price of fresh squid decreased with the increase in total catch of squid (Fig. 7). This trend was similar to the commonly used demand–and–supply curve.

Fig. 8 shows relationship between the annual total amount

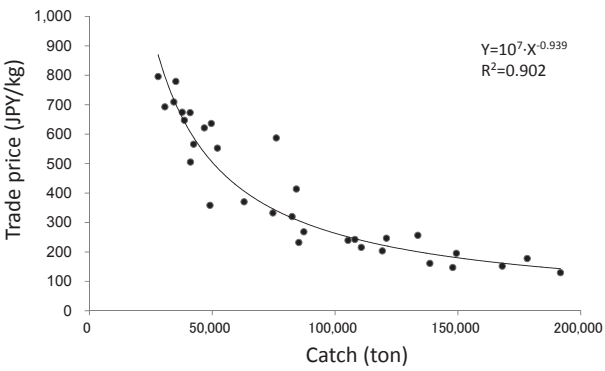

Fig. 7. Relationship between catch and trade price of Japanese common squid.

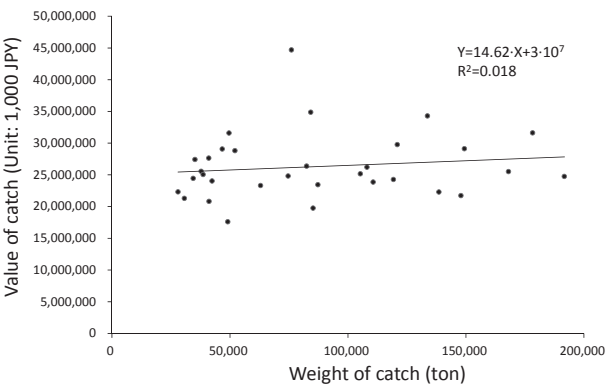

Fig. 8. Relationship between weight and price of catch of Japanese common squid.

Table 1. Fuel consumption in each distance from harbor to fishing ground.

Distance from harbor to fishing ground (km)	fuel consumption (kg)	
	move	operation
10	69,900	509,886
20	139,800	470,664
30	209,700	431,442
40	279,600	392,220

of catch and the total sales of catch in the coastal squid jigging fishery (1975–2006). There was no correlation between the amount of catch and the total value of fresh squid. And this trend indicates that the total value of fresh squid did not increase with the increase in total amount of catch.

Relationship between distance from harbor to fishing ground and fuel cost

The fuel consumption when operating squid jigging at 30 km, 20 km and 10 km from the harbor was 95%, 91% and 86% of the consumption when operated in 40 km (Table 1).

Income fluctuation in each situation and condition

In 2009, Hamade–Maru operated 181 times, and the average amount of squid caught during one operation by Hamade–Maru was 214 cases.

The class with the highest frequency was the 0–50 cases class, and the frequency decreased with the increase in catch (number of cases) of squid (Fig. 9). We categorized catch of squid classes into four catch levels as very poor catch (0 to 50 cases per day), poor catch (50 to 150 cases per day), regular catch (150 to 350 cases per day) and good catch (over 350 cases per day) (Table 2). Representative values in the third oil crisis used in the fishery income simulation are 50 cases (very poor catch), 100 cases (poor catch), 200 cases (regular catch) and 350 cases (good catch).

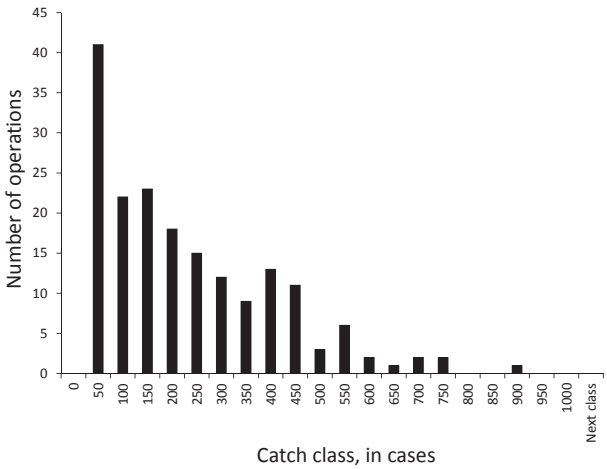

Fig. 9. Frequency distribution of number of operations in each catch class.

Table 2. Frequency distribution of number of operations in each catch class.

Type of catch class	Catch class (case)	Frequency	Relative frequency (%)	Cumulative frequency (%)	Relative frequency (%)
Very small catch	0-50	41	22.7	22.7	22.7
Small catch	50-100	22	24.9	34.8	12.2
	100-150	23		47.5	12.7
Normal catch	150-200	18	29.8	57.5	9.9
	250-300	15		65.7	8.3
	300-350	12		72.4	6.6
Large catch	350-400	9	27.6	77.3	5.0
	400-450	13		84.5	7.2
	450-500	11		90.6	6.1
	500-550	3		92.3	1.7
	550-600	6		95.6	3.3
	600-650	2		96.7	1.1
	650-700	1		97.2	0.6
	700-750	2		98.3	1.1
	750-800	2		99.4	1.1
	800-850	0		99.4	0.0
	850-900	0		99.4	0.0
	900-950	1		100.0	0.6
Total		181			

But, the yearly total catch of fresh squid fluctuated (Fig. 4), because the stock of squid changed (Shikata, 2009) and fishing intensity went up as the years has increased. So, we defined the representative value of before and after the second oil crisis, the second oil crisis, the bubble economy and following the collapse of the bubble economy, and the deflation era as 36%, 51%, 48% and 115% of the representative values of the third oil crisis.

In the fishery income simulation, the distance from the harbor to the fishing ground was changed from 10 km to 40 km, and the catch level was also changed from the very poor catch to the good catch in each social situation.

When the fishing ground is located at 40 km far from the harbor, following the collapse of the bubble economy, and the deflation era is the situation that fishermen receive the highest income for the very poor catch condition, before and after the second oil crisis is the situation that fishermen receive the highest income for the poor catch condition, and the second oil crisis is the situation that fishermen receive the highest income for the regular and good catch conditions (Table 3).

When the fishing ground is located at 30 km far from the harbor, following the collapse of the bubble economy, and the deflation era is the situation that fishermen receive the highest income for the very poor catch condition, before and after the second oil crisis and the second oil crisis are the situations that fishermen receive the highest income for the poor catch condition, and the second oil crisis is the situation that fishermen receive the highest income for the regular catch condition, and the third oil crisis is the is the situation that fishermen receive the highest income for the good catch condition.

When the fishing ground is located in 20 km far from the harbor, following the collapse of the bubble economy, and the deflation era is the situation that fishermen receive the highest income for the very poor catch condition, the before and after the second oil crisis and the second oil crisis are the situations that fishermen receive the highest income for the poor catch condition, and the second oil crisis is the situation that fishermen obtain the highest income for the regular and good catch conditions.

When the fishing ground is located at 10 km far from the harbor, following the collapse of the bubble economy, and the deflation era is the situation that fishermen receive the highest income for the very poor catch condition, the second oil crisis is the situation that fisherman get highest income at the poor, the regular and the good catch conditions.

On the other hand, income at the third oil crisis is the lowest for all catch levels and for all fishing grounds.

Principal component analysis

Both the unit price of fresh squid and the unit price of type A oil were at a high level in the second oil crisis (Fig. 6). After that, the unit price of fresh squid became lower, but the unit price of type A oil remained elevated at the level of before and after the second oil crisis. After the collapse of the bubble economy, the unit price of fresh squid remained at a low level even as the unit price of type A oil increased at a

Table 3. Fishery income fluctuation calculated by the fishery income simulation, by selecting the fishing grounds and changing the catch levels in each social situation.

Catch (case)	Income (Unit : 10,000 ¥)				
	Before and after second oil shock	Second oil shock	Bubble economy	Deflation	Third oil shock
50	3.4	2.0	3.7	4.6	−2.2
100	13.2	13.0	11.7	12.9	6.8
200	32.7	34.7	27.3	27.5	23.2
350	61.7	66.9	50.7	48.8	47.3

Distance from harbor to fishing ground is 40 km.

Catch (case)	Income (Unit : 10,000 ¥)				
	Before and after second oil shock	Second oil shock	Bubble economy	Deflation	Third oil shock
50	3.6	2.4	3.8	4.8	−1.7
100	13.4	13.4	11.8	13.0	7.2
200	32.9	35.0	27.5	27.6	23.6
350	61.9	67.3	50.8	48.9	47.7

Distance from harbor to fishing ground is 30 km.

Catch (case)	Income (Unit : 10,000 ¥)				
	Before and after second oil shock	Second oil shock	Bubble economy	Deflation	Third oil shock
50	3.8	2.7	3.9	4.9	−1.3
100	13.7	13.7	11.9	13.2	7.7
200	33.1	35.4	27.6	27.8	24.0
350	62.1	67.6	50.9	49.0	48.1

Distance from harbor to fishing ground is 20 km.

Catch (case)	Income (Unit : 10,000 ¥)				
	Before and after second oil shock	Second oil shock	Bubble economy	Deflation	Third oil shock
50	4.1	3.1	4.1	5.0	−0.8
100	13.9	14.1	12.1	13.3	8.1
200	33.3	35.7	27.7	27.9	24.5
350	48.7	66.9	50.7	48.8	47.3

Distance from harbor to fishing ground is 10 km.

faster rate. So, the rate of rise of expenditure in recent years is caused by the increasing of the unit price of type A oil and decreasing of the unit price of the fresh squid.

Discussion

We discuss about the relationship between yearly average unit price of the fresh squid and yearly total catch of fresh squid. In the squid jigging fishery, increasing total weight of catch did not lead to an increase of the total value of the catch (Fig. 8). It is indicated that the decrease of total catch of fish did not cause an increase in the unit price of catch in recent years, because of two factors (MAFF, 2008). The first factor is the increase in imported aquatic products, and the second factor is the wide gap between supply and demand of fishery products. So, it is assumed that the effective method for improving the management of squid jigging fisheries households is not increasing of weight of catch but decreasing the cost.

The estimated incomes in the third oil crisis were lowest in all social conditions despite the catch condition. On the other hand, the estimated incomes in the third oil crisis were

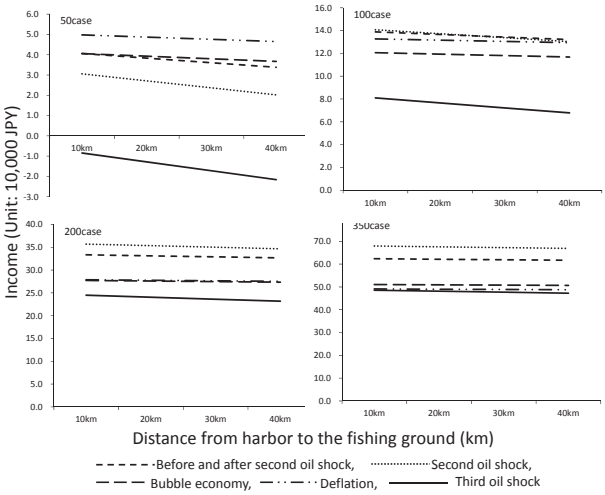

Fig. 10. Relationship between the distance from harbor to fishing ground and fishery income in each era.

at a high level for the regular and good catch conditions, although the incomes to the very poor and poor catch conditions were at a low level. So, in the third oil crisis fishermen can not operate an optimal fishing in a similar way that operated in the second oil crisis. One of the reasons that management of squid jigging fisheries households had not been in crisis at past two oil crisis was that the unit price of squid was above standard in the second oil crisis, as indicated by Baba (2008a-c).

The additional cost caused by increasing the distance from the harbor to the fishing ground was larger in the second oil crisis and the third oil crisis than other eras (Fig. 10). Total fuel consumption calculated by the fuel consumption simulation from Hamade-Maru became higher as the distance from the harbor to the fishing ground increased (Table 1). So, operating squid jigging fishery near the harbor without decreasing of squid catch increases fishery income.

In the present circumstances, fishermen can not know the expected catch of squid before they leave port, so we can not use fishery income simulation for estimating anticipated profit.

There are previous researches about attempting to forecast catch of fish and where fishing grounds are formed (Hara et al., 2009 ; Yoshinaga et al., 2004). The distribution of Japanese common squid is affected by sea temperature (Fukuda et al., 1991a-b), and searching technology of fishing ground advance in squid jigging fishery (Tameishi, 1999). In addition, there is a study attempted to share information of fishing ground using the Marine Broadband (Wada and Hatanaka, 2009). On the other hand, there is a previous study to maximize anticipated value of agricultural income with mathematical model designed with uncertainty factor, in cropping plan (Ito, 2006). Thus, we believe that we can forecast the catch of squid before leaving port and selecting the fishing ground in the future.

The fishery income simulation model makes it possible to quantify the coastal squid jigging fishery in terms of fisheries management, and based on the simulation results, just a little changes of social and fishing ground situations can change the optimized fishing ground for maximizing fishermen's income.

Conclusion

So, we concluded that fishermen selecting fishing grounds only with their own knowledge and/or intuition might not choose the fishing ground in which can maximize their income, and it is necessary to develop the scientific methods to select fishing grounds which can maximize their income. But, the unconsidered factors, i.e. skills of fishermen and oceanic condition, have the potential to change product system of fishery significantly (Yamashita, 2003). So, it is necessary to compare actual measurements in real operations and results estimated by operating simulation for improving the precision of estimated value as future works.

Acknowledgements

The authors thank Shigeto Hamade, director of Towa Denki Seisakusho Co. Ltd., and Masashi Honma, captain of Hamade-Maru for supporting this research. This article is a part of the doctoral thesis entitled "Quantitative assessment of fishery operation of Japanese coastal squid jigging fishery" and submitted to the Graduate School of Fisheries Science, Hokkaido University (2010).

References

Baba, Y. (2008a) Inflationary crude oil prices and fishery I. *Bull. Jpn. Soc. Sci. Fish.*, **74**, 738-739 (in Japanese).

Baba, Y. (2008b) Inflationary crude oil prices and fishery II. *Bull. Jpn. Soc. Sci. Fish.*, **74**, 455-456 (in Japanese).

Baba, Y. (2008c) Inflationary crude oil prices and fishery III. *Bull. Jpn. Soc. Sci. Fish.*, **74**, 324-325 (in Japanese).

Fukuda, I. (2003) Psychological approach to the theory of decision-making. *Journal of Business Administration and Information Setsunan University*, **10**, 65-90.

Fukada, K., Maeda, H. and Shirota, K. (1991a) Studies on fishing information to decide the squid jigging position using image processed vertical distribution of water temperature in the Japan Sea-I. *Bull. Jpn. Soc. Sci. Fish.*, **57**, 1487-1493 (in Japanese).

Fukada, K., Maeda, H. and Shirota, K. (1991b) Studies on fishing information to decide the squid jigging position using image processed vertical distribution of water temperature in the Japan Sea-II. *Bull. Jpn. Soc. Sci. Fish.*, **57**, 1677-1701 (in Japanese).

Furuyama, E. (2008) Behavioral (Psychological) Economics and Neuroscience. *The Bulletin of Nihonbashi Gakkan University*, **7**, 67-80.

Hara, Y., Kato, N., Mahapatra, K. and Okada, Y. (2009) An attempt to forecast favorable temperature zone for fishing ground formation of skipjack tuna *Katsuwonus pelamis* using satellite data and fishing ground data. *Journal of the School of Marine Science and Technology Tokai University*, **7**, 35-43.

Hiramatsu, K. (2004) Evaluation of the ABC decision rule by the operating model approach. *Bull. Jpn. Soc. Sci. Fish.*, **70**, 879–883.

Ito, T. (2006) Mathematical programming problem in farm management. *Communications of the Operations Research Society of Japan*, **51**, 264–267 (in Japanese).

Kahneman, D. and Lovallo, D. (1993) Timid choices and bold forecasts : A cognitive perspective on risk taking. *Management Science*, **39**, 17–31.

Kato, F. and Matsumiya, Y. (1993) Management simulation for shrimp pot fisheries by mesh size control. *Bulletin of the Faculty of Bioresources Mie University*, **10**, 141–145.

Katsukawa, T. (2004) Numerical investigation of the optimal control rule for decision-making in fisheries management. *Fish. Sci.*, **70**, 123–131.

Katsukawa, T. (2007) Fisheries impact on Japanese sardine. *Bull. Jpn. Soc. Sci. Fish.*, **73**, 763–766.

Kikuzawa, K. (2006) Mental accounting analysis of manager's behavior. *Mita Business Review*, **49**, 131–147 (in Japanese).

Kishi, J.M. (2008) Review of marine ecosystem modeling. *Oceanography in Japan*, **17**, 7–18.

Kubo, S. (2004) Modeling of netting motion in water. *Bull. Jpn. Soc. Sci. Fish.*, **70**, 348–353 (in Japanese).

Ministry of Agriculture, Forestry and Fisheries (2008) White paper on fisheries 2008/2009. Association of Agriculture and Forestry Statistics, Tokyo.

Shikata, T. (2009) Resource of Japanese common squid and squid jigging fishery at offshore area of the Japan Sea. *Report of the 2009 Annual Meeting on Squid Resources*, 58–64.

Suzuki, K. (2006) Quantitative assessment of fish behavioral properties by using physical model. PhD Dissertation, Hokkaido University, Hokkaido (in Japanese).

Suzuki, M., Ouchi, A. and Fukuoka, J. (1979) Construction of the mathematical model of the lower trophic levels of the marine ecosystem and its stability analysis. *Bulletin of the Faculty of Fisheries Hokkaido University*, **30**, 216–229.

Takagi, T., Suzuki, K. and Hiraishi, T. (2002) Development of the numerical simulation method of dynamic fishing net shape. *Bull. Jpn. Soc. Sci. Fish.*, **68**, 320–326.

Takagi, T., Shimizu, T. and Suzuki, K. (2004) Numerical simulation technology for fishing gear engineering and its potentiality. *Fisheries Engineering*, **41**, 53–59.

Tameishi, H. (1999) Technology for finding squid fishing grounds. *Bull. Jpn. Soc. Sci. Fish.*, **65**, 121–122.

Tversky, A. and Kahneman, D. (1992) Advances in prospect theory : Cumulative representation of uncertainty. *Journal of Risk and Uncertainty*, **5**, 297–323.

Wada, M. and Hatanaka, K. (2009) Applying an information technology in fishing industry-IV. *Japan Institute of Navigation*, **120**, 65–71.

Wakayama, K. (2008) Fundamental study on estimation of the fishing mortality coefficient based on gill net selectivity for fisheries management. PhD Dissertation, Hokkaido University, Hokkaido (in Japanese).

Wakayama, K., Fujimori, Y., Itaya, K., Murakami, O. and Miura, T. (2006) Mesh selectivity of gillnet for pointhead flounder *Cleisthenes pinetorum*. *Bull. Jpn. Soc. Sci. Fish.*, **72**, 174–181.

Yamashita, S. (2003) Studies on the systematization of industrial technology in fisheries production. *Bull. Jpn. Soc. Sci. Fish.*, **69**, 693–696.

Yoshinaga, K., Masumitsu, S., Hidaka, M., Uchiyama, M., Azuma, T. and Fukuda, R. (2004) A basic study on the prediction method of tuna abundant regions using satellite altimetry sea surface height data. *Memoirs of Faculty of Fisheries Kagoshima University*, **53**, 1–5.