Evaluating the competitiveness of Japanese fishery applying efficiency indicators: taking the Pacific saury stick-held dip net fishery as an example

Doctoral Dissertation

EVALUATING THE COMPETITIVENESS OF JAPANESE FISHERY APPLYING EFFICIENCY INDICATORS: TAKING THE PACIFIC SAURY STICK-HELD DIP NET FISHERY AS AN EXAMPLE

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Abstract

With the demand for seafood keeping increasing since the Second World War, the global fishery developed rapidly since then. The fishery production of Japan reached the peak in 1980s and became one of the largest seafood-exporting countries. Contrary to the declining domestic supplies of fishery products, the import of seafood has kept expanding since 1960s. According to the annual Food Balance Sheet published by the Ministry of Agriculture, Forestry and Fishery in Japan (MAFF), the ratio of imported seafood quantity to Japan's total demand was less than 2% in 1960 while rose to around 52% in 2013 (MAFF). In other words, Japan is facing a fierce competition with foreign countries in its domestic seafood market. Under this background, enhancing the competitiveness of Japanese fishery has become one of the focuses in national fisheries policies. As the concrete approaches to enhance competitiveness of Japanese fishery, various opinions are raised in academic field. Not only the controversy appears in the academic field, the explicit policy has not yet been formulated by Japanese government. Before the controversy comes to an end, it may be necessary to clarify the extent of competitiveness in current Japanese fishery through empirical studies.

Although the word 'competiveness' is still an ambiguous concept, efficiency has been applied as indicators to evaluate competitiveness. Previous studies prove that efficiency analysis will be helpful in clarifying the competitiveness of Japanese fishery. In terms of the methodologies, stochastic frontier analysis (SFA) and data envelopment analysis (DEA) are widely used to evaluate the efficiency of a decision-making unit. In this thesis, efficiency analyses of the Japanese marine fishery and Pacific saury fishery in Habomai were carried out to examine the efficiency condition from both a macro and a micro view point.

Important results of the efficiency score of Japanese marine fishery production in 2013 were as follows: 1) tonnage of powered vessels and fishers quantity are positively related with Japanese marine fishery production value; 2) there still exists a range of 22% to 44% scope to improve the marine fishery production value theoretically, without adding more inputs; 3) in terms of the single prefectural government, Ehime prefecture showed the highest TE whatever estimation method was applied, while Osaka was the least efficient by use of SFA and DEA-CRS, and Yamaguchi displayed the lowest TE by means of

DEA-VRS; 4) there may exist inconsistency between large production value of one prefectural government and high technical efficiency.

Significant results of the TE study on the Pacific saury stick-held dip net fishery in Habomari region, Hokkaido prefecture using SFA approach are summarized as follows: 1) vessel tonnage, monthly fishing days, monthly crew size and stock abundance are essential and positive determinants of the sampled fishing vessels; 2) saury production can be averagely increased by 30% without adding more inputs if fishing vessels can operate fully efficiently; 3) vessel ownership of skipper, specialization in saury fishery, large vessel tonnage are estimated to be several factors positively affecting technical efficiency. Results of the efficiency study on the Pacific saury stick-held dip net fishery in Habomai region, Hokkaido prefecture using DEA approach in Chapter 6 were as follows: 1) vessels showed the highest TE do not guarantee high AE and CE; 2) the sampled fishing vessels can improve their TE as well as CE to a considerable extent; 3) vessel tonnage and behavioral motivation of vessel owner or skipper showed positive influence on TE as well as CE.

Results of this thesis are expected to provide some policy implications. Firstly, efficiency analysis can be applied to evaluate the competitiveness of fishery. Secondly, with regard to the Pacific saury SHDN fishery in Japan, vessel ownership, specialization and larger vessels may be positively related to a higher TE and CE, which can be considered in further research or policies formulation aiming at improving the efficiency or competitiveness of this specific fishery. In particular, the importance of incentives in crew members' behaviors have been shown, which is the common characteristic of vessel ownership and specialization. Meanwhile, it should be cautious to conclude that large vessels are superior to small vessels. Finding a balance between competitiveness improvement and social stability would be desirable.

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Chapter 1

Introduction

1.1 Background and problem statement

1.1.1 Decline of Japanese fishery production and international competition in domestic seafood market

According to the *Annual Statistics on Fishery and Aquaculture Production* issued by the Ministry of Agriculture, Forestry and Fisheries (abbreviated as MAFF) (MAFF 2013), the yearly changes of Japanese marine capture fishery production volume can be clarified in Fig.1-1.

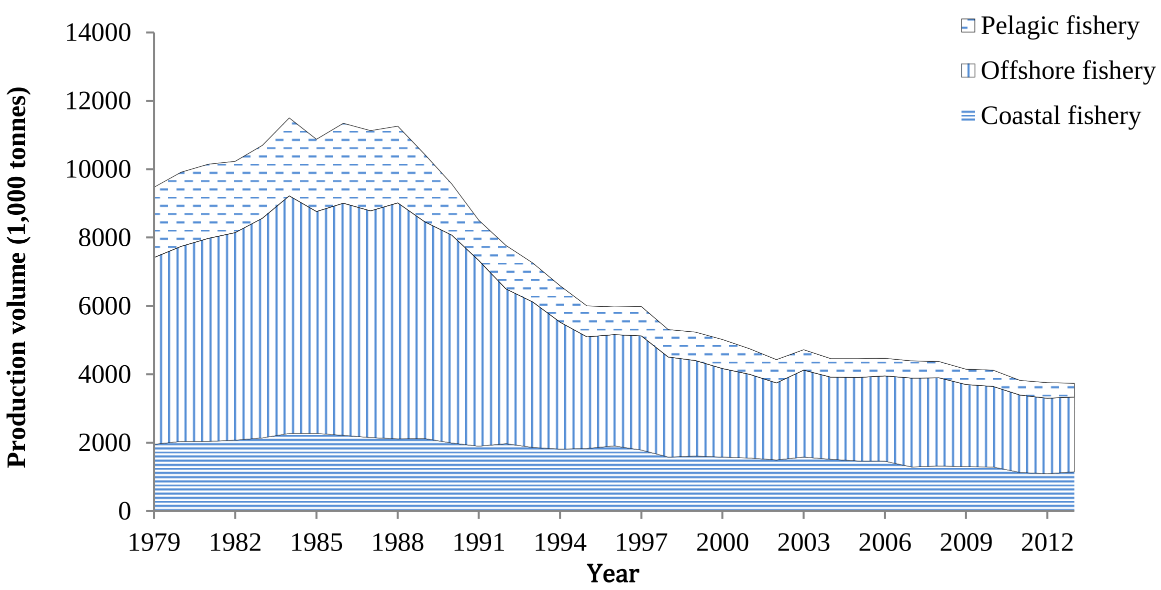

Fig.1-1 Production volume of marine capture fishery from 1979 to 2013

(Data source: *Annual Statistics on Fishery and Aquaculture Production*, MAFF)

After the Second World War, fisheries in Japan developed rapidly with its economic growth and reached the peak in early 1980s. The largest production volume of Japanese fishery (excluding aquaculture and inland water fishery) was seen in 1984 as 11.5 million tonnes. Nevertheless, the high-level period did not last long and kept decreasing since 1989 at an average rate of 9.4%. From 1996 to 2013, the total catch of marine fishery still kept shrinking in most of the years with few exceptions (e.g. increased production in 1997, 2003, 2005 and 2006), at a relatively slower decreasing speed.

The breakdown of total fishery production into different categories provides a much clearer view. Table 1-1 shows the yearly changes of production volume in pelagic, offshore and coastal fishery from 1984 to 2013, respectively. Although the decline of production volume can be seen from all the three fishery types, the offshore and pelagic fisheries contribute a larger weight to the decrease in total catch of marine fishery. From 1984 to 2013, the total catch of pelagic and offshore fisheries decreased at a rate of 82.6% and 68.5%, respectively; while the coastal fishery catch declined at a ratio of 49.2%.

Table 1-1 Change rate of Japanese marine fishery catch from 1984 to 2013

Year	Total catch	Pelagic	Offshore	Coastal
1984 (A)	11,501(100%)	2,280 (19.8%)	6,956(60.5%)	2,265 (19.7%)
2013 (B)	3,734 (100%)	396 (10.6%)	2,188(58.6%)	1,150(30.8%)
Decreasing rate	67.5%	82.6%	68.5%	49.2%

Notes: a) Unit of fishery catch is 1,000 tonnes; b) Decreasing rate is calculated as (A-B)/A; c) Data source: *Annual Statistics on Fishery and Aquaculture Production*, MAFF.

Contrary to the declining domestic supplies of fishery products, the import of fish and fishery products started to increase from 1960s and kept expanding since then (Hasegawa 1993). The enlargement of fishery products import quantity was also pointed out by other scholars, such as Kingston et al. (1991), who described as follows, ‘in the past twenty years, Japan has moved from being the world’s largest exporter to the largest single importer of fisheries products. Seafood products now account for the largest single component of Japanese food imports'.

The flesh orange bars in Fig.1-2 present the annual change in the quantity of imported fish and fishery products into Japan from 1985 to 2014, according to the *White Paper on Fisheries* issued by Fisheries Agency of Japan (abbreviated as JFA) every year. A steady increase can be found in the volume of fishery products import, which reached the peak in 2001 as 3,824 thousand tonnes. However, in recent years, the import volume generally exhibited a steady declining trend. In 2014, the import volume of fishery products was 2,543 thousand tonnes, shrinking down to 67% of the peak point in 2001. This is related with the drop in domestic consumption of fishery products (*White Papers on Fisheries*, JFA 2013).

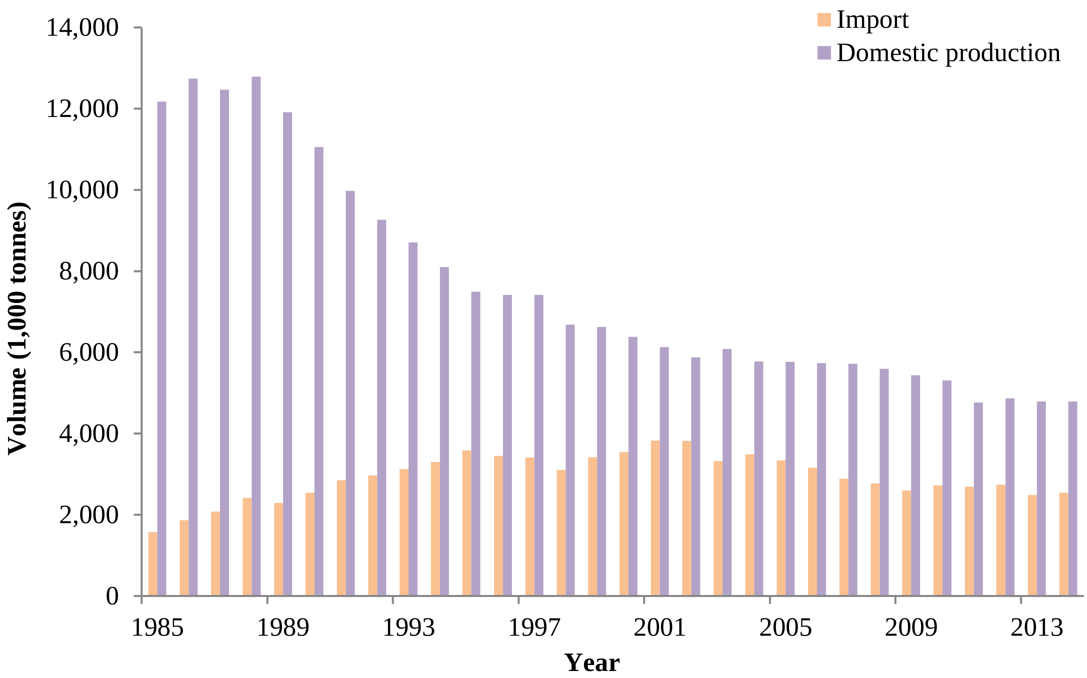

Fig.1-2 Comparison between imported fish and fishery products quantity and domestic fishery production volume in Japan from 1985 to 2014

Notes: a) Domestic fishery production volume is composed of marine and inland water fishery and aquaculture; b) Data source: *White Paper on Fisheries*, JFA 2014.

Despite the recent decrease in import quantity of fish and fishery products, the contribution of import to total supply of aquatic products in Japan has improved to a large extent. Pink dots in Fig.1-3 show changes in the self-sufficiency rate of fish and fishery products in Japan from 1960 to 2012. In 1964, the self-sufficiency rate of fish and fishery products peaked as 113%, and generally continued decreasing and stayed relatively stable around 50%. The self-sufficiency rate was 58% in 2012. The decrease in self-sufficiency rate shows the increasing dependence of Japan on the imported fish and fishery products. Fig.1-3 and Table 1-2 jointly represent the comparison between imported fish and fishery products quantity and domestic fishery production volume in Japan from 1985 to 2014. In 1985, the import volume was only 13% of domestic production, while the ratio increased rapidly in the next ten years and stayed around 50% in recent years.

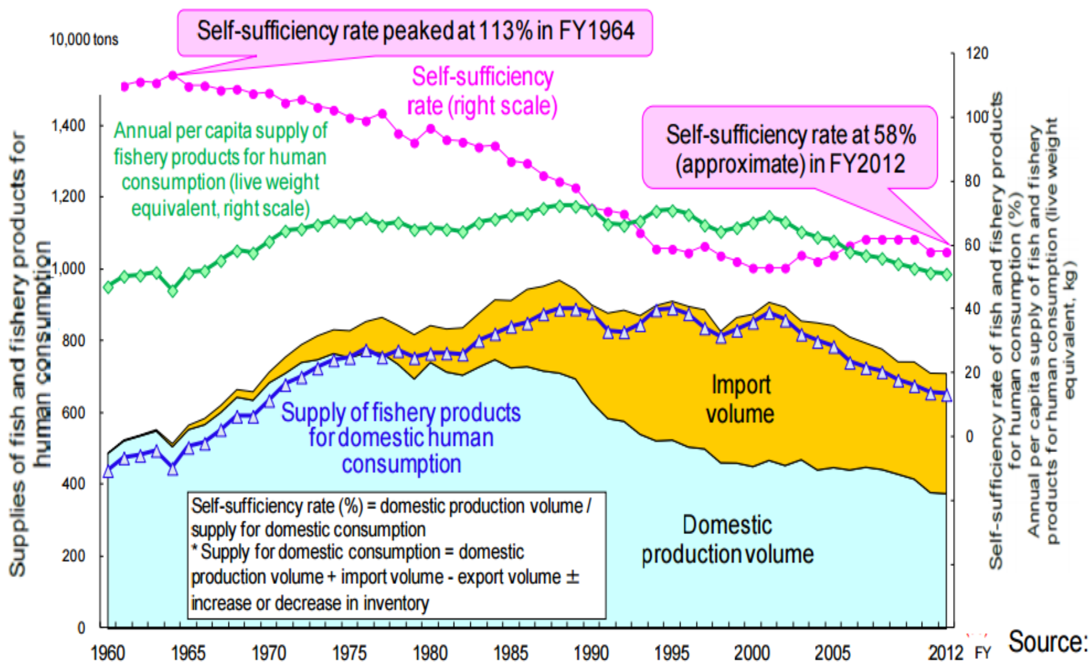

Fig.1-3 Changes in the self-sufficiency rate, etc. of fish and fishery products for human consumption

Note: Data source: *White Paper on Fisheries*, JFA 2013.

Table 1-2 Comparison between imported fish and fishery products quantity and domestic fishery production volume from 1989 to 2013

	1985	1990	1995	2000	2005	2010	2011	2012	2013
Import (A)	1,577	2,546	3,582	3,544	3,343	2,723	2,694	2,737	2,488
Domestic (B)	12,171	11,052	7,489	6,384	5,765	5,313	4,766	4,865	4,792
A/B	13%	23%	48%	56%	58%	51%	57%	56%	52%

Notes: a) Catch unit: 1,000 tonnes; b) Domestic fishery production volume is composed of marine and inland water fishery and aquaculture; c) Data source: *White Paper on Fisheries*, JFA 2013

The decline in Japanese fishery production and increase in imported fish and fishery products, which have mutual influence, are brought out by changes in national and international environment. The rapid decrease in Japanese fishery production is usually concluded to be caused by two changes, the collapse of Japanese sardine (*Sardinops melanostictus*) and the decline of Japan's distant water fishery after the introduction of the 200 nautical miles exclusive economic zones (EEZ) in the international environment (Yagi 2011). With the decrease in domestic supply of aquatic products, particularly those with strong need, the gap between domestic demand and supply was enlarged (*White Papers on Fisheries*, JFA 1989). On the other hand, the introduction of EEZ in other countries and improvement of fishing techniques fostered the development of their fisheries, such as expanding fishing vessels (Yagi 2011). Moreover, the Plaza Accord signed in 1985 between the governments of France, West Germany, Japan, the United States, and the United Kingdom, depreciated the U.S. dollar in relation to the Japanese yen by intervening in currency markets. The appreciation of Japanese yen facilitates the import of fish and fishery products into Japan (Tada 2014). The progressing of globalization and free trade bring about low customs duty, which further facilitates the import.

Although the increasing import of fish and fishery products provides the Japanese customers various choices, it also brings about the decrease in fish price in Japanese market. As noted by Yokoyama (2012), the large amount of cheap imported aquatic products reduces the fish price in Japanese market. Yagi (2011) wrote in his book that the competition with foreign aquatic products in domestic market is one the reasons causing the low profitability of Japanese fishery.

In conclusion, Japan is facing a fierce competition with foreign countries in its domestic seafood market. Under this background, how to enhance the competitiveness of Japanese fishery has become the focus in Japan.

1.1.2 Debate of competitiveness enhancement

As the concrete approaches to enhance competitiveness of Japanese fishery, various opinions are raised in academic field. Some scholars suggest providing the access to fishery right to private enterprises, and introducing the individual quota or individual transferrable quota systems, which will improve the efficiency and productivity of Japanese fishery and consequently enhance its competitiveness (Komatsu 2007, 2014). On the contrary, some scholars disagree with this opinion by raising the risks of open access to fishery right, such as the collapse of coastal fishery regions. They encourage to weaken the dependence on import and to make full utilization of the seafood caught by Japan itself (Sano 2015). Other scholars hold the opinions that reinforcing the quality competitiveness of fishery products through building brand or increasing the added value will help enhance the competitiveness of Japanese fishery (Lou et al. 2007, Lou and Hazumi 2010, Miyata et al. 2008). Not only the controversy appears in the academic field, the explicit policy has not yet been formulated by Japanese government. Before the controversy comes to an end, it may be necessary to clarify the extent of competitiveness in current Japanese fishery through empirical studies.

1.1.3 National fishery policies related with competitiveness

Given this background, enhancing the competitiveness of Japanese fishery has become one of the focuses in national fisheries policies. The Basic Law on Fisheries Policy was established in 2002 to overhaul Japanese fisheries in a comprehensive manner. Repelling the Coastal Fishery Promotion Law of 1963, the Basic Law on Fisheries Policy aimed to provide measures for ensuring sustainable exploitation of fisheries resources, a stable supply of fishery products for the country, the development of fisheries communities, as well as the protection of the marine environment. In line with the concept of the Basic Law on Fisheries Policy, the Fisheries Law and the other principal laws have been amended and supplemented with some additional legislation.

As one of the institutional frameworks for Japanese fisheries, the Basic Plan on Fisheries Policy was developed to realize the measures stipulated in the Basic Law on Fisheries Policy. In the last revised version of the Basic Plan in 2012, culturing the fisheries establishments with international competitiveness was put forward as necessary for Japan, a large importer of fishery products. The Basic Plan also set the aims of realizing a renewed coastal fishery with competitiveness and adaptation to environment changes. Meanwhile, in light of offshore and pelagic fisheries, efficient and profitable fishing was raised as one of the objectives (JFA 2012).

1.2 Existing empirical studies and insufficiency

1.2.1 Definition and evaluation of competitiveness

Although 'competitiveness' is often mentioned in everyday practice and the need of competitiveness gaining is frequently discussed in economic literature, it is a complex economic phenomenon with many definitions and evaluation methods (Furková and Surmanová 2011).

The European Commission interprets 'competitiveness' as 'the ability to produce goods and services which meet the test of international markets, while at the same time maintaining high and sustainable levels of income or, more generally, the ability of companies, industries, regions, nations and supra-national regions to generate, while being exposed to international competition, relatively high income and employment levels' (Gardiner 2003). In the report of Latruffe (2010), competitiveness can be defined as the ability to face competition and to be successful when facing competition. Competitiveness would then be the ability to sell products that meet demand requirements (price, quality, quantity) and, at the same time, ensure profits over time that enable the firm to thrive. Competition may be within domestic markets or international.

The general consensus has neither been reached in the aspect of definition of competitiveness, nor in the aspect of evaluation methods. Some scholars reviewed the measurements of competitiveness and attempted to group the methods into different categories. As stated by Latruffe (2010), measurements of competitiveness can be categorized based on two different disciplines: the neoclassical economics focusing on trade success which adopts real exchange rate, comparative advantage indices and export/import indices as measurements; and the strategic management school emphasizing a firm's structure and strategy. For the latter, competitiveness is defined as 'cost leadership and non-price supremacy'. Cost competitiveness is measured by cost indicators, profitability, productivity as well as efficiency. Castillo-Manzano et al. (2009) concluded that 'methodologies can be grouped into two categories: firstly, quantitative methods that include DEA, productivity analysis, and regression techniques; and secondly, a set of procedures, which under the multi-criteria decision-making method (MCDM), allow us to consider qualitative and quantitative indicators'.

Therefore, efficiency and productivity are often used to evaluate the competitiveness issue. Furková and Surmanová (2011) applied Stochastic Frontier Analysis for measuring the technical efficiency of NUTS2 regions of Visegrad four countries from 2001 to 2008, as one measurement of regional competitiveness. A few past studies have examined the relationship between efficiency and competitiveness and revealed that technical efficiency, a component of efficiency, has a considerable positive effect on market competitiveness (Porter 1980, Odeck 2000, Los and Timmer 2005, Dai et el. 2012). Therefore, efficiency analysis will be helpful in clarifying the competitiveness of Japanese fishery, and the indicator of profitability also provides a tool to evaluate competitiveness. As noted by Tongzon and Heng (2005), the port competitiveness is not linked to a single indicator and they developed a composite index to quantify port competitiveness, named port competitiveness index (PCI). Eight indicators were included as the factors affecting port competitiveness, among which the efficiency level of port was also considered. Results show that the operation efficiency is of crucial importance to achieve a competitive edge. In the research work of Jiang and Sharp (2014), an investigation into the cost efficiency of New Zealand dairy farms was conducted applied stochastic frontier analysis. New Zealand dairy farming is competitive considering 'its low cost, high quality pasture based production systems and high levels of technological expertise'. However, the competitive edge has been eroded with the increasing competition from other countries. They conducted the cost efficiency analysis to provide some insights into competitiveness maintaining. Cracolici et al. (2006) applied two approaches, Stochastic Frontier Analysis and Data Envelopment Aanalysis, in evaluating the technical efficiency of different tourism regions in Italy, as one measure of competitiveness among these regions. Castillo-Manzano et al. (2009) applied MCDM to construct a low-cost port competitiveness index in Spain and used productivity of labor as one of the indicators, with other indicators as economic profitability, dynamism of port activity, specialization in containers, investment in fixed capital, importance of the strictly port business and economic dynamism.

1.2.2 Empirical studies in the fishery and aquaculture context

Net private profitability and domestic resource cost were employed by Lee et al. (2003) to investigate the competitiveness of eel aquaculture in Taiwan, Japan and China mainland. Net private profitability is calculated as total revenue minus total production cost, while domestic resource cost 'represents the value of domestic resources spent in saving or earning a unit of foreign exchange.'

Cost comparison was used as an indicator to evaluate the international competitiveness of Chilean farmed salmon by Bjørndal, (2002). As stated by Bjørndal (2002), commercial salmon and trout farming has become a major industry in Chile during the 1990s. The work reviewed the development of the Chilean salmonid industry focusing on its production patterns, legislation and main markets. In order to assess the international competitiveness of Chilean salmonid industry, cost comparison between Chilean and Norwegian farmed salmon was analyzed.

Using constant market share analysis, Singh and Dey (2011) analyzed the international competitiveness of catfish in the U.S. market. Not only the competiveness of catfish in the U.S. market exported by different major countries was studied, the competiveness of the farm-raised catfish by U.S. in the U.S. market was also assessed.

FCI team (2005) overviewed the various factors affecting the competitiveness of the Icelandic and Norwegian fishing industries, and constructed the Fisheries Competitiveness Index (FCI). The FCI index takes into account a comprehensive range of factors including fisheries management, production, processing, marketing etc. Among these factors, efficiency and productivity were also included in their index, which were pointed out by FCI team (2005) as important.

In spite of the fact that competitiveness enhancement issue becomes crucial in Japanese fishery, which is gaining attentions from both Japanese government and academic circle, empirical studies in this aspect are insufficient. The existing studies on the competitiveness related with Japanese capture fishery and aquaculture usually adopt cost indicator (Tada 2014, Yoo and Yamao 2007) or comparative advantage index (Jiang et al. 2011). Although the objectives are not directly with the competitiveness issue, two efficiency studies were published with respect to Japanese fishery. One paper examined the efficiency of the whole Japanese fisheries through a modified Johanson model (Yagi and Managi 2011) while the other studied the technical efficiency of the offshore bottom trawl fishery in Hokkaido Prefecture by the Stochastic Frontier Analysis approach (Sakai et al. 2012).

1.3 Analytical methods and target

1.3.1 Analytical methods

In this thesis, efficiency indicators will be applied to evaluate the competitiveness of Japanese fishery production, including technical efficiency, allocative efficiency as well as cost efficiency, based on the idea of Farrell (1957). In terms of the analytical tools to estimate these efficiencies, the two most widely applied methods will be used, i.e. the Stochastic Frontier Analysis approach and the Data Envelopment Analysis approach. These two methods are parametric and nonparametric, respectively. Stochastic Frontier Analysis approach is employed to estimate the technical efficiency score and factors influencing it; while Data Envelopment Analysis approach is employed to estimate three types of efficiency scores composing of technical efficiency, allocative efficiency and cost efficiency. The factors affecting these efficiencies will also be studied by conducting a Tobit regression analysis after the efficiency scores are estimated. This can also be considered as a two-stage Data Envelopment Analysis approach.

1.3.2 Analytical target

First of all, Japanese marine fishery will be chosen as the target. As shown in the background, this thesis is produced to evaluate the competiveness of Japanese fishery. Therefore, we choose Japanese marine fishery in 2013 as the first case study and conduct TE analysis at a prefectural level by use of both Stochastic Frontier Analysis and Data Envelopment Analysis approaches. Nevertheless, the technical efficiency study at a prefectural level may not sufficiently satisfy the basic requirement of Stochastic Frontier Analysis and Data Envelopment Analysis because the choice of decision-making units should consider the homogeneity. In other words, the prefectures we choose are supposed to be similar with each other in fishery production. Obviously, the heterogeneity other than homogeneity can be considered as the characteristic of Japanese marine fishery. Due to this, selecting a specific fishery and conducting efficiency analysis to a more micro extent is desirable, which may improve the accuracy of results and also provide more practical implications.

Therefore, following the technical efficiency analysis of Japanese marine fishery, the Pacific saury stick-held dip net fishery in Japan will be chosen as another analytical target, which is also the key target of this thesis. In this situation, a specific fishery rather than national or global fisheries will be studied, based on the homogeneity requirement of efficiency study. In other words, the decision-making units are close to be homogenous when the study target is a specific fishery. Reason for selecting the Pacific saury fishery is partly due to the importance of this fishery in Japan. As one of the typical offshore fisheries, the Pacific saury fishery production contributed to almost 6% of the total marine capture fisheries catch in 2012 (Annual Statistics on Fishery and Aquaculture Production, MAFF 2012). Meanwhile, Pacific saury is among the few fish species with 100% self-sufficient ratio in Japanese seafood market. However, this fishery has faced with increasing competition from abroad in recent decade. Although among the main countries operating the Pacific saury fishery, Japan had kept the top one position in terms of production volume for a long time, the catch by Taiwan is increasing rapidly and exceeded Japan in 2013 as well as 2014. China mainland, which is actively developing its Pacific saury fishery, will become another competitor in the future. Meanwhile, in Korean and Russian seafood market, the Pacific saury from Taiwan is gaining more popularity due to its competitiveness in price. In the selection of data set, the Pacific saury fishery in Habomai region of Hokkaido Prefecture will be chosen, considering its top position in Japan's saury production, its key role in local economy, and data availability.

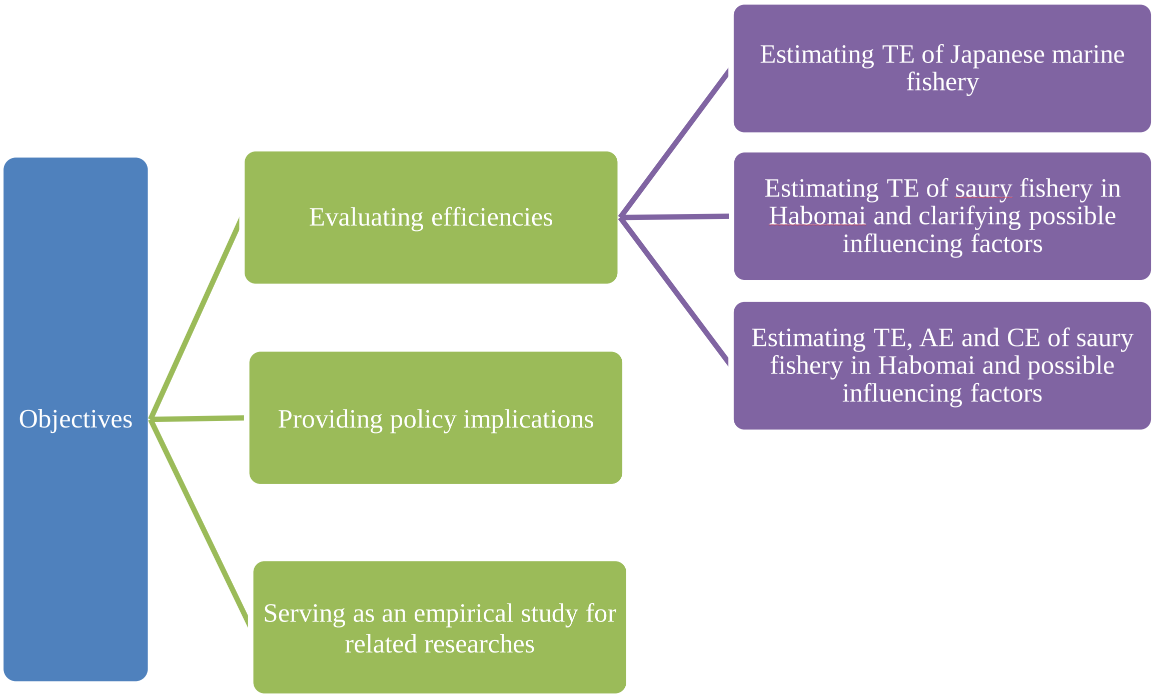

Fig. 1-4 Representation of research objectives of this thesis

Notes: TE, AE and CE are the abbreviations of technical efficiency, allocative efficiency and cost efficiency

1.4 Research objectives

As illustrated in Fig. 1-4, the overall objectives of this thesis are composed of three aspects: 1) evaluating the efficiency and competiveness of Japanese fishery using two case studies; 2) providing policy implications for enhancing the competitiveness of the sampled fishery based on the results of case studies; and 3) serving as an empirical study for researches in related to the efficiency or competitiveness enhancement of Japanese fishery, which provides a new point of view to evaluate the fishery's competitiveness and detailed process of applying Stochastic Frontier Analysis and Data Envelopment Analysis in fisheries cases. For the first overall objective, it is further divided into three detailed objectives, corresponding with three chapters in the thesis. The first detailed objective is to estimate the technical efficiency score of Japanese marine fishery in 2013 and comparing the results achieved using two different approaches, which forms the content of Chapter 3; the second one is to estimate the extent of technical efficiency in the Pacific saury stick-held dip net fishery in Habomai region of Hokkaido Prefecture and clarifying the possible factors affecting the inefficiency using Stochastic Frontier Analysis approach (Chapter 5); and the third one is to estimate the extent of technical efficiency, allocative efficiency, cost efficiency in Pacific saury fishery in Habomai region and analyzing the factors affecting the inefficiencies by means of Data Envelopment Analysis approach (Chapter 6).

1.5 Thesis structure

This thesis is divided into seven chapters. Chapter 1 is provided here as the Introduction, clearly stating the background as well as problem statement, existing empirical studies and insufficiency, analytical methods and target, research objectives. Chapter 2 gives an introduction to the methodologies adopted in the thesis and a review of their empirical studies in the fisheries context, which will provide a theoretical background. Chapter 3 conducts a technical efficiency analysis of Japanese marine fishery at a prefectural level by use of both Stochastic Frontier Analysis and Data Envelopment Analysis approaches. The technical efficiency scores in different methods will be compared. Chapter 4 introduces the basic background information of the key case study target, the Pacific saury fishery. This chapter comprehensively describes the overview of the Pacific saury fishery production as well as the economic performance in Japan as well as in the case study area, i.e. Habomai region of Hokkaido Prefecture. Chapter 5 applies a one-stage Stochastic Frontier Analysis approach to study the technical scores and factors influencing technical inefficiency in Habomai region by choosing 12 sampled fishing vessels operating Pacific saury stick-held dip net fishery. And Chapter 6 applies Data Envelopment Analysis approach which not only evaluates the technical efficiency of the sampled fishery but also extends the efficiency study to allocative as well as cost efficiencies. This chapter also carries out a Tobit regression analysis to evaluate the influencing factors of each type of efficiency. Based on the study results achieved, concluding remarks and policy implications are provided in Chapter 7.

Chapter 2

Methodologies of efficiency analysis and literature review

2.1 Introduction

This chapter aims to provide an introduction of the methodologies widely applied in carrying out efficiency analyses. Meanwhile, the literature review of the previous studies, which applied the same methodologies with those in this thesis to study the efficiency of capture fisheries as well as aquaculture, will also be conducted to understand the empirical studies in fisheries context. Section 2.2 firstly explains the related economic concepts of efficiencies. Section 2.3 and 2.4 will introduce the two types of methodologies used in this thesis, including the history and theoretical development, model descriptions and literature review of applications in fisheries context. Section 2.5 provides a comparison between the two popular methodologies, which will facilitate the understanding of different methods.

2.2 Economic concept of efficiency

The measurement of efficiency in modern economics follows the ideas of Farrell (1957), who built his work on the basis of the studies conducted by Debreu (1951) and Koopmans (1951) (Coelli et al. 2005). According to Farrell, efficiency of a decision-making unit (abbreviated as DMU), which can be a firm, a section, a fishing vessel, an aquaculture company etc., can be simply decomposed into two components: technical efficiency (TE) and allocative efficiency (AE).

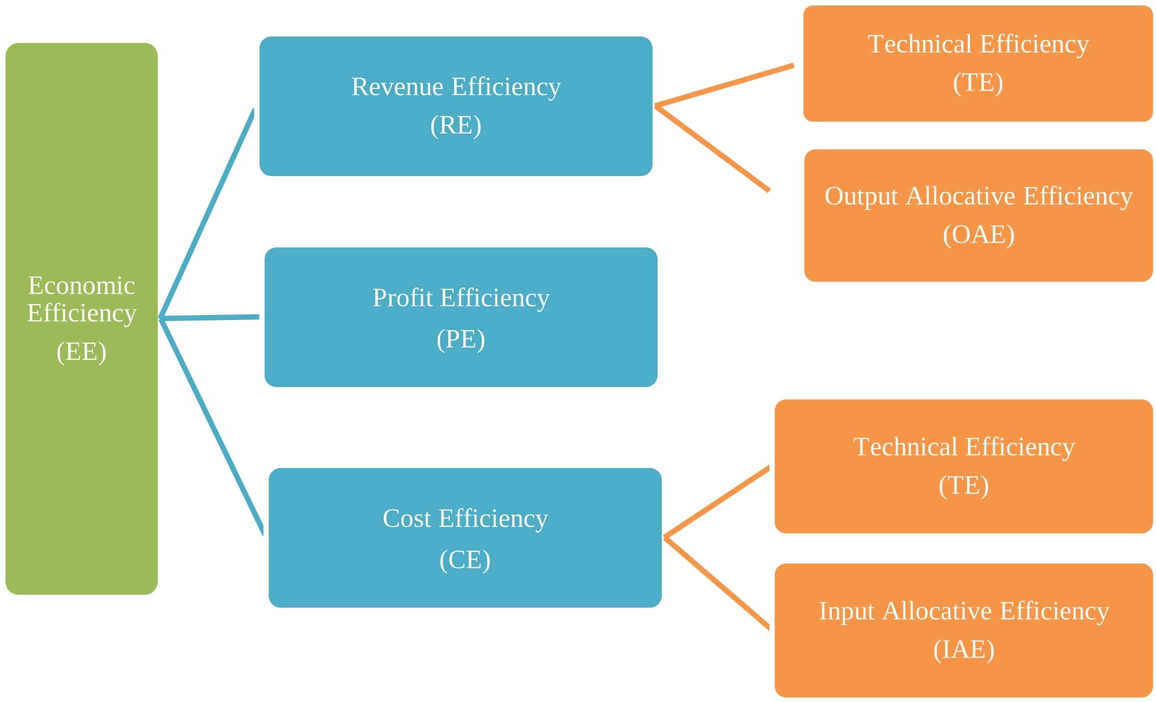

Fig. 2-1 Categorization and abbreviations of efficiencies

As concluded in the work of Coelli et al. (2005), Farrell (1957) proposed that TE 'reflects the ability of a firm to obtain maximal output from a given set of inputs', AE 'reflects the ability of a firm to use the inputs in optimal proportions, given their respective prices and the production technology', and TE as well AE measures jointly 'provide a measure of total economic efficiency (EE)'. It should be noted that in Farrell's original work, the term 'price efficiency' and 'overall efficiency' were mentioned instead of AE and EE (Farrell 1957). AE and EE are mentioned more usually in recent literature (Coelli et al. 2005). Actually, AE not only defines the ability to allocate inputs in an appropriate way, but also reflects the ability of a firm to allocate outputs (in the case when a firm produces several types of outputs) to achieve maximum revenue. In this case, AE means the output-AE and EE therefore denotes the revenue efficiency (RE). To clearly define the concepts of each type of efficiency, we follow the names of efficiencies as represented in Fig. 2-1, in this thesis.

Several more complicated and stricter definitions can also be found in literatures. The definitions of technical efficiency usually mentioned in related literatures were proposed by Koopmans (1951) and by Debreu (1951) as well as Farrell (1957). As concluded by Porcelli (2009), Koopmans described the definition of TE like this: 'a producer is technically efficient if an increase in an output requires a reduction in at least one other output or an increase in at least one input, and if a reduction in any input requires an increase in at least one other input or a reduction in at least one output'; while Debreu-Farrell defined TE of a firm as 'one minus the maximum equiproportionate reduction in all inputs that still allows the production of given outputs with the value of one indicating full technical efficiency and a score less than unity indicates the severity of technical inefficiency'.

Here, we will make further explanations about TE and AE by use of some economic curves, to facilitate a deeper understanding of these important concepts. Fig. 2-2 illustrates the concepts of TE and AE adopting input-oriented measure following Farrell (1957); hence, AE here equals to IAE. Suppose that the production technology is known, the firm operates in the condition of constant returns to scale and two inputs (x_1,x_2) are used to produce a quantity of output (q). The curve SS' is the unit isoquant, where the firm uses different combinations of x_1 and x_2 to produce the same output q. The firm is considered as technically efficient if it uses the combinations of two inputs along the curve SS'. If the firm uses a different combination of two inputs, for example, at point P to produce the same output q, technical inefficiency occurs because the inputs combination at point P is not the minimum. Therefore, the value of TE can be measured by OQ/OP, which falls into the range between 0 and 1. The TE at point Q is equal to 1, which is fully technical efficient. Next, the illustration of IAE will be explained. Suppose that the price information of x_1 and x_2 is known and we get the isocost line AA'. Therefore, the inputs combination at point Q' cost the least compared with other points along SS'. Hence, although the TE at point Q is the same with that of Q', which is both 1, the total cost at Q is higher than Q'. CE and AE at Q are both lower than those at Q'. The value of CE at point P can be measured by OR/OP; and thus IAE at P equals to OR/OQ.

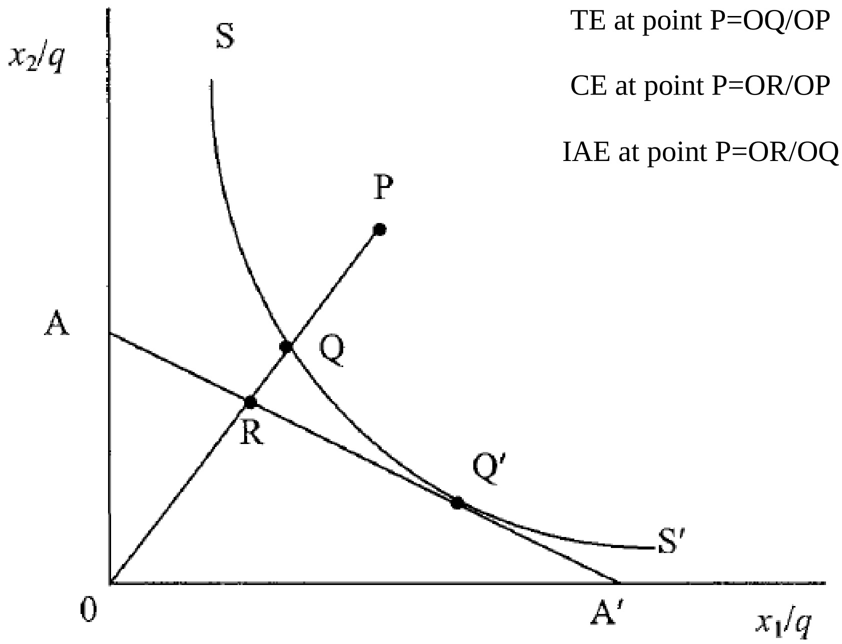

Fig. 2-2 Illustration of TE and input AE from input-oriented perspective

Note: adapted from Coelli et al. (2005)

It should be noted that several assumptions were set in advance in Farrell's interpretation of a firm's efficiency, including constant returns to scale. This restriction was relaxed in future studies conducted by Farrell and Fieldhouse (1962), which allowed non-decreasing returns to scale; and by Afriat (1972) which allowed variable returns to scale. Meanwhile, the maximum isoquant curve SS' is unknown in practice and needs to be estimated using the input-output data of sampled observations, which forms the core idea of Stochastic Frontier Analysis and Data Envelopment Analysis approaches.

2.3 Stochastic Frontier Analysis (SFA) approach

2.3.1 History and theoretical development

Stochastic Frontier Analysis approach was almost simultaneously proposed by Meeusen and van den Broeck (MB team) in June of 1977 in their published paper entitled 'Efficiency estimation from Cobb-Douglas production functions with composed error'

(Meeusen and Van den Broeck 1977), and Aigner, Lovell and Schmidt (ALS team) in July of 1977 in the paper named ‘Formulation and estimation of stochastic frontier production function models’ (Aigner et al. 1977). Shortly afterwards, Battese and Corra (BC team) published a third SFA paper titled ‘Estimation of a production frontier model: with application to the pastoral zone of Eastern Australia’ in the same year (Battese and Corra 1977). These three papers all considered a composed error term in their production frontier econometric models, with the primary difference lying in the distribution assumption of inefficiency error term.

In terms of the distribution of the inefficiency error component u which is intended to capture the effects of technical inefficiency, MB team (Meeusen and Van den Broeck 1977) considered an exponential distribution; BC team adopted a half-normal distribution (Battese and Corra 1977) while ALS team assigned both exponential and half-normal distributions (Aigner et al. 1977). The distributions they assumed are single-parameter distributions and more flexible distributions were developed in the following years. For example, Greene (1980) proposed Gamma distribution and Stevenson (1980) proposed both Gamma and truncated normal distributions, which are both two-parameter distributions. Moreover, Lee (1983) proposed a more flexible four-parameter Pearson family of distributions to u.

After the original SFA model was proposed in 1977, this new approach has experienced a series of theoretical developments besides the different distribution assumptions of inefficiency error component, which was describe in the former paragraph. Some of the significant developments were concluded in Kumbhakar and Lovell (2003) as follows: 1) Jondrow et al. suggested using the mean or the mode of the conditional distribution $[u_i|v_i - u_i]$ to estimate the technical inefficiency of each DMU in the sample (Jondrow et al. 1982). This development brought about a wider application of SFA, which was restricted to estimate the mean technical inefficiency score over the sample before; 2) Pitt and Lee (1981) extended cross-sectional maximum likelihood estimation techniques to panel data, permitting a consistent estimation of the technical efficiency of individual DMU; 3) These early panel data models were based on the assumption of time-invariant efficiency, which was finally relaxed by Cornwell et al. (1990), Kumbhakar (1990) and Battese and Coelli (1992), permitting the variation of DMUs’ technical inefficiency with time changes.

2.3.2 Descriptions of SFA models

The SFA model should consider various factors which result in different constructions of econometric models. The components need to be considered include the function form of production function, the distribution of error term, etc. The general stochastic frontier production function model can be written as follows (Aigner et al. 1977):

$$y_{it} = f(x_{it};\beta) + \varepsilon_{it}, \tag{2.1}$$

$$\varepsilon_{it} = v_{it} + u_{it}, \tag{2.2}$$

$$\mathrm{TE}_{it} = y_{it}/[f(x_{it};\beta) + v_{it}] \quad i = 1,\cdots,N \ \text{ DMUs} \tag{2.3}$$

where $f(x_{it};\beta)$ represents the maximum output attainable by the i^{th} DMU at t time, y_{it} denotes the real output by the i^{th} DMU at t time, x_{it} is a vector of inputs applied by the i^{th} DMU at t time, and β represents the vector of unknown parameters to be estimated. Here, ε_{it} designates the difference between real output and potential maximum output, which is composed of two error components, v_{it} and u_{it}. v_{it} represents the symmetric disturbance out of the control of decision-making units, while u_{it} is assumed to be distributed independently of v_{it} and represents the deviation from potential maximum output caused by technical inefficiency which is under the control of decision-making units.

Suppose the Cobb-Douglas production form is adopted and technical efficiency for each DMU is time-invariant, then the stochastic production frontier model for panel data in the case of a single output can be described as follows:

$$\ln y_{it} = \beta_0 + \sum_n \beta_n \ln x_{nit} + v_{it} - u_i \tag{2.4}$$

$$exp\{-u_{it}\} = TE_{it} \tag{2.5}$$

In order to evaluate the effects of potential factors which may influence the technical inefficiency, the technical inefficiency model can be applied which was specified by Battese and Coelli (1995) as follows:

$$\mathrm{U}_{it} = \mathrm{Z}_{it}\delta + \mathrm{W}_{it} \quad (2.6)$$

where $\mathrm{U_{it}}$ designates the technical inefficiency of the i^{th} firm in t time, Z_{it} represents the DMU-specific variables which are considered to exert their influences on the inefficient performance of DMUs, δ is a vector of unknown parameters, and $\mathrm{W_{it}}$ is random error.

2.3.3 Literature review of SFA applications in fisheries context

With the development of SFA theory, this quantitative analytical tool has been applied in numerous empirical studies, which cover an extensive range of industries, such as banking, agriculture, manufacturing and tourism. The empirical studies on the efficiency analyses in the context of fisheries generally started from the late 1990s. As concluded by Sharma and Leung (1998a), the lack of efficiency studies in the context of marine fisheries can mainly be attributed to the complexity of methodologies and difficulty in data collection. The author conducted a search of the literatures which applied SFA and DEA approaches to study the efficiency of fisheries, and listed the results in Table 2-1 and 2-2. Although this search may not be claimed to be complete, it can still be considered as comprehensive.

In terms of marine capture fisheries (Table 2-1), Kirkley et al. (1995) were believed to be the pioneers to employ a stochastic production frontier in estimating the technical efficiencies of the Mid-Atlantic sea scallop fishery. An overview in Table 2-1 implied that SFA approach was more frequently applied before 2005. The study targets expanded from artisanal fisheries to commercial fisheries; and the associated regions included both developing and developed countries, with the western countries as the majority. Meanwhile, allocative efficiency and economic efficiency were not studied so often than technical efficiency. Overall, the empirical studies of SFA in the context of marine capture fisheries can be mainly classified into three categories according to their objectives and data availability: 1) estimating the technical efficiency scores of each decision-making unit and conducting preliminary economic analysis; 2) conducting the same analysis as the first category and further finding the underlying factors resulting in technical inefficiency; 3) evaluating the management approaches on technical efficiency based on the same analysis with the second category.

With respect to the application in aquaculture, related studies in Asian countries form the majority, corresponding with the prosperity of aquaculture in Asian region. Compared with studies in the context of marine capture fisheries, more analyses of allocative efficiency and economic efficiency could be found in aquaculture. This is related with the relatively easier collection of price data on inputs or outputs in aquaculture operations. To the best of our knowledge, the first published journal paper related with the technical efficiency study on aquaculture was the work by Sharma and Leung (1998b). In their study, SFA approach was used to estimate the technical efficiency level of a sampled 490 carp culture farms in the Tarai region of Nepal from 1994 to 1995, and also the determinant factors of technical inefficiency.

2.4 Data Envelopment Analysis (DEA) approach

2.4.1 History and theoretical development

Similar to SFA, DEA approach is also built on the earlier work of Farrell (1957). As stated by (Roland and Vassdal 2003), DEA should be considered as an approach, which applies different models depending on the actual situation or problem. The core idea of DEA is to solve linear programming problem and the solutions 'provides a numerical description of a piecewise linear production frontier' (Roland and Vassdal 2003).

As an alternative to SFA for measuring the efficiency of a decision-making unit, the conventional DEA model shows several characteristics. Firstly, it is deterministic, which attributes all the deviations of real output from frontiers to inefficiency, without considering stochastic factors; secondly, it is a non-parametric approach which does not estimate parameters as SFA; thirdly, it puts no assumptions on the functional form of the production function or the distribution of the error term (Chandrasekar and Gopal 2015). The term 'envelopment' in the name of DEA is used because the frontier envelops the set of all the observations (Chandrasekar and Gopal 2015).

Table 2-1 List of the applications of SFA and DEA in the context of marine capture fisheries

Publication Year	Target	Country	Efficiency	Approach	Author
1995	Sea scallop fishery	U.S.	TE	SFA	Kirkley et al.
1998	Sea scallop fishery	U.S.	TE	SFA	Kirkley et al.
1998	Pole-and-line fishery	Solomon Islands	TE	SFA	Campbell and Hand
1998	Longline fishery	U.S.	TE	SFA	Sharma and Leung
1999	Pacific coast ground fish trawl fishery	U.S.	TE	SFA	Squires and Kirkley
2000	Halibut fishery	Canada	TE, AE, EE	SFA	Grafton et al.
2001	Trawl fishery	Malaysia	TE	SFA	Viswanathan et al.
2001	Beam trawl fishery	Netherlands	TE	SFA	Pascoe et al.
2002	Demersal trawl fishery	UK	TE	SFA	Pascoe and Coglan
2002	Trawl fishery	Danish	TE	SFA	Vestergaard et al
2003	Trammel netter fishery	Greece	TE	SFA	Fousekis and Klonaris
2003	Gill net artisanal fishery	Malaysia	TE	SFA	Squires et al.
2003	South-Atlantic trawl fishery	Spain	TE	SFA	Herrero and Pascoe
2004	Purse seine fishery	Spain	TE	SFA	del Hoyo et al.
2004	Northern prawn fishery	Australia	TE	SFA	Kompas et al
2005	Fishing vessels in English Channel	EU	TE	SFA, DEA	Tingley et al.
2005	Mini-purse seine fishery	Indonesia	TE	SFA	Susilowati et al.
2005	Trawl fishery	Spain	TE	SFA, DEA, SDF	Ines Herrero
2006	Fishing vessels	Iran	TE	SFA	Esmaeili
2006	Ocean prawn trawl fishery	Australia	TE	SFA	Greenville et al.
2007	Trawl fishery	Denmark	TE	DEA	Lindebo et al

Continued on next page

Table 2-1 List of the applications of SFA and DEA in the context of marine capture fisheries

(Continued from previous page)

Publication Year	Target	Country	Efficiency	Approach	Reference
2007	Marine capture fishery	China	TE	DEA	Zhang
2008	Purse seine fishery	Greece	TE	DEA	Maravelias and Tsitsika
2009	Small-scale fishery	Italy	TE	DEA	Madau et al.
2009	Artisanal fishery	Portugal	TE	DEA	Oliveira et al.
2009	Coastal purse seine fishery	Korea	TE	SFA	Kim et al.
2010	Artisanal dredge fishery	Portugal	TE, AE, EE	DEA	Oliveira et al
2010	Shrimp fishery	U.S.	TE	SFA	Vinuya
2011	Sandfish coastal gillnet fishery	Korea	TE	SFA	Kim et al.
2011	Marine fishery in Shandong Province	China	TE	DEA	Gao and Ding
2012	Offshore bottom trawl fishery	Japan	TE	SFA	Sakai et al.
2012	Multispecies northern prawn fishery	Australia	TE	SFA	Pascoe et al.
2013	Menhaden purse seine fishery	U.S.	TE	DEA	Vázquez-Rowe and Tyedmers
2013	Red king and snow crab fisheries	U.S.	TE	SFA	Schnier and Felthoven
2014	Commercial fishery	Turkey	TE, AE, EE	DEA	Ceyhan and Gene
2014	Groundfish trawl fishery	U.S.	TE	DEA	Collier et al.
2014	Gillnet fishery	Vietnam	TE	DEA	Pham et el.
2015	Dredge fishery	Portugal	TE, AE, EE	DEA	Oliveira et al.
2015	Lobster fishery	U.S.	TE	DEA	Chen et al.
2015	Marine fishing vessels in Chabahar region	Iran	TE	SFA	Jamnia et al.
2015	Marine fishery	Worldwide	TE	DEA	Lee and Midani
2015	Coastal and offshore fisheries	Korea	TE	DEA	Lee and Midani
2016	Purse seine tuna fishery	U.S., JP, TW, KR	TE	DEA	Tidd et al.

Table 2-2 List of the applications of SFA and DEA in aquaculture

Publication Year	Target	Country	Efficiency	Approach	Reference
1998	Carp	Nepal	TE	SFA	Sharma and Leung
1999	Carp	Malaysia	TE	SFA	Iinuma et al.
1999	Polyculture of carp	China	TE, AE, EE	DEA	Sharma et al.
2000	Tilapia	Philippines	TE	SFA	Dey et al.
2000	Carp	South Asia	TE	SFA	Sharma and Leung
2000	Carp	India	TE	SFA	Sharma and Leung
2000	Seabass and seabream	Greece	TE, AE, EE	SFA	Karagiannis et al.
2000	Tilapia	Philippines	TE	SFA	Bimbao et al.
2002	Seabass and seabream	Greece	TE	SFA	Karagiannis et al.
2003	Freshwater & brackish water fish farm	Philippines	TE	SFA	Irz and McKenzie
2004	Milkfish	Taiwan	TE	SFA	Chiang et al.
2005	Freshwater pond polyculture	Asia	TE	SFA	Dey et al.
2006	Trout	Turkey	TE, AE, EE	DEA	Cinemre et al.
2006	Catfish	U.S.	TE, AE, EE	DEA	Kaliba and Engle
2008	Concrete and earthen pond fish culture	Nigeria	TE, AE, EE	SFA	Kareem et al.
2009	Freshwater aquaculture	India	TE	SFA	Singh et al.
2010	Fish farm	Ghana	TE	SFA	Onumah et al.
2010	Aquaculture firm	Taiwan	TE	DEA	Chang et al.
2011	Freshwater trout culture	Denmark	TE	DEA	Nielsen
2011	Pangas	Bangladesh	TE, AE, EE	DEA	Alam
2012	Tilapia	Bangladesh	TE	SFA	Alam et al.

Continued on next page

Table 2-2 List of the applications of SFA and DEA in aquaculture (Continued from previous page)

Publication Year	Target	Country	Efficiency	Approach	Reference
2012	Tilapia	China	TE	SFA	Dai et al.
2013	Pond fish farming	Ugenda	AE	SFA	Bukenya et al.
2013	Salmon	Norway	TE	SFA	Asche and Roll
2013	Shrimp	Bangladesh	TE	SFA	Begum et al.
2014	Shrimp	Vietnam	TE, AE, EE	DEA	Nguyen and Fisher
2014	Crucian carp polyculture	China	TE, AE, EE	DEA	Yin et al.
2014	Aquaculture farm in Hawaii	U.S.	TE	DEA	Arita and Leung
2016	Freshwater aquaculture	Malaysia	TE	DEA	Iliyasu et al.
2016	Carp polyculture	China	TE	SFA	Yin et al.
2016	Cage fish farming	Malaysia	TE	SFA	Iliyasu et al.

The first original DEA model was developed by Charnes, Cooper and Rodes in 1978 and their paper entitled 'Measuring the efficiency of decision making units' was published in European Journal of Operational Research (Charnes et al. 1978). This model is known as CCR model and considered the inception of DEA. In CCR model, constant returns to scale is assumed. In 1984, Banker, Charnes and Cooper developed CCR model to allow for variable returns to scale, which was known as BCC model (Banker et al. 1984). Their work was written in a paper entitled 'Some models for estimating technical and scale inefficiencies in data envelopment analysis' and published in *Management Science*. CCR and BCC models are the most traditional models in DEA approach, which are widely applied in estimating the relative efficiencies of DMUs in various industries. Besides, many additional model extensions have been proposed following CCR and BCC models.

Some popular extensions were concluded in Coelli et al. 2005 as follows: 1) the stochastic DEA models proposed by Land et al. (1993) and Olsen and Petersen (1995); 2) the additive model developed by Charnes et al. (1985); 3) the Flexible Disposable Hull (FDH) approach proposed by Deprins et al. (1984); 4) the inclusion of panel data using the window analysis method proposed by Charnes et al. (1984); 5) the Malmquist index approach developed by Färe et al. (1994); 6) a further estimation of allocative efficiency when price data can be accessed. In this thesis, the last extension will be applied in estimating the allocative and economic efficiency of the research target.

2.4.2 Descriptions of DEA models

(1) CCR DEA model (constant returns to scale model)

CCR model is the first model and also the basis of DEA approach, which was proposed by Charnes et. al (1978).

Suppose there are a set of N decision-making units. For each DMU j $(j = 1, \dots, N)$, it applies N inputs to produce M outputs. Hence, for DMU_i, the ratio of all outputs it produces to all inputs it uses is expressed as follows:

$$\text{Max}_{u,v}\ (u'q_i/v'x_i),$$

subject to:

$$u'q_j/v'x_j \leq 1; \quad j = 1, \dots, N,$$

$$u, v \geq 0. \tag{2.7}$$

where q_i denotes the vector of outputs of the i^{th} decision-making unit and x_i the inputs vector of the i^{th} decision-making unit, which are all positive. u and v are also positive in values, which designate the variable weights of outputs $(M \times 1)$ and inputs $(N \times 1)$. When we solve the mathematical programming problem in 2.7 and obtain the optimal weights for each input and output of DMU_i, the value of 2.7 in this case represents the efficiency of DMU_i.

As described in Charnes et al. (1978), the model 2.7 is 'an extended nonlinear programming formulation of an ordinary fractional programming problem'. In order to solve the problem of an infinite number of solutions (Coelli et al. 2005) and to simplify mathematical calculation, the fractional programming problem in 2.7 is reduced to linear programming form by adding a constraint as follows :

$$\text{Max}_{u,v}\ (u'q_i),$$

subject to:

$$v'x_i = 1$$

$$u'q_j/v'x_j \leq 1; \quad j = 1, \ldots, N,$$

$$u, v \geq 0. \tag{2.8}$$

The linear programming problem expressed in 2.8 is known as the multiplier form. Based on the duality in linear programming, an equivalent envelopment form can be derived as follows (Coelli et al. 2005):

$$\text{Min}_{\theta,\lambda}\ \theta$$

subject to:

$$-q_i + Q\lambda \ \geq\ 0$$

$$\theta x_i - X\lambda \ \geq\ 0$$

$$\lambda \geq 0 \tag{2.9}$$

where θ denotes the scalar, ranging from 0 to 1; λ is an $I \times 1$ vector of weights defining the linear combination of the peers of the ith DMU. Compared with the multiplier form in 2.8, this envelopment form in 2.9 contains less constraints hence is 'generally the preferred form to solve' (Coelli et al. 2005).

(2) BCC DEA model (variable returns to scale model)

As mentioned above, the CCR model assumes all the DMUs are operating at an optimal scale, i.e., the constant returns to scale. In this case, the scale efficiency can be ignored. However, this assumption is not appropriate when some of the DMUs are not operating at the optimal scale. In this case, the scale efficiency should be separated from the efficiency score, i.e. technical efficiency and scale efficiency need to be measured separately. The assumption of constant returns to scale would result in a misleading measure of technical efficiency when not all the DMUs are operating at optimal scale. The call for adjusting CCR model with constant returns to scale assumption to take into consideration of variable returns to scale situation was put forward in Afriat (1972), Färe, et al. (1983) and Banker et al. (1984). The DEA model considering variable returns to scale proposed by Banker et al. (1984) was well-known and named after the authors as BCC model as follows:

$$\text{Min}_{\theta,\lambda}\ \theta$$

subject to:

$$-q_i + Q\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \tag{2.10}$$

A careful observation shows that the linear programming problem in 2.10 is a modification of 2.9 by adding the convexity constraint. The technical efficiency calculated in BCC model is also called the pure technical efficiency; while the efficiency measured in CCR model is a composite technical efficiency measurement combining pure technical efficiency as well as scale efficiency. Therefore, scale efficiency can be calculated by the following formulation:

$$SE = \frac{TE_{CRS}}{TE_{VRS}} \tag{2.11}$$

(3) Extended DEA models to estimate cost efficiency, revenue efficiency and profit efficiency

The CCR and BCC models introduced above are the two traditional models in DEA theory. The estimated result of CCR model is used to measure the technical efficiency of

DMUs, while the results of BCC model are adopted to measure the technical efficiency as well as scale efficiency of DMUs. Based on Farrell (1957), allocative efficiency as well as economic efficiency also exist. When price data on outputs or/and inputs are also available, DEA approach can be used to estimate the cost efficiency, revenue efficiency and profit efficiency of DMUs, and the allocative efficiency in each case can also be calculated correspondingly. In the following models, we assume variable returns to scale.

When the DMUs are assumed to aim at cost minimization, the cost efficiency can be estimated as follows:

$$\text{Min}_{\lambda, x_i^*} \; w_i' x_i^*$$

subject to:

$$-q_i + Q\lambda \geq 0$$

$$x_i^* - X\lambda \geq 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \tag{2.12}$$

where w_i is the vector of input prices for the i^{th} DMU, and x_i^* is the corresponding vector of cost-minimizing input quantities, which needs to be calculated by solving the linear programming problem. Then, the cost efficiency (CE) is calculated in the following formulation:

$$CE = \frac{w_i' x_i^*}{w_i' x_i} \tag{2.13}$$

The input-mix allocative efficiency can be acquired as follows:

$$INPUT\ AE = \frac{CE}{TE} \tag{2.14}$$

If revenue maximization is assumed for DMUs, another extended DEA model can be used to estimate the revenue efficiency of DMUs, as shown in the following model:

$$\text{Max}_{\lambda, y_i^*}\ p_i' q_i^*$$

subject to:

$$-q_i^* + Q\lambda \geq 0$$

$$x_i - X\lambda \geq 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \qquad (2.15)$$

where p_i is a $M \times 1$ vector of output prices for the i th DMU, and q_i^* is the corresponding vector of revenue-maximizing outputs, which needs to be calculated by solving the linear programming problem. Then, the revenue efficiency (RE) is calculated in the following formulation:

$$RE = \frac{p_i' q_i}{p_i' q_i^*} \qquad (2.16)$$

The output-mix allocative efficiency can be acquired as follows:

$$OUTPUT\ AE = \frac{RE}{TE} \qquad (2.17)$$

If profit maximization is assumed for DMUs, the third extended DEA model can be used to estimate the profit efficiency of DMUs, as shown in the following model:

$$\text{Max}_{\lambda, y_i^*, x_i^*} (p_i' q_i^* - w_i' x_i^*)$$

subject to:

$$-q_i^* + Q\lambda \geq 0$$

$$x_i^* - X\lambda \geq 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \qquad (2.18)$$

where q_i^* and x_i^* are the profit-maximizing quantities of output and input, respectively, which needs to be calculated by solving the linear programming problem. Then, the profit efficiency (PE) is calculated in the following formulation:

$$PE = \frac{p_i' q_i - w_i' x_i}{p_i' q_i^* - w_i' x_i^*} \tag{2.19}$$

Unlike cost efficiency and revenue efficiency, it is not straight forward to decompose profit efficiency into technical efficiency and allocative efficiency as done in formulations 2.14 and 2.17. This is beyond the scope of this thesis and therefore ignored here.

2.4.3. Literature review of DEA applications in fisheries context

Since the first DEA model was proposed in 1978 and the development in the following decades, this method has been widely applied in many industries, with the top five as banking, hospitals, agriculture, transportation and education (Iliyasu and Mohamed 2016, Liu et al. 2013a, 2013b, Emrouznejad et al. 2008). In the context of fisheries, the empirical studies on efficiencies employing DEA approach started several years later than SFA. And a summary of related literatures was concluded in Table 2-1 and 2-2.

To the best of our knowledge, the empirical work of Sharma et al. (1999) may be the pioneer of DEA application in fisheries. They used the nonparametric DEA technique to measure the technical efficiency, allocative efficiency as well as economic efficiency of the sampled 115 carp polyculture fish farms in China from 1984 to 1985. As the DEA model in their study was output-oriented, the economic efficiency was equal to revenue efficiency. As claimed by Sharma et al. (1999), their work was ‘the only study using DEA to empirically estimate all three measures of Farrell (1957) technical, allocative and economic efficiencies’. Compared with aquaculture, capture fisheries see fewer applications of DEA approach, which may be explained by the uncertain feature of capture fisheries and the absence of stochastic noise in DEA model. Meanwhile, even in the studies related with capture fisheries employing DEA, allocative efficiency and economic efficiency are not measured as frequently as technical efficiency, which may be attributed to the difficulty in collecting price data.

2.5 Comparisons between SFA and DEA

After the invention and nearly-forty-year development of SFA and DEA approaches, no agreement has been reached about which method should be employed in empirical studies. Both of these two widely-used approaches show advantages as well as disadvantages, as listed in Table 2-3.

Table 2-3 Comparisons between SFA and DEA

Method	Merits	Demerits
SFA	Inclusion of stochastic noise Hypothesis testing	Requirement of single output Sophisticated parameter estimation Large sample size necessary
DEA	Multi-inputs/multi-outputs Small sample size feasible No assumption of function form/error component distribution	Sensitive to variables and data size Ignoring the noise component No hypothesis testing

As concluded in Table 2-3, SFA normally requires that a single output is used, while DEA can include multiple outputs as well as a single output. Although development of SFA makes it gradually deal with multi-outputs cases, the calculation process is more sophisticated. SFA takes noise into consideration which is approaching the real world more than DEA; while DEA attributes all the deviation from the frontier to the inefficiency component. Function forms and distributions of error term should be assumed in SFA approach while this is unnecessary in DEA approach. When variables are large, a large sample size is required in SFA approach while DEA is advantageous in sample size requirement.

Chapter 3

Technical efficiency study on Japanese marine fisheries applying SFA and DEA approaches

3.1 Introduction

In this chapter, technical efficiency analysis will be carried out targeting Japanese marine capture fishery and aquaculture (combined called Japanese marine fishery) in 2013, applying both the Stochastic Frontier Analysis and Data Envelopment Analysis approach. The reason to conduct technical efficiency study on the whole marine fisheries in Japan is to acquire a deep understanding of its TE from a general perspective. As Japanese marine fisheries are composed of various fishing vessels using different fishing methods to harvest different marine animals and plants, it is difficult to consider the vessel as the decision-making unit. Data availability also restricts the evaluation of TE of each fishing vessels in Japanese marine fishery. Therefore, each prefecture in Japan will be taken as the decision-making unit in this analysis, based on data accessibility and previous literatures.

3.2 An overview of Japanese marine fishery production in 2013

3.2.1 Production volume and value

(1) Production volume

Table 3-1 Production data of Japanese marine fishery in 2013 divided by prefectural governments

Prefecture	Production value (million JPY)			Production volume (tonne)			Vessel quantity	Vessel tonnage	FMU	Fisher quantity
	Total	Capture	Aquaculture	total production	Capture	Aquaculture				
Total	1354169	947800	406369	4730917	3733824	997097				
Hokkaido	298444	259224	39220	1279960	1141234	138726	22494	71376.5	12882	29652
Aomori	46125	38454	7671	166823	115523	51300	5780	29359	4501	9879
Iwate	31362	26535	4827	144618	113423	31195	5740	13835.5	3365	6289
Miyagi	57002	43709	13293	246260	184507	61753	4704	29537.1	2311	6516
Akita	3241	3177	64	7930	7713	217	1031	2383.8	758	1011
Yamagata	2653	2653	0	6245	6245	-	516	1740.9	359	474
Fukushima	7919	7919	0	45322	45322	x	32	7555.2	14	343
Ibaraki	18893	18893	0	154314	154314	x	511	11316.7	413	1435
Chiba	26622	23656	2966	147039	134085	12954	4019	11117	2441	4734
Tokyo	22670	22670	0	68328	68328	x	655	10069.4	604	972
Kanagawa	13808	13374	434	42272	41071	1201	2096	15366.2	1157	2273
Niigata	11122	10900	222	30731	29869	862	2499	5437.5	1798	2579
Toyama	14727	14670	57	45889	45868	21	568	10030.6	301	1428
Ishikawa	21375	21068	307	75058	73458	1600	2425	11774.2	1718	3296
Fukui	8111	7757	354	14613	14334	279	1498	5411.3	1012	1735
Shizuoka	51634	49645	1989	200181	197199	2982	3492	31982.7	2678	5750
Aichi	20174	16504	3670	96377	81039	15338	4021	10669.3	2348	4319
Mie	46212	31855	14357	183801	159088	24713	7791	21801.9	4118	7791
Kyoto	3644	3092	552	11529	11106	423	1246	2159.5	814	1421
Osaka	3148	3020	128	18329	17919	410	810	4721.9	589	1036
Hyogo	38303	25558	12745	115989	57340	58649	5650	25029.3	3168	5334
Wakayama	11915	8674	3241	25391	23638	1753	2892	11453	2033	2907
Tottori	15007	14637	370	56954	56426	528	756	8676.8	669	1320
Shimane	19982	19729	253	140046	139643	403	2655	10911.7	1929	3032
Okayama	8718	2501	6217	33394	4476	28918	2177	5139.1	1183	1658
Hiroshima	23414	7183	16231	129518	18874	110644	3889	14013.5	2538	4003
Yamaguchi	16053	14342	1711	31838	28980	2858	4734	14412.7	3618	5106
Tokushima	14069	7586	6483	27736	13252	14484	2916	7764.8	1599	2512
Kagawa	18121	6679	11442	48994	18810	30184	3155	9454.6	1591	2484
Ehime	84912	25475	59437	143238	77078	66160	6674	19588.1	4045	7416
Kochi	48957	28820	20137	98528	79605	18923	3321	15973.9	2244	3970
Fukuoka	29360	15938	13422	93031	44444	48587	5345	14755.7	2734	5140
Saga	26714	4630	22084	98448	17968	80480	5194	9651.7	1871	4260
Nagasaki	92140	64199	27941	265360	244050	21310	12025	51849.1	7690	14310
Kumamoto	32336	7559	24777	78706	21803	56903	5794	12031	3467	6882
Oita	37275	14090	23185	62188	36183	26005	3544	12102.8	2371	4110
Miyazaki	34324	25791	8533	118141	104884	13257	1736	12697.5	1153	2677
Kagoshima a	76637	25542	51095	145570	89430	56140	5680	40412.7	3807	7200
Okinawa	17046	10093	6953	32228	15294	16934	2933	8705.7	2616	3731

Notes: 1) Data source: Annual Statistics on Fisheries and Aquaculture Production 2013 and Fisheries Census 2013, MAFF; 2) FMU denotes the quantity of fishery management unit.

In 2013, the total production volume of Japanese marine fishery (capture and aquaculture) was 4,730,917 tonnes, within which the capture fishery harvest was 3,733,824 tonnes while aquaculture was 997,097 tonnes. The detailed production data are listed in Table 3-1.

Table 3-2 shows the production volumes of marine fishery in different regions. In 2013, Honshu, composed of 26 prefectures, accounted for nearly 50% of the total marine fishery production, while Hokkaido kept being the top one single prefecture with the largest marine fishery production. Table 3-2 also represented the components of marine fishery production in each region. Among the total marine fishery production, 78.9% came from capture fishery while the remaining 21.1% was from aquaculture. The percentage of capture fishery was also large in Hokkaido, where almost 90% was from capture fishery, and Honshu, where over 80% came from capture fishery. The opposite situation can be found in Okinawa, where over half the production volume was attributed to marine aquaculture (52.5%). In Shikoku and Kyushu, the ratio of aquaculture to total marine fishery production volume was also higher than Hokkaido and Honshu.

Table 3-2 Production volume of Japanese marine fishery divided by regions in 2013

Region	**Total production (A)**	**Capture fishery (B)**		**Aquaculture (C)**	
Total	4,730,917	3,733,824	78.9%	997,097	21.1%
Hokkaido	1,279,960	1,141,234	89.2%	138,726	10.8%
Honshu	2,238,789	1,829,788	81.7%	409,004	18.3%
Shikoku	318,496	188,745	59.3%	129,751	40.7%
Kyushu	861,444	558,762	64.9%	302,682	35.1%
Okinawa	32,228	15,294	47.5%	16,934	52.5%

Notes: 1) Data source: Annual Statistics on Fisheries and Aquaculture Production 2013 and Fisheries Census 2013, MAFF; 2) The unit of production volume is tonne; 3) Ratio equals to B/A, C/A, respectively

Fig.3-1 represents the distribution of marine fishery production volume in the top ten prefectures, in terms of the total marine fishery production (a), the marine capture fishery production (b) and the marine aquaculture production (c).

Hokkaido prefecture achieved the largest production volume of both capture fishery and aquaculture, hence became the top one in terms of marine fishery production volume in 2013. Although Hokkaido displayed an obvious superiority in marine capture fishery production volume (30.6%), which was nearly five times the production volume of the second largest prefecture, Nagasaki, its superiority in marine aquaculture production volume was relatively weaker (13.9%), which was slightly higher than the second largest prefecture, Hiroshima (11.1%).

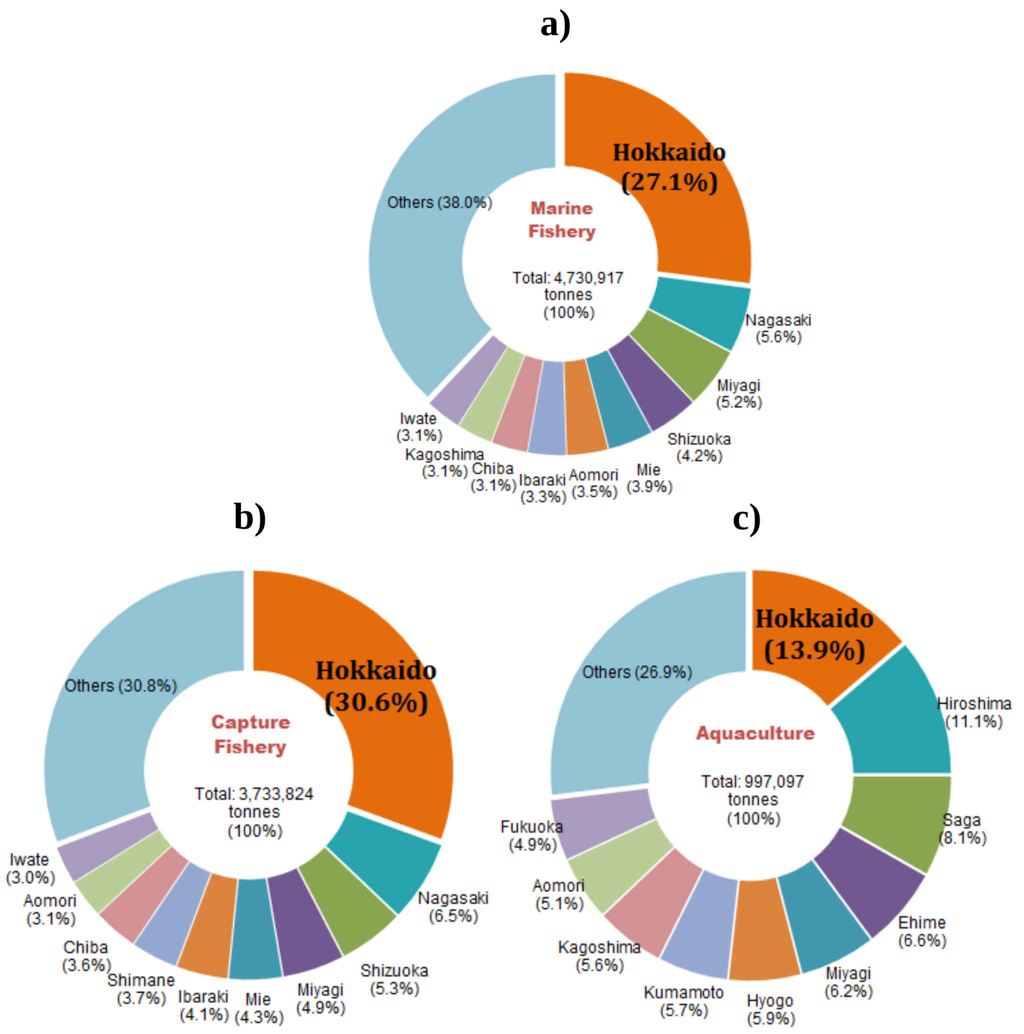

Fig. 3-1 Distribution of Japanese marine fishery production volume in top ten prefectures in 2013
a) total marine fishery production; b) marine capture fishery; c) marine aquaculture
(Note: made by the author based on data in Table 3-1)

Table 3-3 Contribution of capture fishery and aquaculture for the top level prefectures in marine fishery production and in marine aquaculture evaluated by volume

Prefecture	Total (A)	Capture		Aquaculture	
		Quantity(B) (B)	Ratio (B/A)	Quantity(C) (C)	Ratio (C/A)
Top in marine fishery production					
Hokkaido	1,279,960	1,141,234	89.2%	138,726	10.8%
Nagasaki	265,360	244,050	92.0%	21,310	8.0%
Miyagi	246,260	184,507	74.9%	61,753	25.1%
Shizuoka	200,181	197,199	98.5%	2,982	1.5%
Mie	183,801	159,088	86.6%	24,713	13.4%
Aomori	166,823	115,523	69.2%	51,300	30.8%
Ibaraki	154,314	154,314	100.0%	0	0.0%
Chiba	147,039	134,085	91.2%	12,954	8.8%
Kagoshima	145,570	89,430	61.4%	56,140	38.6%
Iwate	144,618	113,423	78.4%	31,195	21.6%
Top in marine aquaculture production					
Hiroshima	129518	18874	14.6%	110644	85.4%
Saga	98448	17968	18.3%	80480	81.7%
Ehime	143238	77078	53.8%	66160	46.2%
Hyogo	115989	57340	49.4%	58649	50.6%
Kumamoto	78706	21803	27.7%	56903	72.3%
Fukuoka	93031	44444	47.8%	48587	52.2%

Note: a) Data source: Annual Statistics on Fisheries and Aquaculture Production 2013 and Fisheries Census 2013, MAFF; b) Although marine aquaculture production data in Ibaraki was not published in 2013, it can be taken as zero due to its insignificant position in Ibaraki's marine fishery; c) Unit of quantity (A,B,C) is tonne.

Among the top ten prefectures in terms of marine fishery production volume, 9 prefectures also fell into the top ten rank of marine capture fishery production, while only 3 fell into the top ten rank of marine aquaculture fishery production. This reveals that most of the marine fishery production quantity for these 9 prefectures in 2013 came from marine capture fishery, which can be further proved in Table 3-3.

From Table 3-3, we can find that among the top ten prefectures in terms of total marine fishery production volume, the ratio of capture fishery all exceeded 60%, revealing the importance of marine capture fishery in these top ten prefectures. On the other hand, for the top prefectures in terms of marine aquaculture production volume which did not enter into the top ten list of marine fishery, the ratio of marine aquaculture was all over 50%

(except Ehime prefecture). Particularly, for the top two in terms of marine aquaculture, i.e., Hiroshima and Saga prefecture, the contribution of marine aquaculture was as high as 85.4% and 81.7%, respectively.

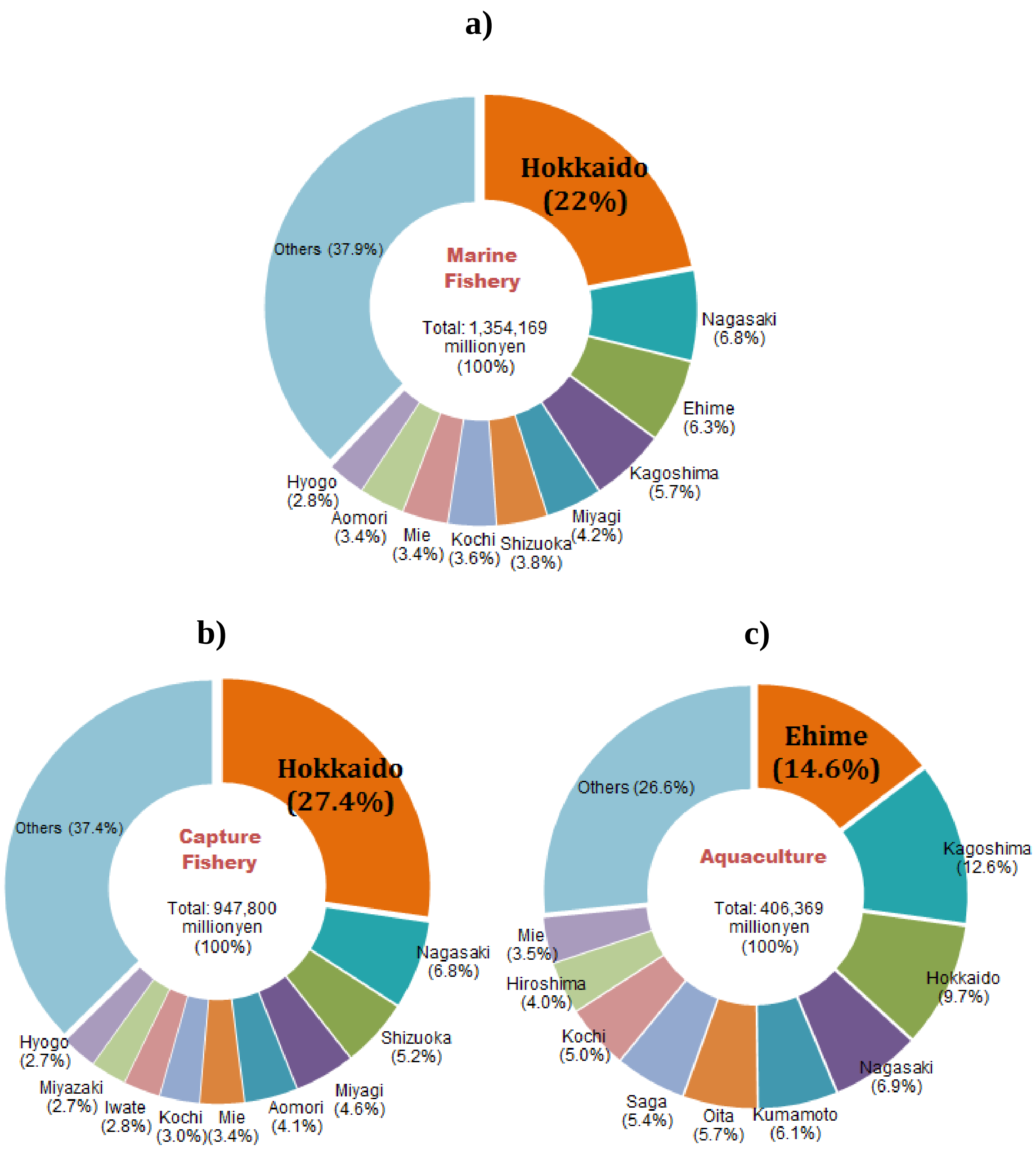

Fig. 3-2 Distribution of Japanese marine fishery production value in top ten prefectures in 2013
a) total marine fishery production; b) marine capture fishery; c) marine aquaculture
(Note: made by the author based on data in Table 3-1)

(2) Production value

As shown in Table 3-3, the total production volume of Japanese marine fishery (capture and aquaculture) in 2013 was 1,354,169 million JPY, within which the capture fishery valued 947,800 million JPY while aquaculture value was 406,369 million JPY.

Table 3-4 Contribution of capture fishery and aquaculture for the top level prefectures in marine fishery production and in marine aquaculture evaluated by value

Prefecture	**Total (A)**	**Capture**		**Aquaculture**	
		Value (B)	Ratio (B/A)	Value (C)	Ratio (C/A)
Top in marine fishery production					
Hokkaido	298444	259224	86.9%	39220	13.1%
Nagasaki	92140	64199	69.7%	27941	30.3%
Ehime	84912	25475	30.0%	59437	70.0%
Kagoshima	76637	25542	33.3%	51095	66.7%
Miyagi	57002	43709	76.7%	13293	23.3%
Shizuoka	51634	49645	96.1%	1989	3.9%
Kochi	48957	28820	58.9%	20137	41.1%
Mie	46212	31855	68.9%	14357	31.1%
Aomori	46125	38454	83.4%	7671	16.6%
Hyogo	38303	25558	66.7%	12745	33.3%
Top in aquaculture					
Kumamoto	32336	7559	23.4%	24777	76.6%
Oita	37275	14090	37.8%	23185	62.2%
Saga	26714	4630	17.3%	22084	82.7%
Hiroshima	23414	7183	30.7%	16231	69.3%

Note: 1) Data source: Annual Statistics on Fisheries and Aquaculture Production 2013 and Fisheries Census 2013, MAFF; 2) Unit of quantity (A,B,C) is million JPY.

Fig. 3-2 illustrates the distribution of Japanese marine fishery production value in top ten prefectures in 2013. Hokkaido prefecture topped in terms of the production value of marine fishery and marine capture fishery. While Ehime earned the most through marine aquaculture. Similar with the case evaluated by production volume, Hokkaido also displayed an obvious superiority in marine capture fishery production value (27.4%), about 4 times the production value of the second largest prefecture, Nagasaki. Contrarily, the rank in marine aquaculture production volume showed a more gradual decrease (14.6%, 12.6%, 9.7%, 6.9% etc.). Compared with Fig. 3-1, we can find that Hokkaido fell into the third largest prefecture concerning its aquaculture value, although it had the largest aquaculture quantity. This can be explained by the different aquatic species in Hokkaido and other top list prefectures.

Among the top ten prefectures in terms of marine fishery production value, 8 prefectures also fell into the top ten rank of marine capture fishery production, while 6 fell into the top ten rank of marine aquaculture fishery production. The comparison between Table 3-3 and 3-4 can reveal some interesting findings. For Nagasaki prefecture, although the ratio between capture fishery quantity and aquaculture quantity was about 9:1, it was 7:3 in terms of production volume. For Ehime prefecture, the ratio changed from 5.4:4.6 to 3:7 when the indicator changes from production volume to value. For Kagoshima prefecture, the quantity ratio between capture fishery and aquaculture was 6:3, while the value ratio was 3:7, revealing the relatively high price of aquaculture products. For Kochi prefecture, although it did not enter into the top ten list in fishery production quantity, it appeared in the top ten list in fishery production volume.

3.2.2 Fishing vessels

The total fishing vessels used in Japanese marine fishery was 152,998, with Hokkaido having the largest ratio as 14.7%. The top ten prefectures in terms of fishing vessels are illustrated in Fig. 3-3, which contributed to more than 50% of the total vessels. Meanwhile, the tonnage of powered vessels was 612,270 GRT in 2013, with Hokkaido being the top one prefecture.

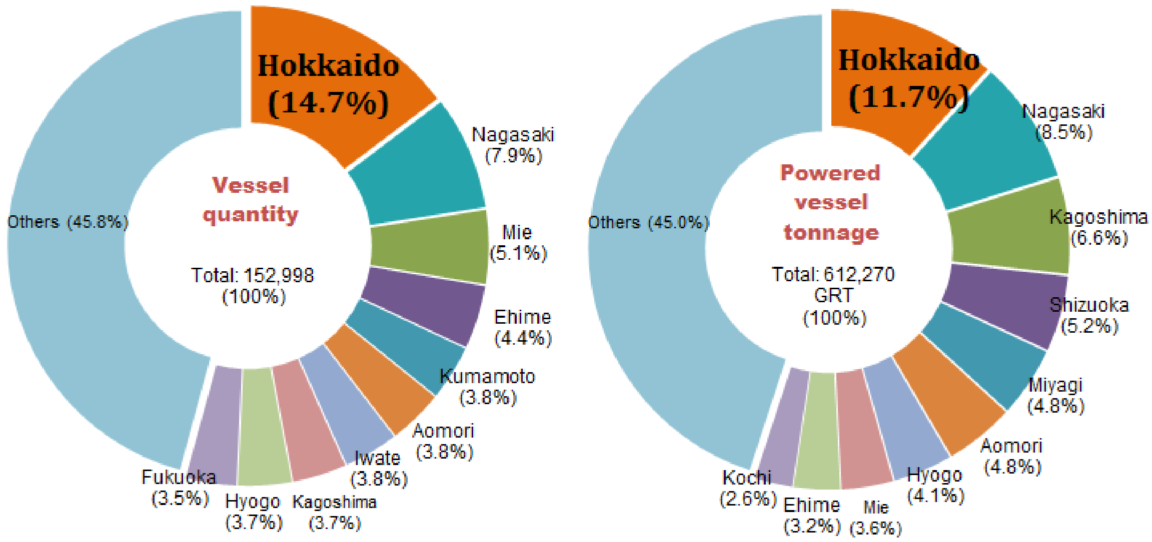

Fig. 3-3 Distribution of vessel quantity and powered vessel tonnage related with marine fishery production in top ten prefectures in 2013
(Note: made by the author based on data in Table 3-1)

3.2.3 Fishery management entities and fishers

Fig. 3-4 shows the distribution of fishery management entities and fisher quantities related with Japanese marine fishery production in the top ten prefectures in 2013. The total management entities in Japanese marine fishery production were 94,507 in 2013, within which Hokkaido was the top one prefecture with the largest management entities. The top ten prefectures contributed to more than half the total fishery management entities in Japanese marine fishery production. Generally, the ratio of management entity in each prefecture to the total entities showed a relatively gradual decrease with the change in the rank (4.8%, 4.4%, 4.3% etc.), except Hokkaido and Nagasaki. The total quantity of fishers engaging in marine fishery was 180,950 in 2013, with Hokkaido being the top one prefecture.

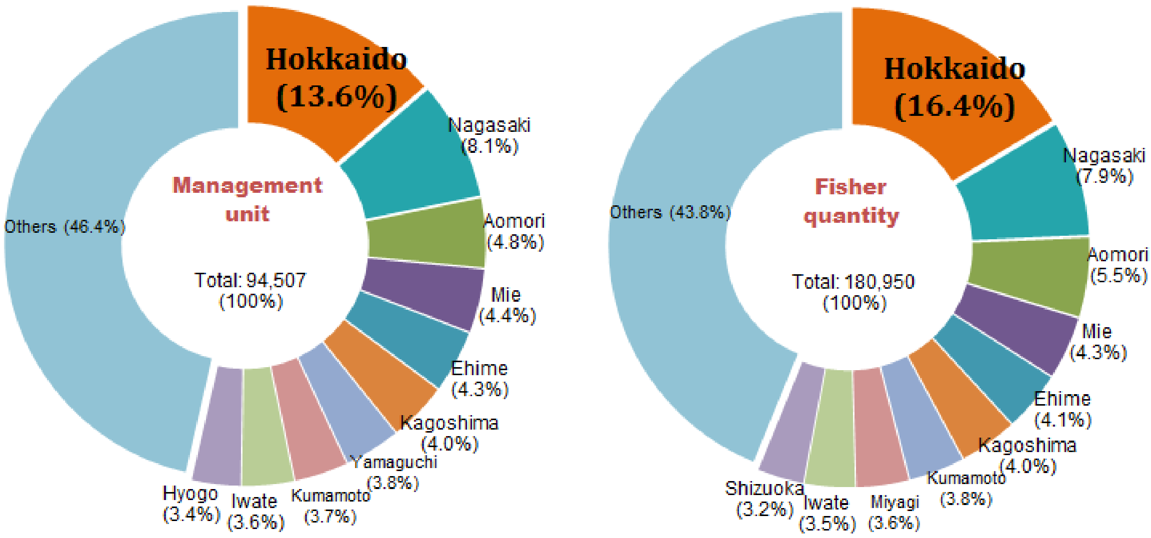

Fig. 3-4 Distribution of fishery management unit and fisher quantity related with marine fishery production in top ten prefectures in 2013
(Note: made by the author based on data in Table 3-1)

3.3 Technical efficiency study by means of SFA approach

3.3.1 Analytical data and model specification

As the general model of SFA has already been described in Chapter 2, it will not be repeated here. This section directly deals with the data and model specification issues.

In this study, a balanced cross section dataset of 39 prefectures in Japan operating marine fishery in 2013 are obtained from the published statistical data by the Ministry of Agriculture, Forestry and Fisheries. Every five years, the Japanese government conducts a fisheries census and publishes the related data. The reason for choosing data in 2013 is that it is the latest source where the current status of Japanese marine fishery can be understood. The dataset covers all of the prefectures involved in marine fisheries in Japan, while provides a comprehensive overview of the whole Japanese marine fisheries.

The dataset includes one output and two inputs which are necessary to conduct TE analysis (Table 3-5). The dependent variable is the value of marine capture fisheries and the marine aquaculture production by each of the 39 prefectures in 2013, which is measured in million Japanese yen. Input data include vessel gross registered tonnages (GRT) and total fishers quantity involved in marine fisheries.

In 2013, the total marine fishery production value of each prefecture ranged from 2,653 million yen to 298,444 million yen, with the mean value as 34,722; the tonnage of powered vessels used in marine fishery distributed from 1,741 GRT to 71,377 GRT, with a mean of 15,699 GRT; and the total number of fishers differed from 343 persons to 29,652 persons, averaging as 4,641.

Table 3-5 Summary statistics of the variables used in TE analysis of Japanese marine fishery in 2013

Variables	Unit	Description	Mean	Max	Min	SD
Production	**Million JPY**	Marine fishery production value	34,722	298,444	2,653	48,516
Gross tonnage	**GRT**	Tonnage of powered vessels in marine fishery	15,699	71,377	1,741	13,891
Man	**Person**	Total quantity of people engaged in marine fishery	4,641	29,652	343	5,004

In this study, the stochastic frontier production function model of Japanese marine fishery can be specified as follows:

$$\ln \mathrm{Y}_i = \beta_0 + \beta_1 \ln ton_{\,i} + \beta_2 \ln man_{\,i} + \mathrm{V}_i - \mathrm{U}_i$$

$$TE = \mathrm{y}_i/[f(x_i;\beta) + v_i] \quad i = 1,\cdots,N \text{ DMUs} \tag{3.1}$$

where $\ln \mathrm{Y_i}$ represents the natural logarithm of yearly production value of the marine fishery by the i^{th} prefecture (i=1,2,…,39) in 2013. The input variables selected for this empirical model consist of vessel gross registered tonnage and fishers quantity applied in

2013 by each prefecture.

3.3.2 Results

(1) Parameter estimates of stochastic production frontier model

Table 3-6 Parameter estimates of the stochastic production frontier model for Japanese marine fishery in 2013

Variables	Parameter	Coefficient
Constant	β_0	-0.55
ln(vt)	β_1	0.89***
ln(fq)	β_2	0.30***
Sigma-squared	σ^2	0.17**
Gamma	γ	0.66**
Log-likelihood		-9.52

Note: * designates statistically significant at 10% level or less, ** means statistically significant at 5% level or less, and *** means statistically significant at 1% level or less.

Based on the maximum likelihood estimation approach, the estimated results of stochastic production frontier are presented in Table 3-6. The coefficient of vessel tonnage is 0.89, which means it is positively related with marine fishery production value, significant as a 1% level. While the other input, i.e. fishers quantity, is also significantly and positively related with fishery production, with the coefficient as 0.30. The variance of the one-sided component γ is 0.66, which can be used to calculate the relative contribution of the technical inefficiency effect to the total variance term. As we adopt Cobb-douglas function form, the coefficients of parameters can be given economic meaning. Theoretically, the value of marine fishery production can be increased by 0.89% if the vessel tonnage increases 1%, while by 0.3% if the fisher quantity extended 1%.

(2)Technical efficiency estimates

Results of TE scores calculated by SFA model reveal that the average TE of the 39 prefectures was 0.783. Ehime prefecture was the most technically efficient with a score as 0.918, while Osaka was the least technically efficient with a score as 0.516. The TE scores of top ten prefectures and last ten prefectures are listed in Table 3-7.

In Fig. 3-5, the mean technical efficiencies of Japanese marine fishery in 2013 divided by geographical regions are represented. The 39 prefectural governments are usually divided into five geographical regions, within which Honshu region is composed of 26 prefectures (Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, Ibaraki, Chiba, Tokyo, Kanagawa, Niigata, Toyama, Ishikawa, Fukui, Shizuoka, Aichi, Mie, Kyoto, Osaka, Hyogo, Wakayama, Tottori, Shimane, Okayama, Hiroshima and Yamaguchi), Shikoku region is composed of 4 prefectures (Tokushima, Kagawa, Ehime and Kochi), and Kyushu region consists of 7 prefectures (Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki and Kagoshima). Hokkaido was the most efficient, followed by Shikoku, Kyushu, Okinawa, and Honshu was the least efficient.

Table 3-7 Technical efficiency scores of the top ten and last ten prefectures calculated by SFA

Top rank	**Prefecture**	**TE score**	**Last rank**	**Prefecture**	**TE score**
1	Ehime	0.918	1	Osaka	0.516
2	Tokyo	0.906	2	Yamaguchi	0.571
3	Kochi	0.898	3	Kanagawa	0.584
4	Miyazaki	0.894	4	Wakayama	0.600
5	Oita	0.893	5	Aomori	0.656
6	Hokkaido	0.878	6	Nagasaki	0.685
7	Saga	0.871	7	Hyogo	0.711
8	Yamagata	0.846	8	Shizuoka	0.733
9	Tottori	0.844	9	Hiroshima	0.752
10	Kumamoto	0.840	10	Akita	0.758

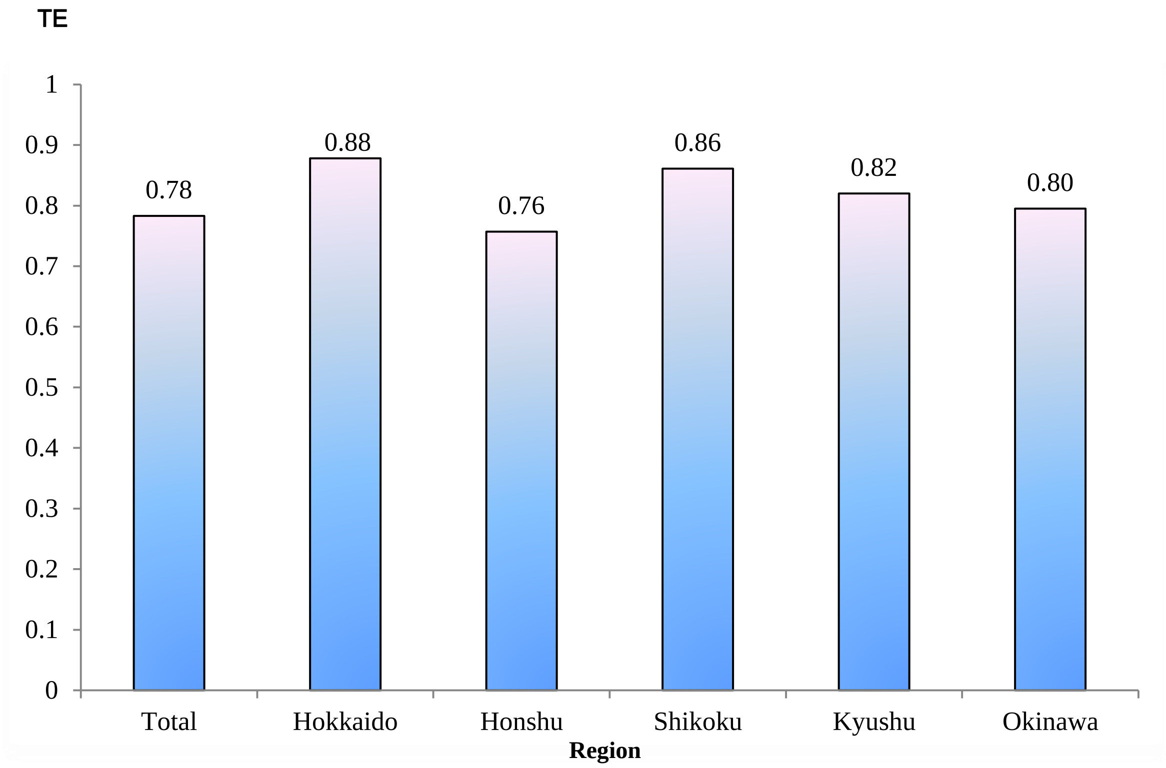

Fig. 3-5 Mean technical efficiencies of Japanese marine fishery in 2013 divided by geographical regions (SFA)

Table 3-8 shows the frequency distribution of technical efficiencies of each geographical regions related with the marine fishery production in 2013. A general view of the total frequency distribution of TE reveals that 2 prefectures were highly technically efficient (TE>=0.90) and 6 prefectures were not efficient (TE<0.7), with about 80% prefectures distributed between 0.7 and 0.9. The two most efficient prefectures are in Honshu and Shikoku region, while the least efficient three prefectures are all in Honshu.

Fig. 3-6 shows the technical efficiency of the top ten prefectures in terms of marine production value in 2013, and as the grey arrow indicates, the marine fishery production value in 2013 decreased from Hokkaido to Hyogo. Although Hokkaido showed an obvious superiority in marine production value, its TE was lower than Ehime and Kochi, where marine aquaculture played a relatively higher position in terms of production value compared with Hokkaido. Meanwhile, Nagasaki, the second largest marine production prefecture calculated by value, showed a low TE as 0.68. The average TE of the top ten prefectures in production value was 0.781, lower than the total mean TE. This is partly attributed to the low TE of Nagasaki and Aomori prefectures.

Table 3-8 Frequency distribution of technical efficiency of Japanese marine fishery in 2013 divided by geographical regions (SFA)

Frequency	Total	Hokkaido	Honshu	Shikoku	Kyushu	Okinawa
0.90-0.99	2		1	1		
0.80-0.89	17	1	9	3	4	
0.70-0.79	14		11		2	1
0.60-0.69	3		2		1	
0.50-0.59	3		3			
0.40-0.49						
0.30-0.39						
0.20-0.29						
0.10-0.19						
0.00-0.09						
Mean	0.783	0.878	0.757	0.861	0.820	0.795

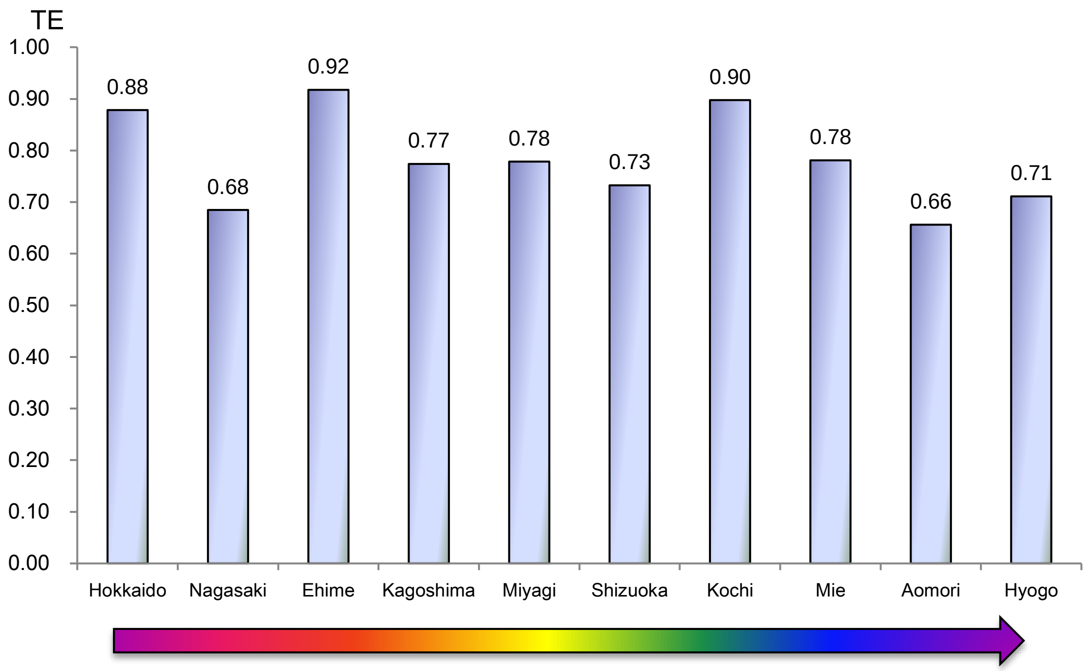

Fig. 3-6 The technical efficiencies of the top ten prefectures in terms of marine fisheries production value in 2013 (SFA)

(Note: As indicated by the arrow mark, Hokkaido is top one while Hyogo is top ten.)

3.4 Technical efficiency study by means of DEA approach

3.4.1 Methodology description

The introduction of DEA approach was conducted in Chapter 2. As described there, DEA approach can be divided into two categories in generally, according to different selections of the envelopment surface, i.e. constant returns to scale (CRS) and variable returns to scale (VRS) surfaces. DEA-CRS model, also known as CCR model, adopts a piece wise constant returns to scale (Charnes et al. 1978); while DEA-VRS model, known as BCC model, assumes a variable returns to scale (Banker et al. 1984).

Since the DEA-CRS and DEA-VRS models have already been introduced in Chapter 2, the detailed descriptions about these models are saved and only the mathematical models are listed again for easier understanding.

DEA-CRS model

$$\text{Min}_{\theta,\lambda}\ \theta$$

subject to:

$$-q_i + Q\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0 \qquad (3.2)$$

DEA-VRS model

$$\text{Min}_{\theta,\lambda}\ \theta$$

subject to:

$$-q_i + Q\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \tag{3.3}$$

where θ denotes the scalar, ranging from 0 to 1; λ is an $I \times 1$ vector of weights defining the linear combination of the peers of the i^{th} DMU.

Table 3-9 Frequency distributions of technical efficiency of Japanese marine fishery in 2013

Frequency	**DEA-CRS**		**DEA-VRS**	
1.00	2	(5.1%)	5	(12.8%)
[0.90, 1.00)	3	(7.7%)	3	(7.7%)
[0.80, 0.90)	1	(2.6%)	2	(5.1%)
[0.70, 0.80)	1	(2.6%)	4	(10.3%)
[0.60, 0.70)	6	(15.4%)	7	(17.9%)
[0.50, 0.60)	9	(23.1%)	12	(30.8%)
[0.40, 0.50)	9	(23.1%)	3	(7.7%)
[0.30, 0.40)	6	(15.4%)	3	(7.7%)
[0.20, 0.30)	2	(5.1%)		
Total	39	(100%)	39	(100%)
Mean	0.559		0.666	
Maximum	1.000		1.000	
Minimum	0.210		0.320	
Standard deviation	0.207		0.194	

Table 3-10. List of prefecture specific technical efficiency of Japanese marine fishery in 2013

Region	Prefecture	DEA-CRS	Rank	DEA-VRS	Rank
Hokkaido	Hokkaido	0.960	4	1.000	1
Honshu region	Aomori	0.390	32	0.400	36
	Iwate	0.520	18	0.580	23
	Miyagi	0.610	13	0.690	15
	Akita	0.310	36	0.780	11
	Yamagata	0.430	30	1.000	1
	Fukushima	0.990	3	1.000	1
	Ibaraki	0.670	8	0.710	14
	Chiba	0.550	16	0.620	20
	Tokyo	1.000	1	1.000	1
	Kanagawa	0.340	35	0.390	37
	Niigata	0.470	25	0.660	18
	Toyama	0.570	14	0.630	19
	Ishikawa	0.500	21	0.560	26
	Fukui	0.380	34	0.540	29
	Shizuoka	0.560	15	0.690	15
	Aichi	0.440	29	0.520	30
	Mie	0.510	19	0.520	30
	Kyoto	0.390	32	0.910	7
	Osaka	0.210	39	0.460	35
	Hyogo	0.490	23	0.490	34
	Wakayama	0.300	37	0.380	38
	Tottori	0.650	10	0.730	12
	Shimane	0.510	19	0.570	24
	Okayama	0.430	30	0.590	22
	Hiroshima	0.460	26	0.500	33
	Yamaguchi	0.270	38	0.320	39
Shikoku region	Tokushima	0.460	26	0.560	26
	Kagawa	0.550	16	0.620	20
	Ehime	1.000	1	1.000	1
	Kochi	0.910	5	0.930	6
Kyushu region	Fukuoka	0.480	24	0.520	30
	Saga	0.640	11	0.720	13
	Nagasaki	0.500	21	0.570	24
	Kumamoto	0.620	12	0.680	17
	Oita	0.760	7	0.800	10
	Miyazaki	0.870	6	0.880	9
	Kagoshima	0.660	9	0.910	7
Okinawa	Okinawa	0.450	28	0.560	26

3.4.2 Results

(1) Technical efficiency estimates

As presented in Table 3-9, technical efficiency of Japanese marine fishery in 2013 estimated by DEA-CRS averaged as 0.559, ranging from 0.21 to 1 and with a standard deviation as 0.207. Mean TE calculated by DEA-VRS was 0.666, ranging from 0.32 to 1. Table 3-9 also indicated that TE estimates by use of DEA model displayed a wide distribution. In DEA-CRS, prefectures with a TE range between 0.5 and 0.6 (also between 0.4 and 0.5) accounted for the largest ratio (23.1%); while in DEA-VRS, over one third of the prefectures (30.8%) fell into the range of 0.5 and 0.6. Two and five prefectures obtained a TE score of 1 in DEA-CRS and DEA-VRS models, respectively. As shown in Table 3-10, Ehime and Tokyo were fully efficient while Osaka was the least technically efficient in the case of DEA-CRS model; in the condition of DEA-VRS model, Yamaguchi obtained the lowest TE while Ehime, Tokyo, Fukushima, Yamagata and Hokkaido were all perfectly efficient.

As represented in Fig. 3-7, in terms of different geographical regions by DEA-CRS model, Hokkaido region showed the highest TE, followed by Shikoku, Kyushu, Honshu and Okinawa, which was similar with the result by SFA model illustrated in Fig. 3-5 expect the reversed order of Honshu and Okinawa. By using DEA-VRS model, the rank of average TE in different geographical regions is the same with that in DEA-CRS.

Table 3-11 shows TE estimates and corresponding ranks of the top ten prefectures in terms of marine production value in 2013 using DEA. In DEA-CRS model, four of the top ten prefectures with the largest marine fishery production entered into the group of top ten technically efficient, i.e. Hokkaido, Ehime, Kagoshima and Kochi. Hokkaido showed an obvious superiority over Ehime in terms of marine production value, while its TE was lower than Ehime. In DEA-VRS model, four of the top ten prefectures with the largest marine fishery production were also the top ten considering TE (Hokkaido, Ehime, Kagoshima and Kochi), which agreed with the corresponding results in DEA-CRS model. Hokkaido showed an obvious superiority over Ehime in terms of marine production value and its TE was the same with that of Ehime.

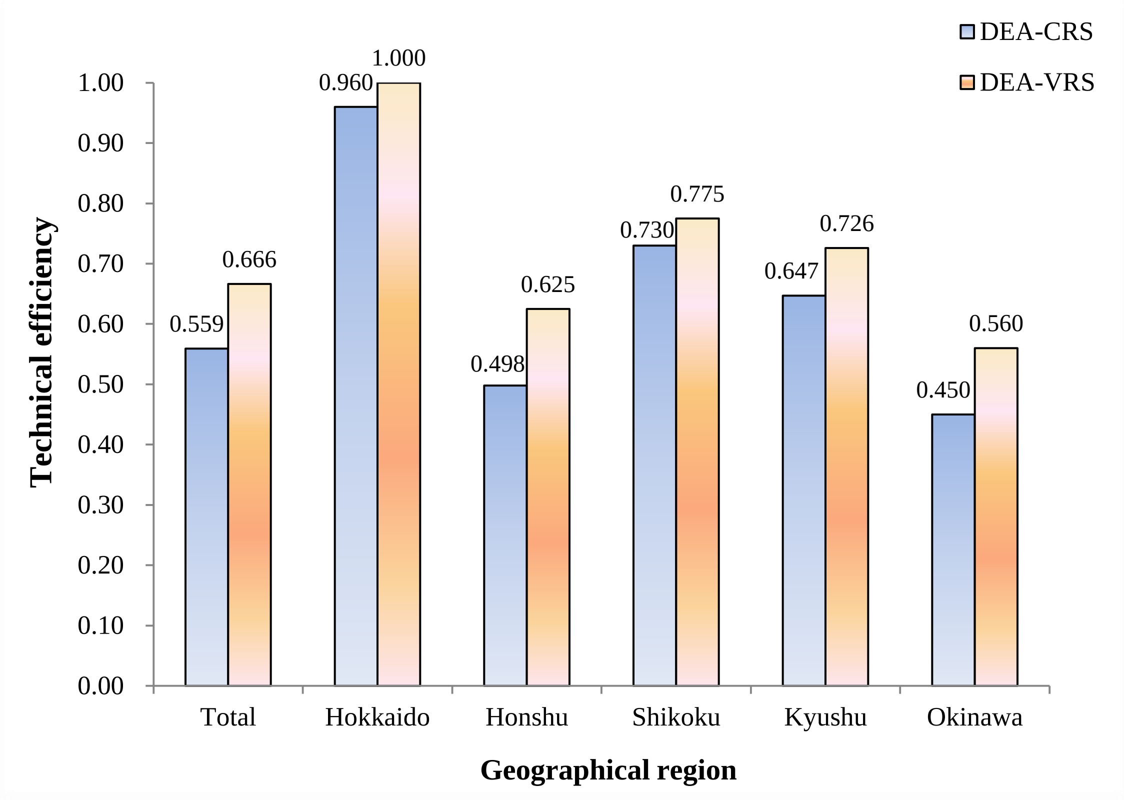

Fig. 3-7. Mean technical efficiencies of Japanese marine fishery in 2013 divided by geographical regions (DEA)

Table 3-11. Technical efficiency ranking of the top ten prefectures in terms of marine fishery production value in 2013 (DEA)

Prefecture	Production value (million JPY)	Rank	DEA-CRS	Rank	DEA-VRS	Rank
Hokkaido	298,444	1	0.96	4	1.00	1
Nagasaki	92,140	2	0.50	21	0.57	24
Ehime	84,912	3	1.00	1	1.00	1
Kagoshima	76,637	4	0.66	9	0.91	7
Miyagi	57,002	5	0.61	13	0.69	15
Shizuoka	51,634	6	0.56	15	0.69	15
Kochi	48,957	7	0.91	5	0.93	6
Mie	46,212	8	0.51	19	0.52	30
Aomori	46,125	9	0.39	32	0.40	36
Hyogo	38,303	10	0.49	23	0.49	34

3.5 Comparisons of technical efficiency between SFA and DEA

As indicated by the results in section 3.3 and 3.4, the mean TE estimates of Japanese marine fishery in 2013 calculated by SFA are higher than those in DEA. Meanwhile, the TE scores of 39 prefectures in SFA concentrated in the range of 0.7 and 0.9, while those in DEA were distributed more widely. This difference can also be found from different standard deviations between SFA and DEA results. In terms of the prefecture with the highest TE, results were consistent between SFA and DEA; while with respect to the least efficient prefecture, results were the same between SFA and DEA-CRS while showing difference in DEA-VRS.

To further verify the association of the results obtained by means of SFA and DEA, Spearman rank correlation analysis (Spearman 1904) was conducted and the coefficients were listed in Table 3-12. The coefficients were all larger than 0.7, designating strong correlations among the ranking results of SFA, DEA-CRS and DEA-VRS. And the TE ranking using SFA showed the best agreement with that applying DEA-VRS.

Table 3-12. Spearman rank correlation matrix of technical efficiency rankings of prefectures

	SFA	**DEA-CRS**	**DEA-VRS**
SFA	1.000	0.745	0.759
DEA-CRS	0.745	1.000	0.716
DEA-VRS	0.759	0.716	1.000

3.6 Discussions

Results of mean technical efficiency of Japanese marine fishery indicate that it still has considerable room to improve the efficiency as the TE score was less than 0.8 regardless of estimation methods. The TE score of overall Japanese marine fishery derived in this study was lower than that of offshore bottom trawl fishery in Hokkaido studied by

Sakurai et al. (2012), which showed an average TE as 0.892. They concluded that the offshore bottom trawl fishery in Hokkaido operated with a high technical efficiency. This may be possible as the analytical target in this study is the overall marine fishery which may include some inefficient fisheries types. Meanwhile, TE estimates of the fishery in other countries can also be found in previous literature despite the small quantity. For instance, a meta-analysis of TE in global aquaculture was conducted by Iliyasu et al. (2014) and it was concluded that the mean TE of aquaculture operations was 0.64 for Asia, 0.71 for Africa, 0.80 for Europe, and 0.73 for the U.S. Kim et al. (2010) estimated the TE of Korean coastal composite fishery in 2005 and found the TE score ranged from 0.48 to 0.74. Comparison among these results indicates that Japanese marine fishery does not demonstrate a superiority over other fishing counties in terms of technical efficiency.

With regard to the prefecture-specific TE, results showed that Ehime was the most efficient no matter which estimation method was applied. This result is within our expectation as Ehime is a primary fishery prefecture in Japan and produces several valuable fish species such as red sea bream, Japanese amberjack and flounder. Although we can imagine that Osaka, which is not a major marine fishery production prefecture, is technically inefficient, it may be beyond one's expectation that the TE of some traditional marine fishing region was not high in 2013. This reveals that large marine production does not guarantee high technical efficiency. This can be easily understood because TE evaluates a decision-making unit's capacity in maximizing its output or minimizing its input. If a prefecture famous for large fishery production uses excessive amounts of inputs to achieve the abundant production, it may be technically less efficient than a prefecture with small fishery production but using the appropriate amount of inputs.

Technical efficiency estimates derived from SFA approach were larger than those from DEA, which corresponds with several previous works (Sharma et al. 1997, Hutton et al. 2003). This is reasonable because DEA attributes the deviation of real output from potential maximum output to inefficiency, without taking into account random error; while SFA considers both. Despite of the variation in TE scores, results in this study indicate that TE estimates applying SFA are closely associated with those by DEA, which was also pointed out in the studies of Kim et al. (2010), Sharma et al. (1997) and Hutton et al. (2003).

3.7 Conclusions

This chapter serves as the first case study of technical efficiency analysis of Japanese marine fishery. By selecting the input and output data on Japanese marine fishery production in 2013, this chapter adopts SFA and DEA approach to estimate the TE scores of each prefectural government engaging in marine fishery production.

The related production data include the yearly production value of marine fishery by each of the 39 prefectural governments, which was adopted as the output; while the input variables are composed of two types of data, i.e. the gross registered tonnage of powered vessels used by one prefecture in 2013 and the overall quantity of fishers operating marine fishery. The reason for choosing value rather than volume as the production output is to taking into account the significance of fishery income. As the 39 prefectural governments diversify in marine fishery production, using the production volume of aquatic species as the output will be misleading when explaining the results of TE.

Results showed that the mean TE of Japanese marine fishery production in 2013 was 0.783, 0.559 and 0.666 using SFA, DEA-CRS and DEA-VRS, respectively. Irrespective of estimation methods, Ehime showed the highest TE. Adopting SFA and DEA-CRS, Osaka showed the lowest efficiency; while using DEA-VRS, Yamaguchi was the least efficient. Although TE estimates were different, there exist strong correlations among SFA, DEA-CRS and DEA-VRS.

As the technical efficiency studies on Japanese fishery are extremely insufficient and comparison of results between SFA and DEA is even much scarcer, this study is significant and meaningful. Despite of this, limitations can be found such as the combination of capture fishery and aquaculture. When input and output data are available, a separate analysis of the technical efficiency of marine capture fishery as well as marine aquaculture will be conducted which is expected to derive more accurate results. Meanwhile, the other aspect of efficiency, i.e. allocative efficiency, will also be analyzed targeting Japanese marine fishery in future works.

Chapter 4

The Pacific saury fishery in Japan: production and economic performance

4.1 Introduction

In this chapter, the Pacific saury fishery in Japan will be introduced from two aspects, i.e. production and economic performance, which aims to provide a clear overview of this specific fishery in Japan. In section 4.2, the Pacific saury production in international environment is firstly introduced, which will manifest Japan's position in international Pacific saury fishery. Section 4.3 analyzes and discusses the yearly changes of the Pacific saury catch in Japan, the regional distribution of Pacific saury production and the position of Pacific saury stick-held dip net fishery. In section 4.4, the fishing methods used in catching the Pacific saury are described, with a focus on the primary fishing technique, stick-held dip netting. Section 4.5 analyzes the changes and regional distribution of Pacific saury fishing vessels; while section 4.6 introduces the variations in fishermen and business entities operating the Pacific saury fishery. In section 4.7, the economic performance analysis is provided based on the cost and revenue statistical data. And in the last section, the management systems related with the Pacific saury fishery in Japan will be introduced.

4.2 International production of Pacific saury and Japan's position

Worldwide production volume of the Pacific saury experienced a great change since 1980s, increasing from 225,755 tonnes to 405,431 tonnes (excluding Mainland China), as shown in Table 4-1. Before 1985, the Pacific saury was generally caught by only two countries, i.e. Japan and Russia. The production of Russia varied greatly in the period of 1980 to 2013, with the lowest catch as 4,665 tonnes in 1998 and highest catch as 119,433 tonnes in 2007. The average catch of Pacific saury by Russia was over 70,000 tonnes in the last decade. The saury catch by Korea was only 1,050 tonnes in 1985 and expanded rapidly to more than 50,000 tonnes in 1997, and stayed relatively stable between 10,000 to 30,000 tonnes in terms of Pacific saury catch in recent years. Although Table 4-1 shows the Pacific saury catch of Taiwan was zero before 1989, the literatures from Taiwan proved that it started the saury fishery earlier than 1989 (Hong 2006). The saury production by Taiwan in 1989 was 12,036 tonnes and developed rapidly since then. In 2013, Taiwan exceeded Japan in terms of Pacific saury landings and became the largest region of Pacific saury production.

According to Ren et al. (2015), China began to build large-scale fishing vessels for the high seas Pacific saury fishery from 2012. Vessels belong to several fishing companies in Zhejiang Province and Shandong Province. Despite the late beginning, China is devoting great efforts to developing its Pacific saury fishery. The saury catch of China in 2014 was estimated to be around 77,000 tonnes (Yantai Daily Newspaper 2015), more than one third of Japanese saury production.

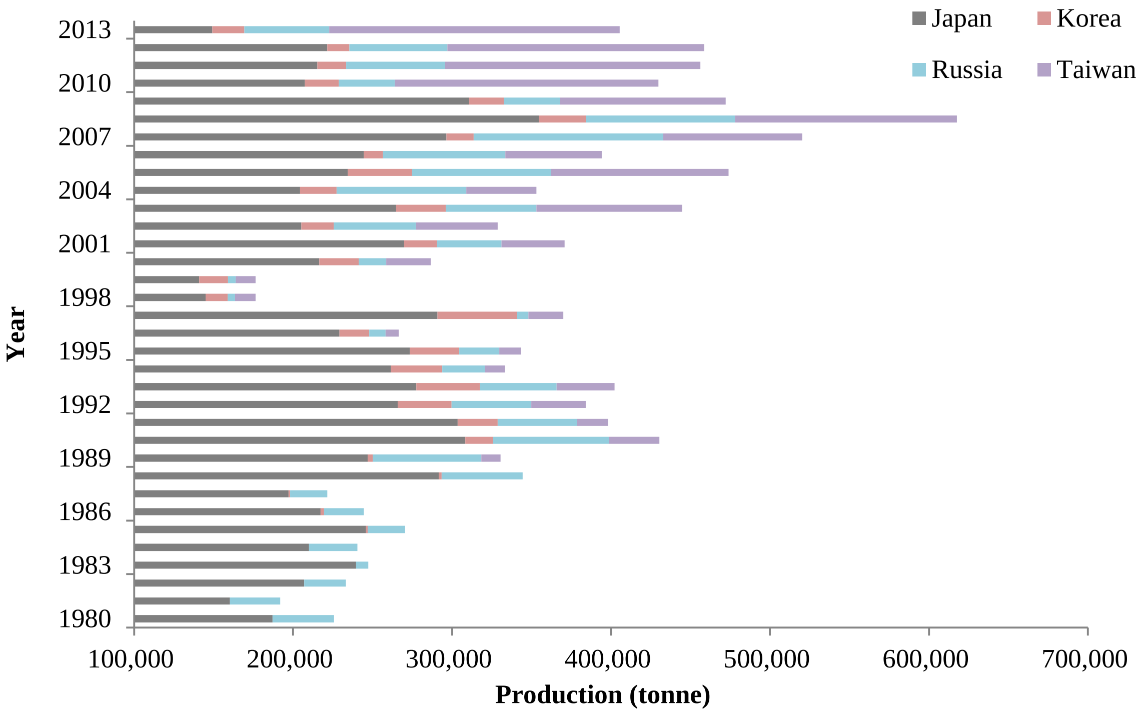

Fig.4-1 The production volume of Pacific saury in Japan, Korea, Russia and Taiwan

Data source: Stock assessment of Pacific saury (*Sanma taiheiyo kitanishibu keigun no shigenhyouka*), 2014

Table 4-1 The worldwide production volume of Pacific saury and Japan's share

Year	Total catch	Japan	Korea	Russia	Taiwan	Japan's share
1980	225,755	187,155	0	38,600	0	82.9%
1981	192,019	160,319	0	31,700	0	83.5%
1982	233,251	206,958	0	26,293	0	88.7%
1983	247,264	239,658	0	7,606	0	96.9%
1984	240,421	209,974	0	30,447	0	87.3%
1985	270,417	245,944	1,050	23,423	0	90.9%
1986	244,436	217,229	2,305	24,902	0	88.9%
1987	221,584	197,084	1,016	23,484	0	88.9%
1988	344,462	291,575	1,960	50,927	0	84.6%
1989	330,461	246,821	3,236	68,368	12,036	74.7%
1990	430,378	308,271	17,612	72,618	31,877	71.6%
1991	398,118	303,567	25,135	49,943	19,473	76.3%
1992	383,999	265,884	33,708	50,172	34,235	69.2%
1993	402,195	277,461	40,154	48,145	36,435	69.0%
1994	333,252	261,587	32,280	26,835	12,550	78.5%
1995	343,418	273,510	30,996	25,140	13,772	79.6%
1996	266,472	229,227	18,729	10,280	8,236	86.0%
1997	370,017	290,812	50,227	7,091	21,887	78.6%
1998	176,368	144,983	13,926	4,665	12,794	82.2%
1999	176,396	141,011	18,036	4,808	12,541	79.9%
2000	286,532	216,471	24,803	17,390	27,868	75.5%
2001	370,837	269,797	20,869	40,407	39,764	72.8%

Continued on next page

Table 4-1 The worldwide production volume of Pacific saury and Japan's share

(Continued from previous page)

Year	Total catch	Japan	Korea	Russia	Taiwan	Japan's share
2002	328,631	205,282	20,345	51,709	51,295	62.5%
2003	444,642	264,804	31,219	57,104	91,515	59.6%
2004	353,148	204,371	22,943	81,572	44,262	57.9%
2005	473,907	234,451	40,509	87,456	111,491	49.5%
2006	394,164	244,586	12,009	76,920	60,649	62.1%
2007	520,207	296,521	16,976	119,433	87,277	57.0%
2008	617,509	354,727	29,591	93,677	139,514	57.4%
2009	472,177	310,744	22,001	35,213	104,219	65.8%
2010	429,808	207,488	21,360	35,268	165,692	48.3%
2011	456,263	215,353	18,068	62,311	160,531	47.2%
2012	458,530	221,470	13,961	61,585	161,514	48.3%
2013	405,431	149,204	20,055	53,553	182,619	36.8%

Notes: a) The unit of production volume is 'tonne'; b) Stock assessment of Pacific saury (*Sanma taiheiyo kitanishibu keigun no shigenhyouka*), 2014.

Table 4-2 concludes the main characteristics of the Pacific saury in the main producing country/region from the aspects of vessel quantity, vessel size measured by the gross register tonnage, other fisheries operations, fishing period, fishing ground and landing form of fish. As shown in the table, the fishing vessel size of Japan is the smallest which is less than 200 GRT. In this case, vessels cannot go far away to the high seas for catching fish. Meanwhile, as the Japanese consumers prefer fresh saury than frozen ones, vessels are required to sail back to the landing ports as soon as possible. This also constrains the high-seas operation for Japan's Pacific saury fishery.

Table 4-2 Comparison of the main characteristics of Pacific saury fishery worldwide

Country/ Region	Vessels No.	Vessel Size	Subsidiary Fisheries	Fishing Period	Fishing Ground	Landing Form
Japan	153	<200 GRT	ST, TL, DN	Aug. – Dec.	Within J-R 200 EEZ	Fresh
Korea	12—3	>300 GRT	SA	June – Nov.	Within JA 200 EEZ, NW Pacific HS	Frozen
Russia	47	1000 GRT	TR	Aug. – Nov.	Within J-R 200 EEZ, SHS	Frozen/Canned/Fresh
Taiwan	67	>500 GRT	PSA	June – Nov.	NW Pacific HS	Frozen
Mainland China	44	>1000 GRT	PSA	June – Nov.	NW Pacific HS	Frozen

Notes: a) Vessel number in Japan is the latest data issued in 2014 and information about Mainland China is from Yantai Daily Newspaper 2015.

b) ST: Salmon and trout fishery; TL: Tuna long line fishery; DN: Drift net fishery with large mesh size; SA: Squid angling fishery; TR: Trawling fishery; PSA: Pelagic squid angling fishery.

c) Within J-R 200 EEZ: Within the Japanese-Russian 200 nautical miles region; Within JA 200 EEZ: Within the Japanese 200 nautical miles region; NW Pacific HS: Northwestern Pacific high-seas region; SHS: Surrounding high-seas region.

e) Data source: Demand, Supply and Distribution of the Main Aquatic Products in Japan (*Shuyo suisanbutsu no jyukyu to ryutsu*) 2011, by Tokyo Fisheries Promotion Foundation.

4.3 National production of Pacific saury in Japan

4.3.1 Yearly changes of the total Pacific saury catch (1894-2014)

In more than one hundred years, Japanese history has experienced four eras, i.e. Meiji period (1868-1912), Taisho period (1912-1926), Shōwa period (1926-1989) and Heisei period (1989-present). During these long years, Japan saw several historic events happening in the world, including the World Wars. Correspondingly, the Pacific saury catch presented tremendous changes with time in Japan.

In 1894 (Meiji 27), the total production of Pacific saury in Japan was 4,412 tonnes, and experienced a fluctuating trend in the continuing years, with 1899 as the lowest year (196 tonnes) and 1907 as the highest year (7,489 tonnes). In 1909, the Pacific saury catch increased more than two fold compared with that in the previous year (6,279 tonnes) and entered into a higher level period (14,798 tonnes) for the first time, which could be attributed to the introduction of new fishing method (drift netting). Since then, the Pacific saury harvest kept at this high level until the end of the Second World War. Although the production of Pacific saury was still 16,697 tonnes in 1943, it decreased sharply to 3,397 tonnes in 1944 and stayed at a low level as 3,088 tonnes in 1945.

After the end of the Second World War, Japan's Pacific saury fishery recovered quickly and developed into another new period with the development and popularity of a new fishing technique, stick-held dip net. In 1946, the Pacific saury harvest increased to 10,265 tonnes, three times as much as that in 1945. Thereafter, it kept increasing and entered into six-digit period since 1950 (126,362 tonnes), which could be attributed to the introduction and wide application of stick-held dip net.

The new introduction of stick-held dip net (SHDN) in the Pacific saury fishery made this fish become one of the most important seafood for Japanese people. The Pacific saury catch reached as 575,087 tonnes in 1958, which recorded the highest harvest level in Japan's history. However, the production of the Pacific saury turned to decrease since the mid-1960s and dropped down to about 60,000 tonnes in 1969. After the sharp decrease, the landings of the Pacific saury began to recover gradually and kept at a relatively high level of 210,000 to 310,000 tonnes from the late-1980s to the mid-1990. In 1998 and 1999, Japan saw another obvious decline in the landings of the Pacific saury to about 140,000 tonnes. Since 2000, the catch of Pacific saury has stayed very stable in a range of 200,000 to 300,000 tonnes and reached another comparatively high level of 350,000 tonnes in 2008, which has not been seen since 1978. Recently, the landings of Pacific saury keep around 200,000 tonnes.

4.3.2 Regional distribution of the Pacific saury catch

Similar with the tremendous changes of the total Pacific saury production from 1894 to 2014, the regional distribution of the Pacific saury catch in Japan also saw great changes during the period of more than one hundred years.

Based on the Annual Statistics on Fisheries and Aquaculture (MAFF), we can calculate the ratio of Pacific saury catch in each prefecture to the total production in Japan from 1894 to 2014. Although some data are missing due to the difficulty of access or no record, trends of regional distribution can be found. Before the end of Second World War, the ratio of each prefecture changed greatly year by year, therefore an up and down trend was seen. While with the end of the Second World War, the regional distribution of Pacific saury tended to become stable year by year. This is the first characteristic we found. The second obvious change is the increasingly importance of Hokkaido in saury production and decreasingly position of Ibaraki, Chiba, Shizuoka and Mie prefectures. While the percentage of Iwate, Miyagi and Fukushima keep relatively stable.

(1) Hokkaido:

The recorded data of Hokkaido began from 1908, which was only 5 tonnes with the total national catch as 6,279 tonnes. In the continuing years, the Pacific saury production kept the same low level until 1921, when the catch increased quickly to 530 tonnes. However, the production decreased again in the next two years (1922 as 221 tonnes and 1923 as 121 tonnes) and kept below 100 tonnes from 1924 to 1935. In 1936, the production of Pacific saury in Hokkaido reached immediately to 727 tonnes and increased to 1,276 tonnes in the next year and never fell down to two-digit level (below 100 tonnes) since then.

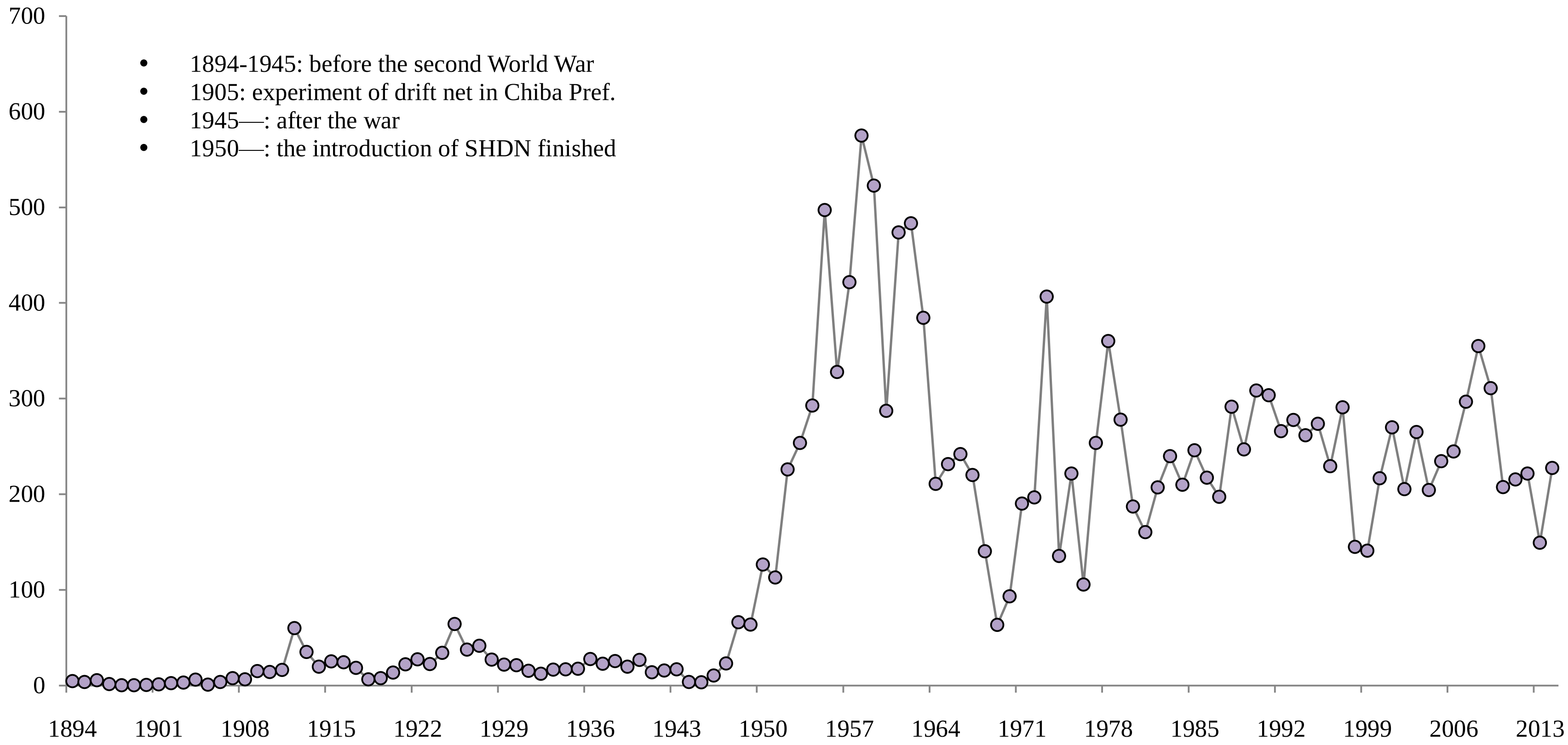

Fig.4-2 Pacific saury production in Japan from 1894 to 2014 (unit: thousand tonne)
Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

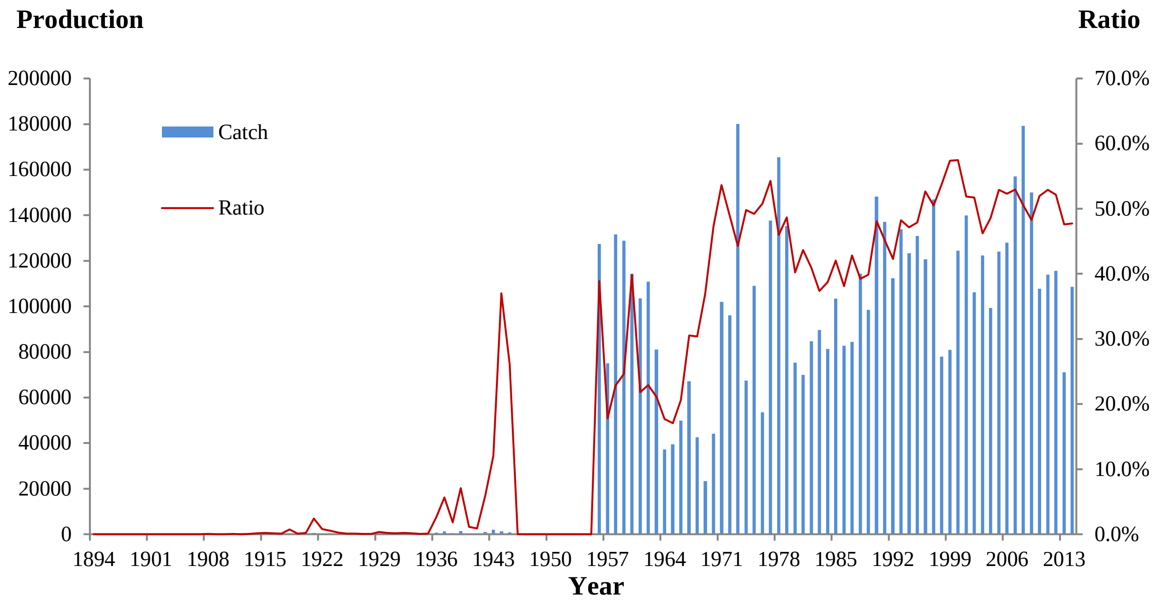

Fig.4-3 Pacific saury production in Hokkaido from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

In 1945, the Pacific saury catch in Hokkaido was 806 tonnes. In terms of the ratio of Hokkaido saury catch to the total national saury production, it was less than 1% in most years from 1908 to 1945, designating the insignificant position of Hokkaido in aspects of saury production. However, with the increase of Hokkaido's saury catch and decrease of total national saury landings, the ratio increased quickly and reached as high as 37% in 1944.

Although the data from 1946 to 1955 are missing, we can still see the great changes of Pacific saury catch in Hokkaido (Fig.4-3). In 1956, Hokkaido's saury catch was as high as 127,470 tonnes, which was 158 times the quantity in 1945. In the following years, although up-and-down was often seen in Pacific saury catch, especially from 1963 to 1970 when the catch almost kept decreasing trend and fell down as low as 23,376 tonnes in 1969, the increasing trend can be found in Hokkaido's saury production. In 2014, the saury catch in Hokkaido recorded as 108,600 tonnes. Considering the ratio of Hokkaido in Japan's saury production, it has kept an increasing trend in most of the years since 1956. Although the ratio decreased to less than 20% in several years such as 1957, 1964 and 1965, Hokkaido has kept the top one position in Pacific saury production in Japan since 1966 and the ratio has been stable as around 40%-50% since 1990.

(2) Aomori:

From Fig.4-4, we can see that the Pacific saury catch in Aomori was rare before 1945, with 360 tonnes as the largest amount in 1937. From 1956 to 1962, the saury catch in Aomori increased at a fast speed and reached 35,374 tonnes in 1962, which is the peak point in its history. In the following years, the saury production in Aomori fell down to the four-digit level (less than 10,000 tonnes) and even decreased to three-digit level (less than 1,000 tonnes) in several years. Since 1993, the saury production in Aomori has been relatively stable between 2,000 tonnes and 8,000 tonnes. Due to its small quantity in production, Aomori cannot be considered as the main producing prefecture in terms of saury now. The ratio of Aomori's saury production to Japan's saury catch was less than 2% before 1955, and recorded the highest level in 1962 as 7.32% due to the increase in production. From 1994 to 2014, the ratio kept between 1% and 3%.

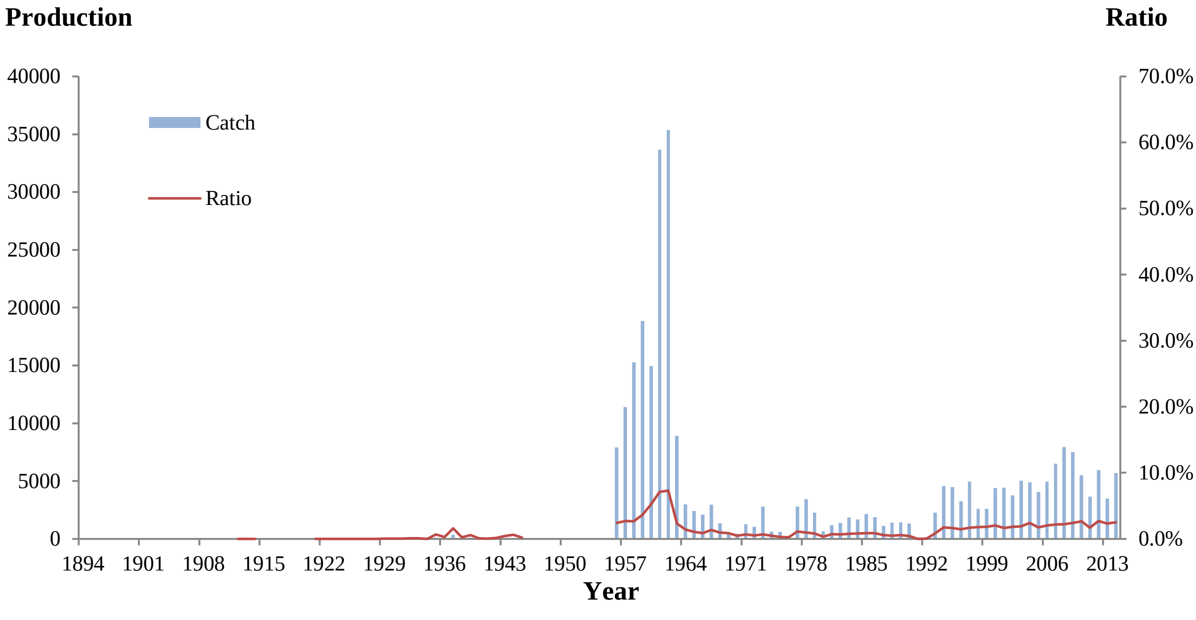

Fig.4-4 Pacific saury production in Aomori from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(3) Iwate:

The recorded data of Iwate's saury catch began from 1915. From Fig.4-5, we can see that the Pacific saury production in Iwate changed greatly from 1915 to 1945, with the lowest level as 1 tonne in 1922 and the highest level as 2,609 tonnes in 1931. While from

1956 to 1963, the saury catch in Iwate entered into a high-level period with the highest amount as 83,140 tonnes in 1958. This high-level catch did not last long and began to decrease in the following years. From 2001 to 2014, the saury production in Iwate kept relatively stable between 10,000 tonnes to 30,000 tonnes.

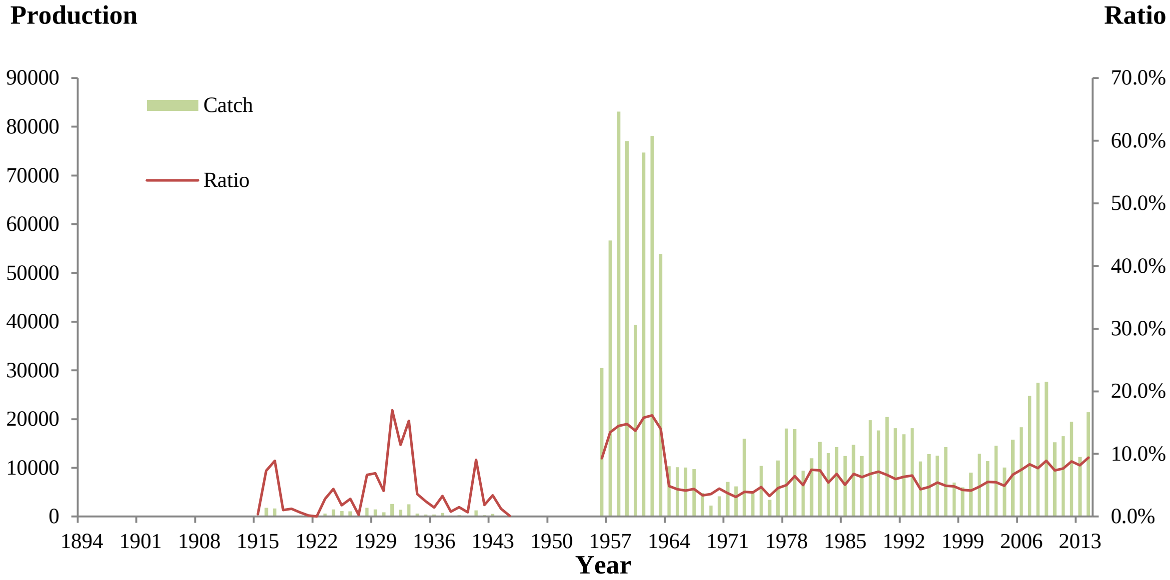

Fig.4-5 Pacific saury production in Iwate from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

Corresponding to the great changes in Iwate's Pacific saury catch from 1915 to 1945, its ratio to Japan's total saury production also presented an obvious up-and-down trend, with 1931 as the highest year (16.98%). The high-level catches from 1956 to 1963 contributed to the increase in Iwate's importance in Japan's saury production, with the ratio being around 10% to 17%. In the continuing years, the ratio changed from 3% to 10%, representing a slightly increasing trend.

(4) Miyagi:

Fig.4-6 represented the yearly changes of the Pacific saury catch in Miyagi Prefecture. From 1912 to 1945, the saury production experienced an up-and-down period, with 7,548 tonnes as the highest level in 1916. From 1956 to 1963, Miyagi saw rich catches in the Pacific saury, with 212,239 tonnes as the highest level in 1958. However, the catch decreased abruptly into 19,600 tonnes in 1964 and never returned to the high level in

1956-1963 period. In recent decades, the saury catch in Miyagi has mostly stabilized between 10,000 tonnes and 50,000 tonnes.

As shown in Fig.4-6, the ratio of Miyagi's saury catch to national saury production was less than 10% or even 1% in most of the time from 1912 to 1945, with several years as the few exceptions. From 1956 to 1963, the saury catch in Miyagi contributed a great part in Japan's national saury production, with the ratio as 27% to 40%, due to the corresponding great increase in saury catch in Miyagi. Although the ratio decreased from 1964 due to reduction in saury catch, it showed a mild up-and down trend and kept stable as around 13% in recent decade.

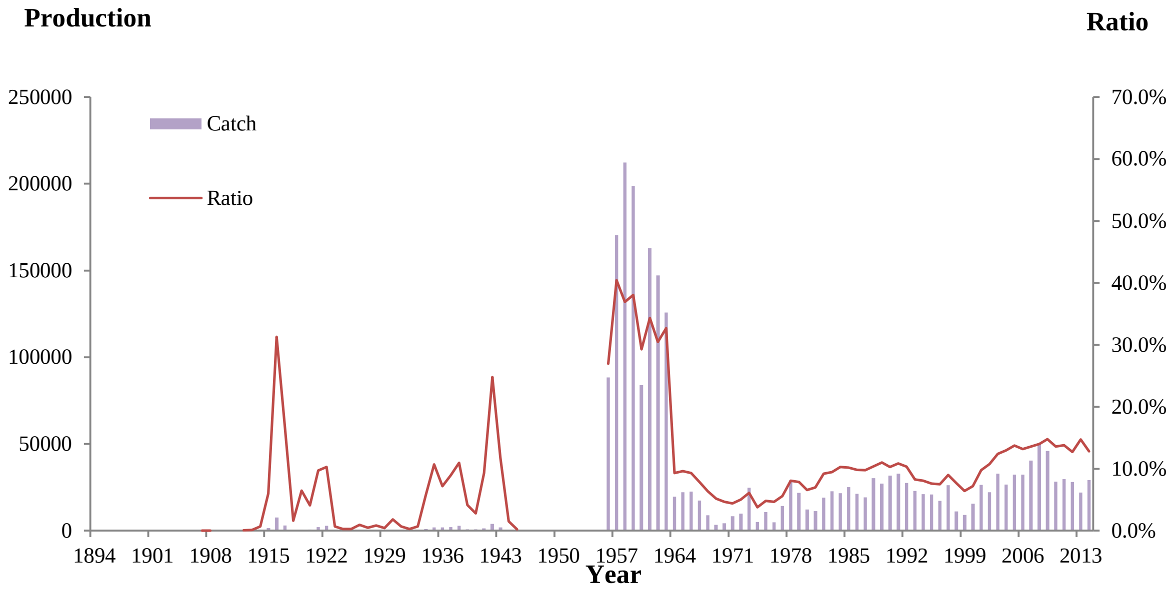

Fig.4-6 Pacific saury production in Miyagi from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(5) Fukushima:

Similar with the other prefectures described above, the Pacific saury production in Fukushima was generally at a low level before 1945, with 8,672 tonnes as the largest catch in 1938 (Fig.4-7). Considering the importance of Fukushima in the aspect of saury production, the ratio kept below 10% in most of the years before 1945, with the year 1938 as the exception. In 1938, Fukushima's saury catch contributed to 34.05% of the total national saury production.

From 1956 to 2014, Fukushima's saury production presented an up-and down scenario, with 80,192 tonnes as the highest level in 1973 and 10,647 tonnes as the lowest in 1969. In the last decade, the production has kept stable between 10,000 tonnes and 30,000 tonnes. This shows a downward trend in Fukushima's saury production. Regarding the ratio of Fukushima's saury production to total national saury catch, it generally increased than those years before 1945, with 20.02% as the highest in 1965. However, the ratio gradually decreased in recent decades. In 2014, Fukushima's saury catch contributed to 7.83% of Japan's total saury production.

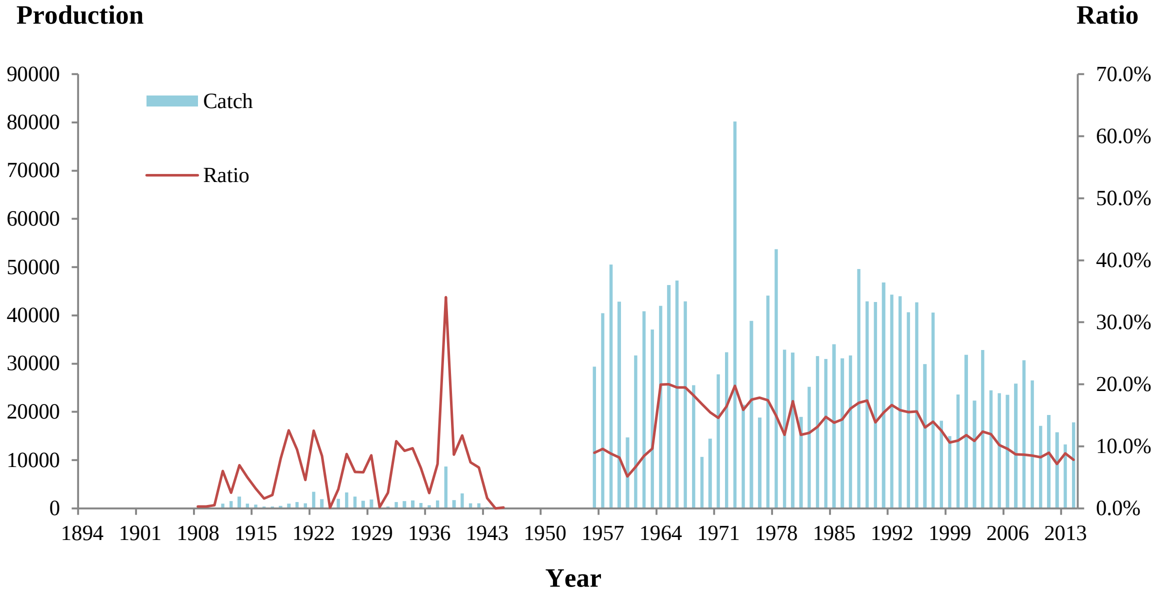

Fig.4-7 Pacific saury production in Fukushima from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(6) Ibaraki:

The recorded data on Ibaraki's saury production began in 1902, which was only 3 tonnes (Fig.4-8). However, it increased quickly into 12,906 tonnes in 1913 and kept a high level with up-and-down trend. Although the quantity was relatively small compared with that in the period between 1956 and 1967, it was still far more than the saury production in other prefectures (except Chiba Prefecture) in the period before 1945. From 1956 to 1967, Ibaraki's saury production developed fast with the highest level as 30,835 tonnes in 1958. However, this trend did not last for a long time and the saury catch decreased abruptly to

7,373 tonnes in 1968. In the following years, although the saury production recovered gradually, the highest catch never exceeded that in 1958. And in the last decade, the saury catch saw an obvious downward trend, which was less than 10,000 tonnes.

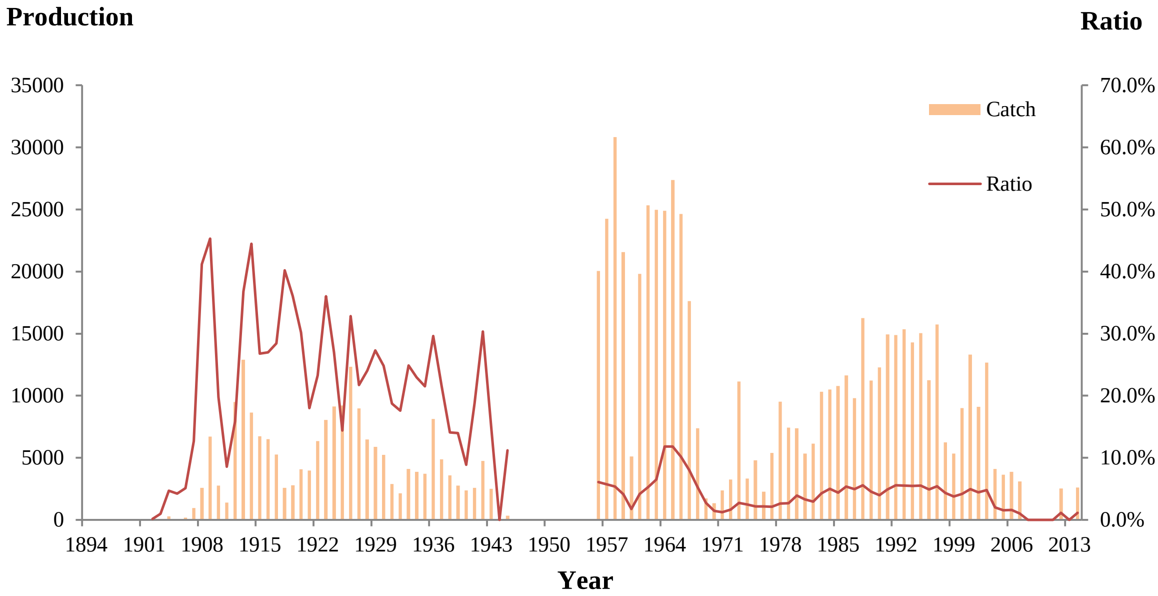

Fig.4-8 Pacific saury production in Ibaraki from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

Corresponding to the changes in Pacific saury catch, the importance of Ibaraki in Japan's saury production also changed. As shown in Fig. 4-8, the ratio of Ibaraki's saury catch to total national saury production has greatly decreased from 1894 to 2014. In most of the years before 1945, Ibaraki can be considered as the top prefecture in saury production, with 45.30% as the highest ratio in 1909. However, the contribution of Ibaraki has diminished from 1956 and stayed as 1%-2% in the last decade, which results from its shrinking saury catch.

(7) Chiba:

According to Fig.4-9, the recorded data on saury catch in Chiba started early from 1894, with 3,447 tonnes as the starting point, which was a relatively large quantity compared with other prefectures. From 1894 to 1945, the Pacific saury production in Chiba went through an up-and-down trend, with the peak point as 15,641 tonnes in 1912. From 1956, Chiba also experienced an increasing trend in its saury catch, with 49,176 tonnes as the largest quantity in 1965. However, the saury production in Chiba began to decrease in the following years and kept stable between 10,000 tonnes and 20,000 tonnes in most of the years in the last decade.

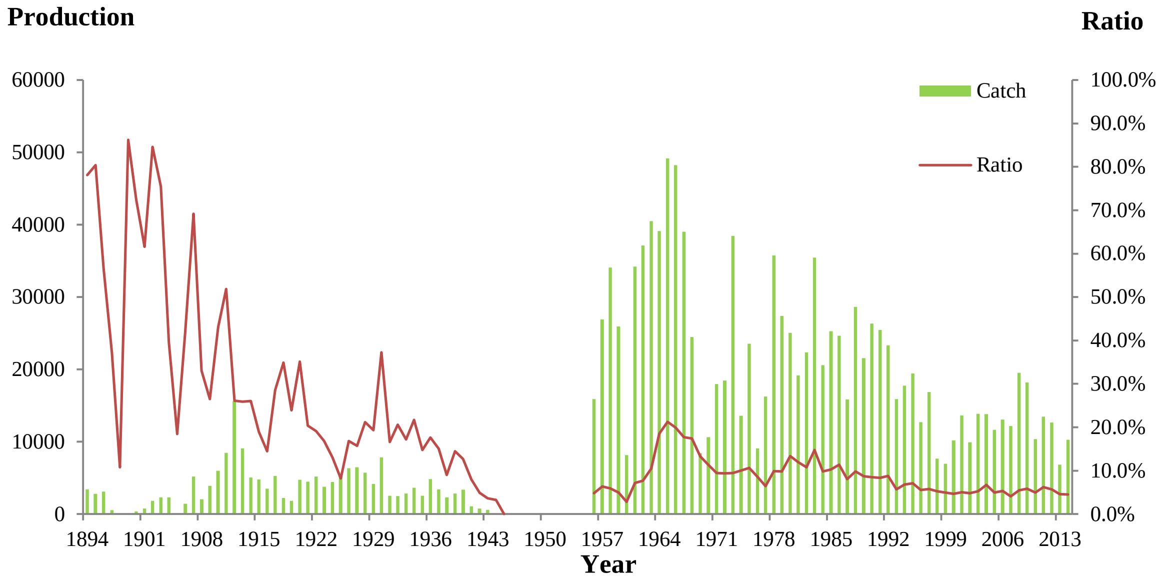

Fig.4-9 Pacific saury production in Chiba from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

With regard to the importance of Chiba in Japan's saury production, its contribution decreased obviously from 1894 to 2014, which contrasts with Hokkaido. In 1894, due to its abundant catch, Chiba contributed 78.13% of the total saury production in Japan. In the continuing years, the ratio was more than 50% in most of the time until 1911. From 1912, the ratio showed a downward trend and this trend continued until 2014. From 1987 to 2014, the ratio never exceeded 10%, designating that Chiba has lost the top position in Japan's saury production. Although the mild decrease in Chiba's saury catch can be considered as one of the reasons, the rapid development of Hokkaido's saury production may be a more powerful affecting factor.

(8) Toyama:

Data on Toyama's saury catch started from 1956, which was only 19 tonnes in that year. Generally, Fig.4-10 shows that the saury production in Toyama has generally increased since 1956. The highest catch appeared in 2008 as 19,933 tonnes. Due to the stable increase of the Pacific saury catch, Toyama played an increasingly important role in Japan's saury production. From Fig.4-10, we can see that the ratio of Toyama's saury catch to Japan's total saury production has kept a stable upward trend and reached the highest value as 8.58% in 2014.

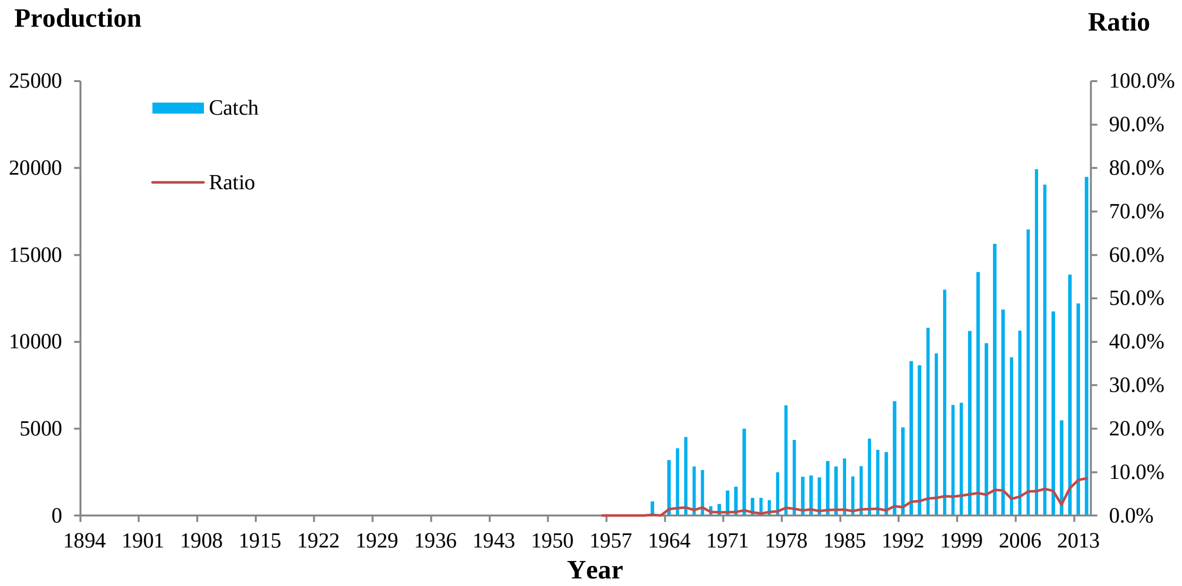

Fig.4-10 Pacific saury production in Toyama from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(9) Shizuoka:

The available recorded data on the Pacific saury catch in Shizuoka began from 1894 (Fig.4-11). From 1894 to 1945, the saury catch in Shizuoka were generally below 2,000 tonnes except in several years. Among these years, 1912 is well-marked for the large catch as 10,324 tonnes. After 1956, although an increasing trend was obvious, the peak point in 1964 (13,200 tonnes) was only slightly more than that in 1912. Through an up-and-down trend, the saury catch has kept decreasing in the last decade and was only 1,200 tonnes in 2014.

In terms of the contribution of Shizuoka in Japan's saury production, it presented a similar trend with Chiba Prefecture (Fig.4-11). Generally, the ratio of Shizuoka's saury catch to the total national saury production has kept decreasing from 1894 to 2014. As shown in Fig.4-11, the ratio was less than 10% in most of the years with some exceptions.

In 1897, the ratio was 43.80% which exceeded Chiba Prefecture (37.18%), pushing Shizuoka to the top one position in terms of saury production. The same scenario also happened in 1898 and 1905. From 1956, the ratio decreased to a further extent, which was less than 5% in most of the years. And from 1998, the downward trend continued and the ratio has kept below 1% until now. The stable decreasing saury catch in Shizuoka is the main cause for this change.

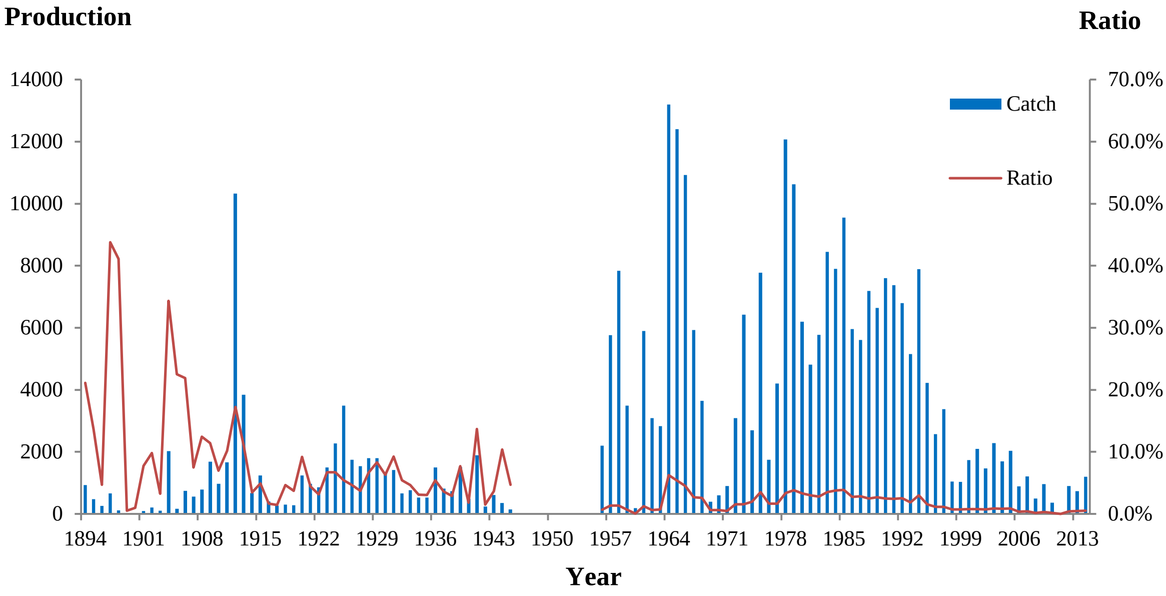

Fig.4-11 Pacific saury production in Shizuoka from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(10) Mie:

According to Fig.4-12, the Pacific saury catch in Mie Prefecture showed a relatively stable trend compared to other prefectures from 1894 to 2014. The saury catch after 1956 generally kept the same level with that in the period from 1894 to 1945. Exception can still be found in 1912 with the catch as 16,806 tonnes, making Mie Prefecture become the largest in saury production in Japan. As shown in Fig.4-12, the saury catch in Mie has kept below 4,000 tonnes in most of the years. Although the saury catch in Mie Prefecture stayed relatively stable, the ratio of Mie's saury catch to Japan's saury production presented a downward trend. From 1894 to 1945, the ratio was less than 10% in most of the years; while from 1956, the ratio has kept below 2% in most of the years.

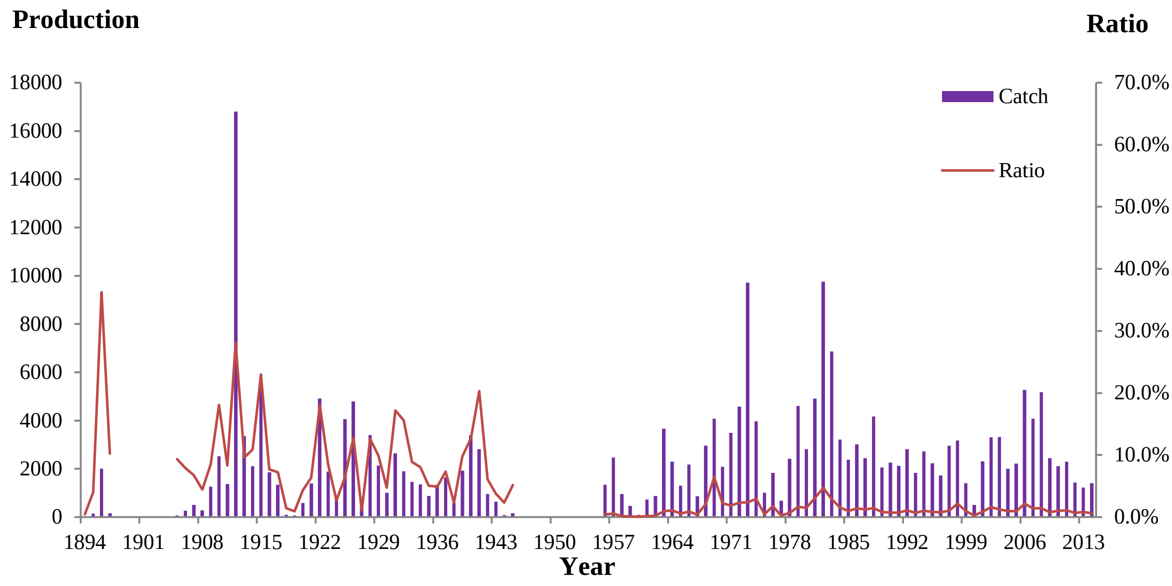

Fig.4-12 Pacific saury production in Mie from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(11) Wakayama:

The recorded data on Wakayama's saury production started from 1900. From Fig.4-13, we can find that its saury catch has generally kept decreasing until now. The catch level has always been relatively low except in 1925 and 1927, when the catch was more than 10,000 tonnes. The saury production in Wakayama Prefecture averaged as more than 2,000 tonnes before the end of the Second World War; while less than 700 tonnes from 1956. In terms of its contribution to Japan's saury fishery, Wakayama played a more important role in the period before the Second World War, compared with the period from 1956. From Fig.4-13, we can find that the ratio of Wakayama's saury catch to Japan's total saury production averaged as 8% before 1945 while less than 1% after 1956.

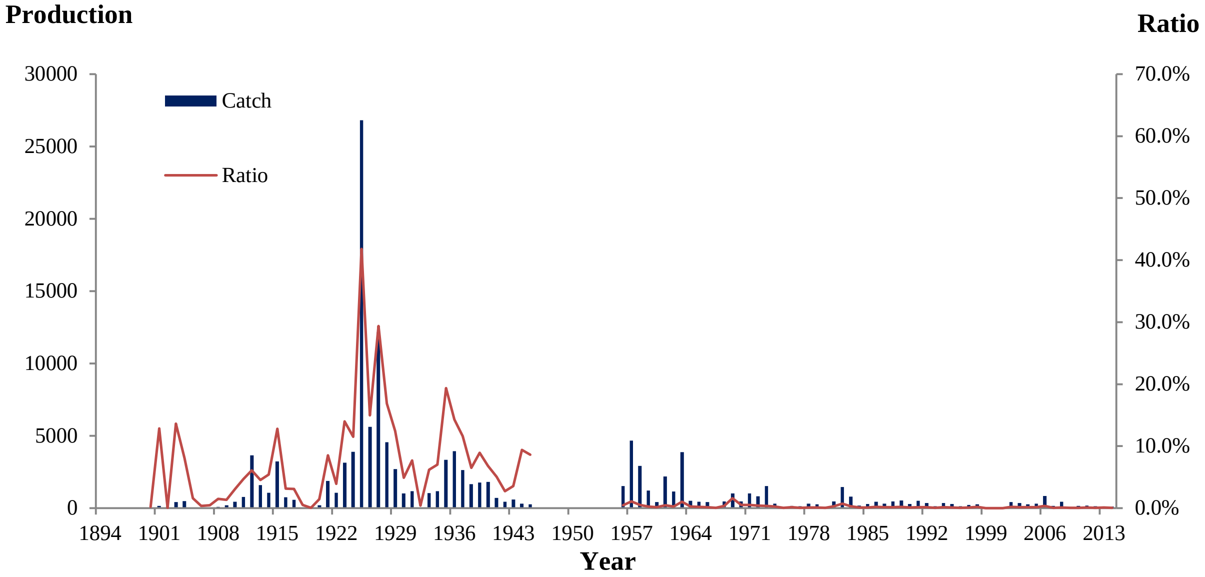

Fig.4-13 Pacific saury production in Wakayama from 1894 to 2014 (unit: tonne)

Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

(12) Kagawa:

Fig.4-14 clearly depicts the changes of Kagawa's saury production. Before 1945, its saury catch was considered as a low level, with the highest catch as 2,001 tonnes in 1934. After the Second World War, Kagawa restarted its saury catch in 1964 according to the data available and improved to a higher level compared with that before 1945. In 1973, Kagawa's saury catch reached the peak point as 17,733 tonnes. However, the catch kept a downward trend since 1987 and has stopped since 1995. With respect to the contribution of Kagawa in Japan's saury production, it showed an up-and-down trend before 1945, with the highest ratio as 11.9% in 1934. From 1964 to 1994, the ratio averaged as 3.19% and kept a relatively stable level in those years.

(13) Conclusions:

Fig.4-3 to Fig.4-14 designates the changes in the regional distribution of Japan's saury production from 1894 to 2014. From these figures and detailed description for each main producing prefecture above, we can conclude some characteristics of the regional distribution of the Pacific saury fishery in Japan: 1) the Pacific saury fishery has distributed widely in Japan; 2) Ibaraki, Chiba and Shizuoka prefectures has gradually lost their top positions in Japan's saury fishery; 3) Hokkaido prefecture has gradually gained its top one position in Japan's saury production and the ratio has kept stable as 40%-50%; 4) The contribution of Iwate, Miyagi and Fukushima prefectures in Japan's saury fishery has stayed relatively stable after the end of the Second World War, and has become the second largest group in terms of saury catch in recent decades; 5) Mie and Wakayama prefectures also lost their ratios in Japan's saury production; 6) Toyama's contribution in Japan's saury fishery tends to increase especially in recent years.

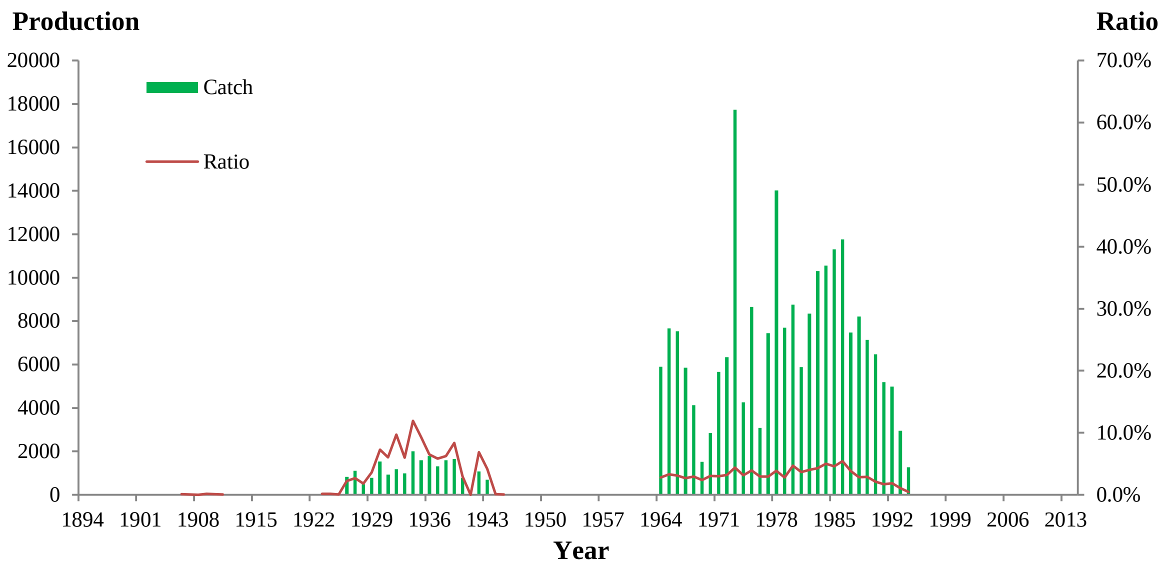

Fig.4-14 Pacific saury production in Kagawa from 1894 to 2014 (unit: tonne)
Data source: Annual Statistics on Fisheries and Aquaculture Production, by MAFF

4.3.3 Regional distribution of Pacific saury landings by *Zensanma* vessels

The landing ports for the Pacific saury vary in response to the changes in fishing grounds. From the beginning of saury fishing season to October, the fishing ground concentrates in Russian 200 nautical miles ocean waters or off the coast of eastern Hokkaido Prefecture. In this period, the Pacific saury is landed mainly in the ports of eastern Hokkaido, including Hanasaki, Akkeshi, Hamanaka and Kushiro. As the fishing ground moves from Hokkaido to Sanriku area, the primary landing places change correspondingly to Ofunato, Kesennuma and Onagawa. Later, the main landing place moves in a further southerly direction to Choshi port (Price Stabilization Fund for Fish 2011). However, other factors also affect the choice of landing ports for saury fishing vessels, such as the landing price of saury, time to be taken in landing ports, etc. In this case, landings in Honshu can also be found even when the fishing grounds still concentrate in Russian ocean waters or the eastern Hokkaido in the early stage of fishing season. Choosing farther ports to landing saury may be constricted to larger vessels in most cases, as they consume less time to move between fishing grounds and landing ports compared with small vessels. As for small vessels, they will face the risk of deterioration of saury freshness if they move to a farther landing port, which may consequently result in a lower fish price although their initial motivation of choosing a more distant landing port is to be paid a higher price.

Table 4-4 Landings of the Pacific saury in main landing ports from 2009 to 2014

Year	**Total (B)**		**Hanasaki (A1)**		**Akkeshi (A2)**		**Kushiro (A3)**		**Miyako (A4)**	
2009	195.3	100%	54.0	27.7%	23.8	12.2%	28.1	14.4%	13.3	6.8%
2010	110.6	100%	47.5	43.0%	15.0	13.6%	16.8	15.2%	15.0	13.6%
2011	207.8	100%	78.5	37.8%	24.6	11.8%	27.2	13.1%	8.7	4.2%
2012	218.4	100%	73.5	33.7%	21.0	9.6%	22.6	10.3%	10.6	4.8%
2013	147.8	100%	59.2	40.1%	14.5	9.8%	13.2	8.9%	5.5	3.8%
2014	224.8	100%	60.6	27.0%	19.6	8.7%	20.4	9.1%	10.6	4.7%
2009	195.3	100%	29.0	14.8%	32.3	16.5%	40.2	20.6%	61.3	31.4%
2010	110.6	100%	21.7	19.6%	25.0	22.6%	23.1	20.9%	13.8	12.5%
2011	207.8	100%	18.4	8.9%	5.6	2.7%	7.8	3.8%	24.2	11.6%
2012	218.4	100%	20.4	9.3%	15.1	6.9%	16.0	7.3%	23.7	10.9%
2013	147.8	100%	14.6	9.9%	10.9	7.4%	12.4	8.4%	8.2	5.5%
2014	224.8	100%	27.1	12.1%	27.2	12.1%	24.1	10.7%	19.6	8.7%

Notes: a) Data source: National Saury Stick-held Dip Net Cooperative Association Fishery, 2009-2014.
b) Unit for production is thousand tonnes; c) Ratio is calculated by A/B.

Table 4-4 shows the landings of the Pacific saury in the main landing places and the corresponding ratios to the total landings in Japan from 2009 to 2014, by the saury vessels managed by MAFF. These vessels are also called *Zensanma* vessels because the organization in charge is abbreviated as *Zensanma* (National Saury Stick-held Dip Net Fishery Cooperative Association). The data show that Hanasaki continued to be largest landing port for the Pacific saury in the past five years. In 2009, the share of saury landing in Hanasaki was as high as 43%. The landings in the three ports belonging to Hokkaido (Hanasaki, Akkeshi and Kushiro) accounted for more than half the total saury production caught by *Zensanma* vessels from 2009 to 2013, with the highest ratio as 72% in 2010.

4.3.4 Production of Pacific saury stick-held dip net fishery and its position

Table 4-5 Catch of Pacific saury by different fishing methods from 2003 to 2013

Year	Total catch	SHDN	Set net	Drift net	Others
2003	264,804	255,518	5,824	3,115	347
2004	204,371	199,208	3,057	1,879	227
2005	234,451	229,970	1,515	2,565	401
2006	244,586	239,239	1,792	2,552	1,003
2007	296,521	290,593	3,882	1,731	315
2008	354,727	346,990	5,776	941	1,020
2009	310,744	306,609	2,377	1,711	47
2010	207,488	205,798	1,086	552	52
2011	215,353	213,942	581	703	127
2012	221,470	218,654	2,592	130	94
2013	149,204	147,750	1,321	84	49

Notes: a) The unit of catch is tonne; b) Data source: Annual Statistics on Fisheries and Aquaculture Production, MAFF; c) SHDN is the abbreviation of stick-held dip net.

Table 4-6 Ratio of saury catch by stick-held dip net to total Japanese saury catch

Year	Total saury catch (A)	By SHDN (B)	Ratio (B/A)
1958	575,087	557,972	97.02%
1959	522,567	515,264	98.60%
1960	287,071	276,146	96.19%
1961	473,792	461,000	97.30%
1962	483,160	475,592	98.43%
1963	384,548	376,816	97.99%
1964	210,689	202,309	96.02%
1965	231,377	226,696	97.98%
1966	241,840	234,739	97.06%
1967	220,087	216,124	98.20%
1968	140,204	126,893	90.51%
1969	63,288	51,364	81.16%
1970	93,129	83,730	89.91%
1971	190,288	171,419	90.08%
1972	196,615	177,483	90.27%
1973	406,445	390,716	96.13%
1974	135,462	127,987	94.48%
1975	221,573	216,488	97.71%
1976	105,419	99,435	94.32%
1977	253,465	244,159	96.33%
1978	360,213	350,617	97.34%
1979	277,960	266,741	95.96%
1980	187,155	180,328	96.35%
1981	160,319	154,879	96.61%
1982	206,958	195,576	94.50%
1983	239,658	233,159	97.29%
1984	209,974	207,045	98.61%
1985	245,944	242,013	98.40%
1986	217,229	214,683	98.83%
1987	197,084	192,228	97.54%

Continued on next page

Table 4-6 Ratio of saury catch by stick-held dip net to total Japanese saury catch

(Continued from previous page)

Year	Total saury catch (A)	By SHDN (B)	Ratio (B/A)
1988	291,575	289,687	99.35%
1989	246,821	243,772	98.76%
1990	308,271	304,586	98.80%
1991	303,567	302,104	99.52%
1992	265,884	264,044	99.31%
1993	277,461	274,865	99.06%
1994	261,587	249,950	95.51%
1995	273,510	267,324	97.72%
1996	229,227	214,027	93.18%
1997	290,812	284,439	97.80%
1998	144,983	139,729	96.36%
1999	141,011	135,200	95.86%
2000	216,471	210,666	97.31%
2001	269,797	263,887	97.81%
2002	205,282	199,128	96.99%
2003	264,804	255,534	96.49%
2004	204,371	199,210	97.47%
2005	234,451	229,970	98.09%
2006	244,586	239,239	97.81%
2007	296,521	290,593	98.00%
2008	354,727	346,990	97.82%
2009	310,744	306,610	98.67%
2010	207,488	205,798	99.19%
2011	215,353	213,953	99.34%
2012	221,470	218,900	98.73%
2013	149,204	148,417	99.03%

Notes: a) The unit of catch is tonne; b) Data source: Annual Statistics on Fisheries and Aquaculture Production, MAFF.

Table 4-7 Ratio of saury in the Pacific saury stick-held dip net fishery from 1994 to 2013

Year	Total catch (A)	Saury (B)	Ratio (B/A)
1994	249,950	249,836	99.95%
1995	267,324	267,276	99.98%
1996	214,027	213,590	99.80%
1997	284,439	284,410	99.99%
1998	139,729	139,712	99.99%
1999	135,200	135,170	99.98%
2000	210,666	210,656	100.00%
2001	263,887	263,882	100.00%
2002	199,128	199,111	99.99%
2003	255,534	255,518	99.99%
2004	199,210	199,208	100.00%
2005	229,970	229,970	100.00%
2006	239,239	239,239	100.00%
2007	290,593	290,593	100.00%
2008	346,990	346,990	100.00%
2009	306,610	306,609	100.00%
2010	205,798	205,798	100.00%
2011	213,953	213,942	99.99%
2012	218,900	218,654	99.89%
2013	148,417	147,750	99.55%

Notes: a) The unit of catch is tonne; b) Data source: Annual Statistics on Fisheries and Aquaculture Production, MAFF.

Currently, the Pacific saury in Japan is caught by several fishing methods, such as stick-held dip net, set net, drift net, etc. Table 4-5 lists the yearly saury catch by different fishing methods from 2003 to 2013. During these years, the total catch of Pacific saury in Japan changed between 149,204 tonnes to 354,727 tonnes. Among the total catch, the quantity by SHDN constitutes the most, ranging from 147,750 tonnes to 346,990 tonnes.

Following SHDN, set net and drift net also catch Pacific saury with an insignificant amount. The great diverge between the catch by SHDN and that of other fishing methods clearly shows the significant position of Pacific saury SHDN fishery, which is one of the characteristics of this fishery. This can be further proved by Table 4-6, which serves as a further evidence of the contribution of stick-held dip net saury fishery. From 1958 to 2013, the ratio of saury stick-held dip net fishery catch to total saury production has exceeded 95% with seldom exceptions and the average ratio is over 96%.

Table 4-7 shows the ratio of saury quantity in the Pacific saury SHDN fishery to the total catch from 1994 to 2013. The ratio changed from 99.55% to 100.00%, designating the high selectivity of SHDN. This is also one of the characteristics of Pacific saury SHDN fishery in Japan.

4.4 Fishing method

4.4.1 Stage 1: Purse seine (1544-1897)

The recorded data on the Pacific saury fishery in Japan started from around 1544 (Tembun 13) and also appeared in Wakayama Prefecture in 1601 (Keichō 6). (Nakai 1981).The pacific saury fishery developed with the application of the fishing method called ‘saira ōami’ or ‘sairi ōami’, a type of purse seine which was mainly operated in coastal areas. Before this type of fishing method was developed, the Pacific saury could not be efficiently caught. Since this special purse seine was introduced, the pacific saury fishery developed especially along the coastal areas in Chiba Prefecture Sotobō, Shizuoka Prefecture Izu and Wakayama Prefecture Kishu, which contributed to around 92% in total value of Japan’s saury fishery in that period (Nakai 1981). Although other fishing methods could be found in that period, the purse seine was the leading method in Japan’s saury fishery until the end of Meiji Era (around 1897-1911). With the introduction and development of drift net in Japan’s saury fishery, the coastal saury fishery based on purse seine began to recess.

4.4.2 Stage 2: Drift net

Although drift net was applied in catching the Pacific saury in Nagasaki Prefecture for a long time, this fishing method was widely used after the end of Meiji Era and gradually became the main fishing method in saury fishery.

After around 1897, the saury production in coastal area of Chiba Prefecture saw an abrupt decrease to 561 tonnes compared with 3,129 tonnes in 1896 (refer to section 4.3.2). The successive decrease in saury catch by the purse seine and introduction of drift net promoted the change in fishing method in saury fishery. In 1905 (Meiji 38), drift net experiments were conducted targeting the Pacific saury in Chiba Prefecture and achieved satisfactory performance. Hereafter, drift net was gradually applied in catching saury by the prefectures along coastal Pacific Ocean and became widely used.

With the introduction of drift net and motorization of fishing vessels, the Pacific saury fishery in Japan presented two obvious changes: a rapid increase in saury catch (refer to Fig.4-2) and the northward shift of main producing prefectures. During the Meiji Era when the purse seine was mostly applied in coastal saury fishery, Chiba, Shizuoka, Mie and Wakayama were the four main prefectures in terms of saury catch; while after the Daisho Era, the main production areas moved northward with Ibaraki, Fukushima, Miyagi and Iwate as the main producing prefectures (refer to section 4.3.2).

Compared with the purse seine, the drift net is advantageous in terms of productivity. For example, the fishing vessels using drift net to catch saury could achieve an average annual revenue of 650 yen with only 10 fishermen (1907-1910); while those applying the purse seine earned 443 yen with 35 fishermen (1902-1906). (Nakai 1981)

4.4.3 Stage 3: Stick-held dip net

In 1939, the stick-held dip net fishing method was developed and applied in Japanese pacific saury fishery by the fishers in Chiba prefecture. The characteristics of this new fishing method are as follows, no ground-bait, simple structure of fishing equipment and operation, and protection of fish from being hurt. And the stick-held dip net fishing method has become the mainstream in Japanese pacific saury fishery until now.

The Pacific saury stick-held dip net fishery is operated from sunset to dawn based on the positive phototaxis of saury in the night. As illustrated in Fig.4-15, the procedures of stick-held dip net fishery is described as follows: 1) firstly, a fish-finder and searchlights are applied to search for schools of saury, fish lamps will be switched on after saury are found, and the fishing vessel will be operated towards the schools of saury; 2) secondly, the lamps on the left broadside of the fishing vessel are turned off and fishnets will be spread, with only the lamps on the right broadside being kept on; 3) next, when the fishing lamps on the right side are turned off one by one from the stern, those on the head (bow) and left broadside will be turned on in succession, in order to attract schools of saury to the left side of the fishing vessel; 4) after this, all the fishing lamps will be switched off and red lights on the left broadside will be turned on at the same time, so as to calm down the excited saury and attract them to swim into the fishing nets prepared in the second step; 5) finally, the fishing nets are reeled in, the Pacific saury caught will be transported into a size-sorting machine and subsequently into a storage tank (*Zensanma*).

Step 1 Step 2 Step 3 Step 4 Step 5

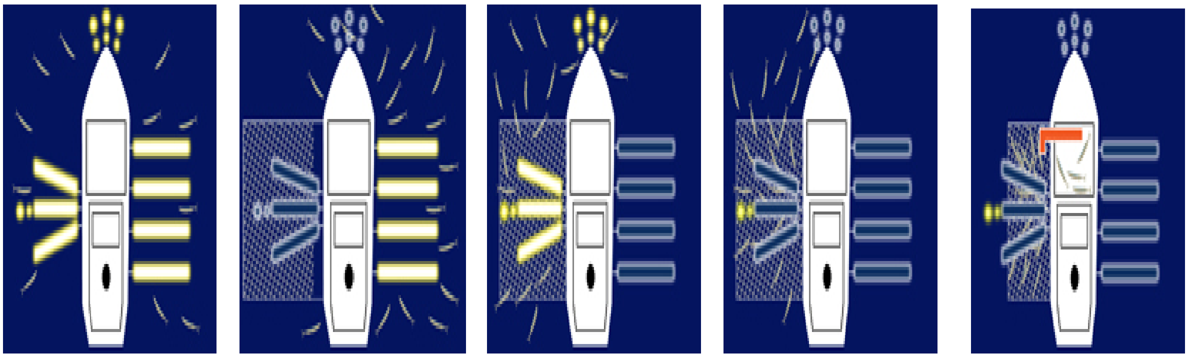

Fig. 4-15 Pacific saury stick-held dip net fishing procedures
(Source: Homepage of *Zensanma*)

4.5 Changes of fishing vessels

Although the recorded data on fishing vessels operating the Pacific saury fishery is not comprehensive and complete as those on production volume and value, the available data on saury vessels can still demonstrate the main changes and characteristics of Japan's saury fishing vessels. The data which we can get access to generally begin from the end of the Second World War.

(1) 1948-1958

As shown in Table 4-8, the saury fishing vessels in Japan generally increased after the end of the Second World War from 1,754 in 1948 to 2,164 in 1958. Although the general trend was positive, the vessel quantity also presented a decline from 1950 to 1953, with 1,395 as the lowest level in 1950.

Table 4-8 Yearly changes of vessel quantities operating the Pacific saury fishery in Japan from 1948-1958

Year	Total	<10t	10-20t	20-30t	30-50t	50-100t	100-200t	unclear
1948	1754	783		350	361	203	35	22
1949	1767	74	716		575	350	48	6
1950	1395	65	540		450	286	52	2
1951	1604	207	682		424	259	32	-
1952	1609	173	620		465	316	41	-
1953	1654	292	462	571		280	43	
1954	1727	361	366	623		316	52	
1955	2060	334	416	713		491	106	
1956	2206	371	486	311	358	574	106	
1957	1963	409	400	276	308	476	94	
1958	2164	445	356	268	365	625	105	

Data source: Nakai 1981.

Despite the total saury vessels showed an upward trend in this period, the vessel quantity in different regions demonstrated dissimilar characteristics. Table 4-9 and Table 4-10 showed the yearly changes of vessel quantities operating the Pacific saury fishery in Hokkaido and Honshu from 1948-1958, respectively. In 1948, the vessel quantity in Hokkaido was only 149, while that in Honshu was 1,605. However, the saury vessels in Honshu gradually decreased and fell down into 1,186 in 1958. At the same year, the saury vessel quantity in Hokkaido climbed up to 978.

Table 4-9 Yearly changes of vessel quantities operating the Pacific saury fishery in Hokkaido from 1948-1958

Year	Total	< 10t	10-20t	20-30t	30-50t	50-100t	100-200t	unclear
1948	149	144		1	3		-	1
1949	285	28	88		98	71	-	-
1950	126	48	59		8	11	-	-
1951	470	150	294		17	9	-	-
1952	…	…	…		…	…	…	…
1953	547	205	295	35		6	-	
1954	477	182	223	63		3	-	
1955	801	284	296	209		12	-	
1956	891	323	327	311	162	29	1	
1957	806	351	240	276	149	21	1	
1958	978	431	282	268	143	48	2	

Data source: Nakai 1981.

A more careful investigation into the vessel quantity changes in different tonnage categories is also necessary. As shown in Table 4-8, the total vessel quantities in the categories of less than 10 t, 50-100 t and 100-200 t presented an obviously increasing trend; while a downward trend was seen in the categories of 20-30 t and 30-50 t. The vessel quantity of those between 10 and 20 t went through an up-and down trend. In terms of Hokkaido (Table 4-9), vessels under 10 t increased rapidly in this period, and those between 30-50 t experienced a drastic change with a general upward trend; meanwhile, the vessels larger than 100 t was seldom in Hokkaido in this period. Regarding Honshu (Table 4-10), vessels in the categories of 50-100 t and 100-200 t increased quickly, while those less than 10 t, 10-20 t, 20-30t and 30-50 t decreased in different rates.

Based on Table 4-8 to Table 4-10, some characteristics of saury fishing vessel structures can be inferred in the period of 1948-1958: (1) the increase of Japan's saury fishing vessels stemmed from the new entry of a larger amount of vessels from Hokkaido Prefecture rather than Honshu; (2) Hokkaido's importance in Japan's saury fishery greatly improved in terms of saury vessel quantity; (3) the saury vessels in Hokkaido were generally small scale, especially those less than 10 t increased rapidly; while those in Honshu were generally large scale, with vessels larger than 50 t developed fast and less than 10 t decreased quickly.

Table 4-10 Yearly changes of vessel quantities operating the Pacific saury fishery in Honshu from 1948-1958

<table>
<tr><th>Year</th><th>Total</th><th>< 10t</th><th>10-20t</th><th>20-30t</th><th>30-50t</th><th>50-100t</th><th>100-200t</th><th>unclear</th></tr>
<tr><td>1948</td><td>1605</td><td colspan="2">639</td><td>349</td><td>358</td><td>203</td><td>35</td><td>21</td></tr>
<tr><td>1949</td><td>1482</td><td>46</td><td colspan="2">628</td><td>477</td><td>279</td><td>46</td><td>6</td></tr>
<tr><td>1950</td><td>1269</td><td>17</td><td colspan="2">481</td><td>442</td><td>275</td><td>52</td><td>2</td></tr>
<tr><td>1951</td><td>1134</td><td>57</td><td colspan="2">388</td><td>407</td><td>250</td><td>32</td><td>-</td></tr>
<tr><td>1952</td><td>…</td><td>…</td><td colspan="2">…</td><td>…</td><td>…</td><td>…</td><td>…</td></tr>
<tr><td>1953</td><td>1107</td><td>87</td><td>167</td><td colspan="2">536</td><td>274</td><td>43</td><td></td></tr>
<tr><td>1954</td><td>1250</td><td>179</td><td>143</td><td colspan="2">560</td><td>313</td><td>52</td><td></td></tr>
<tr><td>1955</td><td>1259</td><td>50</td><td>120</td><td colspan="2">504</td><td>479</td><td>106</td><td></td></tr>
<tr><td>1956</td><td>1315</td><td>48</td><td>159</td><td>149</td><td>309</td><td>545</td><td>105</td><td></td></tr>
<tr><td>1957</td><td>1157</td><td>58</td><td>160</td><td>127</td><td>264</td><td>455</td><td>93</td><td></td></tr>
<tr><td>1958</td><td>1186</td><td>14</td><td>74</td><td>125</td><td>293</td><td>577</td><td>103</td><td></td></tr>
</table>

Note: a) Data source: Nakai 1981; b) '…' means that no data are available.

(2) 1975-2013

The statistical data on the yearly changes of vessel quantities operating the Pacific saury stick-held dip net fishery in Japan from 1975-2008 were provided by MAFF (Table

4-11). Although these data are limited to those vessels catching the Pacific saury applying the stick-held dip net, which excluded vessels using other fishing methods such as drift gillnet and set net, this limitation may not be a problem because the Pacific saury SHDN fishery averagely contributed 97.3% to the total saury production volume in Japan from 1975 to 2008 (refer to Table 4-6).

Table 4-11 Yearly changes of vessel quantities operating the Pacific saury stick-held dip net fishery in Japan from 1975-2008

Year	Total	<10t	10-20t	20-50t	50-100t	>100t
1975	938	432	91	29	378	8
1976	983	430	120	16	409	6
1977	1440	806	189	15	426	4
1978	1290	572	258	17	438	5
1979	1118	301	340	9	453	15
1980	1002	264	315	10	402	11
1981	1019	329	300	9	370	11
1982	1163	488	322	8	336	9
1983	953	292	302	9	323	27
1984	685	123	218	4	287	53
1985	691	132	232	4	247	76
1986	773	214	237	3	221	98
1987	563	126	154	3	132	148
1988	536	119	143	2	101	171
1989	509	128	123	2	75	181
1990	497	124	143	2	65	163
1991	361	60	113	2	52	134
1992	377	85	130	3	40	119
1993	336	69	120	3	22	122

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Table 4-11 Yearly changes of vessel quantities operating the Pacific saury stick-held dip net fishery in Japan from 1975-2008

(Continued from previous page)

Year	Total	<10t	10-20t	20-50t	50-100t	>100t
1994	387	136	121	4	17	109
1995	352	132	97	4	14	105
1996	365	151	97	4	12	101
1997	444	214	109	7	11	103
1998	441	225	101	5	11	99
1999	414	195	109	2	10	98
2000	409	182	114	2	10	101
2001	368	152	110	2	10	94
2002	337	131	103	2	10	91
2003	335	103	120	14	8	90
2004	372	128	146	14	6	78
2005	307	93	114	15	6	79
2006	285	88	105	17	4	71
2008	184	49	79	12	0	44

Notes: a) the original statistical data is the number of fishing unit. For the Pacific saury stick-held dip net fishery in Japan, a single fishing vessel is used when catching, therefore, the quantity of fishing units is the same with fishing vessel numbers; b) in the original version of statistical data, the quantity of fishing vessels in the 20-50t category from 1988 to 1991 was not publicized for privacy. However, based on the total quantity and those in each tonnage category, the unpublicized data can be calculated; c) Data source: data from 1975-2006 are from Annual Statistics on Fisheries and Aquaculture Production, MAFF; data for 2008 is from Fisheries Census, MAFF.

As shown in Table 4-11, the total saury SHDN fishing vessels changed greatly from 938 in 1975 to only 184 in 2008, with the highest level as 1,440 in 1977. Regarding the composition of vessels in terms of tonnage, it also demonstrated an obvious change. In 1975, vessels less than 10 t were the largest (46%) and those between 50 and 100 t were the second largest (40%), with large scale vessels more than 100 t as the fewest (0.9%). However, the vessels in the category of 50-100 t decreased drastically and those larger than 100 t increased. In 2008, among the 184 saury SHDN fishing vessels, those between 10-20 t were the largest as 79 (43%), and those in the categories of less than 10 t (27%) and more than 100 t (24%) were the second and third largest, respectively.

Table 4-12 Regional distribution of vessel quantities operating the Pacific saury stick-held dip net fishery in Japan from 2002-2013

Prefecture	2002	2003	2004	2005	2008	2013
Total	335	372	307	285	184	166
Hokkaido	173	219	162	152	94	81
Aomori	2	2	2	2	1	2
Iwate	34	31	30	29	25	19
Miyagi	32	34	34	31	25	22
Akida	-	-	-	-	-	-
Yamagata	-	-	-	-	-	-
Fukushima	17	16	14	12	10	8
Ibaraki	8	5	4	4	3	2
Chiba	17	17	16	15	8	5
Tokyo	-	-	-	-	1	1
Kanagawa	2	2	2	-	-	-
Niigata	1	1	1	-	-	-
Toyama	8	7	6	6	4	7
Ishigawa	2	-	-	-	-	-
Fukui	-	-	-	-	-	-
Shizuoka	4	3	3	2	-	-
Aichi	-	-	-	-	-	-
Mie	14	14	13	13	12	12
Kyoto	-	-	-	-	-	-
Osaka	-	-	-	-	-	-
Hyogo	-	-	-	-	-	-
Wakayama	20	20	19	18	-	6
Tottori	-	-	-	-	-	-

Continued on next page

Table 4-12 Regional distribution of vessel quantities operating the Pacific saury stick-held dip net fishery in Japan from 2002-2013 (Continued from previous page)

Prefecture	2002	2003	2004	2005	2008	2013
Shimane	-	-	-	-	-	-
Okayama	-	-	-	-	-	-
Hiroshima	-	-	-	-	-	-
Yamaguchi	-	-	-	-	-	-
Tokushima	-	-	-	-	-	-
Kagawa	-	-	-	-	-	-
Ehime	-	-	-	-	-	-
Kochi	-	-	-	-	-	-
Fukuoka	-	-	-	-	-	-
Saga	-	-	-	-	-	-
Nagasaki	1	1	1	1	1	1
Kumamoto	-	-	-	-	-	-
Oita	-	-	-	-	-	-
Miyazaki	-	-	-	-	-	-
Kagoshima	-	-	-	-	-	-
Okinawa	-	-	-	-	-	-

Notes: a) The original statistical data is the number of fishing unit. For the Pacific saury stick-held dip net fishery in Japan, a single fishing vessel is used when catching, therefore, the quantity of fishing units is the same with fishing vessel numbers; b) Data source: data from 2002-2005 are from Annual Statistics on Fisheries and Aquaculture Production, MAFF; data for 2008 and 2013 are from Fisheries Census, MAFF.

In the respect of regional distribution of saury SHDN fishing vessels, Table 4-12 presented the detailed changes from 2002 to 2013. Due to the change of Japan's fishery statistics system, yearly data are not publicized from 2006; therefore discontinuous data are demonstrated in Table 4-12. From this Table, we can see that Hokkaido Prefecture has the largest saury SHDN fishing vessels in Japan, with the top one position unchanged since 2002. The saury SHDN vessels are mainly distributed in Hokkaido, Iwate, Miyagi, Fukushima, Chiba, Mie and Wakayama Prefectures.

Although the related data on vessel quantity divided by tonnage category in the main producing prefectures are not easily acquired, we may estimate some obvious characteristics in vessel tonnage distribution in main producing prefectures through Table 4-13 and Table 4-14.

Table 4-13 Rank of vessel quantities and production volume for the main saury producing prefectures from 2002 to 2013

Prefecture	2002	2003	2004	2005	2008	2013
Hokkaido	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)	1 (1)
Iwate	2 (4)	3 (5)	3 (6)	3 (4)	2 (4)	3 (4)
Miyagi	3 (3)	2 (2)	2 (2)	2 (2)	2 (2)	2 (2)
Fukushima	5 (2)	6 (3)	6 (3)	7 (3)	4 (3)	5 (3)
Ibaraki	7 (7)	9 (7)	9 (7)	9 (7)	7 (x)	9 (x)
Chiba	5 (5)	5 (6)	5 (4)	5 (5)	5 (6)	8 (6)
Toyama	7 (6)	8 (4)	8 (5)	8 (6)	6 (5)	6 (5)
Mie	6 (8)	7 (8)	7 (8)	6 (8)	3 (7)	4 (7)
Wakayama	4 (9)	4 (9)	4 (9)	4 (9)	x (8)	7 (8)

Notes: a) Rank of vessel quantities (rank of saury catch); b) ‘x’ denotes the value is not publicized; c) Data source: data from 2002-2005 are from Annual Statistics on Fisheries and Aquaculture Production, MAFF; data for 2008 and 2013 are from Fisheries Census, MAFF.

Table 4-13 listed the rank of the main saury producing prefectures in terms of vessel quantity and saury catch (inside the parentheses) from 2002 to 2013. With respect to Hokkaido prefecture, it led the top both in vessel quantity and saury catch. Considering Iwate and Miyagi prefectures, they are the second largest group in Japan’s saury production. However, although the vessel quantities are similar, the saury catch in Miyagi is obviously prior to Iwate, which may imply a larger vessel tonnage in Miyagi compared with Iwate. For Fukushima Prefecture, it generally kept the top third position in Japan from

2002 to 2013 in terms of saury production despite its variable and relatively low rank in vessel quantity. Meanwhile, the average saury catch by each vessel in Fukushima shown in Table 4-14 is advantageous to other prefectures, which possibly implies that the saury vessels are relatively large scale. The similar conclusion may also be acquired as for Toyama prefecture. Contrarily, vessels in Mie and Wakayama prefectures seem to be relatively smaller, which can be inferred from their low ranks in catch (although their ranks in vessel quantities are not the lowest) and catch by each vessel.

Table 4-14 The Pacific saury catch per vessel in main producing prefectures from 2002 to 2013 (unit: tonne)

Prefecture	2002	2003	2004	2005	2008	2013
Hokkaido	614	559	613	816	1907	877
Iwate	335	469	336	544	1098	644
Miyagi	690	966	781	1040	1990	1000
Fukushima	1314	2050	1747	1989	3068	1654
Ibaraki	1139	2533	1028	907	x	x
Chiba	585	816	865	778	2443	1368
Toyama	1241	2234	1977	1519	4983	1744
Mie	236	237	154	170	431	101
Wakayama	21	18	14	17	x	20

Notes: a) ‘x’ denotes the value is not publicized; b) although the production volume also includes those caught by vessels employing different fishing methods except the stick-held dip net, this may not be a big problem because the production volume by SHDN contributes more than 90% of the total saury catch; c) Source: data from 2002-2005 are from MAFF, data for 2008 and 2013 are from Fisheries Census.

(3) Permitted saury SHDN vessels by MAFF

In Japan, vessels catching the Pacifc saury by applying stick-held dip net are managed by two bodies. Those vessels more than 10 t are permitted by the Ministry of Agriculture, Forest and Fisheries (MAFF); while those less than 10 t are managed by each prefectural government.

Table 4-15 Quantities of the permitted (approved) vessels operating the Pacific saury stick-held dip net fishery managed by MAFF

Year	Total	10-20t	20-50t	50-100t	>100t
1989	513	182	4	110	217
1990	493	184	4	93	212
1991	421	194	4	66	157
1992	381	192	4	50	135
1993	339	177	4	30	128
1994	313	164	5	19	125
1995	284	148	5	16	115
1996	263	137	4	13	109
1997	253	132	5	11	105
1998	242	124	3	12	103
1999	239	124	2	11	102
2000	234	122	2	10	100
2001	231	124	2	9	96
2002	228	124	2	9	93
2003	226	112	20	9	85
2004	213	109	20	6	78
2005	207	105	20	7	75
2006	181	91	23	2	65
2007	171	88	23	1	59
2008	165	83	23	1	58
2009	165	83	23	1	58
2010	163	83	21	1	58
2011	144	78	22	1	43
2012	153	77	23	0	53
2015	159	83	22	0	54

Data source: data for 1989-2011 is from Plan for the Reconstruction Project of Fishing Regions Related with Pacific saury Stick-held Dip Net Fishery, *Zensanma* (2013); data for 2015 is from the Name List of the Permitted Pacific saury Vessels Managed by MAFF, JFA (2015).

The available data in Table 4-15 shows the changes of vessel quantity in different tonnage categories permitted by MAFF from 1989 to 2015. Vessels are categorized into four types: 10-20t, 20-50t, 50-100t and more than 100t. The total permitted vessels has sharply decreased from 513 in 1989 to 159 in 2015. Vessels of 10-20t went through a relatively slow decrease from 182 in 1989 to 83 in 2015, while vessels of 50-100t and more than 100t declined rapidly. In 2015, there was no recorded data of permitted vessel by MAFF in the category of 50-100t. Despite the decrease in vessel quantities of the other three categories, vessels of 20-50t has been increasing since 2003. Currently, the saury fishing vessels applying SHDN permitted by MAFF are mostly distributed into two tonnage categories: 10-20t and more than 100t.

Table 4-16 Quantities of the permitted vessels operating the Pacific saury stick-held dip net fishery managed by MAFF divided by vessel age

Year	Total	<5Y	5-10Y	10-15Y	15-20Y	20-25Y	>25Y
2008	165	13	43	18	37	49	5
2009	165	6	26	36	17	54	26
2010	163	6	18	42	16	45	36
2011	144	6	16	39	12	35	36
2012	153	17	13	37	13	29	44

Data source: Plan for the Reconstruction Project of Fishing Regions Related with Pacific saury Stick-held Dip Net Fishery, *Zensanma* (2013).

Table 4-16 shows the age distribution of *Zensanma* vessels, which are permitted by MAFF and larger than 10 t using stick-held dip net. In 2012, nearly half of the vessels were used for more than 20 years and the ratio of those older than 25 years almost exceeded 30%. A steady and rapid increase can be found in the number of vessels older than 25 years, which is not shown in other categories. A simply calculation shows that the ratio of vessels more than 20 years to total went up from 32.73% in 2008 to 47.71% in 2012; while the ratio of those less than 10 years went down from 33.94% to 19.61%.

4.6 Fishers and fishery business entities

According to the Fisheries Census, changes of the number of fishermen and business entities which depend mainly on the saury stick-held dip net fishery can be found from Table 4-17 and 4-18, which present an obvious downward trend.

Specifically, Table 4-17 shows the changes of total fishermen, which was 6,046 in 1963 and generally kept decreasing and fell down to 1,553 in 2003. Its regional distribution presents some changes in the position of each prefecture. For example, Ibaraki and Chiba were once the largest two prefectures in terms of fishermen number in 1963, which accounted 21.72% and 24.21% of the total. However, their importance declined sharply in the following years and decreased to 1.42% and 4.44% in 2003, respectively, which corresponds with the changes in their saury production volume. Hokkaido gradually moved to the top one in terms of fishermen number and contributed nearly 40% to the total in 2003. For Iwate and Miyagi, the fishermen quantity depending on saury SHDN fishery went through an up-and-down trend, but with an increasing contribution to the total (15.13% and 22.15% in 2003, respectively). As for Fukushima, the fishermen quantity also showed a downward trend with a relatively slow speed compared with Ibaraki and Chiba.

In terms of the fisheries business entities which mainly operate saury SHDN fishery, changes in their quantities and regional distribution from 1963 to 2008 are represented in Table 4-18 and. Similar with fishermen number, it also generally kept decreasing in recent decades, from 479 in 1963 to 163 in 2008. Hokkaido kept as the largest prefecture with respect to business entities numbers from 1963 to 2008, which accounted for around 50% of the total from 1993. Other main prefectures include Iwate, Miyagi, Fukushima, Chiba, and Mie, although the saury production volume in Mie was far less than that in the other four prefectures.

Table 4-17 Number of fishermen depending on the Pacific saury stick-held dip net fishery from 1963 to 2003

Year	Total	Hokkaido	Iwate	Miyagi	Fukushima	Ibaraki	Chiba	Toyama	Shizuoka	Mie	Kagawa	Others
1963	6046	774	332	530	1020	1313	1464	25	25	156	41	366
1968	2771	247	84	309	549	380	856	5	5	169	25	142
1973	2304	540	145	233	497	57	615	2	4	106	11	94
1978	2581	803	204	294	503	50	478	17	18	33	45	136
1983	2504	532	225	306	544	90	542	16	26	76	51	96
1988	2324	668	166	270	571	67	284	39	7	90	51	111
1993	1290	422	190	152	268	34	84	18	2	57	21	42
1998	1521	543	228	248	260	28	118	16	-	44	1	35
2003	1553	621	235	344	192	22	69	16	2	30	2	20

Data source: Fisheries Census, MAFF (1963-2003).

Table 4-18 Number of the fisheries business entities depending on the Pacific saury stick-held dip net fishery from 1963 to 2008

Year	Total	Hokkaido	Iwate	Miyagi	Fukushima	Ibaraki	Chiba	Toyama	Shizuoka	Mie	Wakayama	Kagawa
1963	479	314	16	-	26	13	33	-	-	20	···	2
1968	152	57	3	1	20	1	24	1	-	33	···	-
1973	255	166	5	-	4	2	43	-	-	24	···	-
1978	305	216	21	2	9	1	23	2	1	13	···	3
1983	230	72	23	12	20	18	34	-	3	24	···	7
1988	137	16	11	5	23	14	23	-	-	29	···	7
1993	134	66	23	-	6	5	11	-	-	20	1	2
1998	192	100	21	13	12	8	16	3	-	14	4	-
2003	187	104	19	17	10	5	10	4	2	12	3	-
2008	163	87	23	21	7	2	6	3	-	11	-	-

Data source: Fisheries Census, MAFF (1963-2008).

4.7 Economic performance

4.7.1 Introduction

The economic performance analysis of the Pacific saury fishery in Japan can be conducted based on the Annual Report on Fisheries Business Survey, which is published by MAFF every year. Generally, this report includes data on the scale of business management, income breakdowns, expenditure breakdowns, profits and losses, assets and labor figures etc. (Makino 2011).

In Japan, the fishery business, also called the fishery management entity (*Gyogyou keieitai*), is defined by MAFF as 'a household or business body that, for the purpose of earning a living or for profit, engaged in acquiring fish and aquatic plants from the sea or conducting marine aquaculture to be sold in the past one year, while private management entities engaged in marine fishery for less than 30 days in the past one year are excluded'. The system of this survey has changed since 2006, which is presented in Fig.4-16.

Due to the changes in the framework of Japan's fishery business survey, statistical targets and indicators are discontinuous which makes the comparison of Japan's saury industry economic performance in time series impossible. Nevertheless, we can still utilize the limited continuous data in some continuous years and analyze the economic performance change of Japan's saury fishery in certain periods and current situation in recent years.

According to MAFF, private fishery business 'denotes a fishery business that personally engages in fishery; while company fishery business includes a joint-stock company, partnership corporation, limited partnership, or private limited company established under the Company Law (Law No.86 of 2005). Joint fishery business is the fishery business conducted by two or more people (including corporations) sharing major production means, such as fishing vessels, fishing nets and so forth' (MAFF).

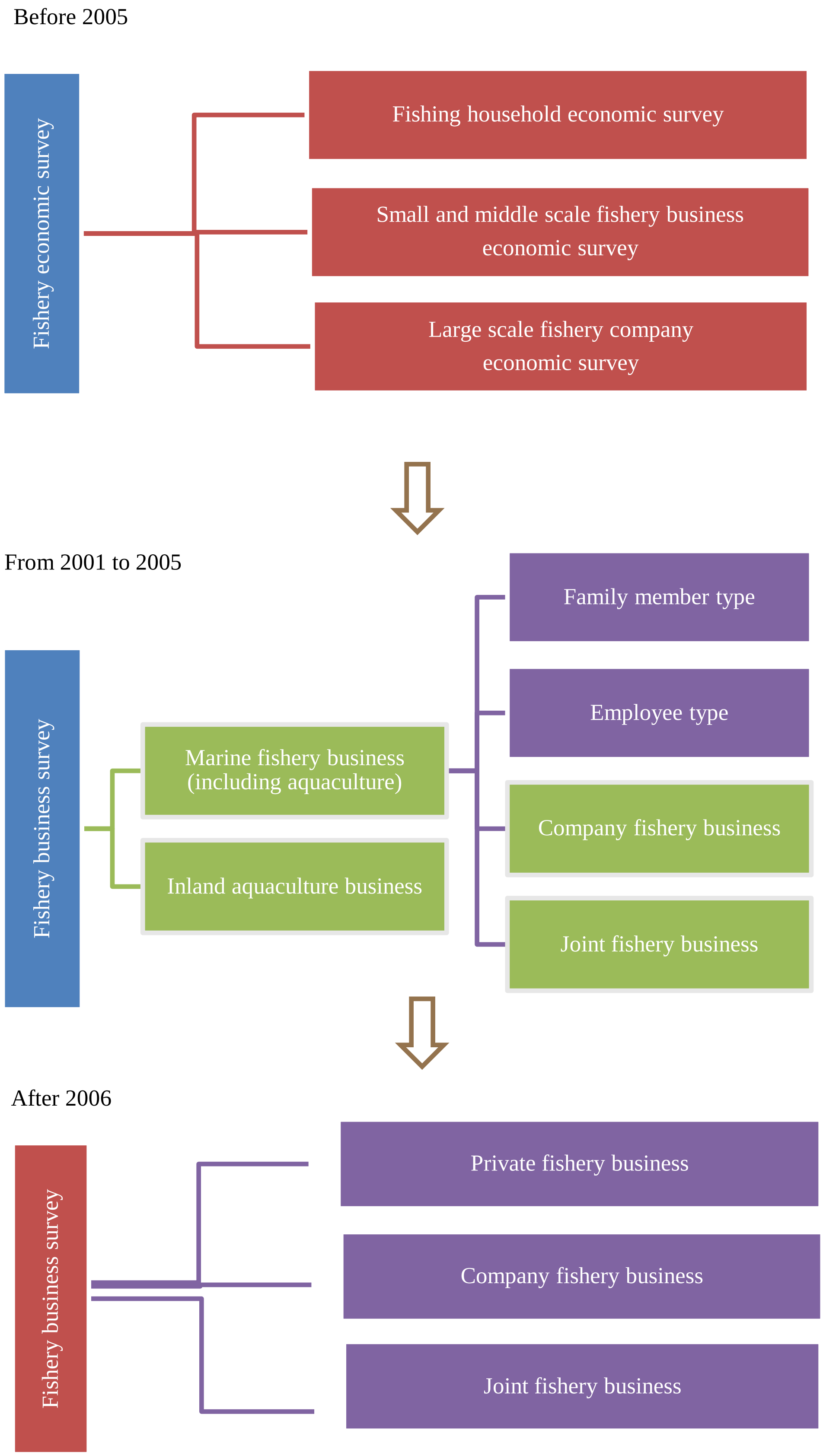

Fig.4-16 Change in the system of fishery business survey since 2006 (MAFF)

The data on the Pacific saury stick-held dip net fishery in Japan are divided by the type of fishery management entities, individual management and company. For the individual management entities operating saury SHDN fishery, it covers those depending on catching saury by use of SHDN and motorized fishing vessels as individual marine enterprises; while for the company, it covers those depending on catching saury applying SHDN and motorized fishing vessels more than 10 t as companies.

4.7.2 Small-scale saury fishery (10-20T) in the form of private enterprise

In the Annual Report of Fishery Business Survey published by MAFF, data concerning the small-scale vessels (10-20 GT) operating the Pacific saury fishery using SHDN are limited in 2012 and 2013. In Table 4-19, we can find information of average tonnage, fishing time, catch, fishery income, fishery cost and capital.

From 2012 to 2013, although the cumulative fishing time increased from 61 days to 65 days, the production volume decreased from 645 t to 425 t, which was related with the general poor catch of saury in 2013. For example, the total saury production volume caught by Japanese fishing vessels in 2013 was only 67% of that in 2012. Contrarily, the fishery income in 2013 (53,439,000 Yen) was higher than that in 2012 (44,750,000 Yen), which increased by nearly 20%. This can be contributed to the high saury price in 2013.

The fishery expenditure in 2013 (48,275,000 Yen) decreased compared with that in 2012 (50,328,000 Yen) by 4%. A further study on the cost structure reveals that employee wage occupied the largest ratio in total expenditure both in 2012 (23%) and 2013 (26%), and oil expenses, depreciation as well as taxes, public imposts and obligations were the other three single costs which accounted for more than 10% in 2012 and 2013. Compared with 2012, the employee wages and oil expenses increased in 2013, while repair cost, other costs, depreciation, as well as taxes, public imposts and obligations decreased in 2013, which resulted in a lower total expenditure in 2013.

Fishery earnings are defined as the gap between fishery income and expenditure, which was -5,578 and 5,164 thousand yens in 2012 and 2013, respectively. Higher profitability in 2013 results from increased fishery income and decreased fishery expenditure, compared with 2012.

Table 4-19 The economic data on the small-scale (10-20 GT) vessels mainly operating the Pacific saury SHDN fishery in the form of private enterprise

Items	**Unit**	**2012**	**2013**
Gross tonnage	T	17.94	17.94
Cumulative fishing time	Days	61	65
Cumulative working time	Hours	5,060	5,075
1a) on-sea working days	Hours	4,287	4,186
by families	Hours	646	690
by employees	Hours	3,641	3,496
1b) on-land working days	Hours	773	889
by families	Hours	241	274
by employees	Hours	532	615
Catch	Kg	645,423	424,931
Fishery income	1,000 Yen	44,750	53,439
Fishery expenditure	1,000 Yen	50,328	48,275
2a) employee wages	1,000 Yen	11,699	12,353
2b) fishing vessel and gear expenses	1,000 Yen	932	1,372
2c) oil expenses	1,000 Yen	7,461	8,252
2d) repair cost	1,000 Yen	4,250	3,810
2e) selling charge	1,000 Yen	2,910	3,070
2f) debt interest	1,000 Yen	232	434
2g) taxes, public imposts and obligations	1,000 Yen	5,726	5,017
2h) others	1,000 Yen	8,767	7,789
2i) depreciation	1,000 Yen	8,351	6,178
Estimated family wages	1,000 Yen	1,563	1,658
Total invested capital for fishery	1,000 Yen	48,870	50,514
3a) fixed capital	1,000 Yen	27,100	28,636
3b) non-fixed capital	1,000 Yen	21,770	21,878
Fishery earnings	1,000 Yen	-5,578	5,164

Data source: the Annual Report of Fishery Business Survey, MAFF, 2012-2013.

4.7.3 Middle-scale saury fishery (20-50T) in the form of company enterprise

Data in the Annual Report of Fishery Business Survey include the economic data on the 20-50 GT category fishing vessels operating the Pacific saury SHDN fishery from 2010 to 2013. These vessels are managed in the form of company enterprises, which are different with the above 10-20 GT type vessels. The total number of saury vessels in the category of 20-50 GT permitted by MAFF increased to 23 in 2012, based on the Plan for the Reconstruction Project of Fishing Regions related with Pacific saury Stick-held Dip Net Fishery in 2013. And through Table 4-20, we can find that the vessels in this category are almost 29 GT.

The catch by these vessels kept relatively stable between 1,200 tonnes and 1,400 tonnes from 2010 to 2013. Although the Pacific saury catch in 2013 generally dropped down nationally, the catch of 20-50 GT vessels seemed to be little affected as the production volume decreased by only 1% from 1,335 tonnes in 2012 to 1,320 tonnes in 2013. The fishery sales averaged as 125,486 thousand yens, with 2012 as the highest year (140,249 thousand yens), which was mostly contributed to high fish price (105 Yen/Kg).

Total fishery cost includes fishery sales cost and selling cost as well as general administrative expense. The average fishery cost was 136,911 thousand yens from 2010 to 2013, with 2011 as the most costly year (148,671 thousand yens). The largest single expenditure is also labour cost, the same with 10-20 GT vessels. Other large costs include oil expenses, repair cost, depreciation, as well as salary, allowance and directors' remuneration.

Fishery profits kept as minus from 2010 to 2013, with the largest catch year 2011 as the worst in profitability and the second least catch year 2013 as the best although in a deficit.

Table 4-20 The economic data on the middle-scale (20-50 GT) vessels mainly operating the Pacific saury SHDN fishery in the form of company enterprise

Items	Unit	2010	2011	2012	2013
Gross tonnage	T	29	29	29	29
Fishing time	Days	85	94	99	87
Catch	Tonnes	1,280	1,362	1,335	1,320
Fishery sales	1,000 Yen	116,452	128,733	140,249	116,509
Fishery sales cost	1,000 Yen	106,952	112,956	108,630	84,619
1a) opening inventory	1,000 Yen	-	-	-	-
1b) labor costs	1,000 Yen	37,604	39,786	43,400	27,919
1c) fishing vessel and gear expenses	1,000 Yen	683	453	698	756
1d) oil expenses	1,000 Yen	11,899	16,124	17,458	14,456
1e) repair cost	1,000 Yen	10,206	14,056	6,123	6,840
1f) taxes, public imposts and obligations	1,000 Yen	3,645	2,044	1,944	1,377
1g) depreciation	1,000 Yen	9,976	15,005	8,825	5,782
1h) others	1,000 Yen	32,929	25,488	30,182	27,489
1i) ending inventory	1,000 Yen	-	-	-	-
Selling cost and general administrative expense	1,000 Yen	28,273	35,715	36,659	33,839
2a) Salary etc.	1,000 Yen	11,572	15,987	15,782	15,195
2b) selling charge	1,000 Yen	4,716	6,650	6,630	6,274
2c) taxes, public imposts and obligations	1,000 Yen	1,787	4,730	6,354	6,343
2d) depreciation	1,000 Yen	212	740	204	195
2e) others	1,000 Yen	9,986	7,608	7,689	5,832
Interest paid and discount received	1,000 Yen	955	697	866	411
Capital invested in fishery	1,000 Yen	112,102	114,766	105,088	86,635
3a) fixed capital	1,000 Yen	49,583	48,303	36,958	30,394
3b) non-fixed capital	1,000 Yen	62,519	66,463	68,130	56,241
Fishery profit	1,000 Yen	-18,773	-19,938	-5,040	-1,949

Data source: Annual Report of Fishery Business Survey, MAFF, 2010-2013.

Table 4-21 The economic data on the large-scale (>100 GT) vessels mainly operating the Pacific saury SHDN fishery in the form of company enterprise

Items	2006	2007	2008	2009	2012
Gross tonnage (GRT)	169.6	170.44	175	170.6	160.00
Fishing time (day)	84	98	102	100	95
Catch (tonne)	1,981	2,533	3,225	3,544	1,601
Fishery sales (1,000 Yen)	121,405	174,173	211,698	205,457	147,055
Fishery sales cost s (1,000 Yen)	99,268	130,754	148,318	131,277	92,360
1a) opening inventory	512	603	7,302	563	-
1b) labor costs	35,409	43,727	48,166	45,054	40,375
1c) fishing vessel and gear expenses	4,058	4,852	6,058	5,299	3,257
1d) oil expenses	24,120	32,632	35,598	29,901	23,694
1e) repair cost	7,550	10,758	19,731	13,237	9,323
1f) taxes, public imposts and obligations	2,049	2,529	1,651	2,616	738
1g) depreciation	7,383	10,070	6,744	8,725	2,499
1h) others	18,841	26,230	36,628	26,382	12,474
1i) ending inventory	653	647	13,559	500	-
Selling cost and general administrative expense	11,022	13,111	18,359	17,869	14,772
2a) salary, allowance, directors' remuneration	3,101	3,000	4,544	3,463	6,178
2b) selling charge	4,099	5,107	7,788	8,194	3,531
2c) taxes, public imposts and obligations	1,064	1,916	1,611	1,469	376
2d) depreciation	462	500	1,678	702	500
2e) others	2,297	2,587	2,739	4,041	4,187
Interest paid and discount received	2,985	4,663	6,752	2,884	1,037
Capital invested in fishery	109,049	122,806	130,198	120,171	70,720
3a) fixed capital	57,826	56,158	51,070	50,311	18,653
3b) non-fixed capital	51,223	66,648	79,128	69,860	52,067
Fishery profit	11,115	30,308	45,021	56,311	39,923

Data source: Annual Report of Fishery Business Survey, MAFF, 2006-2009, 2012.

Table 4-22 The economic data on the large-scale (>100 GT) vessels specializing in the Pacific saury SHDN fishery in the form of company enterprise

Items	**2006**	**2007**	**2008**	**2009**	**2013**
Gross tonnage (GRT)	176.83	172.6	178.6	173.5	160.00
Fishing time (day)	83	107	109	111	106
Saury catch (tonne)	1,887	2,433	3,402	3,672	1,291
Fishery sales (1,000 Yen**)**	112,456	161,108	231,178	208,828	162,274
Fishery sales cost (1,000 Yen**)**	76,643	106,973	151,972	122,410	106,847
1a) opening inventory	854	1,085	10,222	704	-
1b) labor costs	27,228	36,108	49,074	42,930	34,028
1c) fishing vessel and gear expenses	2,853	2,617	5,655	4,931	3,473
1d) oil expenses	21,144	29,255	40,608	30,878	26,170
1e) repair cost	4,412	8,748	22,888	13,218	13,396
1f) taxes, public imposts and obligations	1,272	2,026	1,480	2,156	1,437
1g) depreciation	8,222	14,035	7,691	9,502	10,226
1h) others	11,746	14,263	33,336	18,716	18,117
1i) ending inventory	1,088	1,164	18,983	625	-
Selling cost and general administrative expense	8,289	10,611	16,942	16,771	18,637
2a) salary, allowance, directors' remuneration	2,089	2,315	5,529	3,590	9,883
2b) selling charge	3,078	5,026	7,388	7,502	4,309
2c) taxes, public imposts and obligations	521	518	933	736	749
2d) depreciation	527	593	739	716	532
2e) others	2,074	2,160	2,351	4,228	3,164
Interest paid and discount received	2,665	3,072	8,832	3,033	3,707
Capital invested in fishery	109,082	122,671	130,503	114,283	100,718
3a) fixed capital	70,990	71,193	50,261	49,801	43,355
3b) non-fixed capital	38,092	51,478	80,242	64,482	57,363
Fishery profit	27,524	43,524	62,264	69,647	36,790

Data source: Annual Report of Fishery Business Survey, MAFF, 2006-2009, 2013.

4.7.4 Large-scale saury fishery (>100 GT) in the form of company enterprise

According to the Plan for the Reconstruction Project of Fishing Regions related with Pacific saury Stick-held Dip Net Fishery, the saury fishing vessel more than 100 GT permitted by MAFF is the second largest among the whole saury vessels in terms of quantity, following those in the 10-20 GT category. Data concerning this large-scale vessels in the Annual Report of Fishery Business Survey cover years 2006-2009 and 2012 (Table 4-21).

The average gross tonnage was between 160 and 175 GT while the fishing time ranged from 84 to 102 days. The catch quantity changed greatly from year to year, with the average as 2,577 tonnes. Fishery sales ranged between 121,405 and 211,698 thousand Japanese yen. Considering the cost structure of large-scale saury vessels, the largest expenditure is still labour cost. Other costly items include oil, repair cost and depreciation. The average ratio of labour cost to total fishery cost was as high as 32% and that of oil averaged as 22%. Fishery profit kept as positive from 2006 to 2009 and 2012, ranging from 11,115 to 56,311 thousand yen.

Table 4-22 shows the data on large-scale vessels specialized in catch saury by SHDN. The total catch ranged between 1,291 and 3,672 tonnes and the fishery sales changed from 112,456 to 231,178 thousand yen. The largest expenditure was labour cost, accounting nearly 30% of total fishery cost on an average. Other costly items include oil, repair cost and depreciation. In terms of fishery profit, it ranged from 27,524 to 69,647 thousand years, with the largest catch year (2009) as the most profitable.

4.7.5 Conclusions

Although the statistical data on the economic situation of saury fishing vessels are limited and unbalanced, i.e., continuous data of each gross tonnage category (10-20 GT, 20-50 GT, >100 GT) in every year from 2006 to 2013 are not available, the existing data can still reveal some characteristics in the economic performance of Japan's saury fishery.

Table 4-23 Comparison of the economic performance between average and specialized large scale saury fishing vessels

	Average	Specialized	Average	Specialized	Average	Specialized	Average	Specialized
	2006	2006	2007	2007	2008	2008	2009	2009
Catch (ton)	1,981	1,887	2,533	2,433	3,225	3,402	3,544	3,672
Fishery sales (1,000 yen)	121,405	112,456	174,173	161,108	211,698	231,178	205,457	208,828
Fishery cost	110,290	84,932	143,865	117,584	166,677	168,914	149,146	139,181
Fishery profit	11,115	27,524	30,308	43,524	45,021	62,264	56,311	69,647
Average price	61.28	59.60	68.76	66.22	65.64	67.95	57.97	56.87
Fishing time (day)	84	83	98	107	102	109	100	111
Catch per day (ton/day)	23.58	22.73	25.85	22.74	31.62	31.21	35.44	33.08
Labour expenditure	35,409	27,228	43,727	36,108	48,166	49,074	45,054	42,930
Oil expenses	24,120	21,144	32,632	29,255	35,598	40,608	29,901	30,878
Salary etc.	7,550	4,412	10,758	8,748	19,731	22,888	13,237	13,218
Repair cost	7,845	8,749	10,570	14,628	8,422	8,430	9,427	10,218
Depreciation	4,099	3,078	5,107	5,026	7,788	7,388	8,194	7,502
Selling charge	3,101	2,089	3,000	2,315	4,544	5,529	3,463	3,590
Taxes etc.	3,113	1,793	4,445	2,544	3,262	2,413	4,085	2,892

Data source: Annual Report of Fishery Business Survey, MAFF, 2006-2009.

In terms of fishery profit, small-scale saury fishing vessels (10-20 GT) presented an unstable profitability, middle-scale vessels (20-50 GT) kept operating at a loss, while large-scale vessels (>100 GT) stayed with considerable profits in the studying years. Moreover, the large-scale vessels specialized in catching saury presented a better economic performance (higher profitability) than the average level of large vessels which are more than 100 GT (Table 4-23). Therefore, we can generally rank the profitability of saury fishing vessels as: specialized vessels larger than 100 GT > non-specialized vessels more than 100 GT > 10-20 GT small-scale vessels > 20-50 GT middle-scale vessels.

With respect to the cost structure (Fig.4-17 and 4-18), labour expenditure accounted for the largest ratio in total fishery cost for all the saury fishing vessels in the studied years, and oil was the second costly single input. The combined ratio of labour and oil expenditure in large-scale vessels exceeded 50%, which was larger than that in small and middle scale vessels (40% and 38%). This implies that labour and oil expenditures affect the total fishery cost of large-scale vessels in a greater extent compared with vessels smaller than 50 GT. Meanwhile, the depreciation cost in small-scale vessels takes up a larger ratio (15%) than others.

Generally speaking, although small and middle size vessels landed the fish at a higher price than large-scale vessels on an average level, the gap in catch quantity leads to the difference in fishery sales. In this situation, effort in saving cost may bring considerable profits for vessels under 50 GT. However, the almost same or even higher cost in 20-50 GT fishing vessel, compared with those larger than 100 GT, consequently results in their economic loss. The comparison between specialized large-scale vessels and average large-scale vessels also reveal some interesting points (Table 4-23). Catch per day in average large-scale vessels kept being higher than specialized vessels, which may denote a worse productivity in specialized large-scale vessels but other possibilities cannot be ignored. For example, non-specialized vessels are even larger than specialized ones since we can only get the average statistical data. Meanwhile, the average fish price landed by average large vessels generally acquired a higher price. This may be explained by that the average data include non-specialized vessels which catch a higher value fish than the Pacific saury, such as tuna, salmon and trout, etc. However, specialized vessels tended to spend more time in fishing, which consequently resulted in a larger or similar catch compared with average large-scale vessels. Correspondingly, the fishery sales in specialized vessels did not fall behind those in average vessels more than 100 GT. Further, the fishery profit in specialized vessels presented a priority, which contributed to their better profitability.

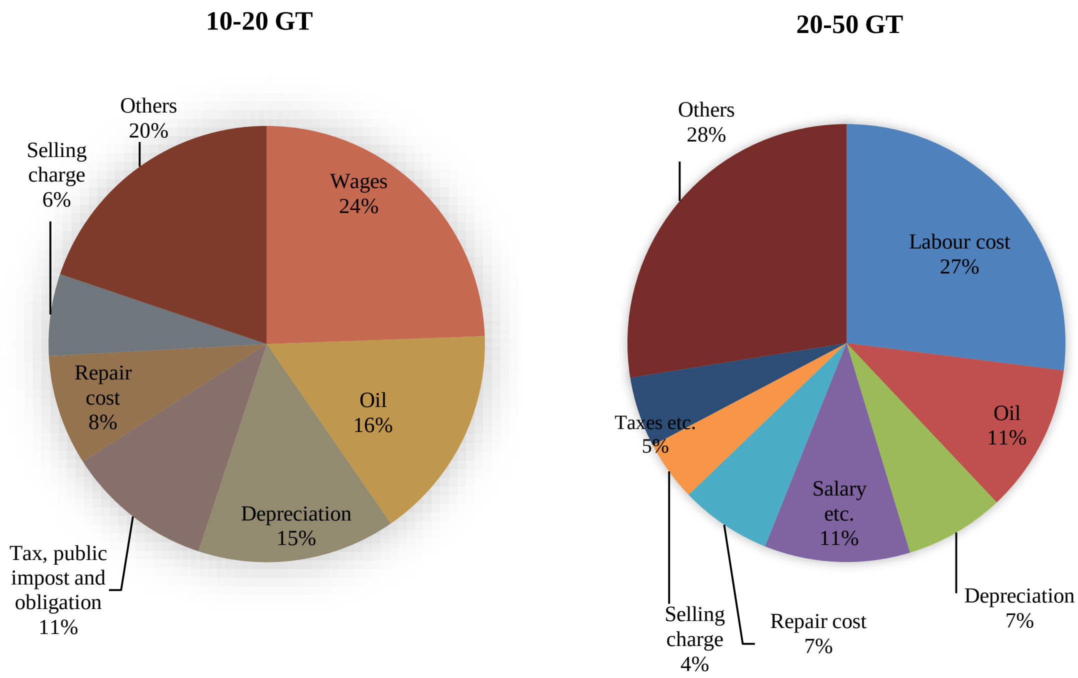

Fig.4-17 Average cost structures of small-scale (left) and middle-scale (right) saury fishing vessels applying SHDN from 2010 to 2013

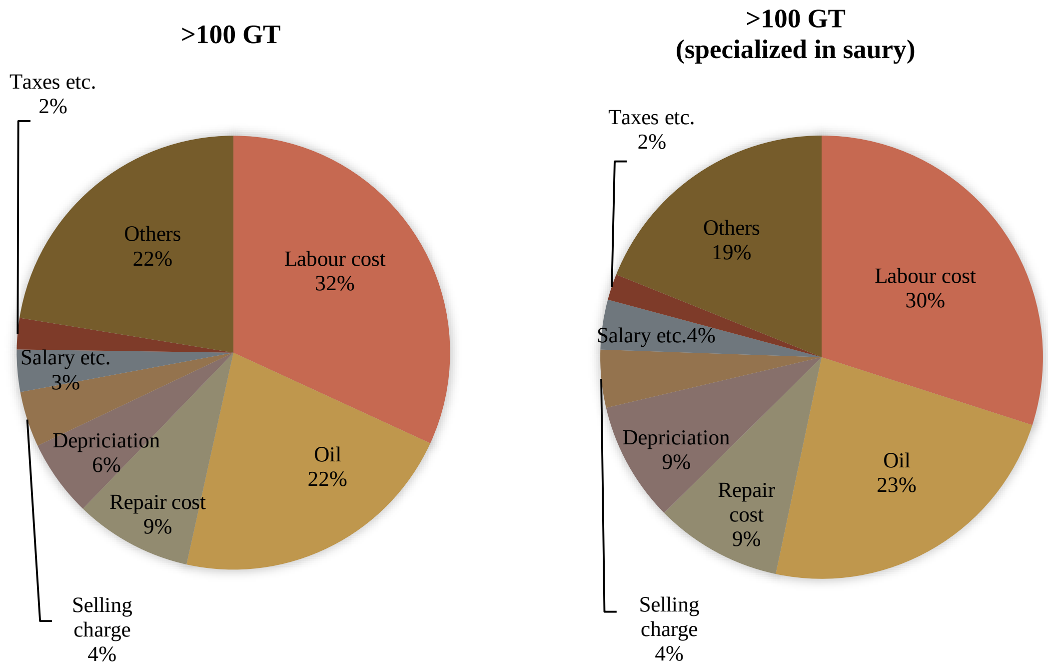

Fig.4-18 Average cost structures of large-scale average (left) and specialized (right) saury fishing vessels applying SHDN from 2010 to 2013

Data source: Annual Report of Fishery Business Survey, MAFF, 2010-2013.

4.8 Management framework

4.8.1 Fishing license system and closed seasons

Currently, the Pacific saury fishery in Japan is regulated by fishing license system. The validity of fishing license lasts for 5 years. The fishing license is granted to individual fishing vessel operating saury fishery by MAFF or prefectural governors. To be specific, the vessels larger than 10 GRT operating the stick-held dip net saury fishery in the North Pacific Ocean acquire the fishing licenses from MAFF; while those smaller than 10 GRT operating SHDN saury fishery or those using other fishing methods (such as drift/gill netting or set netting) to catch the Pacific saury obtain the licenses from each prefectural governor they belong to.

For those saury vessels acquiring the licenses from MAFF, they are now managed by National Saury Stick-held Dip Net Fishery Cooperative Association (*Zensanma*). *Zensanma*, established in June 1998 based on the Fishery Cooperative Act, is organized by the fishers operating the Pacific saury stick-held dip net fishery with fishing licenses from MAFF. Focusing on the guiding enterprise of member fishers, the primary activities of *Zensanma* can be concluded as follows: 1) the management of the TAC system; 2) dealing with international issues such as the operation in Russian oceans; 3) working on the stability and profitability of saury fishery enterprises; and 4) undertaking the reconstruction and support of fisheries and aquaculture.

As a part of the requirement of fishing licenses, the Pacific saury fishing vessels are subject to some restrictions and prohibitions. Among these, the closed season is an important restriction and will be further introduced here. Closed season determines the certain periods of the year when the saury fishing is prohibited, in order to achieve ‘resource conservation and the coordination of fishing operations among fishermen’ (Asada 1973). As shown in the following Table 4-24, the re-starting date of fishing seasons varies with the fishing methods as well as tonnage. The drift net fishing vessels catching the Pacific saury are the first to be allowed to restart the operation, and the large-scale SHDN vessels being the last group to restart their operations. The data in the table explains another phenomenon, i.e., in recent years, the restarting dates are postponed for several days, which can be explained by the movement of fishing ground to more distant places.

Table 4-24 Starting date of fishing season for different Pacific saury fishing vessels

Vessel	2011	2012	2013	2014	2015
Drift net	Jul. 8	Jul. 8	Jul. 8	Jul. 8	Jul. 8
SHDN 10- 20GT	Aug. 2	Aug. 2	Aug. 10	Aug. 10	Aug. 10
SHDN 20-100 100GT	Aug. 5	Aug. 5	Aug. 15	Aug. 15	Aug. 15
SHDN > 100GT	Aug. 15	Aug. 15	Aug. 20	Aug. 20	Aug. 20

Note: a) Data in 2011-2012 is from the homepage of Uoichi Co., Ltd. http://www.uoichi.co.jp/; b) data on drift net in 2013-2015 is from homepage of Kushiro News, http://www.news-kushiro.jp/news; c) data on SHDN>20GT in 2013-2015 is from homepage of Ochiishi Fisheries Cooperative Association, http://www.ochiishi.or.jp/html/topics_blk.html.

4.8.2 Production adjustment and TAC system

Total allowable catch (TAC) system was established in 1996 in Japan, and the Pacific saury was included into TAC management system from 1997. In the TAC management system for the Pacific saury, the Minister of Agriculture, Forestry and Fisheries (MAFF) will determine the total allowable catch of the whole country, and the quotas managed by MAFF and the governors of 47 prefectures, respectively; then, each prefecture will further allocate the saury quota it acquires.

The target of TAC is selected mostly based on the following three standards: 1) it is of crucial importance to people’s living or fisheries with large catch and consumption; 2) the resource is in a poor status needing urgent conservation and management; and 3) it is also caught by foreign vessels in the surrounding waters of Japan. Meanwhile, an accumulation of scientific knowledge necessary for setting TAC is also a prerequisite for the selection (Japanese Fisheries Information Center 2007). With respect to the Pacific saury, it satisfied the first and third standards in the time it was considered as one target of TAC system, and enough scientific information was available.

In order to manage the TAC system smoothly, the participants of *Zensanma* signed an agreement since the introduction of saury TAC in 1997 to manage the MAFF-part saury total allowable catch. Meanwhile, a similar agreement was also signed in Hokkaido Prefecture in 2001 to manage a part of the prefectural government-part saury TAC. Moreover, an administration committee of the Pacific saury fishery agreement was also organized to facilitate the smooth progress of fishery agreement in *Zensanma*. Meanwhile, an operation committee of Pacific saury fishery agreement in Hokkaido Prefecture was also organized.

Table 4-25 lists the distribution of TAC related with the Pacific saury since 1997. In the past decades, the TAC of Pacific saury varied from around 264,000 tonnes to 455,000 tonnes, with the largest quantity in 2008, 2009 as well 2010 and the least quantity in this year. The distribution of TAC showed that more than 70% of the quota was given to the vessels applying stick-held dip net larger than 10 GRT, which are managed by *Zensanma*; while the rest are distributed into various prefectures and managed by prefectural governments, within which Hokkaido Prefecture and Iwate Prefecture acquire most of the remaining quotas.

The management of TAC by *Zensanma* will be introduced to a further extent here. When the total allowable catch is determined, the administration committee will revise *Guide of TAC management* and the expected ratio of monthly saury catch as well as the trigger conditions of fishing suspension. The expected ratio of monthly saury catch is decided based on the catch data in the past five years and the estimated saury stock approaching. Fishing suspension, fishing closing and measures taken when the fisher members disobey the rules will be determined in detail.

Table 4-25 Distribution of Pacific saury TAC and catch in Japan from 1997 to 2015

Year	Stock	Japan		Managed by MAFF		Managed by Hokkaido		Managed by Iwate	
		TAC	Catch	TAC	Catch	TAC	Catch	TAC	Catch
1997		30.0	28.5	25.0 (24.0)	24.8	1.2 (2.2)	2.7	0.8	0.6
1998		30.0	14.1	25.0 (24.0)	11.3	1.2 (2.2)	2.3	0.8	0.3
1999		33.0	14.0	25.0 (24.0)	10.4	1.2 (2.2)	3.3	0.8	0.3
2000		31.0	20.6	22.5	17.0	2.9 (3.2)	3.1	0.6	0.4
2001		31.0	26.5	22.5	22.4	2.9 (4.0)	3.3	0.6 (0.8)	0.6
2002		31.0	21.1	22.5 (23.0)	17.3	2.9 (3.7)	2.3	0.6 (0.7)	0.4
2003	442	33.4	27.0	24.0	23.8	4.3	2.0	0.7	0.2
2004	315	28.6	20.9	20.4	18.7	3.7	1.3	0.6	0.1
2005	354	28.6	23.4	20.4	20.8	3.7	1.3	0.6	0.3
2006	323	28.6	24.8	21.3	22.1	2.2 (3.2)	1.3	0.3 (0.5)	1.9
2007	201	39.6	30.1	30.0	26.9	3.2 (4.1)	1.7	0.5	0.4
2008	398	45.5	35.3	35.0	31.7	5.8	1.9	0.8	0.5
2009	301	45.5	31.6	35.0	28.5	5.8	1.6	0.8	0.4
2010	135	45.5	19.9	35.0	18.4	5.8	0.5	0.8	0.2
2011	249	42.3	20.5	33.5	19.4	4.8	1.0	0.7	-
2012	160	45.5	22.1	33.5	20.5	4.8	1.2	0.7	1.5
2013	208	33.8	14.8	23.5	14.0	3.2	0.6	0.5	<0.1
2014		35.6	22.6	24.2	21.7	3.3	0.7	0.5	<0.1
2015		26.4	-	20.2	-	2.8	-	0.4	-

Data source: Fisheries Agency of Japan (1997-2015) Yearly changes of TAC and fish catch *(Gyokakukanouryou oyobi saihojisseki no suii)*

4.8.3 Price stabilization fund for fish

After the end of Second World War, fisheries in Japan developed rapidly due to factors like the enlargement of vessel size, the popularization of synthetic fiber fishing nets, the improved capacity in searching fishing schools and introduction of more efficient fishing method such as the stick-held dip netting. A rapid increase in fishery production will be a problem especially for those 'one-time mass catch' species, such as the Pacific saury, horse mackerel (*aji*), Japanese common squid (*surumeika*) etc. For these species, landings are limited in certain periods or places, which will easily bring about a phenomenon called 'large catch while worse benefits' (*tairyobinbo*). Against this background, Law of the Price Stabilization Fund for fish (*gyoka antei kikinho*) and Law of the Fisheries Production Adjustment Cooperative (*gyogyo seisan chosei kumiaiho*) were promulgated on June 13th 1961, and came into force on Aug. 5th in the same year. The Price Stabilization Fund for Fish was established in Sept. 1961 based on the corresponding law.

The Price Stabilization Fund for Fish grants two types of subsidies, i.e. the subsidy for production adjustment (*seisan chosei kohukin*) and the subsidy for holding fish (*hokan kohukin*). In terms of the Pacific saury, when the National Saury Stick-held Dip Net Fishery Production Adjustment Association (*zenkoku sanm boukeaimi gyogyo seisan chosei kumiai*) needs to limit the operation or landing of its member fishers in case of low fish price and pay the fishers monetary compensation, the total or part of its costs can be paid back in the form of production adjustment subsidy by the Fund. On the other hand, when the consignment selling of processed saury (saury pickled in sake lees) happens after more than 30-day holding period meanwhile the difference between selling price and fish holding as well as selling costs is lower than the pre-decided standard, all or part of the cost for holding saury can be paid back by the Fund.

However, the subsidy for holding fish was provided by the Fund only in the first two years (1961 and 1962) and was not put in operation in the following years. This is because that the Pacific saury was the only fish species included in the Fund and the price for saury sake lees was kept in a relatively high level due to several reasons including the obvious decreases in catch since 1963. The Price Stabilization Fund for Fish was dissolved in 1968 after seven years of its establishment.

Although the Price Stabilization Fund for Fish was dissolved, the price stability of the 'one-time mass catch' species continues to be a critical issue. The oil shock in 1973 caused a rapid increase in oil price and consequently brought the economic performance of Japanese fisheries to a difficult situation. Under this background, the stabilization of fish price was again put forward as an urgent issue. Consequently, a new organization was founded in 1976 called 'The Price Stabilization Fund for Fish (Incorporated Foundation)' (*zaidanhojin gyoka antei kikin*). Compared with the Fund established in 1961, the new fish fund included more aquatic species besides the Pacific saury, and the adjustment and holding was performed mainly in the form of purchase (*kaitori*) rather than consignment selling (*jyutaku hanbai*).

Table 4-26 Capital composition of the Price Stabilization Fund for Fish

Capital provider	Capital (1,000 Yen)	Ratio
Total	162,900	100.0%
Central government	80,000	49,1%
Prefectural governments	40,800	25.0%
Zensanma	37,000	22.7%
National and Prefectural Gyoren	4,800	2.9%
Hokkaido and Ishinomaki Kakokyoku	300	0.2%

Notes: a) Gyoren: Federation of Fisheries Cooperative Associations b) Kakokyoku : Aquatic products processing cooperative association; c) Data source: Nakai 1981.

With respect to the Pacific saury, the framework of the fish fund is illustrated in Fig. When the price of saury is or tends to be lower than the upper limit of the purchase price range, the frozen processors will purchase the raw fish from the local fish markets, and sell the frozen saury to the implementation bodies including *Zengyoren* (National Federation of Fisheries Cooperative Associations), *Dogyoren* (Hokkaido Prefecture Federation of

Fisheries Cooperative Associations) and *Zensuikakoren* (National Federation of Aquatic Products Processing Cooperative Associations) The implementation bodies keep the frozen saury and sell them to the consumption markets mostly between two fishing seasons. The holding cost, processing cost and the interest rate of purchase payment paid by the implementation bodies can be subsidized by the Price Stabilization Fund for Fish, which receives funding from the central government.

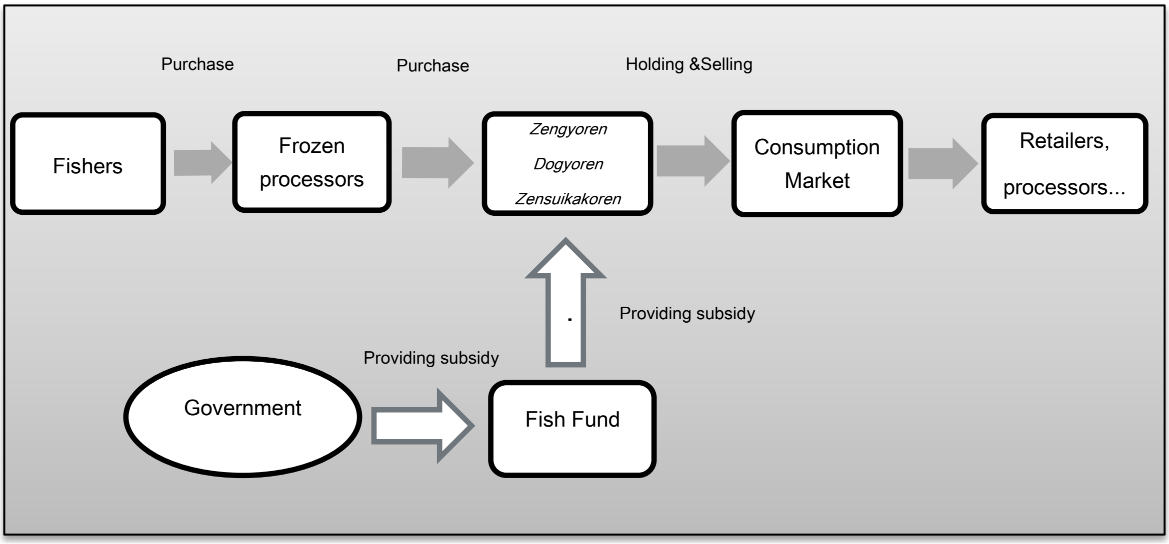

Fig.4-19 The general framework of the Fish Fund for the Pacific saury.

Note: adapted from Funamoto (2014).

Table 4-27 shows the yearly changes in the quantities of the Pacific saury purchased by different implementation bodies. The Pacific saury is purchased by three implementation bodies, within which *Zengyoren* has kept being the largest share and *Dogyoren* being the fewest. This difference can be explained by that the period when the Pacific saury is landed in Hokkaido is usually the beginning of saury fishing season. In this time, fresh saury is the main form of landing and the price fluctuates violently, while the fish fund usually is put into function in a continuing low-price situation. The ratio of total purchased saury relative to the national saury production ranges around 5%-7% in recent years.

Table 4-27 The purchase quantities of the Pacific saury by different implementation bodies

Year	*Zengyoren*	*Dogyoren*	*Zensuikakoren*	Total purchase	National saury catch	Ratio
1977	*	*	*	2,048	253,465	0.8%
1980	*	*	*	2,358	187,155	1.3%
1985	*	*	*	7,297	245,944	3.0%
1989	*	*	*	5,882	246,821	2.4%
1993	*	*	*	32,682	277,461	11.8%
1998	*	*	*	86	144,983	0.1%
1999	1,029	1,173	0	2,202	141,011	1.6%
2000	7,523	2,300	1,031	10,854	216,471	5.0%
2001	18,120	2,160	2,149	22,429	269,797	8.3%
2002	5,015	1,096	1,968	8,079	205,282	3.9%
2003	12,049	877	5,801	18,727	264,804	7.1%
2004	6,677	967	5,600	13,244	204,371	6.5%
2005	9,055	850	4,896	14,801	234,451	6.3%
2006	11,718	520	4,172	16,410	244,586	6.7%
2007	8,712	513	5,210	14,435	296,521	4.9%
2008	13,000	600	10,000	23,600	354,727	6.7%
2009	18,010	87	0	18,097	310,744	5.8%
2010	0	0	0	0	207,488	0.0%
2011	*	*	*	10,027	215,353	4.7%
2012	*	*	*	16,198	221,470	7.3%

Notes: a) Unit of quantity is tonne; b) Data source: Price Stabilization Fund for Fish (2011)

Chapter 5

The technical efficiency study on the Pacific saury stick-held dip net fishery in Habomai region of Hokkaido prefecture through SFA approach

5.1 Introduction

In this chapter, technical efficiency (TE) analysis is carried out as a measurement to evaluate the competitiveness of the Pacific saury fishery in Japan, applying the stochastic frontier analysis (SFA) approach. The reasons for targeting the Pacific saury fishery can be explained from several aspects. Firstly, the Pacific saury fishery is one of the representatives in Japanese offshore fisheries. In 2013, the Pacific saury fishery catch contributed to 10% of the total offshore fisheries production in Japan (Annual Statistics on Fisheries and Aquaculture Production, MAFF, 2013). Secondly, Pacific saury is among the few fish species with 100% self-sufficient ratio in Japanese seafood market, indicating the significance of this fish species (MAFF). Thirdly, this fishery in Japan is facing increasingly intense competition from abroad. In Korean and Russian seafood market, the Pacific saury from Taiwan is gaining more popularity due to its competitiveness in price. Moreover, the Pacific saury catch by Taiwan is increasing rapidly and exceeded Japan in 2013 as well as 2014. Mainland China, which is actively developing its distant water Pacific saury fishery, will become another competitor in the near future. All the reasons stated above justify that it is essential to conduct studies on the competitiveness of Pacific saury fishery in Japan. In the selection of data set, the Pacific saury fishery in Habomai region of Hokkaido Prefecture is chosen, considering its top position in Japan's saury production, its key role in local economy, and data availability.

The objectives of current work are stated as follows: 1) estimating the extent of technical efficiency in the Pacific saury stick-held dip net fishery in Habomai; 2) clarifying the possible factors affecting the technical efficiency scores of the sampled fishery; 3) providing policy implications for enhancing the competitiveness of the sampled fishery; and 4) serving as an empirical study for researches in related to the competitiveness enhancement of Japanese fishery.

5.2 An overview of the Pacific saury fishery production in Habomai

5.2.1 A general introduction of Habomai region

Fig. 5-1 The geographical location of Habomai Fisheries Cooperative Association in Japan

(Source: Google map 2015)

Before the description of Habomai region, it is necessary to simply introduce Nemuro City, which is located in Nemuro Subprefecture within Hokkaido Prefecture of Japan, and also the capital city of Nemuro Subprefecture. The history of Nemuro City can be dated back to 1900, when it was founded and called 'Nemuro town'. It combined Wada village and formed 'Nemuro City' in 1957. Two years later, Habomai village was merged into Nemuro City (Wikipedia 'Nemuro, Hokkaido'). The geographical location of Habomai can be clearly seen from Fig.5-1.

As one of the leading fishery production areas, Habomai, which is situated in the easternmost region of Hokkaido Prefecture and under the jurisdiction of Nemuro City, relies on fisheries to a deep extent. Based on the information provided by Habomai Fisheries Cooperative Association, the important fisheries in Habomai include Wakame seaweed fishery, autumn salmon set net fishery, flatfish gill net fishery, sea urchin fishery, the Pacific saury fishery etc. The annual production value reached nearly 12 billion Japanese yen in 2014. Most of the fishers in Habomai take participate in the Habomai Fisheries Cooperative Association.

5.2.2 The Pacific saury fishery in Habomai region

The Pacific saury fishery harvested by the fishing vessels belonging to Habomai Fisheries Cooperative Association (FCA) takes a significant ratio among the total saury production in Hokkaido. Based on the statistical data provided by Habomai FCA and the published data by MAFF, the Pacific saury catch by Habomai vessels changed from 10,488 t to 19,675 t from 2011 to 2014, where the ratio of Habomai to Hokkaido ranged between 11.8% to 18.1%.

According to the data provided from Habomai FCA, the total catch of Pacific saury by Habomai vessels in 2014 was 18,916 tonnes, which is one of the supporting sub-industries in Habomai. The yearly changes in the production volume caught by Habomai FCA vessels are presented in the following Table 5-1.

Table 5-1 Production volume of Pacific saury in Habomai Fisheries Cooperative Association from 2008 to 2014

Year	Total	LOCAL VESSELS			NON-LOCAL (GAIRAI) VESSELS				Landing ports distribution			
		SHDN<10t	SHDN<40t	Nagashiami	SHDN<10t	SHDN<40t	SHDN>100t	Nagashiami	Hanasaki	Nemuro	Outside Hokkaido	Hanasaki ratio
2008	23,296	1,122	17,179	61	776	3,188	970	0	20,614	564	2,118	0.9
2009	19,117	925	13,926	137	603	2,130	1,396	0	16,464	163	2,490	0.9
2010	17,909	584	11,103	44	377	3,131	2,668	1.8	14,285	130	3,494	0.8
2011	23,191	939	13,733	36	389	5,531	2,562	2.1	22,854	-	337	1.0
2012	23,204	920	12,715	0.3	439	5,916	3,212	0	21,284	1,042	878	0.9
2013	18,335	558	9,928	2.1	309	5,487	2,049	2	16,879	640	816	0.9
2014	26,883	760	18,916	0.08	320	4,855	2,033	0	x	x	x	x

Notes: a) The unit of production volume is tonne; b) ‘x’ denotes no data available; c) Data is from Habomai Fisheries Cooperative Association.

Using different fishing methods, the Pacific saury fishing vessels in Habomai can be classified into two categories: drift-net vessels and stick-held dip net (SHDN) vessels, the quantity of which in 2014 was 4 and 22, respectively. As the same with the whole country, the SHDN vessels are either managed by MAFF (>10 GRT) or by Hokkaido Prefecture (<10 GRT), the quantity of which in 2014 was 20 and 2, respectively. Among all the saury fishing vessels, the 20 saury SHDN vessels managed by MAFF catch more than 90% of the total saury. It should be noted that only two types of MAFF-managed saury fishing vessels exist in Habomai, 19 GRT (with one exception as 18 GRT) and 29 GRT. For most of the Pacific saury SHDN fishing vessels in Habomai, they catch the Pacific saury from August to November, and salmon as well as trout from May to July, which may guarantee their catches all around one year and improve profitability. Some vessels also catch cod from December to March.

The general pattern of the Pacific saury SHDN fishing vessels in Habomai is described as follows: when the fishing season comes, vessels begin operation according to the opening date in that year. Usually, a fishing vessel sets sail at 4 or 5 in the afternoon, arrives at the fishing area and starts the operation, and sails to landing ports at 5 or 6 in the next early morning when the earliest fisheries production auction usually starts in most landing ports. In this case, the fresh Pacific saury is the most favorable which can be sold at a high price, called ‘higaeri samma’ in Japanese. In recent years, the fishing area of the Pacific saury shifts to a more distant place away from the coastline, which is more time-consuming and costly to arrive at the fishing areas and return to the ports; therefore, if the vessels cannot go back in time for the auction they are forced to stay for one or two more nights at sea, or choose to stay longer for catching more to balance their cost and benefit. In this condition, the Pacific saury caught is less fresh and sold at a lower price, called ‘tome samma’ (one night at sea) or ‘tometome samma’ (two nights at sea).

5.2.3 Characteristics of the sampled fishing vessels in Habomai region

In order to conduct the technical efficiency study on the Pacific saury fishery, Habomai region, one of the leading production region for the Pacific saury, was selected as the case study target. The author visited Habomai FCA in June 2014 for the first time and in December 2015 for the second time. As analyzed in Chapter 4, Pacific saury is caught mainly by those vessels using the stick-held dip net (SHDN) fishing method and larger than 10 GRT, hence, only those SHDN saury fishing vessels more than 10 GRT (*Zensanma* saury vessels) are set as the target. As mentioned in section 5.2.2, the quantity of *Zensanma* saury vessels in Habomai was 20 in 2014, composed of 19 GRT and 29 GRT group. During the first time of the visit, related data on 6 vessels were acquired, with 3 of them being 19 GRT (one vessel is 18 GRT) and the remaining 3 as 29 GRT; while during the second visit, data on another 6 vessels were obtained, with one being 29 GRT and the other five as 19 GRT. Therefore, the sample size is 12 in total, accounting for 60% of the *Zensanma* saury vessels in Habomai, designating the representativeness of the sample.

The collected data of the sampled saury fishing vessels mainly concentrate on the saury production aspect, vessel characteristics as well as skipper characteristics, including saury production volume and value (monthly and yearly), monthly fishing days, crew size including the skipper (captain), vessel size measured by GRT as well as overall length, specialization in saury fishery of vessels, skipper's age, skipper's experience in fisheries measured by years, the relationship between skipper and vessel owner. The twelve fishing vessels are numbered as Vessel 1, 2, 3…12. Related data to be used in following technical efficiency study are summarized in Table 5-2.

Table 5-2 shows that the sampled vessels are generally divided into 29 GRT and 19 GRT categories (with the exception Vessel 5 as 18 GRT). The overall length of vessel changes with vessel tonnage, ranging from 13.93 m to 20.69 m, with the average length for 29 GRT group as 19.9 m and that for 19 GRT group as 15.2 m. In terms of skipper's age, Vessel 11's skipper is the oldest as 69 years old while that of Vessel 10 is the youngest as 42 years old. Skipper's experience in fishery distributes between 17 and 47. In terms of the relationship between skipper and vessel owner, the skippers of vessel 7, 8, 10 and 12 are employed by vessel owners while the owners of remaining eight vessels work as the skipper themselves. Among these twelve vessels, only Vessel 4 specializes in catching the

Pacific saury while the rest also operate other fisheries besides the Pacific saury.

Table 5-2 Characteristics of the sampled fishing vessels in Habomai region

Vessel	**GRT**	**Length** (m)	**SA** (year)	**SEF** (year)	**SEO**	**SPS**
1	29	19.29	65	47	Yes	No
2	29	20.69	46	28	Yes	No
3	29	19.91	65	47	Yes	No
4	19	17.79	62	44	Yes	Yes
5	18	14.05	51	33	Yes	No
6	19	13.98	61	43	Yes	No
7	29	19.72	47	22	No	No
8	19	17.72	62	37	No	No
9	19	16.23	67	37	Yes	No
10	19	13.97	42	17	No	No
11	19	13.93	69	47	Yes	No
12	19	14.15	58	37	No	No

Notes: a) SA = skipper's age, SEF = skipper's experience in fishing, SEO = skipper is also the vessel owner, SPS = the vessel is specialized in catching saury. For SA and SEF, the data are based in 2016; b) Source: based on the data provided by Habomai Fisheries Cooperative Association

In terms of annual catches, the data for the twelve sampled fishing vessels from 2009 to 2014 is illustrated in Fig. 5-2. Annual landings of the Pacific saury changed from 401.1 tonnes to 1300.9 tonnes, with 2011 as the most prosperous year and 2013 as the poorest year. All the twelve vessels showed the same trend of changes in the Pacific saury catches with years. Compared with 19 GRT category vessels (Vessel 4, 5, 6, 8, 9, 10, 11, 12), 29 GRT category vessels (Vessel 1, 2, 3, 7) caught a larger quantity of fish due to the access to farther fishing ground and a larger capacity of storage. Among the large tonnage group, Vessel 2 exhibited a slight advantage in annual catches over the other 29 GRT vessels; while among the small tonnage group, Vessel 8 showed an obvious advantage than other 19 GRT vessels.

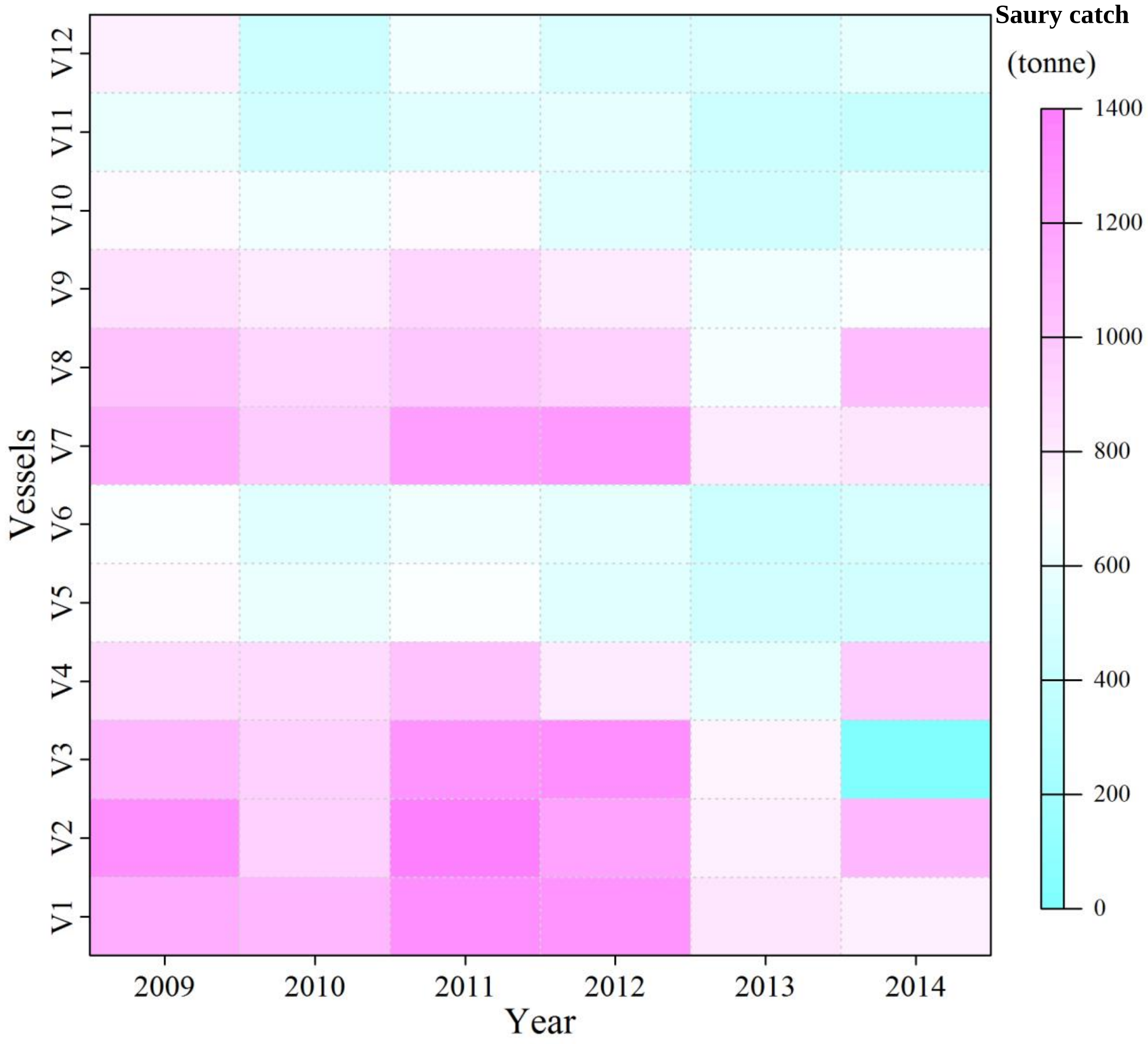

Fig.5-2 Annual catches of the Pacific saury by the twelve sampled vessels from 2009 to 2014
(Source: Based on the data from Habomai FCA)

According to the data provided by Habomai FCA, in terms of seasonal change in the Pacific saury landings, September and October are generally the most prosperous months for all the sampled vessels, while landings are obviously fewer in August and November. This trend corresponds with the general knowledge of the production characteristics of the whole Japanese Pacific saury SHDN fishery.

5.3 Methodology and data

5.3.1 Methodology: SFA

The term 'economic efficiency', which is often mentioned by economists, is actually composed of two components: technical efficiency (TE) and allocative efficiency (AE) (Farrell 1957). TE measures the capacity of one decision-making unit (e.g. firm) to maximize its output given the inputs (output-oriented) or minimize its inputs given the output (input-oriented). To be specific, in the output-oriented case, the ratio of actual output by one firm to its potential output frontier is the TE of this firm, which is between the value 0 and 1. If the TE value is 1, the firm operates on its production frontier, implying that it is fully efficient; while a TE close to 0 indicates that the firm operates in an extremely poor efficiency.

The stochastic frontier production function was independently constructed by Aigner et al. (1977) and Meeusen and Van den Broeck (1977). In stochastic frontier analysis, the production model for panel data is specified as:

$$\mathrm{Y}_{it} = f(\mathrm{X}_{it}; \beta)\exp(\mathrm{V}_{it} - \mathrm{U}_{it}) \tag{5.1}$$

where $\mathrm{Y_{it}}$ represents the production by the i^{th} firm (i=1,2,…,n) in the t^{th} time (t=1,2,…,p), $\mathrm{X_{it}}$ denotes a 1×k vector of input quantity applied by the i^{th} firm in the t^{th} time, and β is a k×1 vector of parameters to be estimated. $\mathrm{V_{it}}$ is random error term which is assumed to be independently and identically distributed, attributed to factors beyond the control of firms; while $\mathrm{U_{it}}$ is used to describe the error term caused by technical inefficient performance of firms, which is non-negative and usually takes four types of distributions, i.e. half-normal, truncated normal, exponential, and gamma. Among the literatures of stochastic frontier analysis in the aspect of production, the functional forms of production usually adopted are Cobb-Douglas and translog production functions.

For the technical inefficiency model, it was specified by Battese and Coelli (1995) as follows:

$$\mathrm{U}_{it} = \mathrm{Z}_{it}\delta + \mathrm{W}_{it} \tag{5.2}$$

where $\mathrm{U_{it}}$ designates the technical inefficiency of the i^{th} firm in t^{th} time, Z_{it} represents the firm-specific variables which are considered to exert their influences on the inefficient performance of firms, δ is a vector of unknown parameters, and $\mathrm{W_{it}}$ is random error.

The technical efficiency score for each firm can be defined as:

$$TE_{it} = \exp(-U_{it}) = {}^{Y_{it}}\!/_{f(X_{it};\beta)\exp(V_{it})} \tag{5.3}$$

5.3.2 Analytical data and model specification

In this study, an unbalanced panel dataset of twelve sampled fishing vessels employing SHDN to catch the Pacific saury in Habomai from 2009 to 2014 are acquired from Habomai FCA. This sample covers over half of the Pacific saury SHDN fishing vessels in Habomai, which include both 19 GRT and 29 GRT vessels, which can be considered as representative.

The dataset includes one output, four inputs and other vessel and skipper-specific information which are necessary to conduct TE analysis (Table 5-3). The dependent variable is the monthly landings of Pacific saury by each sampled fishing vessel measured in tonne. When applying SFA to fisheries, an obvious limitation is unavoidable, i.e., the SFA approach can only deal with a single output, while many fisheries are multi-species. However, this limitation of SFA is not a problem in the Pacific saury SHDN fishery in Habomai as more than 95% of the catch is the Pacific saury, which is a very special characteristic of this fishing method. Input data include vessel gross registered tonnages (GRT), vessel length, number of days fished per month, crew size per month and yearly stock biomass. For the sampled fishing vessels, GRT ranges from 18 to 29 GRT, with a sample mean of 22.1 GRT; fishing days per month ranges from 0 to 21 days, with the mean value as 10.5; monthly crew size ranges 5 to 10 persons, with the sample mean of 7.4; skippers' fishing years are from 10 to 45 years, with a relatively large value as 31.9; and skippers' ages are from 35 to 67 years old in 2016, with its mean value as 53.3, indicating an ageing characteristic of the sampled skippers. Of all the twelve fishing vessels, only one vessel is specialized in catching the Pacific saury while the remaining vessles also target salmon and trout, or cod in other seasons.

Table 5-3 Summary statistics of the variables used in TE analysis

Variables	Description	Mean	Max	Min	SD
output (tonne)	monthly saury landings	190.9	608.2	4.3	144.7
ton (GRT)	vessel tonnage	22.1	29.0	18.0	4.7
day (day)	monthly fishing days	10.5	21.0	0	5.1
man (persons)	monthly crew size	7.4	10.0	5.0	1.3
stock (10,000 tonne)	yearly saury stock biomass	257.3	375.6	192.0	58.5
rso	dummy variable for the skipper-owner relationship	0.7	1.0	0.0	0.5
sis	dummy variable for specialization	0.1	1.0	0.0	0.3
vt	dummy variable for large tonnage vessel	0.3	1.0	0.0	0.5
sfy (year)	years of skipper engaging in fishery	31.9	45.0	10.0	9.7
sa (year)	skipper's age	53.3	67.0	35.0	8.9

In fisheries, production functions are generally described as the relationship between production and fishing effort as well as stock biomass (Cunninghum and Whitmarsh 1980, Hannesson 1983, Fousekis and Klonaris 2003). And the empirical model in this study takes the form of Cobb-Douglas instead of the translog production function following Sakai et al.

(2012). The specified production model is described as follows:

$$\ln Y_{it} = \beta_0 + \beta_1 \ln ton_{\ it} + \beta_2 \ln day_{\ it} + \beta_3 \ln man_{\ it} + \beta_4 \ln stock_t + \beta_5\ dum9 + \beta_6\ dum10 + \ \beta_7\ dum11 + V_{it} - U_{it} \quad (5.4)$$

where $\ln Y_{it}$ represents the natural logarithm of monthly landings of the Pacific saury by the i^{th} vessel (i=1,2,…,12) in the t^{th} month (t=1,2,…,24). The input variables selected for this empirical model consist of vessel gross registered tonnage, number of days fishing per month, crew size per month, and yearly stock biomass. Although the overall length are also available, it is excluded from the input list as it is proved to be highly correlative to vessel tonnage, which is considered as an important vessel physical factor for deciding the landings of Pacific saury fishery. Monthly dummy variables, representing September, October and November, are also considered to include seasonal variations in stock as we could only get access to yearly stock biomass data.

For the technical inefficiency model, it is specified in the form following Battese and Coelli (1995),

$$U_{it} = \delta_0 + \sum_{k=1}^{9} \beta_k Z_{it} + W_{it} \quad (5.5)$$

where U_{it} designates the technical inefficiency of the i^{th} vessel in the t^{th} month, Z_{it} represents the vessel- and skipper-specific variables which are considered to exert their influences on the inefficient performance of vessels, and W_{it} is the error term to explain random differences. In this study, nine variables are considered in the inefficiency model, i.e., dummy variable for the relationship between skipper and vessel owner (Z_rso) (1 if skipper is also vessel owner while 0 if skipper is employed), dummy variable for specialization in Pacific saury fishery (Z_sis) (1 if the vessel is specialized in saury fishery while 0 if it also operates other fisheries), dummy variable for large vessel tonnage (Z_vt) (1 if the vessel is 29 GRT while 0 if it is 19 GRT), years for skippers engaging in fishing (Z_sfy), skipper age (Z_sa) and fishing operation month dummy variables (from Z_dum8 to Z_dum11). The inclusion of month dummy variables in the inefficiency model is expected to evaluate whether different months affect the TE of saury vessels. The choice of variables included in the inefficiency model is based on data availability and review of related literatures (Pascoe and Coglan 2002, Kirkley et al. 1995, 1998, Sakai et al. 2012).

5.4 Results and discussion

5.4.1 Parameter estimates of stochastic production frontier model

Based on the maximum likelihood estimation approach, the estimated results of stochastic production frontier are presented in Table 5-4.

According to the estimated results in Table 5-4, all of the selected inputs are found to show a positive relationship with Pacific saury productions. Among the four independent variables, coefficients of the natural logarithm of vessel tonnage, monthly fishing days, monthly crew size, and stock abundance are 0.40, 1.03, 0.87 and 0.37 respectively, which are all significant at a 1% level. Meanwhile, three monthly dummy variables for September, October and November are all found to be significantly positive compared with August.

The variance of the one-sided component γ is 0.97, which can be used to calculate the relative contribution of the technical inefficiency effect to the total variance term. The corrected relative contribution of technical inefficiency is equal to 88% (Coelli 1995), implying that technical inefficiency plays a major part in explaining the deviation from potential output. The remaining portion 12% can be attributed to the random factors out of the control (such as weather, measurement errors).

Based on the estimated results, vessel tonnage, monthly fishing days, monthly crew size and stock abundance are essential determinants of the Pacific saury output in the sampled fishing vessels from 2009 to 2014. As the empirical model takes the form of Cobb-Douglas production function, the parameter of input designates its elasticity. In this case, when vessel tonnage, fishing days, crew size or stock abundance increases by one unit, the output of Pacific saury will be theoretically raised by 0.40%, 1.03%, 0.87% and 0.37%, respectively. These four inputs show a positive correlation with the Pacific saury output. In other words, the empirical results in this study prove that vessels with larger tonnage or taking more time fishing are supposed to catch a larger quantity of the Pacific saury, when other inputs are constrained to be constant. And when the stock abundance is higher, fishing vessels will theoretically catch more Pacific saury. Although the increase in crew size is proved to theoretically contribute to a larger saury production, this may be related with the vessel tonnage as a larger crew size often corresponds with a large vessel size. A positive significance of dummy variables for September and October indicate that catches in these months are significantly larger than those in August, which corresponds with the characteristics of the Pacific saury production in Japan. However, the positive significance of dummy variable for November differs with the data to some extent. The production data of the sampled fishing vessels show the total saury catch in November exceeded that in August in 2010, 2013 and 2014, while the opposite situation could be found in the other three years.

Table 5-4 Parameter estimates of the stochastic production frontier and technical inefficiency model for the sampled fishing vessels in Habomai region, Hokkaido

Variables	Parameter	Coefficient
Constant	β_0	-2.45***
ln(ton)	β_1	0.40***
ln(day)	β_2	1.03***
ln(man)	β_3	0.87***
ln(stock)	β_4	0.37***
dum9	β_5	0.44***
dum10	β_6	0.72***
dum11	β_7	0.83***
Sigma-squared	σ^2	0.44***
Gamma	γ	0.97***
Log-likelihood		-50.11

Note: * designates statistically significant at 10% level or less, ** means statistically significant at 5% level or less, and *** means statistically significant at 1% level or less.

5.4.2 Parameter estimates of technical inefficiency model

Results of technical inefficiency model are presented in Table 5-5. Among the selected explanatory variables for inefficiency model, all of them except for the dummy variable for October show a highly significant relationship with technical inefficiency. It is important to remember that the dependent variable of inefficiency model is technical inefficiency; hence, a negative coefficient of one explanatory variable means that it will facilitate the increase in TE, and vice versa. The coefficients of Z_rso, Z_sis, Z_vt, Z_sa and the dummy variable for September are negative; therefore, they may show a positive influence on technical efficiency. For Z_sfy and dummy variables for August and November, their coefficients are positive which means they exhibit a negative effect on technical efficiency.

According to our results of inefficiency model, the vessel ownership of skipper shows positive influence on TE in our sampled saury vessels. To be specific, if the skipper is also the owner of one vessel, this vessel seems to operate more efficiently than those vessels where the skipper is hired. The relationship between vessel ownership and TE was also evaluated in the work of Squires et al. (2003). They studied the TE score and influencing factors of TE in the Malaysian gill net artisanal fishery, where the 'non-owner-operator' dummy variable was considered in technical inefficiency model. Although their results showed that vessels ownership was not significant in 'explaining differences in technical inefficiency', they mentioned that owning and operating a vessel may influence incentives which can be explained by Marshallian inefficiency concept. This economic concept is originally applied in agriculture and states that the efficiency of owner-operated land is higher than rented-in land of the same household (Holden 2013).

The findings also reveal that specialization in Pacific saury fishery may be another factor affecting the technical inefficiency differences. In this study, the fishing vessel specialized in Pacific saury production (Vessel 4) seems to be more efficient than most of those operating several types of fisheries in the same tonnage group (Vessels 5, 6, 8, 10, 11 and 12), consistent with the findings noted by Pascoe and Coglan (2002). To be more specific, with the inputs being the same, the vessel which operates during saury season only is supposed to catch more fish than those vessels which also operate other fisheries when the Pacific saury season ends. However, it is likely to be inappropriate to simply conclude that specialization will improve the TE of the Pacific saury fishing vessels. A fishing vessel specialized in Pacific saury fishery will catch for only four months during the whole year, indicating that fishery income may be limited for this vessel. In this situation, the skipper (also owner in the sampled vessel) may exhibit a high motivation in operation as he may exclusively rely on the income of Pacific saury landings. Therefore, it is the skipper/owner's motivation underlying the specialization indicator that may affect the efficiency of Pacific saury fishing vessels. 'Incentive' has been proved to possibly affect the efficiency of a vessel, which was mentioned in the previous paragraph.

Table 5-5 Parameter estimates of the technical inefficiency model for the sampled fishing vessels in Habomai region, Hokkaido

Variables	Parameter	Coefficient
Constant	δ_0	0.79
Z_rso	δ_1	-0.34*
Z_sis	δ_2	-0.70**
Z_vt	δ_3	-0.37*
Z_sfy	δ_4	0.08***
Z_sa	δ_5	-0.07***
Z_dum8	δ_6	1.12**
Z_dum9	δ_7	-1.64**
Z_dum10	δ_8	-0.01
Z_dum11	δ_9	1.32**
Sigma-squared	σ^2	0.44***
Gamma	γ	0.97***
Log-likelihood		-50.11

In the case of vessel tonnage, it shows a positive effect on TE, indicating that larger vessels tend to be more technically efficient than small ones. This result corresponds with the study conducted by Esmaeili (2006), in which the TE of larger vessels is 0.85 and that of smaller ones is 0.6 on an average. The same result was also proved by Staffan (2006), who examined the capacity and efficiency in Swedish pelagic fisheries and concluded that larger vessels seemed to be preferred than small vessels in the perspective of efficiency. Based on our study result, fishing vessels with larger tonnage are proved to be more technically efficient that those with smaller tonnage. However, it would be misleading to simply conclude that larger vessels are definitely better than small ones. Possible reasons include: 1) our data only cover two tonnage types, i.e. 19 and 29 GRT, whether the result can be applied to other fishing vessels with different tonnages needs to be further studied when a wider range of vessels are included; 2) in practice, other aspects except TE need to be considered such as vessel construction cost, impact to regional society etc.

Although the skipper's age and his experience in fishery are both significantly related with TE in our sample, the effects are contradictory. As one vessel with an older skipper operates more technically inefficient than that with a younger skipper, the longer years in fishery operation negatively influence the TE of the sampled vessel.

5.4.3 Technical efficiency estimates

In Fig. 5-3, results show that the mean TE of the twelve sampled vessels catching Pacific saury in Habomai was 0.7 from 2009 to 2014, ranged from 0.59 (Vessel 12) to 0.79 (Vessel 9). Among the twelve fishing vessels, the average TE for the four 29 GRT fishing vessels was 0.72, while it was 0.69 for the 19 GRT category vessels. In terms of monthly TE, the maximum value was 0.97 (Vessel 4 in Oct. 2012) while the minimum value was 0.09 (Vessel 4 in Nov. 2009).

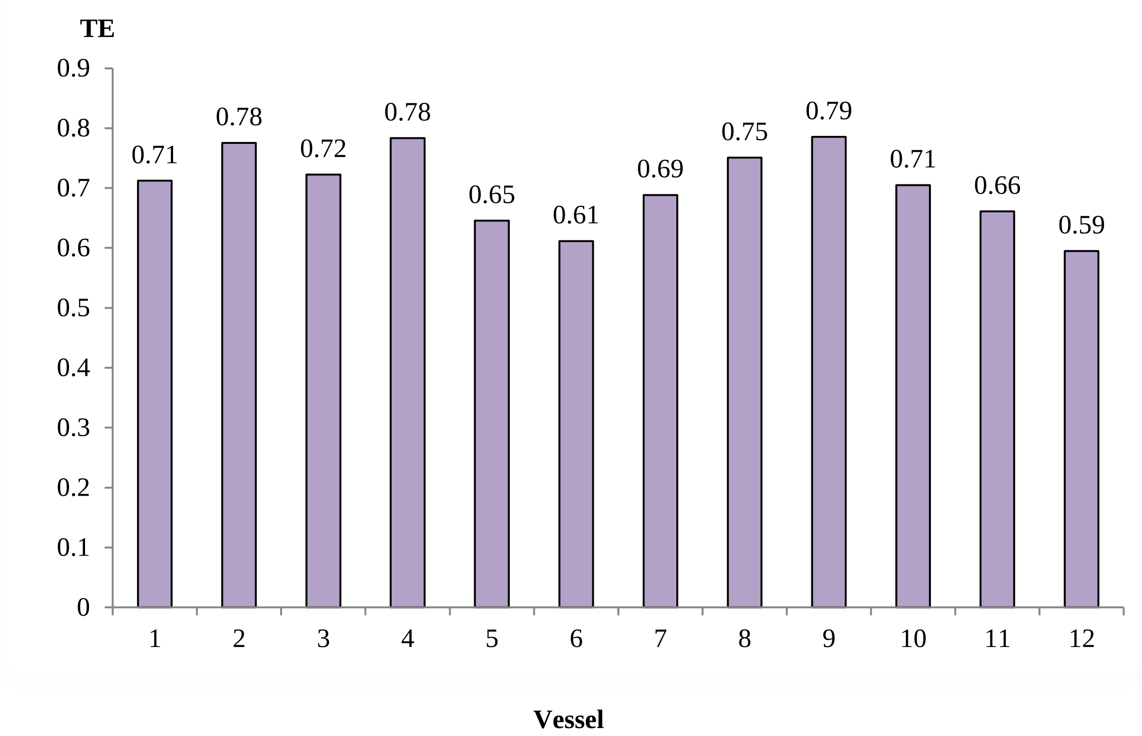

Fig. 5-3 Mean technical efficiencies of the twelve sampled fishing vessels from 2009 to 2014

The average TE for the sampled Pacific saury SHDN fishery in Habomai region is estimated to be about 0.7, which is lower than that of offshore bottom trawl fishery in Hokkaido (0.89) (Sakai et al. 2012). This result indicates that there exists an appreciable potential for the sampled fishing vessels to improve their Pacific saury catches. They could increase the Pacific saury production by 30% at the present state of technology without adding any variable or fixed inputs. The efficiency score of the sampled fishery indicates that it can increase output to a further extent through approaching fully technically efficient operation.

In Table 5-6, the frequency distribution of TE scores is listed under the different categories of effects. In terms of month effect, we can see the frequency distribution of TE in different months. Compared with August and November, the TE scores in September and October show a higher concentration in high TE scores, which corresponds with the negative coefficients of the dummy variables for these two months in inefficiency model.

5.5 Conclusions

This study works as a preliminary step to evaluate the competitiveness and efficiency in present Japanese fishery, taking the Pacific saury fishery in Habomai, Hokkaido as the case. The review of existing literatures in related with competitiveness evaluation proves that technical efficiency can be adopted as a measurement of competitiveness. The Stochastic Frontier Analysis approach, one of the most widely used methods, is applied to conduct the technical efficiency analysis of the sampled fishing vessels operating the Pacific saury stick-held dip net fishery in Habomai. A sample of 12 saury fishing vessels using stick-held dip net above 10 GRT is studied to represent the overall situation of Habomai region.

The estimated results show that vessel tonnage, fishing days, crew size and stock abundance have significantly positive effects on Pacific saury production in a monthly context, indicating that the increased quantities of these four inputs are supposed to bring about more saury landings. The mean technical efficiency of the 12 sampled vessels is about 0.7, implying that saury production can be averagely increased by 30% without adding more inputs if fishing vessels can operate fully efficiently. Vessel ownership of skipper, specialization in saury fishery, large vessel tonnage are estimated to be several factors positively affecting technical efficiency.

Table 5-6 Frequency distribution of TE classified by different effects

	Month effect				Tonnage effect		Skipper-Owner effect		Specialization effect		Skipper experience effect				Skipper age effect		
	Aug.	**Sept.**	**Oct.**	**Nov.**	**29 GRT**	**19 GRT**	**Yes**	**No**	**Yes**	**No**	**<20**	**21-30**	**31-40**	**>40**	**41-50**	**51-60**	**61-70**
0.90-0.99	6	37	16	3													
0.80-0.89	15	19	12	15													
0.70-0.79	5	11	19	4	3	4	5	2	1	6	1	1	2	3	2		5
0.60-0.69	10	2	14	10	1	3	3	1		4		1	1	1	1	1	2
0.50-0.59	8	2	7	6		1		1		1			1			1	
0.40-0.49	10		3	7													
0.30-0.39	9			5													
0.20-0.29	8			10													
0.10-0.19				3													
0.00-0.09				1													

Results of this study are expected to provide some policy implications. With regard to the Pacific saury SHDN fishery in Japan, vessel ownership, specialization and larger vessels may be positively related to a higher TE, which can be considered in further research or policies formulation aiming at improving the TE or competitiveness of this specific fishery. In particular, the importance of incentives in crew members' behaviors have been shown, which is the common characteristic of vessel ownership and specialization.

This present work is one of the first few studies on evaluating the competitiveness and efficiency of Japanese fishery on an econometrical basis. However, it is still a preliminary study with several limitations. In the future study, enlarged sample size, and a comprehensive consideration of other indicators such as allocative efficiency are desired.

Chapter 6

Technical, allocative and cost efficiency study on the Pacific saury stick-held dip net fishery in Habomai region of Hokkaido Prefecture through DEA approach

6.1 Introduction

In this chapter, further extension of efficiency analysis of the Pacific saury stick-held dip net fishery in Habomai region will be carried out, following the analysis conducted in Chapter 5. Based on the idea of Farrell (1957), efficiency is composed of two components, i.e., technical efficiency and allocative efficiency, which jointly combines economic efficiency. This chapter will study the TE, AE, and CE by means of DEA approach, which means the non-parametric methodology will be adopted. As the study target is the same with that in Chapter 5, the input and output quantity data are the same but the input price data are newly added in this chapter, to achieve the AE and CE study.

The objectives of current work are stated as follows: 1) estimating the extent of TE, AE, and CE in the Pacific saury stick-held dip net fishery in Habomai; 2) clarifying the possible factors affecting the TE, AE and CE scores of the sampled fishery; 3) providing policy implications for enhancing the competitiveness of the sampled fishery; and 4) serving as an empirical study for researches in related to the competitiveness enhancement of Japanese fishery.

6.2 Methodology and data

6.2.1 Methodology description

(1) DEA-CRS and DEA-VRS model to calculate efficiencies

The introduction of DEA approach was made in Chapter 2. As described there, DEA approach can be divided into two categories in generally, according to different selections of the envelopment surface (Lam and Shiu 2008), i.e. constant returns to scale (CRS) and variable returns to scale (VRS) surfaces. DEA-CRS model, also known as CCR model, adopts a piece wise constant returns to scale (Charnes et al. 1978); while DEA-VRS model, known as BCC model, assumes a variable returns to scale (Banker et al. 1984).

Since the DEA-CRS and DEA-VRS models have already been introduced in Chapter 2, the detailed descriptions about these models are saved and only the mathematical models are listed again for easier understanding, where equation 6.1 is DEA-CRS model while equation 6.2 is DEA-VRS model, to calculate TE of decision-making units.

$$\text{Min}_{\theta,\lambda}\ \theta$$

subject to:

$$-q_i + Q\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$\lambda \geq 0 \qquad (6.1)$$

$$\text{Min}_{\theta,\lambda}\ \theta$$

subject to:

$$-q_i + Q\lambda \geq 0$$

$$\theta x_i - X\lambda \geq 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \tag{6.2}$$

where θ denotes the scalar, ranging from 0 to 1; λ is an $I \times 1$ vector of weights defining the linear combination of the peers of the i^{th} DMU.

As one of the objectives of this chapter is to estimate the input allocative efficiency and cost efficiency of targeted fishing vessel, extended models to calculate inputAE and CE will be mentioned here again to facilitate an easier understanding of the analysis in this chapter. When the DMUs are assumed to aim at cost minimization, the cost efficiency can be estimated as follows:

$$\text{Min}_{\lambda, x_i^*} \; w_i' x_i^*$$

subject to:

$$-q_i + Q\lambda \; \geq \; 0$$

$$x_i^* - X\lambda \; \geq \; 0$$

$$N'\lambda = 1$$

$$\lambda \geq 0 \tag{6.3}$$

where w_i is the vector of input prices for the i^{th} DMU, and x_i^* is the corresponding vector of cost-minimizing input quantities, which needs to be calculated by solving the linear programming problem. Then, the cost efficiency is calculated in the following formulation:

$$CE = \frac{w_i' x_i^*}{w_i' x_i} \tag{6.4}$$

The input-mix allocative efficiency can be acquired as follows:

$$INPUT\ AE = \frac{CE}{TE} \tag{6.5}$$

(2) Tobit regression model to evaluate the factors influencing efficiencies

After the efficiency score of each decision-making unit is estimated by the models from (6.1) to (6.5), more interests will be diverted into this question: 'why some of the decision-making units show higher TE than others?'. To answer this question, Tobit regression analysis was conducted by use of the following model:

$$y_i^* = \beta_0 + \sum_{m=1}^{M} \beta_m x_{im} + \varepsilon_i, \ \varepsilon_i \sim IN\ (0, \sigma^2) \tag{6.6}$$

where y_i^* is a latent variable representing the efficiency score for the decision-making unit i; β_0 and β_m are unknown parameters to estimate; x_{im} represents the DMU-specific variables of i, which are the possible factors affecting efficiency; ε_i is the error term independently and normally distributed with zero mean and constant variance σ^2. The latent variable y_i^* is expressed in terms of the observed variable y_i, i.e., the efficiency score calculated by DEA model, as follows:

$$y_i = 1, \text{ if } y_i^* \geq 1$$

$$y_i = y_i^*, \text{ if } 0 \leq y_i^* \leq 1$$

$$y_i = 0, \text{ if } y_i^* \leq 0 \tag{6.7}$$

6.2.2 Analytical data and model specification

As the study target is the same with that in Chapter 5, the input and output quantity data described in Chapter 5 will also be applied again in this chapter. Nevertheless, new data are needed due to the inclusion of allocative efficiency and cost efficiency.

In this study, an unbalanced panel dataset of twelve sampled fishing vessels (Table 6-1) employing SHDN to catch the Pacific saury in Habomai from 2009 to 2014 are acquired from Habomai Fisheries Cooperative Association. This sample covers 60% of the Pacific saury SHDN fishing vessels in Habomai consisting of both 19GRT and 29GRT vessels, which can be considered as representative.

Table 6-1 Characteristics of the sampled fishing vessels in Habomai region

Vessel	GRT	Length (m)	SA (year)	SEF (year)	SEO	SPS
1	29	19.29	65	47	Yes	No
2	29	20.69	46	28	Yes	No
3	29	19.91	65	47	Yes	No
4	19	17.79	62	44	Yes	Yes
5	18	14.05	51	33	Yes	No
6	19	13.98	61	43	Yes	No
7	29	19.72	47	22	No	No
8	19	17.72	62	37	No	No
9	19	16.23	67	37	Yes	No
10	19	13.97	42	17	No	No
11	19	13.93	69	47	Yes	No
12	19	14.15	58	37	No	No

Notes: a) SA = skipper's age, SEF = skipper's experience in fishing, SEO = skipper is also the vessel owner, SPS = the vessel is specialized in catching saury. For SA and SEF, the data are based in 2016; b) Source: based on the data provided by Habomai Fisheries Cooperative Association

The dataset includes one output, three inputs and other vessel and skipper-specific information which are necessary to conduct TE analysis (Table 6-2); moreover, the prices of three inputs are also concluded to conduct IAE and CE analysis. The dependent variable is the yearly landings of Pacific saury by each sampled fishing vessel measured in tonne. Input data include vessel gross registered tonnages (GRT), number of days fished per year and crew size per year. The data on the input prices cannot be directly acquired; therefore, the indirect measurement of input price was conducted. For the price of vessel tonnage, it is calculated by the costs of depreciation and maintenance divided by the vessel tonnage; for the price of crew, it is calculated by the costs of crew-related expenses divided by the crew size; and for the price of fishing days, it is calculated by the costs of oil and ice divided by the fishing days.

For the sampled fishing vessels, the yearly saury catch ranged from 385.2 tonnes to 1,300.9 tonnes, with the average value as 744.7 tonnes; GRT ranges from 18 to 29 GRT, with a sample mean of 22.1 GRT; accumulated fishing days per year ranges from 29 to 56 days, with the mean value as 41; regular crew size ranges 5 to 10 persons, with the sample mean of 7.4. Other vessel-specific characteristics are the same with that in Chapter 5, hence the detailed description will not be repeated here.

Table 6-2 Summary statistics of the variables used in efficiency analysis by use of DEA

Variables	Description	Mean	Max	Min	SD
output	yearly saury landings	744.7	1,300.9	385.2	248.0
Ton (GRT)	vessel tonnage	22.1	29.0	18.0	4.7
day	accumulated yearly fishing days	41	56	29	7
man	crew size	7.4	10.0	5.0	1.3
Input price 1 (yen)	Average cost per GRT	364,753	1,442,783	131,579	300,239
Input price 2 (yen)	Average cost per fisher	2,586,079	4,486,216	1,396,667	788,591
Input price 3 (yen)	Average cost per fishing day	426,262	1,763,855	152,113	286,113
rso	dummy variable for the skipper-owner relationship	0.7	1.0	0.0	0.5
sis	dummy variable for specialization	0.1	1.0	0.0	0.3
vt	dummy variable for large tonnage vessel	0.3	1.0	0.0	0.5
sfy	years of skipper engaging in fishery	31.9	45.0	10.0	9.7
sa	skipper’s age	53.3	67.0	35.0	8.9

For the Tobit regression model, it is specified as follows:

$$y_i^* = \beta_0 + \sum_{m=1}^{5} \beta_m x_{im} + \varepsilon_i, \ \varepsilon_i \sim IN\,(0, \sigma^2)$$

$$y_i = 1, \text{if } y_i^* \geq 1$$

$$y_i = y_i^*, \text{if } 0 \leq y_i^* \leq 1$$

$$y_i = 0, \text{if } y_i^* \leq 0 \tag{6.8}$$

In this study, five variables are considered in the inefficiency model, i.e., dummy variable for the relationship between skipper and vessel owner (Z_rso) (1 if skipper is also vessel owner while 0 if skipper is employed), dummy variable for specialization in Pacific saury fishery (Z_sis) (1 if the vessel is specialized in saury fishery while 0 if it also operates other fisheries), dummy variable for large vessel tonnage (Z_vt) (1 if the vessel is 29 GRT while 0 if it is 19 GRT) and years for skippers engaging in fishing (Z_sfy), skipper age (Z_sa). To keep consistent with the results applying SFA in Chapter 5, the possible factors affecting efficiency are the same with those in SFA approach.

6.3 Results and discussion

6.3.1 Technical, allocative and cost efficiency estimates

The mean technical efficiency, allocative efficiency as well as cost efficiency of each sampled fishing vessel operating the Pacific saury stick-held dip net fishery in Habomai region was illustrated in Fig.6-1 and Fig.6-2, estimated by DEA-CRS and DEA-VRS model, respectively.

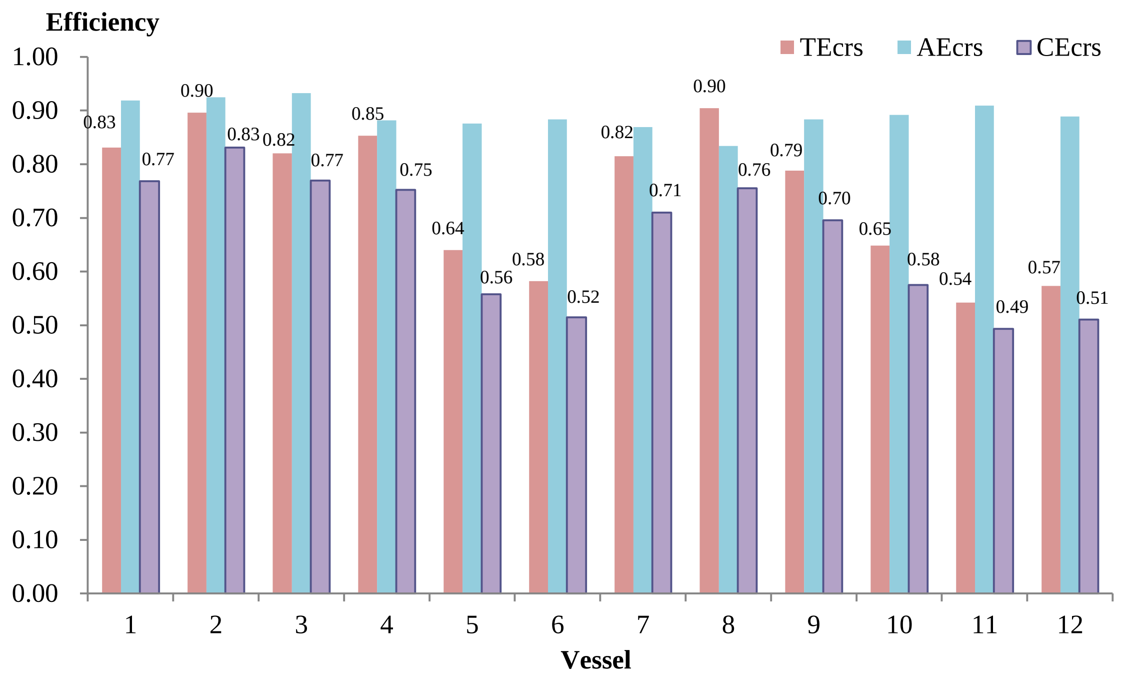

Fig.6-1 Mean TE, AE and CE of the sampled fishing vessels from 2009 to 2014 by using DEA-CRS model

By DEA-CRS model (Fig.6-1), the mean TE score of the 12 vessels from 2009 to 2014 was 0.741, ranging from 0.542 to 0.904; AE score averaged as 0.891, ranging from 0.834 to 0.932; CE score averaged as 0.661, ranging from 0.493 to 0.831. For vessel 8, although it was the most technically efficient, it was only ranked as the fourth considering the total cost efficiency. For vessel 11, it displayed the lowest TE as well as CE.

By DEA-VRS model (Fig.6-2), the mean TE score of the 12 vessels from 2009 to 2014 was 0.958, ranging from 0.898 to 1; AE score averaged as 0.92, ranging from 0.873 to 0.961; CE score averaged as 0.881, ranging from 0.813 to 0.935. For vessel 5, it was the most technically efficient with a TE score as 1, it was only ranked as the sixth place considering the total cost efficiency. For vessel 7, it displayed the lowest TE as well as CE.

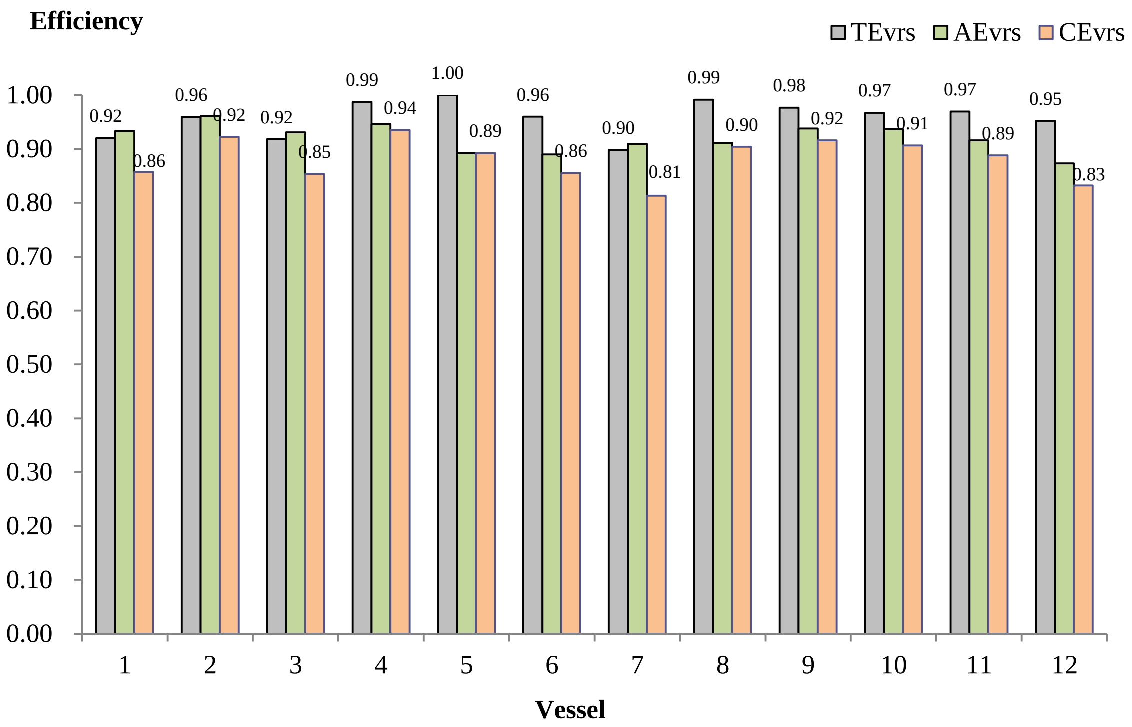

Fig.6-2 Mean TE, AE and CE of the sampled fishing vessels from 2009 to 2014 by using DEA-VRS model

Table 6-3 Efficiency scores of the sampled 12 vessels by DEA-CRS and DEA-VRS model

Vessel	TEcrs	AEcrs	CEcrs	TEvrs	AEvrs	CEvrs
1	0.831	0.919	0.768	0.920	0.933	0.857
2	0.896	0.925	0.831	0.959	0.961	0.922
3	0.820	0.932	0.770	0.918	0.931	0.854
4	0.853	0.882	0.752	0.988	0.947	0.935
5	0.640	0.876	0.557	1.000	0.892	0.892
6	0.582	0.883	0.515	0.960	0.890	0.856
7	0.815	0.869	0.710	0.898	0.910	0.813
8	0.904	0.834	0.755	0.992	0.912	0.904
9	0.788	0.883	0.696	0.977	0.938	0.916
10	0.648	0.892	0.575	0.967	0.937	0.906
11	0.542	0.910	0.493	0.970	0.916	0.888
12	0.573	0.889	0.510	0.952	0.873	0.832
Mean	0.741	0.891	0.661	0.958	0.920	0.881

Table 6-4 lists the efficiency distribution of the sampled 12 vessels operating Pacific saury fishery in Habomai region by use of DEA-CRS and DEA-VRS model. Under DEA-CRS model, half of the vessels displayed a relatively high TE (>0.8), all of the vessels showed a relatively high AE, whereas most of the vessels presented a relatively low CE (<0.8). On the other hand, under DEA-VRS model, the efficiency scores exceeded those in DEA-CRS model. Almost all of the vessels except one exhibited an extremely high TE (>0.9), 75% vessels were extremely allocatively efficient, whereas 42% vessels showed an extremely high CE.

Table 6-4 Frequency distribution of efficiency scores of the sampled 12 vessels

Efficiency	TEcrs		TEvrs		AEcrs		AEvrs		CEcrs		CEvrs	
1			1	8%								
0.90-0.99	1	8%	10	84%	4	33%	9	75%			5	42%
0.80-0.89	5	42%	1	8%	8	67%	3	25%	1	8%	7	58%
0.70-0.79	1	8%							5	42%		
0.60-0.69	2	17%							1	8%		
0.50-0.59	3	25%							4	33%		
0.40-0.49									1	8%		

6.3.2 Tobit regression analysis of technical, allocative and economic efficiency

Results of Tobit regression model are presented in Table 6-5, divided by three types of efficiencies and two methodologies. All of the vessel ownership coefficients are positive, designating the possible positive influence of ownership on TE, AE and CE, but they are significant only under DEA-VRS model. Specialization in saury fishery shows positive impact on TE and CE under DEA-CRS model, and also positively affects AE under DEA-VRS model. Vessel tonnage was proven to significantly and positively affect TE and

CE under DEA-CRS model as well as AE under DEA-VRS model, but a contradictory result on TE can be found under DEA-VRS model. Skippers' age displayed significant and positive impact on TE and CE under DEA-CRS model. While skippers' fishing years showed negatively influence on TE and CE under DEA-CRS model and on AE under DEA-VRS model.

Table 6-5 Parameter estimates of the Tobit regression model for the sampled fishing vessels in Habomai region, Hokkaido

Variables	TEcrs	TEvrs	AEcrs	AEvrs	CEcrs	CEvrs
Constant	0.40***	1.04***	0.91***	0.86***	0.35***	0.86***
Z_rso	0.02	0.03*	0.03	0.04**	0.04	0.05**
Z_sis	0.26***	0.01	-0.01	0.05**	0.21***	0.05*
Z_vt	0.21***	-0.07***	0.02	0.03**	0.21***	-0.02
Z_sa	0.01**	-0.002	-0.001	0.002	0.01**	0.002
Z_sfy	-0.01***	0.0006	0.001	-0.004**	-0.01**	-0.004
Log-likelihood	31.93	70.14	108.6	90.88	48.8	85.04

6.4 Conclusions

This chapter applies DEA model to study the technical, allocative and cost efficiencies of the 12 sampled saury fishing vessels in Habomai from 2009 to 2014. Efficiency scores among different vessels are compared and the possible factors affecting efficiencies are further examined by Tobit regression model.

Results showed that the sampled fishery still has a 26% potential to increase its production quantity under DEA-CRS model, but is highly technically efficient under DEA-VRS model. The allocative efficiency was generally at a high level with all of the vessels displayed their AE score more than 0.8. Contrary to AE, the sampled fishery still has to improve it cost efficiency, with an improving scope as 12% to 34%.

Considering the possible factors affecting efficiency scores, the results acquired by DEA-CRS model showed that specialization, vessel tonnage and skippers' age all positively influence TE as well as CE; while the fishing years of skippers showed a negative influence, which is consistent with the result estimated by SFA model.

Combined with the results of Chapter 5, it can be concluded that the technical efficiency and cost efficiency of the Pacific saury stick-held dip net fishery in Habomai still have considerable potential to improve. In terms of the possible methods to improve the efficiency condition, attentions may suggested to be paid on the size of vessels, vessel owner or skipper's behavioral motivation.

Chapter 7

Conclusions and Policy implications

7.1 Conclusions

As a country consuming a great amount of fish and fishery products, Japan is facing intense competition with foreign countries in its domestic market of aquatic products. The increasing share of imported fish and fishery products in Japanese seafood market is due to changes in national and international environment, including the decline of Japanese fishery, Japanese Yen appreciation, and low import tariff rates for fish and fishery products etc. The progress in globalization and free trade is not supposed to cease in the near future; hence, competitiveness enhancement of Japanese fishery facing fierce competition is gaining attention from national government and academic circle. Opinions diverge with respect to the concrete approaches for improving competitiveness and explicit policies have not yet been formulated. The argument will not finish in a short period until sufficient empirical studies have been carried out.

The review of existing literatures in related with competitiveness evaluation proves that efficiency can be adopted as a measurement of competitiveness. The Stochastic Frontier Analysis (SFA) approach and Data Envelopment Analysis (DEA) approach are two most widely used methods to conduct efficiency analysis. Therefore, this study also adopts these two popular approaches to evaluate the efficiency of Japanese marine fishery.

The Japanese marine fishery production in 2013 and the Pacific saury stick-held dip net fishery in Habomai region of Hokkaido from 2009 to 2014 were selected as the two case studies, in order to study the efficiency of Japanese marine fishery from both a general viewpoint and a detailed micro perspective. Among the complicated Japanese marine fishery, the Pacific saury stick-held dip net fishery is selected considering the significance of this fishery in Japan and the increasing competition from abroad in recent years.

Results of the efficiency score of Japanese marine fishery production in 2013 were shown in Chapter 3 and some of the main findings are provided here. 1) the input variables chosen, i.e., tonnage of powered vessels and fishers quantity, were proved to be positively related with Japanese marine fishery production value. When the quantity of powered vessel tonnage or fisher increases 1%, the marine production value in Japan is supposed to increase a 0.89% and 0.30%, respectively; 2) the mean technical efficiency of Japanese marine fishery was 0.78, 0.56 and 0.67 in 2013, by use of SFA, DEA-CRS and DEA-VRS, respectively, which means that there still exists a range of 22% to 44% scope to improve the marine fishery production value theoretically, without adding more inputs; 3) considering the mean technical efficiency of marine fishery production in different geographical regions, Hokkaido region was the most efficient, followed by Shikoku region and Kyushu region no matter which methodology was adopted; while Honshu region was the least technically efficient if the SFA was adopted; 4) in terms of the single prefectural government, Ehime prefecture showed the highest technical efficiency whatever estimation method was applied, while Osaka was the least efficient by use of SFA and DEA-CRS, and Yamaguchi displayed the lowest TE by means of DEA-VRS; 4) there may exist inconsistency between large production value of one prefectural government and high technical efficiency.

Results of the technical efficiency study on the Pacific saury stick-held dip net fishery in Habomari region, Hokkaido prefecture using SFA approach were described in Chapter 5. The important findings are summarized as follows: 1) vessel tonnage, monthly fishing days, monthly crew size and stock abundance are essential and positive determinants of the sampled fishing vessels; when vessel tonnage, fishing days, crew size or stock abundance increases by one unit, the output of Pacific saury will be theoretically raised by 0.40%, 1.03%, 0.87% and 0.37%, respectively; 2) the mean technical efficiency of the 12 sampled vessels is about 0.7, implying that saury production can be averagely increased by 30% without adding more inputs if fishing vessels can operate fully efficiently; 3) vessel ownership of skipper, specialization in saury fishery, large vessel tonnage are estimated to be several factors positively affecting technical efficiency.

Results of the efficiency study on the Pacific saury stick-held dip net fishery in Habomai region, Hokkaido prefecture using DEA approach were described in Chapter 6. In this chapter, technical efficiency, allocative efficiency and cost efficiency scores were estimated and possible factors affecting inefficiency were evaluated. The important findings are concluded as follows: 1) vessels showed the highest TE do not guarantee high AE and CE; 2) the sampled fishing vessels can improve their TE as well as CE to a considerable extent; 3) vessel tonnage and behavioral motivation of vessel owner or skipper showed positive influence on TE as well as CE.

7.2 Policy implications

Results of this thesis are expected to provide some policy implications. Firstly, efficiency analysis can be applied to evaluate the competitiveness of fishery. The evaluation of a country's fishery competitiveness can be achieved from macro or micro scales. As fishery is a rather complex system with heterogeneity as its main characteristic, it would be reasonable to clarify the competitiveness of each specific fishery and combine each result to achieve a composite evaluation index. Improving the competitiveness of a specific fishery or fish species can be realized by enhancing its price (cost) competition and non-price competition (brand as well as quality) (Lou et al. 2007). Efficiency analysis can clarify to what extent a fishery can increase the output without additional inputs or decrease the inputs with the output being constant, i.e. whether this fishery can improve its cost competition to a further extent. Therefore, although the choice of competitiveness indicators has not yet achieved a consensus, efficiency is proved to be a key and necessary measurement.

Secondly, with regard to the Pacific saury SHDN fishery in Japan, vessel ownership, specialization and larger vessels may be positively related to a higher TE and CE, which can be considered in further research or policies formulation aiming at improving the efficiency or competitiveness of this specific fishery. In particular, the importance of incentives in crew members' behaviors have been shown, which is the common characteristic of vessel ownership and specialization. However, it should be cautious to conclude that large vessels are superior to small vessels although the results in this thesis showed that larger vessels displayed higher efficiency compared with small ones. The existence of small vessels in practice manifests its importance. In Japan, the fishery management objectives are not limited to efficiency or competitiveness improvement, equality and social stability are also major considerations when constructing fisheries management frameworks. Small vessels play a significant role in providing job opportunities, keeping social stability etc. Therefore, finding a balance between competitiveness improvement and social stability would be desirable.

7.3 Limitations and future work

This present work is one of the first few studies on evaluating the competitiveness and efficiency of Japanese fishery on an econometrical basis. However, it is still a preliminary study with several limitations. First of all, Japanese marine capture fishery was not separated from marine aquaculture due to data restrictions. As capture fishery is greatly different from aquaculture, it is desirable and more appropriate to conduct efficiency study separately. Secondly, although Japanese marine fishery is composed of various types of fishery, only the Pacific saury fishery was selected as the study target from a micro viewpoint which may constrain a comprehensive efficiency study on Japanese marine fishery. Thirdly, when studying the efficiency of Pacific saury fishery, the sampled fishing vessels are composed of two tonnage group less than 30 GRT and did not include those large scale vessels more than 100 GRT, which are of great significance in Japanese saury fishery. Lastly, the evaluation of competitiveness of Japanese marine fishery in this thesis considers only efficiency indicators.

In the future work, enlarged sample size, more fishery types (including aquaculture), and a comprehensive consideration of other indicators such as productivity and trade measures are desired to extend the competitiveness study on Japanese fishery.

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