Climate Adaptation in Japanese Fisheries: A Policy Analysis

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Abstract

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The adverse impacts of climate change on Japanese fisheries have been pronounced since 2010. A literature review overviews climate change impacts on three fisheries sectors: coastal fisheries, aquaculture, and offshore fisheries. Next, this study examines if existing policies in Japan are sufficient to address these impacts. This assessment determines that offshore fisheries that rely on single species need further policy discussion under a scenario where an adversely impacted stock will not recover despite management efforts due to climate change. Finally, this study conducts a policy analysis using data sets for the North Pacific saury fishery. Four policy options are proposed for analysis, i.e., management change, partial permit termination, income support, and diversification. Eight criteria assessed in the analysis are profit gain, impacts on the local community, cost to government, distributive equity, procedural equity, political feasibility, uncertainty, and duration. The result highlights key trade-offs among options, suggesting that diversification and permit termination are most likely to be favorable options.

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Chapter 1. Introduction

1.1 Overview of Japanese fisheries

Japan is surrounded by the sea and blessed with in various fisheries resources. Its total territorial waters and exclusive economic zones (EEZs) are approximately 11 times the size of its land area (Japan Coast Guard, n.d.). There are several ocean currents around Japan, including the cold current Oyashio and the warm current Kuroshio, which contribute to providing some of the most productive fishing grounds in the world (Makino, 2011). The marine biodiversity is also high, with various climatic zones ranging from subarctic in the north to subtropical in the south, and a wide variety of fish species inhabiting the area (Makino, 2011). Supported by these geographical and natural factors, Japan has long been one of the world's leading fishery countries, producing a variety of marine products as important food sources and developing a rich fish-eating culture.

According to the Food and Agriculture Organization of the United Nations (FAO), Japan's marine capture fisheries production in 2020 was 3.13 million tons, ranking it 8th in the world, while its aquaculture production was 249 thousand tons of fish, ranking it 9th in the world; 310 thousand tons of shellfish, ranking it 4th in the world; and 397 thousand tons of seaweed, ranking it 6th in the world (FAO, 2022). Detailed statistics published by the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF) show that its marine capture fisheries production in 2022 was 2,893,700 tons, coastal aquaculture production was 910,900 tons, and inland aquaculture production was 54,000 tons, with sea-based production accounting for over 98% of the total (MAFF, 2023). The trend in production shows a steady decline. In 2022 production was only 28% of its peak of 11,510,000 tons in 1984 (MAFF, 2023), due to strengthened international restrictions on Japan’s distant water fisheries, worsening stock status in many domestic species, a decrease in fishermen, and recent ocean environment changes (Government of Japan, 2002; Government of Japan, 2022). Ten years after the peak, the production had already dropped to about half, mainly because of stock fluctuation of Japanese sardine (*Sardinops melanostictus*). Excluding the impact of the sardine, total production dropped to half of the peak by 2011. For the next ten years, the decline accelerated and further dropped to less than 30% of the peak. As for aquaculture production, it continued to increase until 1988, reaching 1.3 million ton, but has been on a downward trend since the 2000s, stabilizing at around one million tons in recent years.

In terms of economic values, the value of marine capture fisheries landings in 2022 was 916.1 billion Japanese yen (JPY), and that of coastal aquaculture was 521.1 billion JPY (MAFF, 2024). The combined GDP of the fisheries and aquaculture industries for the same year was 627 billion JPY, accounting for 0.1% of Japan's total GDP of 559,710 billion JPY (Cabinet Office of the Government of Japan, 2023). Although the share of fisheries as a primary industry is small for Japan (which is common in developed countries), it is noteworthy that the fishing and aquaculture industry’s ripple effects on related industries in the region such as fish processing, material-related manufacturing, and distribution sectors is more significant. For example, Kaneko et al. (2013) quantitatively analyzed the impact of the collapse mentioned above of Japanese sardine stock in the early 1990s on the local economy of a fishing city (Kushiro, Hokkaido Prefecture) and estimated that over the three years 1990-1993, the fishery sector lost 100 million JPY while the entire region lost 11.3 billion JPY.

Marine capture fisheries in Japan are commonly classified into coastal, offshore, and distant-water fisheries (Fisheries Agency of Japan, n.d.a). Coastal fisheries are relatively small-scale (usually involving fishing vessels up to 10 gross tons (GT)) and generally family-run businesses. The target species and fishing methods used vary depending on the season and region, and it is common for fishermen to engage in multiple types of fishing. Offshore fisheries are industrial fisheries operated within EEZs by medium to large-scale fishing vessels. Some fisheries (e.g., offshore bottom trawl fishery) target a wide variety of fish species, while others (e.g., large- and medium-scale purse seine fishery) target specific pelagic fish caught in large volumes, such as chub mackerel (*Scomber japonicus*) and sardine. Some fisheries land their catch within their region, while others operate over a wide area in pursuit of migrating fish and land their catch at multiple fishing ports. The distant-water fisheries occur on the high seas or in waters of other nations. They operate aboard for long periods, with the distant-water tuna fishery being a representative example.

As for coastal aquaculture, labor-intensive family-owned businesses have been a typical form, farming finfish such as yellowtail and sea bream, shellfish such as oysters and scallops, and algae such as laver and wakame seaweed. Large finfish farming operated by vertically integrated enterprises with capital strength has recently emerged (Fisheries Agency of Japan, 2020).

Looking at the share of employment in each of the categories above, of the 156 thousand people engaged in all fisheries and aquaculture production as of 2018, 79 thousand were in coastal fisheries, and 43 thousand were in coastal aquaculture, together accounting for about 80% of the total, while 28 thousand fishers worked for offshore fisheries, and five thousand engaged in distant-water fisheries (MAFF, 2021). The same proportional breakdown applies to the number of management entities and fishing vessels. In contrast, the share of production volume from coastal fisheries (24%), aquaculture (24%), offshore fisheries (46%), and distant-water fisheries (6%), respectively, was dominated by offshore fisheries accounting for almost half of the total production

(MAFF, 2023). In this way, many fishers engage in small-scale fishing and aquaculture in the coastal areas, supplying a wide variety of fish species to the market, whereas most industrial-scale fishery enterprises with high fishing capacity operate mainly in the offshore areas, contributing to a stable supply of major species to domestic consumption with some exports.

Generally, harvested fish are collected at the local fish market adjacent to the port of landing, sorted by species, size, quality, etc., and sold to local shippers and processors through auction. Products from coastal areas are kept fresh deploying well-developed cold chains and shipped to wholesale markets in urban areas and subsequently to retailers and consumers. The seafood processing industry in Japan has approximately 3 trillion JPY in sales and 140,000 employees (Ministry of Economy, Trade and Industry, 2021).

1.2 Overview of fisheries management in Japan

Fisheries in Japan are managed under the Fisheries Law (Makino, 2011; Fisheries Agency of Japan, n.d.a). Coastal fisheries and aquaculture are co-managed by local governments (prefectures) and fisher organizations and cooperatives, while the central government directly manages offshore and distant-water fisheries. In coastal areas, the fishery rights system, a type of territorial use rights of fisheries (TURFs), functions as a means of marine spatial management. In accordance with the Fisheries Law, prefectural governors license fishery rights to local fishers or fisheries cooperative associations (FCAs). Under the Law, there are three categories of fishery rights: common fishery rights (only for FCAs), large-scale set-net fishery rights, and demarcated rights (for aquaculture). An example of common fisheries is harvesting for sedentary species such as seaweed and shellfish. After public consultations, each fishery right defines where and how right-holders can operate specific fisheries. Fishery rights can be granted to both individuals or FCAs, but in most cases, rights are granted to FCAs, which are then responsible for coordinating further spatial management among FCA members. In this regard, FCAs play a critical role in keeping the order of local fishing communities as well as supporting members by running fish markets and providing supplies to them. Approximately 900 fishing cooperatives nationwide cover almost all coastal areas, and most fishers belong to a local cooperative association (Fisheries Agency of Japan, 2024a).

In offshore waters beyond the area where fishery rights are exercised, small to medium-sized vessels operate fishing methods with relatively high catchability, which require licenses from the prefectural governor. These fisheries are called governor-licensed fisheries, exemplified by small-scale bottom trawl fishery and boat seine fishery. These fisheries are managed through regulations such as entry limit, gear restriction, area closure, and seasonal closure. In implementing management, fishers representatives and experts as well as government officials participate in discussions on resource management through Area Fisheries Coordinating Committees established in each prefecture, as a form of co-management.

Offshore fisheries are managed directly by the national government, because operations often straddle jurisdictions of multiple prefectures. The distant-water fisheries are also managed directly by the national government, as it is necessary for the national government to take responsibility for ensuring compliance with international agreements. Specifically, 17 types of fisheries such as large- and medium-sized purse seine fishery, offshore bottom trawl fishery and North Pacific saury fishery, require licenses from the minister of MAFF. The Fisheries Agency of Japan (FAJ), a part of MAFF, is the national administrative body for overseeing fisheries matters.

The central government imposes regulations on licensed vessels, such as gear restriction, time closure, and area closure. In some cases, associations consisting of licensed fishers adopt voluntary operation rules by agreement. Although offshore fisheries management historically focused on input controls and technical controls, the ratification and entry into force of the United Nations Convention on the Law of the Sea in 1996 drove the Japanese government to introduce output control. Total Allowable Catch (TAC) management was introduced for seven major fish species in 1997 (and one additional species later in 2018). Now, TAC-managed stocks account for approximately 60% of the total catch in Japan. TACs are determined annually and allocated to each fishery after the Allowable Biological Catch (ABC) is calculated by the national research institution, the Japan Fisheries Research and Education Agency (FRA), based on the latest stock assessment.

Although Japan adopted various methods to manage its fisheries, the landing volume continues to decline, as mentioned earlier. While various factors contribute to the declining trend, there have been cases where the decline could have been prevented or mitigated if appropriate resource management had been implemented to keep the stock status healthy. To reverse the trend, the government is working on “fisheries policy reform” (Government of Japan, 2022). The Fisheries Law was drastically amended in 2018, and the new law explicitly stipulates that output control based on Maximum Sustainable Yield (MSY) is the primary measure for fishery resource management. The central government set a goal of increasing the number of TAC-managed stocks and raising the coverage of TAC species in the total catch from 60% to 80%. However, as of April 2024, TAC measures have yet to be officially applied to any additional species, partly because fishers are concerned about what they consider to be the rapid introduction of TAC management.

1.3 Overview of current ocean environment change around Japan

Over the past three decades, the Japanese fishing industry has faced various challenges, including overfishing, an aging and decreasing workforce, deteriorating fishing vessels due to a lack of finance for renewal, and diminishing demand for seafood (Government of Japan, 2017). Some people go so far as to say that the fishery is a sunset industry (Abe et al., 2019). In response to these challenges, the Japanese government is now implementing “fisheries policy reform” to revitalize the fishing industry with appropriate fisheries management, aiming to improve fishers’ lives and attract the younger generation (Government of Japan, 2022).

Beside for these structural challenges, the changing ocean environment and its adverse impacts on fisheries resources have been a big concern since 2010s. Some environmental change impacts are already evident around Japan, as exemplified by the recent “poor catch” problem for important commercial species despite continuous fisheries management (Fisheries Agency of Japan, 2021). For example, the landings of Pacific saury (*Cololabis saira*) dropped from 229,000 tons in 2014 to 30,000 tons in 2020. For Japanese flying squid (*Todarodes pacificus*), the landings decreased from 173,000 tons to 48,000 tons in the same period. For chum salmon (*Oncorhynchus keta*), there was a decline from 147,000 tons to 56,000 tons. This poor catch problem continues, with negative influences on fishers and entire regions dependent on the fishing industry. In 2021, coastal communities along the Pacific coast in Hokkaido experienced an unprecedented massive red tide caused by a harmful algae bloom, with devastating damage to the fishing industry there (Hokkaido Government, 2022a). It turned out later that an intense marine heatwave triggered this event. Another example of unusual ocean conditions is seen in the extended “Kuroshio Meander.”

The Kuroshio current occasionally flows differently from its original straight path. The latest Kuroshio Meander has continued for four years and eight months as of March 2022, breaking the past record of the longest duration since 1965 (JAMSTEC, 2022). The mechanism of this prolonged meandering is under investigation. At the end of July 2023, scientists observed water temperatures in the deep ocean off the Pacific coast of Northeast Japan to be about ten degrees higher than average, which might be attributed to the prevailing Kuroshio extension, with concerns about the adverse impacts on marine ecosystems (Japan Meteorological Agency, 2023).

Further details of these issues related to recent changes in the ocean environment are highlighted in Chapter 2.

1.4 Study objective

The negative impacts of climate change on the Japanese fishery may differ from the challenges the fishing industry has faced over the past three decades. First, unprecedented events have been occurring suddenly since 2010. The fishing industry is, by nature, heavily influenced by the ocean environment. The ocean environment is inherently variable, and in response, fishery resources are also variable. For example, the "regime shift" theory is widely known in which the abundance of pelagic fish fluctuates significantly in response to decadal patterns in atmospheric and oceanic conditions (Kawasaki, 2010). Meanwhile, as mentioned in the previous section, unprecedented declines in catch have suddenly become apparent in multiple fish species since the 2010s. These changes are not unique to Japan but are happening in the context of global climate change, exemplified by the stock collapse of Gulf of Alaska Pacific cod and Bering Sea snow crab in the late 2010s driven by intense marine heatwaves (Free et al., 2023). The Intergovernmental

Panel on Climate Change (IPCC) stated in its Sixth Assessment Report that "it is unequivocal that human influence has warmed the atmosphere, ocean and land" and "human-induced climate change, including more frequent and intense extreme events, has caused widespread adverse impacts and related losses and damages to nature and people, beyond natural climate variability." (IPCC, 2022).

Second, the impacts of climate change on the fishery are not only severe but also potentially irreversible. Unlike overfishing cases where depleted stocks can recover under appropriate management, the current changes in the ocean environment may be pushing some fish stocks beyond the limits of recovery. If these changes, driven by the accumulation of multiple drivers caused by human factors, are occurring beyond a certain threshold, the original state may not be restored. IPCC (2022) warns that the adverse effects of global warming will continue to worsen and that some of these effects may exceed the capacity of natural systems to adapt. This suggests that the existing fisheries policy may no longer be effective in coping with the new phase, necessitating a reevaluation of the current approach.

Socioeconomic impacts on people involved in the fisheries industry have already been prominent. These adverse effects will not affect the Japanese people equally. Coastal areas heavily dependent on fisheries for their economy and culture are vulnerable to the impacts of climate change. Local communities and people relying on the fishing industry are at risk of losing their livelihood, dignity, and culture passed down from generation to generation, even though they are not solely responsible for the adverse impacts of climate change, which is attributable to greenhouse gases resulting from human activities, especially in urban areas. In this regard, this problem is different from conventional overfishing problems for which fishers themselves are responsible.

The urgency of the situation calls for immediate action. While the fundamental solution to climate change is mitigation, it is crucial to understand that even if the reduction of greenhouse gas emissions meets the target, the temperature rise will continue for some time due to overshoot (IPCC, 2022). Adaptation measures to cope with the inevitable impacts are indispensable for the fishing industry to survive, as the ocean temperatures and environment are expected not to return to the past levels any time soon. This study aims to answer the following questions: "Are the current adaptation measures sufficient, and if not, what additional policies are needed?" In so doing, it also aims to contribute to developing and improving adaptation measures by government officials, the fishing industry, and other relevant stakeholders.

This study comprises six chapters: Chapter 2 provides an overview of the impacts of climate change on the Japanese fishery. Chapter 3 provides an overview of policies currently proposed to address these impacts. Chapter 4 examines the existing policies in terms of the question above, “Are the current adaptation measures sufficient, and if not, what additional policies are needed?” This study suggests that further examination and decision-making of rationalization strategies is needed for a scenario where an adversely impacted stock will not recover despite management efforts because of unfavorable ocean conditions. Chapter 5 conducts a policy analysis using data from the Japanese saury fishery as a case study for exploring rationalization strategies. Finally, Chapter 6 outlines necessary adaptation measures and their implementation.

Chapter 2. Impacts of ocean environment change on Japanese fisheries

2.1 Observed trends and future projection of the ocean environment

According to the Japan Meteorological Agency (JMA), sea surface temperatures (SSTs) averaged over the 13 sea areas around Japan are observed to have risen by 1.14°C during the more than century between 1900 and 2019 (Japan Meteorological Agency, 2020). This rate of increase is higher than the global average of 0.55°C per century. Projected changes in SST around Japan for the end of the 21st century (i.e., 2081-2100 average) relative to the end of the 20th century (i.e., 1986-2005 average) are estimated to be 1.1 ± 0.6°C higher according to IPCC's low emission scenario of RCP 2.6 and 3.6 ± 1.3°C higher for the high emission scenario of RCP8.5 (90% confidence interval). These estimates are higher than the global average increase rates (RCP2.6: 0.73 ± 0.13°C and RCP8.5: 2.58 ± 0.24°C with 90% confidence interval) (IPCC, 2022).

In addition to the incremental SST increases, marine heatwaves (MHWs) contribute to temporary but extreme SST increases. IPCC (2022) points out that MHWs have become more frequent, more intense, and longer since the 1980s and have likely been attributed to anthropogenic climate change since at least 2006. One of the most severe MHWs is “the Blob” observed in the Northeast Pacific from 2013 to 2016, lasting more than 700 days, spanning more than 2.5 million square kilometers, and increasing SST by more than 2.0°C than the climatological mean (Free et al., 2023). In Japan, a recent study by the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) found that ocean heat waves occurred annually off the Pacific coast of the Hokkaido and Tohoku region during the summers of 2010-2016 (Miyama et al., 2021). In July 2021, averaged SSTs in July in the Sea of Japan and the offshore area of southeast Hokkaido reached the highest on record (Kuroda and Seto, 2021). Regarding future projections, the IPCC (2022) indicates that the frequency of ocean heat waves in the future (2081-2100) compared to the present (1995-2014) is projected to be 2-9 times higher in the RCP2.6 scenario and 3-15 times higher in the RCP8.5 scenario.

Ocean warming will also affect other climatic drivers. IPCC (2022) indicates that ocean stratification has occurred since the 1970s and is projected to continue throughout the 21st century, driven by intensified surface warming and near-surface freshening at high latitudes. In the Sea of Japan, strong winter cooling off Vladivostok drives cold surface water to sink because of its high density. After sinking, the cold and oxygen-rich seawater circulates across the interior of the Sea of Japan. However, ocean warming and stratification are thought to have weakened this downwelling and circulation, which may cause deoxygenation. A long-term observation at 2,000m depth in the Sea of Japan revealed that the increase rate in water temperature is 0.02°C per decade, and the decrease rate in dissolved oxygen is 7- 9 μmol/kg per decade (Japan Meteorological Agency, n.d.a).

Atmospheric and oceanic circulations is closely tied to heat balance, and global warming could affect ocean circulations. For example, the IPCC (2022) detects no clear change trend in the Atlantic Meridional Overturning Circulation (AMOC) but provides some possibility of AMOC weakening. More pessimistic model predictions suggest that the circulation may collapse by the end of this century (Ditlevsen and Ditlevsen, 2023). Around Japan, the major ocean currents are the Kuroshio, a warm current that flows northward along the Pacific coast of the Japanese archipelago, and the Oyashio, a cold current that flows southward in the North Pacific. Kuroshio is known for its occasional diverted flow called the “Kuroshio meander.” As of April 2024, it has been six years and nine months since the latest Kuroshio meander began, which is the most extended duration since the observation started in 1965 (JAMSTEC, 2022). However, the JMA concluded in its report that no significant trend in the Kuroshio flow has been found since 1970 (Japan Meteorological Agency, 2020). The trend of Kuroshio primarily affects the ocean environment around its path. For example, the MHWs mentioned above from 2010 to 2016 are likely to be caused by the Kuroshio-derived warm-water eddy that blocked the cold Oyashio current from flowing southward (Miyama et al., 2021). In addition, at the end of July 2023, the interior of water temperatures off the Tohoku region were observed to be 10°C above average, which is likely to be caused by the northward shift of the Kuroshio Extension (Japan Meteorological Agency, 2023).

With respect to the Oyashio, it shows seasonal variations, extending southward in spring and slowly retreating northward from summer to autumn (Japan Meteorological Agency, n.d.b). According to the FAJ, however, the southward extension has weakened, and the limit of the southern flow has shifted northward (Fisheries Agency of Japan, 2023). The future trends in the paths of the Kuroshio and Oyashio Current are uncertain, but a study predicts that the mean flow path of both the Kuroshio and Oyashio currents will shift northward by the end of this century (Nishikawa et al., 2020).

Ocean acidification caused by anthropogenic carbon dioxide emitted into the atmosphere is observed in the oceans worldwide. Global surface seawater's hydrogen ion exponent (pH) has been decreasing at an average rate of approximately 0.02 per decade, with the same trend seen along the Japanese coast (Japan Meteorological Agency, 2020). Comparing the conditions at the end of the 20th century (1986-2005 average) to the 21st century (2081-2100 average), the global surface seawater pH is projected to decrease by 0.31 under the RCP8.5 scenario on average and by 0.065 under the RCP2.6 scenario, with the almost same rate of change expected around Japan.

Melting ice sheets and glaciers driven by global warming increased the global mean sea level (GMSL) by 0.16 m between 1902 and 2010. Along the Japanese coast, a clear trend of mean sea level rise has been observed since 1980, with an annual rise of 2.8 mm from 1993 to 2015 and 4.19 mm per year from 2004 to 2019, some of which can be attributed to natural variability (Japan Meteorological Agency, 2020). The sea level rise in Japan is projected to be 0.39 m for the RCP2.6 scenario and 0.71 m for the RCP8.5 scenario, which are the same level as projections for GMSL (IPCC, 2022).

Finally, changes in precipitation patterns and typhoons deserve attention as they directly affect the fishing industry. JMA's report says there is no statistically significant long-term trend in Japan's annual or seasonal precipitation patterns (Japan Meteorological Agency, 2020). Still, it states that the frequency of daily and hourly extreme precipitation has increased. With respect to typhoons, there is no long-term trend in the number of approaching or hitting Japan between 1951 and 2019. In the future, the annual number of extreme precipitation events is expected to continue to increase, and typhoons are expected to intensify around Japan due to increased SSTs and water vapor in the atmosphere.

2.2 Biological responses to ocean environment change

As ocean temperature increases, the geographic distribution of marine species generally shifts poleward, following the pace and direction of ocean warming. According to the IPCC, since the 1950s, the distribution range of marine organisms has shifted poleward at a rate of about 59.2

± 15.5 km per decade as water temperatures have increased (IPCC, 2022). The extent to which changes in the geographic distribution have happened depends on species and regions. Climate change also affects phenology. In general, marine organisms adapt to warmer ocean temperatures by changing their distribution areas and altering the timing of seasonal events. IPCC (2022) indicates that seasonal events for plankton, such as spring bloom, have occurred 4.3 ± 1.8 to 7.5 ± 1.5 days earlier per decade and 3 ± 2.1 days earlier per decade for fish since the 1950s (90% confidence interval). It has also been suggested that trophic mismatches may be more frequent due to differences in the response of seasonal events to climate change among marine taxa. Thus, although marine species have the potential to adapt to climate change on their own, if adaptation does not keep pace with change, they will fail to sustain their populations.

More frequent extreme events like MHWs driven by climate change have caused massive mortality, sweeping changes in ecosystems, and habitat losses (Smale et al., 2019). As mentioned earlier, Gulf of Alaska Pacific cod and Bering Sea snow crab collapsed mainly because of a change in their metabolic rate due to abnormally warmer temperatures (Barbeaux et al., 2020; Szuwalski et al., 2023). The Blob also induced a massive loss of kelp forests in northern California, where warmer temperatures reduced the productivity of kelp and increased predation pressure by sea urchins, whose major predator, sunflower stars, died off due to an MHW-related disease outbreak (Free et al., 2023). Coral reefs, another important ecosystem, have suffered from mass coral bleaching events and disease outbreaks globally due to more frequent and severe heat stress associated with ocean warming (IPCC, 2022).

Ocean acidification caused by climate change can adversely affect the larval stage of marine species, especially shellfish and crustaceans building shells. Deoxygenation can decrease the size and abundance of marine organisms. While laboratory studies show these adverse impacts of ocean acidification and deoxygenation, observed evidence of the impacts is limited (IPCC, 2022). Detecting and attributing influences by ocean acidification and deoxygenation outside of laboratories is challenging because the symptoms can emerge in combination with other environmental conditions.

An ensemble model projects that the overall impacts of climate change will decrease marine animal biomass by −3.5 ± 4.8% and −14.0 ± 14.6% under RCP2.6 and RCP8.5 scenarios, respectively, by 2080-2099 relative to 1995-2014 (IPCC, 2022). These declines are thought to be due to warming and decreased primary production, but they are uncertain because of considerable regional variation and the complexity of food-web mechanisms.

2.3 Impacts of ocean environment change on Japanese fisheries

Ocean environment changes and biological responses to them directly affect fisheries in multiple ways (Figure 2.1). The magnitude of impacts depends on the region and type of fisheries, even within Japan. The following subsections investigate observed impacts on coastal fisheries, coastal aquaculture, and offshore fisheries, respectively.

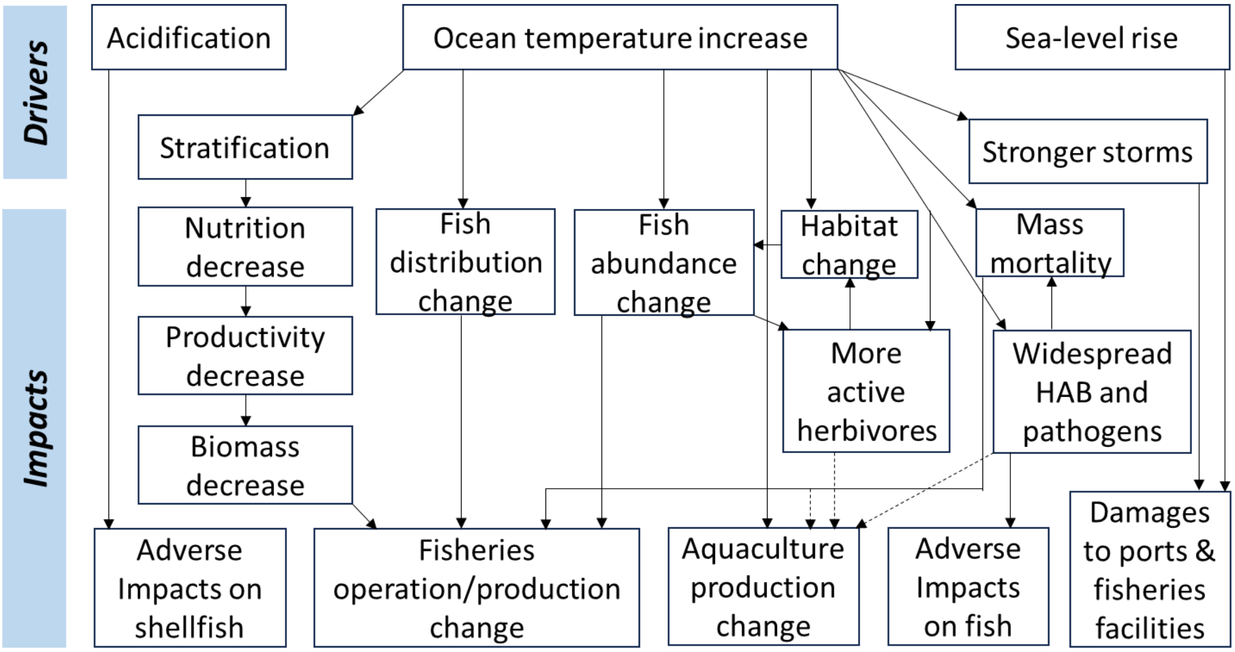


Figure 2.1. Mechanism of impacts of ocean environment changes on fisheries.

Source of the figure is the Assessment Report on Climate Change Impacts in Japan (written in Japanese) (Ministry of Environment, 2020). The dotted arrows are added by the author.

2.3.1 Impacts of climate change on coastal fisheries

Operation areas of coastal fisheries are usually confined to local waters. If the range of the main target species shifts northward due to ocean warming, it is difficult for fishers to change their fishing grounds in pursuit of targeted fish. They are also unlikely to relocate their fishing area base even if the fish habitat in their accustomed fishing ground collapses due to environmental changes. Therefore, coastal fisheries are relatively more exposed to the impacts of climate change because fishers can only pursue fish inhabiting local waters. However, there can be positive outcomes, like emergent species becoming available as a new income source. Whether positive impacts offset negative impacts varies by region.

An example of species composition changes is found in the Tohoku region, where the fishing area off the coast is the northern edge of Kuroshio, overlapped by the southern edge of Oyashio. Because of that geographical feature, both warm-water and cold-water fishes are landed, and the species composition of catch has dramatically changed due to ocean warming since 2010 (Takahashi, 2022). For example, the landings of two warm-water species, cutlassfish (*Trichiurus lepturus*) and Japanese blue crab *(Portunus trituberculatus*), used to be negligible at Ishinomaki port, one of the major fishing ports in the region, but recorded 500 tons and 300 tons in the 2020s, respectively. Recently, spawning and juvenile individuals have emerged, implying that their spawning area has extended to the region as water temperature increases. However, the period also saw substantial drops in the landings of cold-water species such as chum salmon, sand eel (*Ammodytes personatus*), and Pacific krill (*Euphausia pacifica*), which used to be important targeted species for the region.

While coastal fisheries typically target multiple species, some are highly dependent on specific fish, in which case a decline in the relevant species can significantly impact the fishers' livelihood. For example, the set-net fishery in Hokkaido recorded over 100,000 tons of chum salmon landings before 2015, accounting for nearly 80% of the total catch, but after 2017, the catch declined by half (Fisheries Agency of Japan, 2021). Some other fish, such as yellowtail (*Seriola quinqueradiata*) and chub mackerel, increased in catch but did not make up for the loss of chum salmon. The landing values from the fishery dropped from 60 billion JPY in 2015 to about 35 billion JPY in 2019. In Japan, the chum salmon stock heavily relies on hatchery programs, and the operating costs are largely covered by part of the revenue of set-net fishers. Hence, the revenue decline threatens the sustainability of the hatchery programs. The poor catch of salmon also affects the local processing industry and salmon-eating culture. Scientists suggest that the diminishing salmon return can be attributed to unsuitable temperature and feed availability for juvenile salmons driven by the weakening of the Oyashio and the changes in the Kuroshio Extension hampering juvenile migration to their destination of the Sea of Okhotsk (Fisheries Agency of Japan, 2021).

An example of mass mortality events associated with climate change is the massive red tide in Hokkaido in 2021 caused by a harmful algae bloom, killing more than 8,000 tons of benthic species, such as sea urchins, whelks, and octopuses. These species are highly valuable, and the economic loss is estimated at 9 billion JPY (Hokkaido Government, 2022a). This case surprised fishers and scientists because such a massive red tide events have never occurred in Hokkaido before, and the plankton causing this event, *Karenia selliformis*, was rarely seen around Japan. It turned out later that this unprecedented incident was triggered by MHWs that happened off Hokkaido and altered plankton compositions, driving the causal species to become dominant (Kuroda et al., 2021; Yamaguchi et al., 2022). Local people are concerned about this kind of event happening again.

Habitat loss caused by ocean warming, especially the loss of seaweed beds, is one of the most critical problems for coastal fisheries. Not only is there a decline in revenue from harvesting seaweeds, but the loss of seaweed beds also decreases the habitat for valuable species such as sea urchins and abalones feeding on seaweeds, and many other fish using the habitat as nurseries for their young (Fisheries Agency of Japan, 2023). A nationwide survey conducted in the early 2000s revealed that an average of 22 percent of seaweed beds were lost since the previous survey in

1989-1991. The loss mechanism is explained by ocean warming, which causes the death of seaweeds and activates overgrazing by herbivore species (Watanabe, 2022).

Ocean environment change can hinder fisheries management efforts. Sand eel fishery in Ise and Mikawa Bay, central Japan, is known for its exemplary management initiated by fishermen's organizations. The management based on protecting spawning fish had been successful since it was introduced after the stock collapse around 1980 (Makino, 2011). However, stock assessment during the pre-fishing season of 2016 revealed a decline in stock abundance, and the fishery was closed. Since then, the fishery has not resumed because of lack of stock recovery. It is challenging for scientists to elucidate the collapse mechanism partly because ocean environment changes and anthropologic activities may have cumulative impacts. One plausible hypothesis is that unusually warm water conditions during 2015 summer caused a massive die-off of spawning stock, combined with malnutrition due to a decrease in primary production, which may be attributed to a lack of nutrition resulting from too stringent pollution control policy (Mie Prefectural Government, 2021). This example indicates the difficulty of attributing to sudden stock collapse under continuous management efforts, given that coastal fisheries are usually affected by cumulative impacts.

2.3.2 Impacts on coastal aquaculture

Since coastal aquaculture is operated in designated areas in bays and other tranquil coastal areas, it is as or more difficult to escape from environmental changes than other coastal fisheries. In this regard, aquaculture is highly exposed to environmental changes except for land-based production systems.

Coastal aquaculture in Japan is classified into two categories: those requiring feeding (i.e., fin fish farming) and those not requiring feeding (i.e., shellfish and seaweed farming). Most of the feed used in Japanese fish farming is imported from overseas. For example, yellowtail farming, which accounts for about half of all fish farming production, relies heavily on imported fishmeal (approximately 70%), especially anchovy meal from Peru (Fisheries Agency of Japan, n.d.). Regarding the impact of climate change on Peruvian anchovy, a decrease in abundance of 8.1-13.9% per decade is projected due to changes in spatial distribution caused by rising water temperatures and a decline in productivity resulting from weakened upwelling (Bahri et al., 2021). With international demand for fishmeal, also used in livestock farming, further price increases due to reduced supply are expected to increase financial pressure on fin fish farmers, for whom feed costs account for 70% of their aquaculture costs (Fisheries Agency of Japan, n.d.b). In this regard, climate change's impact on Peruvian anchovy indirectly affects fin fish farmers in Japan.

Shellfish and seaweed farming do not require feeding, but their growth heavily depends on the ocean environment on site. For example, nori (*Pyropia yezoensis*), which accounts for about 70% of Japanese seaweed aquaculture production, starts growing in the fall after SSTs become sufficiently low and is harvested several times until spring, when SSTs go up and nutrients for nori run out. However, ocean warming has gradually shortened the period suitable for nori growth, resulting in a decrease in harvest in many areas (Fisheries Agency of Japan, n.d.c). Higher SSTs also contribute to growth problems and increase grazing damage by wild herbivore fish. Nori production in Japan is on a downward trend and has decreased by approximately 30% since 2000 (MAFF, 2023). If water temperatures continue to rise, there is a risk that areas suitable for aquaculture will move northward, making current farming areas no longer viable.

Extremely high water temperatures can cause mass mortality in shellfish and fish farming. For example, in 2010, an abnormally high SSTs in Mutsu Bay, northern Japan, caused 60% of farmed scallops (*Mizuhopecten yessoensis*) to die off (Aomori Prefectural Government, 2012). Another mortality event followed this in 2023 due to persistent high water temperatures from July to October (Hayase, 2023). Even when high SSTs are not the direct cause of mortality, the heat stress on organisms, in combination with other factors such as pathogens, can lead to deaths, exemplified by multiple cases of recent chronic mortality in Japanese pearl oyster (*Pinctada martensii*) farming (Matsuyama et al. 2021; Fisheries Agency of Japan, n.d.d). Because shellfish and fish farming generally require multiple years until harvest, farmers usually introduce rotation cycles to harvest part of their assets annually to and secure a sustainable source of revenue. More frequent mass mortality events driven by climate change can disrupt the cycle and threaten business stability.

Changes in weather patterns can also affect aquaculture. In the Ariake Sea, western Japan, a significant decrease in precipitation during the nori farming season in 2022-2023 resulted in a decrease in the supply of nutrients from the river, which caused “color fading,” a deterioration in the quality of the nori, leading to a significant decrease in yield and revenue (Saga Prefectural Government, 2023). More frequent extreme precipitation events and intense typhoons can cause significant damage to aquaculture facilities.

Although the effects of ocean acidification on the aquaculture industry have not yet been seen in Japan, acidification caused the mass mortality of oyster larvae on the U.S. West Coast in the late 2000s (IPCC, 2022). Most oyster farming in Japan relies on natural seed collection, and if acidification increases seed collection failure, a substantial impact could be anticipated (Fujii et al., 2023).

2.3.3 Impacts on offshore fisheries

Offshore fisheries operate in much broader areas than coastal fisheries and can follow targeted fish, mainly pelagic species, even if their distribution shifts northward. However, some species have not simply moved northward in their distribution as the ocean environment changes but shifted farther off the coast, leading to a loss of fishing opportunities. In extreme cases, primary fishing grounds have shifted towards foreign waters or the high seas, with the species then being exploited by foreign vessels (e.g., Japanese flying squid (Fisheries Agency of Japan, 2021)). The abundance of pelagic fish fluctuates significantly in response to decadal patterns in atmospheric and oceanic conditions, and the patterns can change due to anthropogenic climate change, making future predictions complex and challenging. For example, Japanese sardines, experiencing high and low recruitment periods, are increasing in abundance after a low recruitment period from 1990 to 2010. Meanwhile, it is uncertain whether the same level of high recruitment as in the past can be achieved given the different environmental conditions from the past (weaker Oyashio current and Aleutian Low) (Furuichi et al., 2024).

Large- and medium-size purse seine fishery account for approximately 40-50% of the total offshore fisheries catch, and the main targets are pelagic species such as Japanese sardine and chub mackerel. The primary distribution range of sardines has shifted northward since 2019, and their catch off the Hokkaido coast has increased, with the total landed volume at Kushiro fishing port in Hokkaido becoming the highest in Japan for the first time in 32 years (Fujii et al., 2022). As for chub mackerel, the landed volume dropped sharply (40% decrease) in 2022 from the previous year, although the stock abundance is estimated to be relatively high. One of the possible reasons can be that the chub mackerel migration route shifted away from the Japanese coast, and away from the customary fishing area, because mackerel avoided anomalous warm water driven by a weakening Oyashio and extended Kuroshio (Yatsu et al., 2023).

The offshore trawl fishery, which accounts for about 15% of the total offshore fishery catch, is a relatively regional fishery, with each fishing vessel landing at its own base port. Like coastal fisheries, the offshore trawl fishery catches a variety of fish species depending on the region and season. For example, in the bottom trawl fishery in Miyako City, in the Tohoku region, the catch of Japanese flying squid and Pacific cod (*Gadus macrocephalus*), which used to be the primary target species accounting for half to 70% of the total landings, has declined significantly since 2015, while the catch of chub mackerel has increased dramatically. The value of total landings has also been supported by the increase in the proportion of mackerel and kichiji rockfish (*Sebastolobus macrochir*) (Ishimura, 2023). The aggregate landed value from the offshore bottom trawl fishery in Japan remains stable at 40-50 billion JPY even after 2010, when changes in the marine environment became more pronounced (National Federation of Medium Trawlers, 2021). It is probably because offshore bottom trawl fishery targets variety of species and increased fish can compensate decreased fish in revenue.

Some offshore fisheries that depend on specific species can be the most vulnerable category to ocean environment changes. North Pacific saury fishery is one of the most exemplary. Chapter 5 investigates the problem and prescriptions for this fishery. The middle- and large-scale squid jigging fishery, that depends on Japanese flying squid, is also facing a difficult situation. This species is caught by several fisheries, but half of them are landed by the middle- and large-scale squid jigging fishery. The landings of this squid in Japan has been on a downward trend since the high of 300,000 tons in 2001 and remained above 200,000 tons in the early 2010s, but dropped to 70,000 tons by 2016 and below 50,000 tons in 2018 and thereafter (MAFF, 2023). The causes of the drop are still under investigation, but a possible explanation is that the squid's spawning timing in the fall has been delayed as temperature increases, exposing their hatched larvae to unfavorable environmental conditions of the winter, leading to higher mortality rates (Fisheries Agency of Japan, 2023). It is also pointed out that changes in larval transport routes and consequently the distributions of harvestable squid have resulted in increased exposure to exploitation by foreign fishing vessels outside of Japan's EEZ (Fisheries Agency of Japan, 2023).

Because of the large volume of landings and middle and large offshore fishing vessels, it is important for harvesters to cooperate with onshore processing industries and freezing facilities that absorb their high volume landings. Abrupt declines in catch have a big impact on these adjacent industries. When flying squid landings halved to 70,000 tons in 2016 from the previous year, the unit price doubled to 600 JPY/kg, and the price has remained high ever since (Fisheries Agency of Japan, 2021). Squid processors struggled to secure enough squid and had to deal with high prices resulting in halving their productions from 2015 to 2017. The squid stock fluctuated, and fishers and processors experienced a similar drop in landing in the 1980s. In those days, fishers were able to seek alternative squid species on the high seas and in foreign waters, to cover the revenue loss of domestic harvest of Japanese flying squid in order to provide processors with enough squid. Squid fishers also had to retreat from overseas as many coastal states started claiming their rights over fish resources and kicking out distant-water Japanese vessels (Sakai, 2022). Now, squid processors resort to imported squids. Recently, they have been outcompeted in the market by cheaper final products exported from other squid-producing countries. The poor catch of squid also affects local culture. For example, Hakodate in Hokkaido, called “Squid city,” experienced a drop in squid landings of 90 percent between 2012 and 2021, and the impact on not only the local processing industry but also tourism and culture has become pronounced (Tanaka and Makino, 2023). Conversely, it is pointed out that even in the case of a sudden and massive increase in catch of emergent species, especially in offshore fisheries, the volume is so large that if the processors or distribution networks are not ready to accept the catch, a mismatch may occur that prevents effective use of the resource (Fisheries Agency of Japan, 2023).

Chapter 3. Policies relevant to climate adaptation and Japanese fisheries

3.1 Overview of climate adaptation policy in Japan

Japan has taken actions to reduce greenhouse gas emissions under the Act on Promotion of Global Warming Countermeasures enacted in 1998. In 2015, the Paris Agreement was adopted at the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21). In addition to setting a goal for reducing emissions, the agreement calls for actions on adaptation: Article 7, paragraph 10 stipulates that "Each Party should, as appropriate, submit and update periodically an adaptation communication, which may include its priorities, implementation and support needs, plans and actions, without creating any additional burden for developing country Parties." In response, the Japanese government immediately developed the Climate Change Adaptation Plan, which the Cabinet approved in November 2015. However, a new law was needed to assess the roles of stakeholders other than the national government, i.e., local governments, private sectors, and citizens, and provide a framework for collecting scientific information on projected future climate change impacts. To address these points, the Climate Change Adaptation Act was enacted in 2018 to provide a legal framework for planning, implementing, and evaluating adaptation measures (Ministry of Environment, 2018).

Based on the law, the national government shall develop a National Adaptation Plan (NAP) and follow up on the progress of its implementation. In addition, the Ministry of Environment (MoE) shall conduct a climate change impact assessment every five years through discussions in the expert advisory body. The NAP is to be revised accordingly. Each governmental body is supposed to implement the NAP within its scope. For example, MAFF has a role in implementing adaptation policies relevant to agriculture, forestry, and fisheries. MoE does not have a mandate in these fields.

The Climate Change Adaptation Act appoints the National Institute for Environmental Studies (NIES) as the information hub on adaptation, and the NIES has developed the Climate Change Adaptation Information Platform (A-PLAT) (National Institute for Environmental Studies, n.d.). The law also encourages prefectural and municipal governments to develop local adaptation plans. This allows adaptation actions to be implemented considering unique circumstances region by region. As of April 2024, 279 plans have been developed by local governments, including all the 47 prefectural governments (National Institute for Environmental Studies, n.d.). Additionally, seven Regional Councils for adaptation, consisting of branch offices of MoE, local governments, experts and other stakeholders are established to integrate adaptation measures on a regional basis.

3.2 Climate adaptation policy and fisheries

The latest Assessment Report on Climate Change Impacts in Japan released by MoE in 2020 includes a section specific to fisheries, with subsections on (1) migratory species, (2) aquaculture and stocking, and (3) coastal and inland-water environment (Ministry of the Environment, 2020). The report identifies observed impacts on fisheries, such as changes in the distribution range of migratory fish, mortality events in aquaculture induced by high water temperatures, and the loss of seaweed beds, predicting that such impacts will continue. The NAP approved by the Cabinet in 2021 recommends basic adaptation measures for the fisheries as follows (Government of Japan, 2021): For the category (1) migratory species, Nap recommends to take ocean environment changes into account for adaptive fisheries management and to do so, improve stock assessments and forecasts of fish migration taking advantage of scientific surveys. For the category (2) aquaculture and stocking, the NAP recommends to improve selective breeding for heat tolerance, develop technologies to forecast and suppress red tide, and promote research on coastal ecosystems. For the category (3) coastal and inland-water environments, the NAP recommends to promote habitat restoration for such habitats as tidelands and seaweed beds. Since the fiscal year of 2021, MoE introduced Key Performance Indicators (KPIs) in consultation with other governmental bodies to follow up implementation progress of the NAP annually (Ministry of the Environment, n.d.). The KPIs specific to the fisheries are (1) the number of species whose stock assessments can identify MSY and (2) the area where seaweed bed restoration projects are implemented. Additionally, MoE lists existing governmental projects with budgets that will contribute to NAP implementation.

Some Regional Councils have been discussing adaptation measures from a local perspective. For example, the Tohoku Regional Council established a subcommittee specific to fishery issues. It developed an action plan to address ocean warming, including improving abalone and flatfish stocking measures and marketing emerging species such as yellowtails (Tohoku Regional Council for Climate Change Adaptation, 2023).

3.3 Fisheries policy and ocean environment changes

The two basic principles of Japanese fisheries policy are (1) securing a stable supply of fishery products and (2) appropriate development of the fishing industry, provided by the Basic Act on Fisheries Policy enacted in 2001 (Makino, 2011). In line with these basic principles, the government shall develop a Basic Plan for Fisheries every five years, representing circumstances in that era. The previous Basic Plan for Fisheries of 2017 set a goal to improve the efficiency of fisheries and increase fishers' income by improving fisheries management, addressing challenges such as overfishing, aging and declining workforce, deteriorating fishing vessel condition, and diminishing seafood demands (Government of Japan, 2017). The following year, “fisheries policy reform” started with the amendment of the Fisheries Law, reinforcing the Basic Plan. However, additional challenges emerged, such as the COVID-19 pandemic and the "poor catch" problem due to ocean environment changes. Considering rapid changes in circumstances encompassing the Japanese fisheries, the latest Basic Plan of 2022 set three pillars: (1) steady implementation of fisheries management taking into account ocean environment changes, (2) development of the fishing industry against increasing risks, and (3) revitalizing local communities (Government of Japan, 2022). Specifically, the plan calls for updating fisheries management based on output controls, improving stock assessments, promoting research on ocean environment changes, diversifying fishing operations to address the "poor-catch" problem, and promoting aquaculture, digitization, capacity building, marketing, and exports of seafood products, and blue economy. Compared to the previous plan, the latest Basic Plan highlights changes in the ocean environment.

To investigate ocean environment changes and their impacts on fisheries, FAJ set up a study group on the poor-catch problem in 2021. This ad-hoc study group comprised experts in relevant fisheries, resource management, ocean environment, fisheries economy, and processing and distribution. In its four meetings, the study group discussed the mechanism of poor catch for saury, flying squid, and chum salmon, its impacts on fishers, and the future direction of measures to sustain the fishery against medium- and long-term risks (Fisheries Agency of Japan, 2021). The discussion summary was considered when developing the next Basic Plan. However, the poor catch problem has continued, and impacts of environmental changes such as shifting fish distribution and the red tide in Hokkaido have become more prominent. Although the existing insurance system mitigated fishers' revenue losses to some extent, additional countermeasures were necessitated. In 2023, FAJ launched another study group on the adaptation measures for fisheries in response to ocean environment changes, with most member experts in the previous study group taking on the role again. After discussion in its five meetings, the study group recommendations covers monitoring and data collection, fisheries management, diversification and transition to aquaculture, improvement of processing and distribution, marketing, and capacity building (Fisheries Agency of Japan, 2023). The recommendations are further analyzed in Chapter 4.

The Japan Fisheries Research and Education Agency (FRA) plays a role in scientific research on ocean environment changes. In 2023, the FRA developed a research plan for climate change adaptation, aligning with the Assessment Report on Climate Change Impacts, the NAP, and the Basic Plan for Fisheries. The goals provided in this plan are to assess the impacts of climate change on the fisheries, promote research and development on technologies that contribute to adaptation, and facilitate science communication on mitigation and adaptation in the context of fisheries (FRA, 2023). These goals are expected to underscore the government's commitment to science-based policymaking and its efforts to address the challenges posed by climate change to the fisheries sector.

Chapter 4. Analysis on existing and proposed adaptation measures

Chapter 2 introduces an overview of the threats currently faced by Japanese fisheries, and Chapter 3 provides an overview of existing policy framework to counter these threats. This study aims to answer the research question, "Are the current adaptation measures sufficient, and if not, what additional policies are needed?" In this chapter, Section 1 examines what measures are necessary to address the threats, and Section 2 analyzes whether the existing policy provide measures to resolve the threats. It should be noted that the policy assessments without citations in this chapter are made based on the author’s knowledge and experience.

4.1 Necessary measures and policies to address threats of climate change

Chapter 2 underscores the urgency of the situation, highlighting that the influence of changes in the ocean environment varies across coastal fisheries, aquaculture, and offshore fisheries. The sudden and unprecedented changes and impacts have been witnessed since 2010 across all sectors. The unforeseen revenue loss caused by these events necessitates immediate response measures post-incident.

Research to elucidate the mechanism of changes and impacts is indispensable to pursue fundamental solutions. Meanwhile, identifying and attributing cause is not easy: an event could be caused by extreme phenomena such as MHWs, incremental ocean warming, anthropologic impacts, or natural variability, which are not mutually exclusive. Given that it can take a long time to fully understand the mechanism, fisheries sectors need to build resilience against adverse impacts and mitigate damage, taking into account the differences among various types of fisheries.

For coastal fisheries, operation areas are confined to local waters, and avoiding exposure from impacts is difficult unless alternative livelihoods are found on land. Still, many coastal fisheries utilize various fish species and have flexible regulations. Fishers can switch target species to make up for revenue losses of primary species by catching increasing or emerging species, and the market can adjust the switching. This flexibility enables fishers to reduce their vulnerability to the threats. A policy to ensure this flexibility is key for building resilience in coastal fisheries. It is worth noting that eliminating or reducing anthropologic stressors through habitat restoration and appropriate resource management is an important precondition.

When it comes to aquaculture, farmers are unable to avoid exposure to climate change impacts because of their low mobility. The growth of farmed shellfish and seaweed is heavily reliant on the local environment, while the feed used for farmed fish is dependent on volatile natural resources such as Peruvian anchovy. Additionally, the risk of mass mortality poses a significant threat to business stability. However, aquaculture production under human control offers more opportunities for technological intervention than capture fisheries. Therefore, a policy that encourages innovation can help mitigate the exposure and vulnerability inherent in aquaculture.

While offshore fisheries have mobility to follow shifting distribution range of targeted species, they are highly vulnerable to climate change. It is because their target is usually pelagic species whose abundance and migration are significantly affected by the ocean environment, except for the offshore trawl fishery. Particularly, fisheries relying on single species are the most vulnerable. Given their reliance on specific species, appropriate resource management to ensure sustainable use is vital for offshore fisheries to build resilience, and taking environmental changes into account is a critical step to improve the management. If actionable, a policy of reducing reliance on specific species can contribute to reducing vulnerability.

4.2 Analysis of the existing measures and policies for climate change in fisheries

4.2.1 Immediate financial relief

The existing insurance system works as an immediate rescue measure to mitigate unforeseen revenue loss resulting from sudden and unprecedented events driven by climate change. Mutual relief insurance has supported Japanese fisheries for over 50 years to cope with various uncertainties under the Act on Compensation of Fishery Disaster. Since 2010, an additional insurance scheme named "Tsumitate-Plus" (hereafter, Compensation Program) has been introduced to stabilize fishery businesses (Makino, 2011; Ono, 2015). While mutual relief usually deals with the loss of more than 20 percent of revenue from the baseline, Compensation Program covers the loss up to the median between the threshold of mutual relief and the baseline. Mutual relief is funded by insurance premiums, with some of them subsidized by the national government. The funding for Compensation Program comes from fishers who bear a quarter of the cost while the national government bears the rest.

These insurance measures have rescued fishers and farmers who suffered from recent poor catch problems and mass mortality events. For example, the saury fishery received a payment of 5 billion JPY in total in 2021 (Gyosairen, 2022). The total compensation paid to fishers and farmers increased more than threefold, from 35 billion JPY averaged 2011-2015 to 134 billion JPY in 2021, as ocean changes become prominent (Gyosairen, 2022).

This kind of safety net is not unique to Japan, exemplified by the Fishery Disaster Assistance in the U.S. In the U.S. case, however, there is a criticism of its timeliness, with the average time to fully process a disaster declaration taking approximately 2.1 years (Bellquist et al., 2021). In contrast, the timeliness of Japan's insurance system is swift enough to work as immediate rescue, with compensation typically paid to victims right after their fishing seasons. Meanwhile, it should be noted that the insurance scheme is not intended to address continuing or persistent revenue loss. Given that the baseline is set at the average catch of the five preceding years, excluding the years of maximum and minimum revenue, compensation diminishes if the poor catch continues for several years. In this regard, combining the insurance scheme above with other measures is indispensable to address the threats of climate change.

4.2.2 Further research on ocean environment changes, impacts and adaptation

The National Adaptation Plan of 2021 and the Basic Plan for Fisheries of 2022 call for further research on ocean environment changes, including ocean monitoring and data collection. The Fisheries Research and Education Agency (FRA) is expected to play a key role in scientific research on issues related to fisheries and ocean changes. Its climate adaptation research plan published in 2023 includes three pillars: research regarding (1) capture fisheries, (2) aquaculture and coastal environment, and (3) net zero emission (Japan Fisheries Research and Education Agency, 2023). The plan provides a to-do list covering all the research needs shown in the previous section (Table 4.1). Aside from FRA, prefectural fisheries research stations, universities, and private sectors such as the Japan Fisheries Information Service Center have been working on fishery-related research regarding ocean environment changes and impacts. Oceanographers from several national research institutes, such as the Japan Meteorological Agency, Japan Coast Guard, and Japan Agency for Marine-Earth Science and Technology, collaborate with FRA.

Table 4.1. A to-do list in the climate change research plan of Japan Fisheries Research and Education Agency.

1. Capture fisheries

- Elucidating mechanism of impacts of ocean changes on fishery resources species by species.
- Improving monitoring and data collection to develop a model for forecasting ocean changes.
- Incorporating ocean environment changes in stock assessments.
- Investigating ocean conditions on survival of juvenile salmons to improve stocking.
- Improving monitoring of HABs and developing a warning system.
- Developing new fishing measures enabling fishers to switch their target species.
- Developing a technology to enhance resilience of hard infrastructures against climate change.

2. Aquaculture and coastal environment

- Promoting selective breeding with heat tolerance.
- Developing a technology of forecasting ocean conditions to increase productivity of seaweed and shellfish farming.
- Developing a technology of preventing herbivore fish from overgrazing.
- Promoting selective breeding of finfish with heat, diseases and HAB tolerance.
- Improving artificial seedling for finfish farming and disseminating the technology.
- Improving technologies for land-based aquaculture.
- Developing alternative feed substituting fish meal with other proteins.
- Developing a technology of forecasting and suppressing HABs.
- Developing a technology of seaweed bed monitoring using eDNA.
- Developing a technology of detecting invasive species.
- Developing a technology of downscaling climate models for forecasting local environment.

3. Net zero emission

- Improving technologies of weather routing to reduce fuel consumption.
- Developing a technology of searching fish schools efficiently to reduce fuel consumption.
- Developing electronic fishing vessels.
- Developing a model to evaluate carbon sequestration in the context of blue carbon.

FRA's capacity and resources for carrying out the to-do list may be limited. An NGO's report points out that the amount of governmental budget for stock assessment and relevant data collection in Japan is one-third as much as that of the U.S (UMINEKO Sustainability Institute, 2023). Looking at research progress, for example, the National Oceanic and Atmospheric Administration in the U.S. uncovered the mechanism of impact of MHWs on Gulf of Alaska Pacific cod and Bering Sea snow crab in approximately three years after the stock collapse was detected (Barbeaux et al., 2020; Szuwalski et al., 2023), whereas the stock collapse mechanism of sand eel in Ise and Mikawa Bay has remained unclear since 2016. Although a detailed analysis of research capacity in Japan is beyond the scope of this study, it is worth paying attention to prioritizing and resource allocation.

4.2.3 Building resilience against ocean environment changes

In order to build resilience in the fisheries, it is necessary to focus on concrete measures, considering the differences among various types of fisheries. While the National Adaptation Plan provides some specific measures for aquaculture, its contents for capture fisheries are too abstract to implement. This is partly because the Ministry of Environment plays a central role in making the adaptation plan, but it has no mandate or budget over fishery matters.

The Fisheries Agency of Japan, in charge of fishery matters, did not refer to the MoE National Adaptation Plan in developing its Basic Plan of Fisheries. Thus seems to be a gap between climate policy and fisheries policy. Meanwhile, the Fisheries Agency has been discussing specific measures to cope with ocean environment changes in its official study group, as mentioned in Chapter 3. The study group provided a recommendation with the following five pillars: (1) Improvement of stock assessment, (2) Diversification of target species and fishing methods, (3) Transition to aquaculture, (4) Improvement in processing and distribution sectors, and (5) Capacity building (Fisheries Agency of Japan, 2023) (Table 4.2). The following sections provide an analysis of the measures proposed in terms of the research question, "Are the current adaptation measures sufficient, and if not, what additional policies are needed?"

Table 4.2. Recommendations of study group on the adaptation measures for fisheries in response to ocean environment changes.

1. Improvement of stock assessment	
1.1	Exchanging information on ocean environment changes etc. with the U.S. and other countries.
1.2	Deploying new methods for collecting richer data on ocean environment and fish stocks.
1.3	Promoting research on biological information for important fish stocks and essential habitats.
1.4	Improving science communication among governments, scientists, and fishers.

2. Diversification of target species and fishing methods	
2.1	Transitioning to multi-species-targeted fisheries and aquaculture.
2.2	Adjusting regulations such as IQ management to enable diversification.
2.3	Supporting diversification by government-initiated experimental fishing and deploying ICT.

3. Transition to aquaculture	
3.1	Promoting domestic fish meal production and developing fish-meal-reduced feed.
3.2	Promoting artificial seedling and selective breeding.
3.3	Considering market size and costs in transition.
3.4	Improving productivity of aquaculture operations.
3.5	Promoting exports of products to expand markets.

4. Improvement in processing and distribution sectors	
4.1	Adjusting processing and distribution in response to changes in landed species and volumes.
4.2	Improving supply chain to adjust to exporting regulations and eco-labelling.
4.3	Enlightening consumers to promote sustainable fisheries.

5. Capacity building	
5.1	Supporting fishers’ diversification through financial assistance and advising.
5.2	Training fishers to acquire necessary knowledge and skills for diversification and securing workforces across different industries.
5.3	Supporting Fisheries Cooperative Associations working on diversification.

Source: Fisheries Agency of Japan (2023)

4.2.3.1 Analysis of proposed adaptation measures for coastal fisheries

A strength of coastal fisheries is their flexibility, which allows them to target multiple species. Using small-scale capitals, vessels, and gears lets fishers switch fishing methods easily. Ocean environment changes could be an opportunity for fishers to take advantage of valuable emerging species (e.g., cutlass fish and blue crab in the Tohoku region). On the other hand, limited access to small-scale capital could entail financial vulnerability and keep fishers from introducing new gears for switching targets, necessitating policies to support fishers financially, such as subsidies and loans. Recommendation 5.1 in Table 4.2 covers this point, and some prefectural governments have already implemented this intervention (Miyagi Prefectural Government, 2024).

Aside from capital, knowledge and skills are also necessary for switching, as mentioned in Recommendation 5.2. A good example of learning is the case of the pufferfish fishery in Soma, Fukushima (Fukushima Prefectural Government, n.d.). In order to take advantage of the emerging Japanese pufferfish (*Takifugu rubripes*), local fishers took collective actions to acquire knowledge and skills of longline fishing efficiently and swiftly. As a result, from 2019 to 2022, the number of fishers engaging in the puffer longline increased fivefold, and the landings increased from 3 tons to 35 tons. Since 2021, fishers have agreed to introduce a size limit and time closure for sustainable use of the new target species. Furthermore, fishers collaborate for puffer branding to increase unit prices in the domestic market. Collective action can be a key to learning knowledge and skills and managing emerging stocks, and FCAs play a crucial role in facilitating. Prefectural fisheries research stations are also robust systems that provide technical support. Meanwhile, a possible challenge is the resource limitation of FCAs and prefectural governments, mentioned in recommendation 5.3. Subsidies relevant to fisheries usually require paperwork by prefectural governments and FCAs, and alleviating the administrative burdens may be necessary to provide them with enough capacity.

Switching species could be difficult in some coastal fisheries that heavily depend on specific fish (e.g., salmon set-net fishery in Hokkaido). In such a case, combining alternative revenue sources other than the fishery can be a potential solution. The study group suggests a transition to aquaculture. There are some cases in which set-net fishers and FCAs in northern Japan have worked on trial salmon farming to make up for the revenue loss due to the poor catch of wild chum salmon (Fisheries Agency of Japan, 2023). In Japan, coastal fisheries and aquaculture are managed under the same entity, i.e., prefectural government, and law, and it is not tricky for incumbent fishers to start aquaculture, compared to the U.S., with its substantial regulatory hurdles. Some existing subsidies help fishers introduce capital for improving aquaculture operations or launching new operations (Fisheries Agency of Japan, n.d.b). Aside from aquaculture, blue economies are another potential alternative revenue source. In 2023, the Act on Development of Fishing Ports and Grounds was amended to promote “umigyo”, whose concept is to use fishing ports and adjacent areas for tourism and other activities to attract people from urban areas and create an economy (Fisheries Agency of Japan, n.d.e). While umigyo’s primary goal is to revitalize local economies, it could also be a helpful tool for climate change adaptation, mitigating income loss from coastal capture fisheries.

As for habitat restoration, coastal fishers have been making efforts in conservation activities such as sowing seeds of eelgrasses and eliminating sea urchins from seaweed beds to avoid overgrazing. The Fisheries Agency has subsidized the conservation costs for about ten years, but the amount is declining due to other pressing matters squeezing the budgets (Fisheries Agency of

Japan, n.d.f). Blue carbon is recently gaining attention and could be leveraged to pass coastal fishers' conservation cost on to society through the carbon credit market, contributing to enhancing conservation activities (Kuwae et al., 2022). Recommendation 1.3 provides no clear explanation but refers to blue carbon.

For issues beyond prefectural jurisdiction, the Regional Councils for adaptation under the Climate Change Adaptation Act can create options for taking action for consideration by stakeholders.

Under the ongoing policy reform, more stringent fisheries management will contribute to sustainable coastal fisheries and adaptation. At the same time, it is worth attention to ensure management flexibility, especially in expanding TAC management, because flexibility is a key to successful adaptation for coastal fisheries. In the U.S. East Coast, for example, the distribution of summer flounder has been shifting northward over time. However, fishers in northern states do not have enough quotas because the quota allocation is based on past catches and does not represent current distribution (Dubik et al., 2019). The new fisheries management in Japan that plans to apply TAC management to more species should be implemented in a manner that does not hamper flexibility, which is the strength of coastal fisheries.

4.2.3.2 Analysis of proposed adaptation measures for aquaculture

For coastal aquaculture, successful adaptation is highly dependent on innovation. For example, land-based aquaculture can eliminate any impacts of ocean warming, but its economic feasibility is up to factors such as the growth rate of farmed species, survival rate, and electricity usage, all of which can be improved by technological advancement. Selective breeding, artificial seedling, and alternative feed (fish-meal-reduced feed) are key innovations to overcome climate change, as recommendations 3.1 and 3.2 suggest. Governments, industry, and research institutions have worked on research and development for this field, and this movement has been accelerated since the Strategic Plan for Aquaculture Development was formulated by the Fisheries Agency of Japan in 2020 (Fisheries Agency of Japan, 2020; Fisheries Agency of Japan, n.d.). FRA's climate change research plan also covers variety of research needs in the second pillar (Table 4.1).

In addition to technological aspects, behavioral adaptation is also important for farmers to increase their productivity and resilience, as touched on in recommendation 3.4. For example, although the recent mass mortality of pearl oysters turned out to be caused by a virus, the Fishery Agency has encouraged farmers to conduct regular monitoring on the environment and accordingly change their accustomed operation to evade heat stress, e.g., sinking the shellfish cages deeper, and avoiding additional stress on pearl oysters, e.g., stop cleaning on the shell surface or selecting by size during high water temperature periods, hoping to increase oyster's survival rate (Fisheries Agency of Japan, n.d.d). Some prefectures have disseminated adaptation handbooks for farmers (Mie Prefectural Government, 2022).

4.2.3.3 Analysis of proposed adaptation measures for offshore fisheries

Typically, offshore fisheries rely on several pelagic species. Because the abundance of these species is highly volatile in response to natural variability of ocean conditions, the fishers have already experienced struggles. For example, the large- and middle-scale purse seine fishery operating off the Japan's northern Pacific coast faced a boom-and-bust cycle of Japanese sardine in the late 1980s (Makino & Saito, 2014). The annual landing of sardines by the fishery exceeded

1.5 million tons during the mid-1980s, but dropped by half in 1990 and eventually decreased to 0.1 million tons by the mid-1990s. Concurrently, chub mackerel stock started increasing but were rapidly depleted. Fishers were driven to overfishing because they had invested much money on building carrier vessels for plentiful sardines in the mid-1980s and tried to cover the loss by substituting chub mackerel. It should be noted that TAC management was yet to be introduced in those days. Losing two primary species drove some fishers to exit from the fishery. The remaining vessels managed to survive by catching other species such as anchovy and tunas until the mackerel stock recovered in the late 2010s. Makino & Saito (2014) suggests that the economic crisis driven by capital stuffing could have been mitigated if the stock collapse of sardine had been anticipated, highlighting the importance of improving stock assessment and taking into account natural variability. As recommendation 1 suggests, TAC management combined with credible stock assessment can ensure sustainable fisheries despite unprecedented ocean patterns. However, some migratory species constitute straddling stocks with other countries, which makes management more complex and challenging.

Another lesson is that diversification saved the remaining fishers. Fisheries relying on single species, especially middle- and large-scale squid jigging fishery and North Pacific saury fishery, are the most vulnerable to climate change, and diversifying portfolio is a key to reducing vulnerability. Obviously, the most important message from the study group’s recommendation is diversification. This is also the case in the U.S., and several papers recommend diversification to address climate change and increase resilience, e.g., adaptation in general (Pinsky and Mantua, 2014), the lobster fishery in the East Coast (Steneck et al., 2011), and Bering Sea snow crab fishery (Szuwalski et al., 2023). However, the two problematic Japanese offshore fisheries mentioned above have a trajectory shifting from multi-target to single-target due to change in international circumstances. As explained in Chapter 2, the squid fishery used to catch variety of squid species all over the world and cope with landing drop of Japanese flying squid (Sakai, 2022). The saury fishery used to be an alternative fishing for the driftnet fishery, but became a primary fishery after the UN High Seas Driftnet Fishing Moratorium took in effect in the early 1990s (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). Even after the moratorium, some saury fishers still engaged in driftnet fishing to catch salmons in the Russian EEZ, but that fishery was terminated in 2015. Therefore, diversification by seeking fishing opportunities outside of Japan may be no longer feasible. However, pursuing alternative fishing opportunity in domestic waters is also challenging because it is likely to cause conflicts with other existing resource users, given that fishing capacity of offshore fisheries is high, and that different types of fisheries belongs to different associations unlike coastal fisheries where local fishers belong to the same FCA. In the meetings of the study group, a representative from a fishery organization expressed concerns about making recommendations that encourage too flexible diversification and likely disrupting the long-standing fishery order. Mesopelagic species such as lantern fish are unexploited but estimated to be abundant, and thus, could offer a new frontier fishery. However, to the author’s knowledge, there is no commercially-viable fisheries targeting mesopelagic species in the world, except for several trial fishing in the South Africa (Bahri et al., 2021).

In the event that diversification is possible, concerted actions among fishers, inshore processors, freezing facilities and distributors are key to success. This is because the catch volume of offshore fisheries is large, and it depends on the inshore capacity whether market can absorb newly-targeted species. For example, there used to be a number of processing plants for producing fish meal in Kushiro, Hokkaido, but most of them went bankrupt after the sardine stock collapse (Kaneko et al, 2013). Now several processing plants are newly built to absorb rapidly-increasing Japanese sardine caught off the coast. The importance of solving mismatch is highlighted in recommendation 4.1. With regard to governmental intervention to facilitate concerted actions among different sectors, the Fisheries Agency has a subsidization scheme, called "fisheries structural reforming projects." This scheme is to support regional trial projects to increase profitability of the fishery, usually involving fishers, FCAs, experts, local governments, and if necessary, processors, distributors and any other stakeholders. For example, a project in Tajima, Hyogo, is demonstrating the viability of combining offshore trawling and squid jigging, with processing and distributing sectors supporting fishers in terms of marketing and branding their products (Hyogo Federation of Fisheries Cooperative Associations, 2019).

4.3 Insights from the analysis

The previous section analyzed whether existing and proposed policies are expected to work as prescriptions for the climate-driven challenges of Japanese fisheries based on the author's knowledge and experience. The existing fisheries insurance system is effective enough to provide a level of immediate relief against impacts of climate change, but it is not designed to subsidize a continuing or persistent revenue loss. Current research plans proposed by the government and FRA well capture research needs on climate change and adaptation for fisheries and aquaculture. Meanwhile, there is room for further discussion on research capacity, prioritization, and allocation of resources, although this is beyond the scope of this study. As for policies to build resilience against ocean environment changes, overall, existing and proposed measures are thought to be helpful in achieving the goal for coastal fisheries and aquaculture. Ongoing fisheries reform to improve fisheries management and stock assessment can also contribute to coastal and offshore fisheries adaptation. Diversification is the main recommendation of the FAJ study group. Diversification is also suggested in other countries as a countermeasure to climate change impacts. However, in Japan there is a difference between coastal and offshore fisheries in the feasibility of diversification. Offshore fisheries with large vessels and fishing capacity can create conflicts with other resource users if diversification is implemented. Even if diversification is possible, it could be only partially implemented because alternative species are unlikely to make up all the loss of primary species. In the FAJ study group’s recommendation, no other solution than diversification was proposed for offshore fisheries.

In summary, while existing and proposed policies are expected to address the climate-driven challenges, further discussions on solutions for offshore fisheries, particularly those reliant on specific species, are crucial. Given the uncertainty of catch recovery under current ocean conditions, the fundamental issue is unprofitability of certain offshore fisheries to sustain the livelihoods of all current fishers. This underscores the need for a rationalization policy, as seen in previous cases of overfishing. The next chapter delves into a policy analysis on a rationalization strategy, using data from the North Pacific saury fishery.

Chapter 5. Policy analysis for offshore fisheries adaptation: Case study of the Japanese saury fisheries

Chapter 5 examines Japanese offshore fisheries that rely on specific species to fill the gap between their current financial struggle and proposed recommendations for relief. The study group recommends diversification, which could work to some extent, but whether it is sufficient for those fisheries to overcome their situation is questionable. Hence, another approach may be required to adjust fishing capacity for the current environment and biomass status.

This chapter focuses on the North Pacific saury fishery for the following reasons: First, saury is a commercially and culturally important species for the Japanese fishery. This fish supported the fifth largest landing volume in 2014 and is a very popular fish for consumers because it represents the taste of the fall season (MAFF, 2015). Second, saury can be one of the most symbolic species in the context of the impacts of ocean environment changes on Japanese fisheries. The landings had been stable for over three decades but suddenly dropped from 229,000 tons in 2014 to around 30,000 tons, driven by ocean environment changes (Japan Saury Stick-held Dip-net Fishery Cooperative Association, n.d.) (Fig. 5.1). Third, the production system of saury is straightforward. Almost all saury landed in Japan comes from a single fishery: the North Pacific saury fishery licensed by the minister of MAFF (Fisheries Agency of Japan, 2021), which can simplify the analysis. Fourth, data for analysis are available for this fishery, coming from a "fisheries structural reforming project" regarding the saury fishery (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). In the documents of this project, the cost structure data of fishing vessels involved are publicly available because the project is subsidized, and performance evaluation is required to be reported.

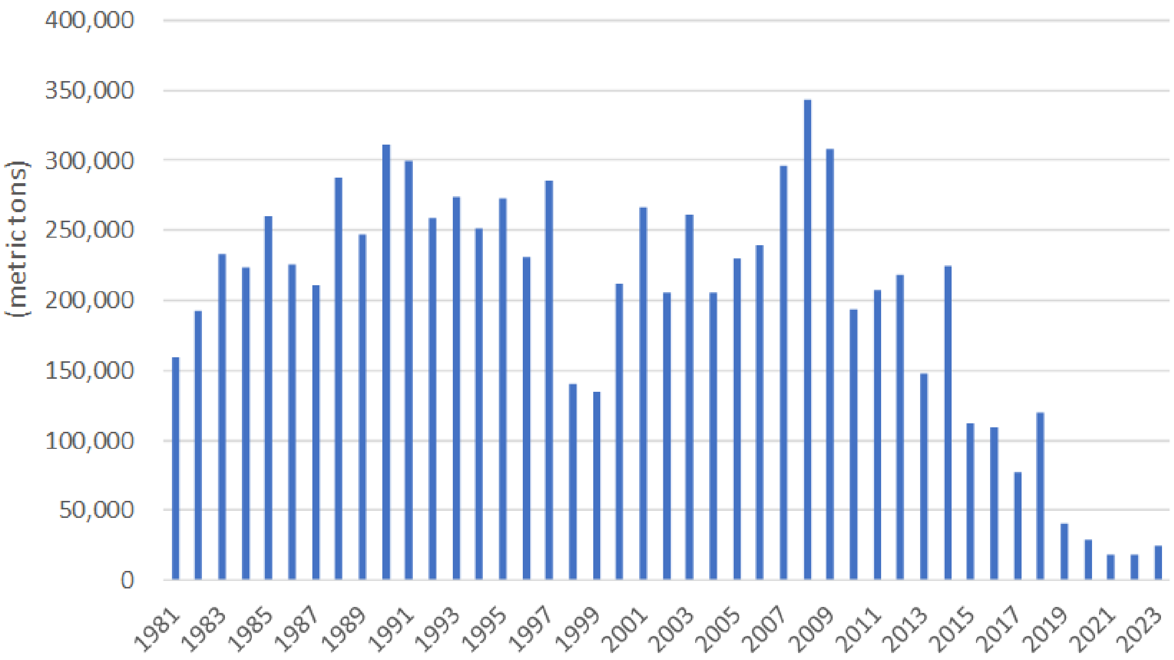


Figure 5.1. Historical catch of Pacific saury in Japan.

(Source: Japan Saury Stick-held Dip-net Fishery Cooperative Association, n.d.)

5.1 Background information

5.1.1 Overview of Pacific saury biology

Pacific saury (*Cololabis saira*) is a highly migratory species in the North Pacific Ocean, ranging from the subarctic to subtropical, and from the west (off the coast of Japan) to the Central Pacific and occasionally to off the coast of North America (NPFC, 2023a) (Fig. 5.2). A previous study suggests that there is a single population (Chow et al., 2009). Saury feeds on zooplankton, and the preferred prey size becomes larger as growing up (Odate, 1977). In summer, feeding grounds are found in subarctic areas. From summer to winter, saury migrates to spawning areas in the subtropics (Kosaka, 2000). The spawning season of saury is relatively long, from September to June of the following year. The spawning area is vast from the Japanese coastal waters to eastern offshore waters, with the main spawning grounds considered to be located in Kuroshio and Kuroshio Extension waters, off the coast of Japan, in winter (Watanabe and Lo, 1989). Saury in offshore areas (east of 160°E) also migrates westward to this spawning area in late fall (Suyama et al., 2012). Thus, the saury's migration for spawning is not only from north to south but also from east to west.

Pacific saury is a short-lived and fast-growing fish. The age-0 fish is mainly transported by currents to the eastern region of its distribution range (east of 170°E) in June and July. Saury grows to approximately 20 cm in body length in 6-7 months after hatching with some variation (Watanabe et al., 1988). The minimum size at maturity is estimated to be about 25 cm, with age-1 fish and a small portion of age-0 fish contributing to spawning (Suyama et al., 2019). The maximum lifespan is estimated to be two years (Suyama et al., 2006).

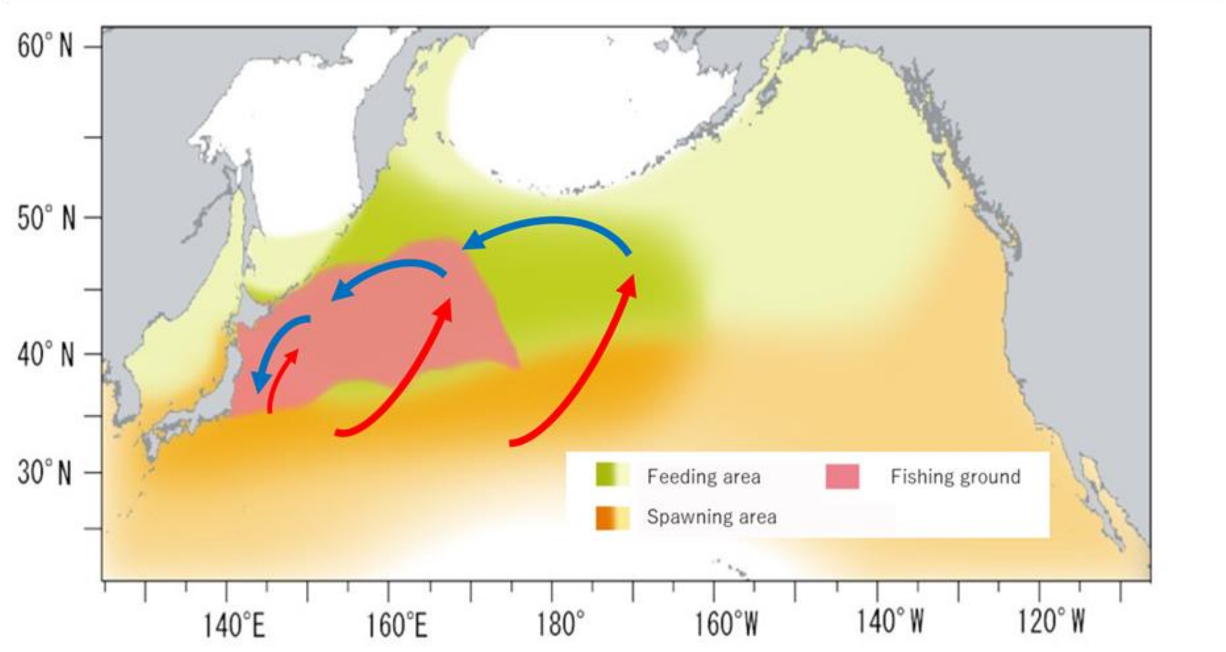


Figure 5.2. Distribution of Pacific saury.

Gradation represents fish density. Blue arrows show spawning migration of age-1 fish during summer to fall. Red arrows show migration of age-1 fish to feeding grounds during spring to summer. Note that migration route of age-0 fish is unclear. (Map source: NPFC, 2023a).

5.1.2 Overview of international fisheries management through NPFC

Pacific saury has been internationally managed since 2015 by a regional fisheries management organization, the North Pacific Fisheries Commission (NPFC), to ensure its sustainable use based on science. The following members catch saury: Japan, Russia, China, Taiwan, Korea, and Vanuatu. NPFC's science committee has worked on conducting stock assessments and providing management advice. The commission members catching saury have agreed to introduce annual catch limits (TACs) in the Convention Area, i.e., on the High Seas, and the areas under their jurisdiction adjacent to the Convention Area, i.e., in the EEZs of Japan and Russia, from the 2020 fishing season (NPFC, 2023a) (Table 5.1). Japan used to account for over 80% of the catch, but other countries catching saury in the High Seas have increased their shares since the 2000s (Nakayama et al., 2024) (Fig. 5.3). The share allocated to Japan under NPFC was reduced to less than half in 2010 and, since then, dropped to 20 percent.

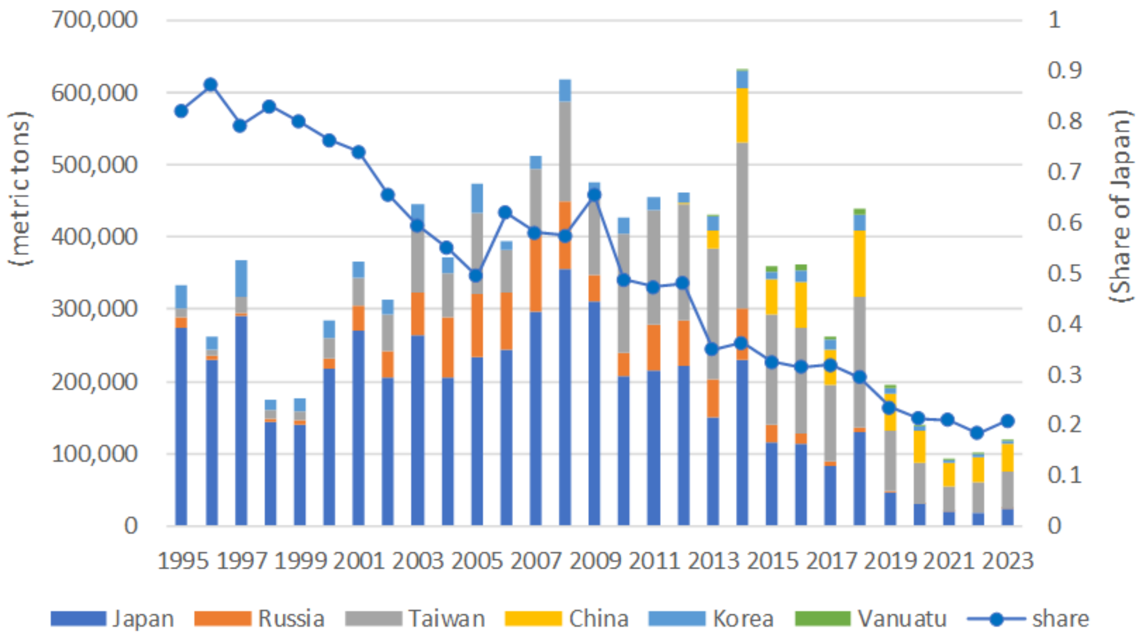


Figure 5.3. Time series of catch of Pacific saury by NPFC members.

The share of Japan is also shown by dotted line. The data source is Nakayama et al. (2024), and the authors state that catch data of NPFC members other than Japan is quoted from NPFC, and Japan's data is quoted from the annual statistics of MAFF.

Table 5.1. Annual TACs (metric tons) and catches of Pacific saury by NPFC members during 2020-2024.

Year	2024		2023			2022			2021			2020		
	TAC		TAC			TAC			TAC			TAC		
	High Seas	EEZs	High Seas	EEZs	Catch	High Seas	EEZs	Catch	High Seas	EEZs	Catch	High Seas	EEZs	Catch
Japan	21,087	90,000	21,087	100,000	24,433	28,115	100,000	17,910	28,115	100,000	18,291	46,859	226,250	29,566
Russia	2,457		2,457		51	3,275		0	3,275		610	5,459		753
Taiwan	81,210	-	81,210	-	50,268	108,280	-	42,177	108,280	-	34,043	180,466	-	56,662
China	40,664	-	40,664	-	39,252	54,219	-	35,477	54,219	-	33,511	90,365	-	44,006
Korea	9,342	-	9,342	-	3,107	12,455	-	3,438	12,455	-	4,365	20,759	-	5,993
Vanuatu	3,704	-	3,704	-	1,108	4,938	-	929	4,938	-	1,270	8,231	-	2,700
Total	135,000	90,000	150,000	100,000	118,219	198,000	100,000	99,931	198,000	100,000	92,090	330,000	226,250	139,680

Source: NPFC (2023a)

The TAC of the 2021 fishing season was reduced and set at decreased catch by 40% from its reported catch in 2018. The TAC of the 2023 fishing season was further reduced by 55% from the catch in 2018. The stock assessment of saury is conducted using a Basian surplus production model. The latest result revealed that the current biomass is much lower than BMSY, and the TAC of 2023 may not reduce fishing mortality (NPFC, 2023a) (Figure 5.4). The science committee recommended in December 2023 that the Commission adopt an interim harvest control rule that reduces the target harvest rate and TAC when biomass is below BMSY (NPFC, 2023b). At the latest annual meeting held in April 2024, the Commission decided to adopt this harvest control rule that TAC is calculated by multiplying the current biomass level by FMSY and is reduced in proportion to biomass if the current biomass is below BMSY, on condition that TAC increases or decreases by no more than 10% each year. Accordingly, the TAC of the 2024 fishing season is reduced by 10% from the previous year (Fishery Agency of Japan, 2024b).

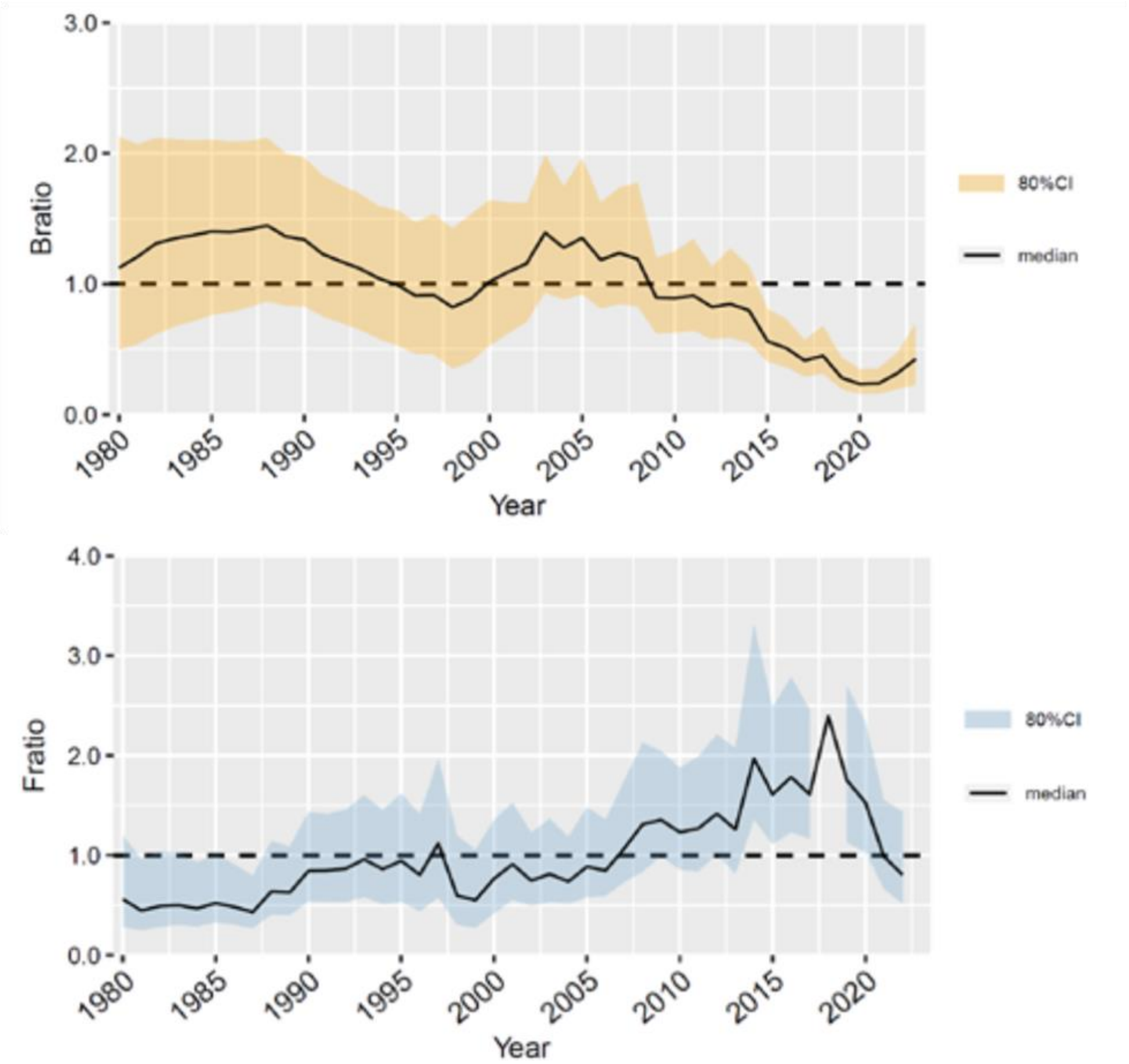


Figure 5.4. Result of Pacific saury stock assessment.

The Figure is quoted from Small Scientific Committee on Pacific Saury (NPFC, 2023a). Time series of median estimated values of six runs by members of NPFC for B/BMSY (upper) and F/FMSY (lower).

5.1.3 Overview of saury fisheries and their management in Japan

In Japan, the stick-held dip net fishery has been the dominant fishing technique for catching saury since it was developed in the 1940s (NPFC, 2023b). The fishers search for schools of saury, lure fish by light, and scoop them up with stock-held dip-nets. After arriving at fishing grounds, the fishers usually end fishing in less than 24 hours and return to the port swiftly to meet market demands for fresh products (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). As of 2021, 45% of saury catch is for fresh products, 37% is for processed products, and the rest is for fish meal or bait (Nakayama et al., 2024). Approximately ten fishing ports along the Pacific coast from east Hokkaido to Chiba Prefecture (the central part of the mainland) are known as major ports where saury is landed. The main fishing season is from August to December. Because saury migrates southward over the fishing period and the fishers follow the fish, the landing ports gradually shift south (Makino, 2011) (Fig. 5.2).

Under the Fisheries Law, the North Pacific saury fishery is defined as a fishery that targets saury using dip net vessels of greater than ten gross tons (GT) and is licensed by the minister of MAFF. Almost all vessels catching saury are in this category (Nakayama et al., 2024). The vessels fishing for saury are customarily classified into three size categories: small (less than 20 gross tonnage (GT)), medium (less than 100 GT), and large (100 GT or more) (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). As of January 2024, the number of licensed vessels is 61, 26, and 46 for small-, medium-, and large-sized classes, respectively. Regarding the trend in number of saury fishing vessels, over 500 vessels engaged in this fishery in 1988, but the number dropped by half in ten years, driven by factors such as High Seas driftnet fishing moratorium combined with the fuel cost increase, and deteriorating condition of fishing vessels due to a lack of financing for renewal (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). The downward trend continued for years following 1988 but has remained stable since the mid-2000s. Aside from the entry limit, this fishery has been managed by output control (TAC) since 1997 (Fishery Agency of Japan, n.d.g) (Fig. 5.5). The TAC was allocated to the entire fishery, followed by internal allocation initiated by the Japan Saury Stick-held Dip-net Fishery Cooperative Association (hereinafter, the Saury FCA), which has a role in determining access rules and harvest plans, considering the high price elasticity of saury as a commodity and fishers' business stability (Makino, 2011). Since the NPFC introduced the TAC scheme among members in the 2020 fishing season, domestic TAC has been set following the NPFC's decision. Since 2023, the Fishery Agency of Japan has introduced individual quota (IQ) management under the "fisheries policy reform." Every year, IQs are allocated as follows (Fisheries Agency of Japan, n.d.h): First, 10% of the national TAC of saury is set aside for a buffer to deal with management uncertainty. Second, a small portion of TAC is allocated to minor fisheries, and the rest of TAC is for the North Pacific saury fishery. Third, a 10% portion of the rest is allocated to the entire fishery from January to July, whereas 90% is allocated to individual vessels for operation during the main fishing season (from August to December). For example, 85,104 out of 110,911 tons of national TAC is set for IQ management for the 2024 fishing season. As for the measure of IQ allocation, the percentage of each IQ to the total, called quota share (QS), is calculated every year as follows (Fisheries Agency of Japan, n.d.h): A sum of (1) 30% divided by the number of all vessels applying for IQ allocation and (2) 70% divided in proportion to the amount of catch by a vessel for the past three years is a QS for the vessel. Accordingly, the IQ of each vessel comes out in proportion to QS. If the government approves, a vessel can transfer its

IQ to other vessels during the fishing season. As of November 2023, 113 vessels have applied for holding IQ (Fisheries Agency of Japan, n.d.i). The gap between the number of vessels with QS and license is probably because some vessels decided not to apply for IQ allocation given the recent poor catch of saury.

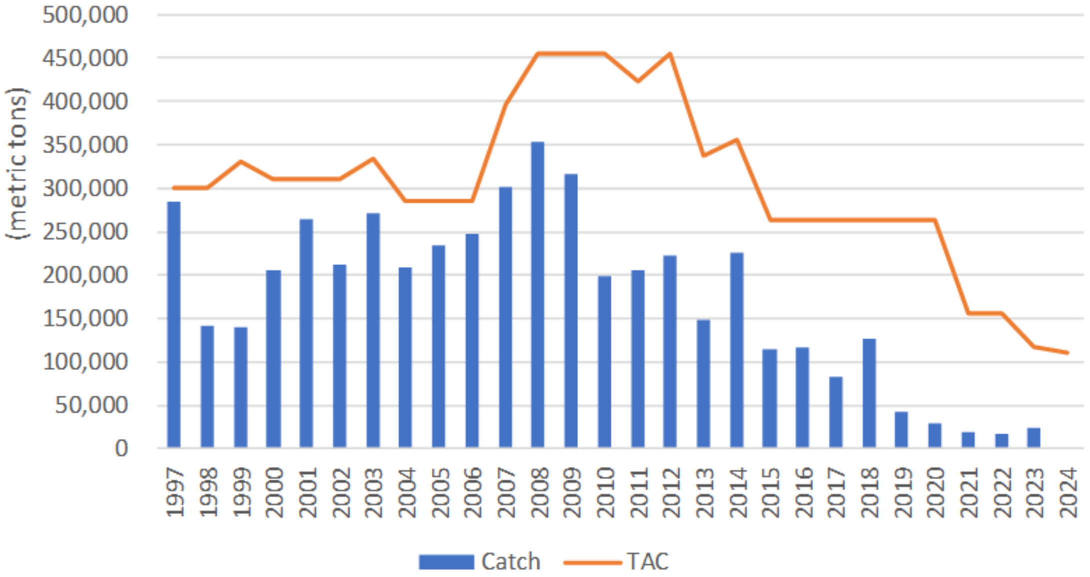


Figure 5.5. Time series of TAC and reported catch in Japan since 1997.

Source: Fisheries Agency of Japan (n.d.g)

5.2 Policy Problem

The landings of saury in Japan were stable for more than three decades 1980-2014. However, the last eight years saw a rapid and dramatic decline in the catch, regardless of the continuing management. Since 2019, the landings have been at historically low levels, less than 20 percent of the catch in 2014. The national TAC of saury was halved from 264,000 tons in the late 2010s to 118,131 tons in 2023, but the actual landing in 2023 was 24,433 tons, well below the TAC (Fig. 5.5). The result of the stock assessment conducted by the NPFC revealed that overfishing happened, i.e., the fishing intensity was above FMSY, and the saury stock was overfished, i.e., biomass was below BMSY, during the decade 2010-1019 (NPFC, 2023a) (Fig. 5.4**)**, when catches on the High Seas increased and Japan's share decreased from about 50% to 20% (Fig. 5.3).

Although overexploitation is one of the causes of catch decrease, other factors can be attributed as causal. Japan has saury's primary spawning ground off its coast, and Japanese fishers take advantage of the spawning migration (Fig. 5.2). Recently, however, less migration has been observed. The main fishing ground for Japanese fishers has shifted eastward, from Japan's EEZ to the High Seas. Japanese catch in the High Seas was negligible until 2014 but accounted for 10-40% of total catch during 2015-2019, and peaked at 90% in 2021 (Nakayama et al., 2024) (Fig. 5.6). FRA research suggests the following hypothesis (Japan Fisheries Research and Education Agency, 2023b): Since 2010, anomalously warm water associated with weakened Oyashio flow has persisted off the coast of Japan, which may have blocked saury from migrating to its primary spawning area. The migration route has shifted eastward to the offshore area, and accordingly, Japan's historical fishing grounds have contracted (Kuroda & Yokouchi, 2017). At the same time, the change in Kuroshio current may have contributed to transporting larval fish to farther offshore areas with less food availability, and stock biomass may have consequently decreased, driven by poorer growth and survival. This may also explain the decrease in catch by other countries whose fishing grounds are only on the High Seas. In addition, reduced body weight due to poor growth conditions in offshore areas may cause delayed initiation of spawning migration (Kakehi et al., 2022). Saury in the offshore areas starts spawning migration westward towards Japan in summer. If the initiation is delayed, saury cannot reach the primary spawning area off Japan's coast but heads to southern spawning grounds offshore, leading to a further decrease in migration to Japan in the fall. Although this hypothesis is not explicitly confirmed in the stock assessment report of NPFC, the report says ocean environment changes may have contributed to the decline and current low stock size of Pacific saury, and further research is needed (NPFC, 2023a).

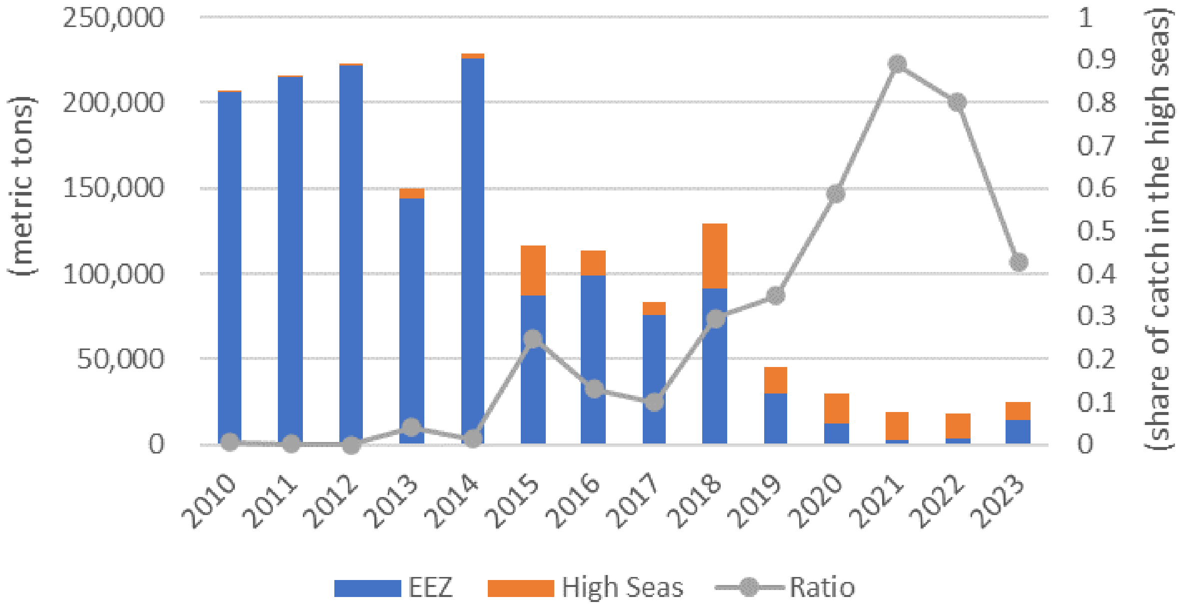


Figure 5.6. Time series of ratio of catch on the High Seas by Japan since 2010.

Blue bars show catches within Japan’s EEZ, and orange bars show catches on the High Seas. The data source is Nakayama et al. (2024), and the authors state that catches on the High Seas is quoted from NPFC and catches within EEZ are calculated by deducting catches on the High Seas from the total catch quoted from the annual statistics of MAFF.

This change has caused adverse effects on saury fishers, such as less successful search for fish, fewer fishing opportunities, and increased fuel consumption, aside from the decrease in stock abundance. The fishery has become less viable due to revenue decreases and cost increases. In addition to the research progress for elucidating the mechanism of catch decrease and the effort on international negotiation at NPFC, the Japanese government and the industry have tackled this problem through “fisheries structural reforming projects.” For example, some vessels attempted to catch saury on the High Seas and sell fish to Russian carrier vessels at sea before the main fishing season opening. This project was meant to diversify fishers’ portfolios after the termination of salmon driftnet fishing in the Russian EEZ, which provided alternative fishing opportunities for saury fishers during the off-season. However, this attempt turned out to be unprofitable at this point (Nakayama et al., 2024). The Fisheries Agency of Japan and Gyosairen also provided direct support up to billions of yen of annual compensation through an insurance program (Gyosairen, 2022). However, the benefit has diminished as the poor catch continues for years because the compensation baseline is calculated on the average catch of the five preceding years. Unfortunately, there is no sign of dramatic recovery of the saury stock (NPFC, 2024) (Fig. 5.7). It is safe to say the situation encompassing saury fishers has been stuck in an adverse pattern for multiple years and the prognosis is not positive in the foreseeable future. For the following policy analysis, this report defines the policy problem as “*there is too little profit from the fisheries to sustain the livelihoods of all the current saury fishers.*”

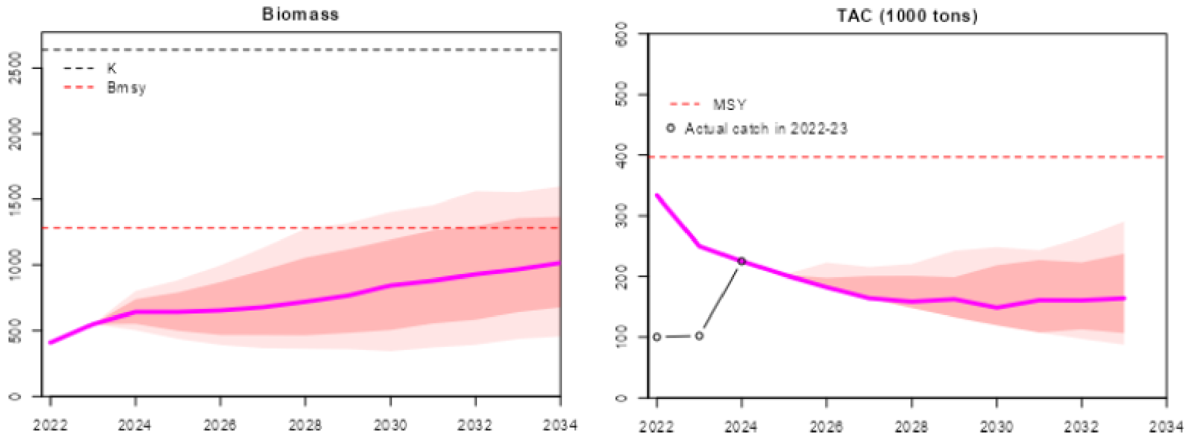


Figure 5.7. Simulation trajectories of biomass and TAC of Pacific saury.

The projection is under the Robustness Case, which assumes negative effects on productivity caused by climate trends (NPFC, 2024). The harvest control rule applied to this simulation is the interim one adopted at the latest NPFC annual meeting in April 2024. The solid pink line illustrates the median trajectory. The dark and light shaded areas correspond to the 60% and 80% intervals, respectively. The result shows that the biomass is unlikely to recover to BMSY in ten years, and TAC is likely to decrease and remain at a low level. This figure is quoted from the final report of NPFC's Fifth Meeting of the Joint SC-TCC-COM Small Working Group on Management Strategy Evaluation for Pacific Saury.

5.3 Methods

5.3.1 Estimation of revenue, cost, and profit of the saury fishery

First, this policy analysis attempts to estimate the current (defined as the end of the 2023 fishing season) revenues, costs, and profits of saury fishers and analyze the fishery's profitability. The analysis considers historical categorization by vessel size classes (i.e., small, medium, and large), and assumes revenues and costs depend on size classes.

Revenue

As mentioned in the previous section, the percentage of each IQ to TAC (i.e., QS) is calculated every year: A sum of (1) 30% divided by the number of all active vessels and (2) 70% divided in proportion to the amount of catch by a vessel for the past three years is a QS for the vessel. This policy analysis defines the latter (2) as the catch potential of vessel *i*, and it is shown by:

$$Catch_i = QS_{i,2023} - 30/N_{total,2023} \tag{1}$$

where $Catch_{i,t}$, $QS_{i,t}$, and $N_{total,t}$ are the catch potential of vessel i, QS of vessel i, and the total number of active vessels in year *t*, respectively. This analysis assumes that catch potential is a unique value assigned to each vessel representing the magnitude of the expected catch and is constant over time. Table 2.2 lists the catch potential obtained by Eq. (1) using QS data as of November 2023, quoted from the Fishery Agency of Japan (Fisheries Agency of Japan, n.d.i).

Table 5.2. A list of quota share (QS) of the licensed vessels for North Pacific saury fishery as of November 2023.

		Original data		Processed data	
No.	GT	Annual QS (%) [A]	Annual IQ (t)	Minimum QS [B]	Catch Potential ([A]-[B])
1	19	0	0	0	**0**
2	19	0	0	0	**0**
3	19	0	471.422	0	**0**
4	19	0	490.202	0	**0**
5	19	0	473.013	0	**0**
6	19	0	471.422	0	**0**
7	199	0.280373	0	0.265486726	**0.014886274**
8	147	0.280373	0	0.265486726	**0.014886274**
9	19	0.33122	471.452	0.265486726	**0.065733274**
10	19	0.356371	471.664	0.265486726	**0.090884274**
11	199	0.374116	1430.435	0.265486726	**0.108629274**
12	19	0.386242	472.494	0.265486726	**0.120755274**
13	19	0.403834	471.798	0.265486726	**0.138347274**
14	19	0.409372	472.16	0.265486726	**0.143885274**
15	19	0.416319	478.39	0.265486726	**0.150832274**
16	19	0.422217	473.684	0.265486726	**0.156730274**
17	29	0.42271	556.279	0.265486726	**0.157223274**
18	19	0.432589	482.792	0.265486726	**0.167102274**
19	19	0.434891	487.315	0.265486726	**0.169404274**
20	19	0.443161	478.258	0.265486726	**0.177674274**
21	19	0.446269	506.719	0.265486726	**0.180782274**
22	188	0.455859	1418.096	0.265486726	**0.190372274**
23	29	0.460316	556.279	0.265486726	**0.194829274**
24	19	0.46556	491.926	0.265486726	**0.200073274**
25	19	0.477536	471.422	0.265486726	**0.212049274**
26	19	0.481865	486.35	0.265486726	**0.216378274**
27	19	0.482629	478.971	0.265486726	**0.217142274**
28	19	0.4843	516.569	0.265486726	**0.218813274**
29	19	0.487828	494.763	0.265486726	**0.222341274**
30	19	0.487975	512.328	0.265486726	**0.222488274**
31	19	0.494252	482.679	0.265486726	**0.228765274**
32	19	0.503548	481.404	0.265486726	**0.238061274**
33	19	0.510301	526.637	0.265486726	**0.244814274**
34	29	0.519126	584.068	0.265486726	**0.253639274**
35	19	0.522268	472.21	0.265486726	**0.256781274**
36	29	0.527827	567.894	0.265486726	**0.262340274**
37	19	0.53912	518.891	0.265486726	**0.273633274**
38	29	0.542422	588.176	0.265486726	**0.276935274**
39	44	0.55382	557.472	0.265486726	**0.288333274**
40	19	0.559807	481.97	0.265486726	**0.294320274**
41	19	0.560996	518.383	0.265486726	**0.295509274**
42	19	0.564363	519.833	0.265486726	**0.298876274**
43	29	0.564959	573.083	0.265486726	**0.299472274**
44	198	0.565661	1282.317	0.265486726	**0.300174274**
45	19	0.579791	472.497	0.265486726	**0.314304274**
46	29	0.582963	590.726	0.265486726	**0.317476274**
47	29	0.594541	594.692	0.265486726	**0.329054274**
48	19	0.595241	499.702	0.265486726	**0.329754274**
49	39	0.616335	575.775	0.265486726	**0.350848274**
50	29	0.622506	579.18	0.265486726	**0.357019274**
51	29	0.624827	597.135	0.265486726	**0.359340274**
52	19	0.627599	486.454	0.265486726	**0.362112274**
53	187	0.631286	1449.9	0.265486726	**0.365799274**
54	41	0.653719	700.067	0.265486726	**0.388232274**
55	19	0.673332	477.191	0.265486726	**0.407845274**
56	29	0.676481	628.889	0.265486726	**0.410994274**
57	19	0.706526	496.494	0.265486726	**0.441039274**
58	42	0.71354	671.153	0.265486726	**0.448053274**
59	29	0.718575	666.217	0.265486726	**0.453088274**
60	19	0.721138	490.588	0.265486726	**0.455651274**
61	29	0.759857	655.023	0.265486726	**0.494370274**
62	49	0.768115	602.35	0.265486726	**0.502628274**
63	29	0.779165	569.633	0.265486726	**0.513678274**
64	120	0.80025	1420.517	0.265486726	**0.534763274**
65	199	0.834595	1557.33	0.265486726	**0.569108274**
66	199	0.868354	1542.812	0.265486726	**0.602867274**
67	29	0.876666	636.134	0.265486726	**0.611179274**
68	199	0.905193	1610.799	0.265486726	**0.639706274**
69	44	0.907156	621.366	0.265486726	**0.641669274**
70	49	0.911547	715.941	0.265486726	**0.646060274**
71	176	0.92057	1775.383	0.265486726	**0.655083274**
72	29	0.922755	623.244	0.265486726	**0.657268274**
73	199	0.967112	1505.098	0.265486726	**0.701625274**
74	29	0.98773	663.91	0.265486726	**0.722243274**
75	49	1.028084	803.978	0.265486726	**0.762597274**
76	198	1.110425	1402.922	0.265486726	**0.844938274**
77	199	1.113737	1535.852	0.265486726	**0.848250274**
78	167	1.126137	1451.355	0.265486726	**0.860650274**
79	199	1.188537	1625.132	0.265486726	**0.923050274**
80	199	1.228727	1525.74	0.265486726	**0.963240274**
81	199	1.260604	1693.062	0.265486726	**0.995117274**
82	199	1.29058	1432.75	0.265486726	**1.025093274**
83	199	1.297297	1440.583	0.265486726	**1.031810274**
84	199	1.337547	1444.586	0.265486726	**1.072060274**
85	199	1.358518	1505.96	0.265486726	**1.093031274**
86	199	1.412129	1475.328	0.265486726	**1.146642274**
87	199	1.454555	1612.946	0.265486726	**1.189068274**
88	199	1.454607	1465.855	0.265486726	**1.189120274**
89	199	1.481691	1547.218	0.265486726	**1.216204274**
90	199	1.514657	1583.67	0.265486726	**1.249170274**
91	199	1.519279	1614.48	0.265486726	**1.253792274**
92	199	1.521172	1560.51	0.265486726	**1.255685274**
93	199	1.532375	1520.121	0.265486726	**1.266888274**
94	199	1.534671	1571.665	0.265486726	**1.269184274**
95	199	1.576339	1522.047	0.265486726	**1.310852274**
96	199	1.583535	1704.18	0.265486726	**1.318048274**
97	199	1.613061	1514.769	0.265486726	**1.347574274**
98	11	1.629686	1500.192	0.265486726	**1.364199274**
99	199	1.636809	1571.611	0.265486726	**1.371322274**
100	199	1.656881	1477.146	0.265486726	**1.391394274**
101	184	1.670423	1551.132	0.265486726	**1.404936274**
102	13	1.671777	1562.38	0.265486726	**1.406290274**
103	199	1.679521	1523.776	0.265486726	**1.414034274**
104	199	1.701594	1572.463	0.265486726	**1.436107274**
105	199	1.705284	1436.795	0.265486726	**1.439797274**
106	199	1.722895	1484.466	0.265486726	**1.457408274**
107	199	1.744973	1567.688	0.265486726	**1.479486274**
108	199	1.786166	1556.018	0.265486726	**1.520679274**
109	199	1.883035	1626.384	0.265486726	**1.617548274**
110	199	1.885247	1686.298	0.265486726	**1.619760274**
111	199	1.91628	1648.212	0.265486726	**1.650793274**
112	199	1.925551	1500.911	0.265486726	**1.660064274**
113	199	2.045705	1662.233	0.265486726	**1.780218274**

The data source is Fishery Agency of Japan (n.d.i). GT (gross tonnage) represents the size of vessel. The permit number and vessel name are deleted because they are not necessary for the analysis. Minimum QS is a portion of QS that is equally distributed to the vessels, calculated by dividing 30% by the number of total vessels (=113). Catch potential can be obtained by QS minus Minimum QS. Note that if a negative value of potential catch is obtained, zero is applied instead.

This analysis defines the relative rate of the catch potential of vessel *i* to all vessels in year *t* as the annual harvest share of vessel *i*, and it is shown by:

$$H_{i,t} = \frac{Catch_i}{\sum_{i=1,\ldots,N_{total,t}} Catch_i} \tag{2}$$

where $H_{i,t}$ is the annual harvest share of vessel *i* in year *t*. Unit price of saury is assumed to be constant among vessels, and the annual revenue of vessel *i* [thousand yen, KJPY] can be obtained as:

$$R_{i,t} = R_{total,t} \times H_{i,t} \tag{3}$$

where $R_{i,t}$ and $R_{total,t}$ are the revenue of vessel *i* and the total revenue from the fishery in year *t*, respectively. Aggregated revenue $R_{size,t}$ and harvest rate $H_{size,t}$ for each size class in year *t* can be obtained by summing up each vessel's harvest rate. The three size categories, again, are small (less than 20 gross tonnage (GT)), medium (less than 100 GT), and large (100 GT or more). The aggregated revenues for each size class are:

$$R_{small,t} = R_{total,t} \times H_{small,t} = R_{total,t} \times \sum H_{i,t}\ (GT_i < 20) \tag{4}$$

$$R_{medium,t} = R_{total,t} \times H_{medium,t} = R_{total,t} \times \sum H_{i,t}\ (20 \leq GT_i < 100) \tag{5}$$

$$R_{large,t} = R_{total,t} \times H_{large,t} = R_{total,t} \times \sum H_{i,t}\ (GT_i \geq 100) \tag{6}$$

where GT_i is the GT of vessel *i*.

Cost

Although no official data set on the cost of the saury fishery is available, there are several accessible documents from "fisheries structural reforming projects" regarding the saury fishery, which include cost structure data for fishing vessels involved. Among those projects, this analysis refers to a project of renewing two large-sized class vessels and improving the profitability of the saury fishery because this project is the latest project regarding the saury fishery. It started in 2018 when the ocean environment changes and poor catch problem already emerged (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). Based on the information shown in the document of this project (hereafter, Business Plan), the component of cost can be obtained as follows:

$$C_{size,t} = Fuel_{size,t} + Ice_{size,t} + Fee_{size,t} + Labor_{size,t} + Fixed_{size,t} \tag{7}$$

where $C_{size,t}$ and $Fixed_{size,t}$ are the aggregated total cost [KJPY] and fixed cost [KJPY] for each size class in year *t*, respectively. $Fuel_{size,t}$, $Ice_{size,t}$, and $Fee_{size,t}$ are the aggregated running costs [KJPY] for each size class in year *t*.

The aggregated fuel cost for each size class can be described as follows:

$$Fuel_{size,t} = Cons_{size,t} \times Trip_{size,t} \times FuelPrice_{t} \tag{8}$$

where $Cons_{size,t}$ and $Trip_{size,t}$ are the average consumption of fuel per trip [KL] and the aggregated number of trips for each size class in year *t*, respectively. The average fuel price [JPY/L] in year *t* is the same regardless of size class. As for the number of trips, smaller vessels had shorter but more frequent trips than larger vessels did, given that their storage capacity was small and the fishing area was close to the ports. Recently, however, their trip distance increased because the saury migration route is shifting eastward. The difference in number of trips between small and large vessels also has become narrower over the decade since 2010 (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018). This analysis assumes that the operation style is not different among size class, and the number of trips for each size class ($Trip_{size,t}$) is simply in proportion to the number of active vessels, as shown in the following equation:

$$Trip_{size,t} = Trip_{total,t} \times \frac{N_{size,t}}{N_{total,t}} \tag{9}$$

where $Trip_{total,t}$ and $N_{size,t}$ are the number of total trips among all size classes and the number of active vessels for each size class in year *t*, respectively.

The aggregate ice cost for each size class can be described as follows:

$$Ice_{size,t} = Usage_{size,t} \times Trip_{size,t} \times IcePrice_t \tag{10}$$

where $Usage_{size,t}$ is the average usage of ice per trip [ton] for each size class in year *t*. The average ice price [KJPY/ton] in year *t* is the same regardless of size class.

The aggregate landing fee for each size class is five percent of the landed value and can be obtained as follows:

$$Fee_{size,t} = 0.05 \times R_{size,t} \tag{11}$$

The aggregate labor cost [KJPY] for each size class in year *t* can be described as:

$$\begin{aligned} Labor_{size,t} = Salary_t \times \{4.96 + 1.16 \times (Crew_{size,t} - 3)\} \times Mon_t \\ + Allowance_t \times Crew_{size,t} \times Mon_t \end{aligned} \tag{12}$$

where $Salary_t$ and $Allowance_t$ are the average monthly salary and allowance for a regular crew in year *t* regardless of the size class. $Crew_{size,t}$ is the average number of the crew members for each size class in year *t*. It is noted that the aggregate monthly salary for captain, chief fisher, and chief engineer is 4.96 times higher than the salary for three regular crew members. Also, the average monthly salary of the rest of crew members is 1.16 higher than the salary for regular crew members ($Salary_t$). The first term in Eq. (12) considers the difference in salary among crew rank, whereas allowance is the same regardless of crew rank in the second term. Mon_t is the length of fishing season in year *t*, which is usually five months from August to December. The labor cost data is quoted from the annual statistics of seafarers conducted by Ministry of Land, Infrastructure, Transport and Tourism (2023), to which the Business Plan referred as well (Japan Saury Stick-held Dip-net Fishery Cooperative Association, 2018).

Net profit

The aggregate annual net profit ($P_{size,t}$) for each size class in year *t* can be obtained by:

$$P_{size,t} = R_{size,t} - C_{size,t} \tag{13}$$

First, the current profit as of the end of 2023 was calculated, with a set of parameter values shown in the Table 5.3.

Table 5.3. Parameters for calculating the current profit (as of the end of 2023).

Parameters	Value	Unit	Source
$N_{total,2023}$	111	no.	Fisheries Agency of Japan
$N_{small,2023}$	38	no.	Fisheries Agency of Japan
$N_{medium,2023}$	25	no.	Fisheries Agency of Japan
$N_{large,2023}$	48	no.	Fisheries Agency of Japan
$R_{total,2023}$	10,117,017	KJPY	Japan Saury Stick-held Dip-net Fishery Cooperative Association
$H_{small,2023}$	0.15	-	Fisheries Agency of Japan (based on Table 2.2)
$H_{medium,2023}$	0.15	-	Fisheries Agency of Japan (based on Table 2.2)
$H_{large,2023}$	0.3	-	Fisheries Agency of Japan (based on Table 2.2)
$Cons_{large,2018}$	17	KL	Business Plan
$Trip_{total,2023}$	1,663	no.	Japan Saury Stick-held Dip-net Fishery Cooperative Association
$FuelPrice_{2023}$	100	JPY/L	Fisheries Agency of Japan
$Usage_{large,2018}$	35	ton	Business Plan
$IcePrice_{2018}$	16	KJPY/ton	Business Plan
$Salary_{2022}$	845,727	JPY	Ministry of Land, Infrastructure, Transport and Tourism
$Crew_{small,2018}$	7	no.	Business Plan
$Crew_{medium,2018}$	8	no.	Business Plan
$Crew_{large,2018}$	17	no.	Business Plan
Mon_{2023}	5	months	Japan Saury Stick-held Dip-net Fishery Cooperative Association
$Allowance_{2022}$	88,460	JPY	Ministry of Land, Infrastructure, Transport and Tourism
$Fixed_{large,2018}$	30,293	KJPY	Business Plan

Note that the number of total vessels is 111, less than 113 in Table 5.2, because two vessels are seen as inactive because of their zero quota. Harvest share for each size is calculated according to Eq. (1) & (2) and Table 5.2. Running cost is only available for large-sized vessels in Business Plan as of 2018.

Since some parameters are not directly available to calculate the profit in 2023, the following assumptions were put:

$$Cons_{large,2018} = Cons_{large,2023} = Cons_{small,2023} = Cons_{medium,2023} \tag{14}$$

$$Usage_{large,2018} = Usage_{large,2023} \tag{15}$$

$$Usage_{small[medium],t} = Usage_{large,t} \times \frac{H_{small[medium],t}}{H_{large,t}} \tag{16}$$

$$IcePrice_{2018} = IcePrice_{2023} \tag{17}$$

$$Salary_{2022} = Salary_{2023} \tag{18}$$

$$Crew_{size,2018} = Crew_{size,2023} \tag{19}$$

$$Allowance_{2022} = Allowance_{2023} \tag{20}$$

$$Fixed_{large,2018} = Fixed_{large,2023} \tag{21}$$

$$Fixed_{small,t} = 0.2 \times Fixed_{large,t} \quad Fixed_{medium,t} = 0.8 \times Fixed_{large,t} \tag{22}$$

It is assumed that the fuel consumption per trip has not changed since 2018 and is constant among vessels, given that the eastward shift of saury's migration route already happened in 2018 and is continuing. The ice usage is assumed to depend on how much saury a vessel can catch. Another assumption is that the average fixed cost for repairing vessels, renewing gears, purchasing lubricant oil and other consumables, and paying for communication charges as well as general and administrative expenses does not change from 2018 to 2023 and that the average fixed cost of the small and medium size class is smaller than the large class. Table 5.4 shows the calculation result, revealing that the saury fishery is no longer viable for any size class.

Table 5.4. Estimation of current (as of the end of 2023) net profit from the saury fishery.

Size class	Revenue (2023)	Cost (2023)	Net profit (2023)
small	1,517,553	2,994,671	-1,477,118
medium	1,517,553	2,602,941	-1,085,388
large	7,081,912	8,088,036	-1,006,124
total	10,117,018	13,685,648	-3,568,630

(Unit: KJPY)

The calculation of total net profit in 2022 resulted in a deficit of 2,417,949 KJPY, implying that the situation is worsening now (Table 5.5). With another parameter set, estimating the total net profit in 2016, when the landed volume already showed a declining trend but was still over 100,000 tons, turned out to be 5,425,950 KJPY, demonstrating a successful business as of 2016 (Table 5.5). Between 2016 and 2023, the total landings have decreased by 80 percent, whereas the price has increased threefold, with the aggregated revenue resulting in a decline of more than half (Fig. 5.8). The cost has declined by 25 percent mainly because of the decrease in the number of trips (less than half) driven by the eastward shift of fishing ground.

Table 5.5. Estimation of current and past net profit from the saury fishery.

Year	**Revenue**	**Cost**	**Net profit**
2016	23,592,528	18,166,578	5,425,950
2022	10,312,799	12,730,748	-2,417,949
2023	10,117,018	13,685,648	-3,568,630

(Unit: KJPY)

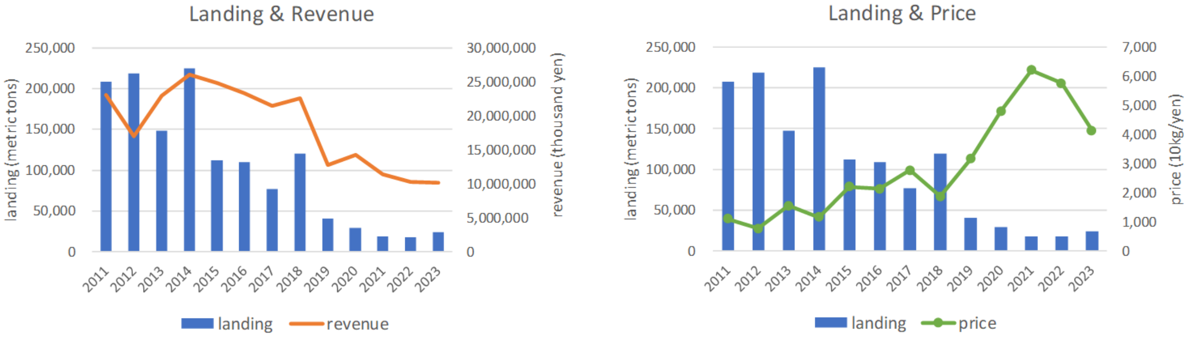


Figure 5.8. Timeseries of landing volume (metric tons), revenue (thousand yen), and average price (10 kilograms per yen) of North Pacific saury fishery.

(Source: Japan Saury Stick-held Dip-net Fishery Cooperative Association. n.d.)

This trend implies that the root cause of this fishery's failure is too little revenue caused by too few landings. However, the abundance of saury is unlikely to return to the BMSY soon despite setting catch limits if the current less productive condition continues (Fig. 5.7). The price of saury is unlikely to increase anymore, given that saury is a commodity in the market offering other species of fish as substitutes for saury. Hence, reducing costs rather than increasing revenue could be a more likely potential solution. Meanwhile, a significant reduction in running or fixed costs per vessel is unrealistic. Therefore, rationalizing the saury fishery may be worth considering. According to Fina (2005), rationalization is "used to describe a management plan that results in an allocation of labor and capital between fishing and other industries that maximizes the net value of production." The following section proposes four rationalization policy options as potential solutions to the policy problem: "*There is too little profit from the fisheries to sustain the livelihoods of all the current saury fishers*."

5.3.2 Projection of future scenarios under policy interventions

Next, a model is developed to simulate the fishery dynamics and project future scenarios from 2024 to 2030 under different policy options. Specifically, this model can project aggregated net profit and the number of vessels for each size class given several assumptions. The total landings and average price of saury in 2024 are assumed to be the average from 2021 to 2023. Accordingly, the total revenue in 2024 can be obtained by:

$$R_{total,2024} = L_{2024} \times P_{2024} \tag{23}$$

where L_{2024} and P_{2024} are the total landings and the average ex-vessel price of saury in 2024, respectively. Although the future stock status and market environment of saury are uncertain, this model assumes that (1) the landings and price will be constant until 2030, (2) the current low-level abundance and eastward shift of migration route are likely to continue, and (3) the market demand for saury is unlikely to change significantly. Similarly, the model assumes that all cost-related parameters will be constant to simplify this analysis (Table 5.6). In principle, the variables of this model are the number of vessels for each size class, letting other parameters remain constant.

Table 5.6. Default parameters used to predict future profit from 2024 to 2030.

Parameters	**Value**	**Unit**	**Assumption**
L_{2024}	20,211	ton	$L_{2024} = L_{2025} = \cdots = L_{2030}$
$Price_{2024}$	5,368	JPY/10kg	$Price_{2024} = Price_{2025} = \cdots = Price_{2030}$
$R_{total,2024}$	10,849,265	KJPY	$R_{total,2024} = R_{total,2025} = \cdots = R_{total,2030}$
$N_{total,2024}$	107	no.	
$N_{small,2024}$	34	no.	4 vessels with no IQ already exited since 2023.
$N_{medium,2024}$	25	no.	
$N_{large,2024}$	48	no.	
$Cons_{size,2024}$	17	KL	$Cons_{size,2024} = Cons_{size,2025} = \cdots = Cons_{size,2030}$
$Trip_{total,2024}$	1,379	no.	$Trip_{total,2024} = Trip_{total,2025} = \cdots = Trip_{total,2030}$
$FuelPrice_{2024}$	100	JPY/L	$FuelPrice_{2024} = FuelPrice_{2025} = \cdots = FuelPrice_{2030}$
$Usage_{large,2024}$	35	ton	$Usage_{size,2024} = Usage_{size,2025} = \cdots = Usage_{size,2030}$
$IcePrice_{2024}$	16	KJPY/ton	$IcePrice_{2024} = IcePrice_{2025} = \cdots = IcePrice_{2030}$
$Salary_{2024}$	845,727	JPY	$Salary_{2024} = Salary_{2025} = \cdots = Salary_{2030}$
$Crew_{small,2024}$	7	no.	$Crew_{small,2024} = Crew_{small,2025} = \cdots = Crew_{small,2030}$
$Crew_{medium,2024}$	8	no.	$Crew_{medium,2024} = Crew_{medium,2025} = \cdots = Crew_{medium,2030}$
$Crew_{large,2024}$	17	no.	$Crew_{large,2024} = Crew_{large,2025} = \cdots = Crew_{large,2030}$
Mon_{2024}	5	months	$Mon_{2024} = Mon_{2025} = \cdots = Mon_{2030}$
$Allowance_{2024}$	88,460	JPY	$Allowance_{2024} = Allowance_{2025} = \cdots = Allowance_{2030}$
$Fixed_{large,2024}$	30,293	KJPY	$Fixed_{large,2024} = Fixed_{large,2025} = \cdots = Fixed_{large,2030}$

This model assumes that vessels will exit at the end of a year if the net profit in their respective size class is negative. The catch potential determines the exit sequence, with the vessel with the lowest catch potential exiting first. As some vessels exit, the remaining vessels will increase their harvest. In principle, this model assumes that the available saury is “re-allocated” to the remaining fishers each year. This means that the total revenue is distributed among the remaining vessels in proportion to their catch potential. Therefore, the harvest share of a remaining vessel *j* in year *t* $(t = 2024, 2025, \cdots, 2030)$ can be obtained by:

$$H_{j,t} = \frac{Catch_j}{\sum_{i=1}^{N_{total,2023}} Catch_i - \sum_{k=1}^{N_{exit,t}} Catch_k} = \frac{Catch_j}{\sum_{j=1}^{N_{total,t}} Catch_j} \tag{24}$$

where $N_{exit,t}$ is the number of vessels which already exited before year *t*. Therefore, the following equation always holds:

$$N_{total,2023} = N_{total,t} + N_{exit,t} \tag{25}$$

This idea to estimate the profits of remaining fishers follows Tanaka (2017).

5.4 Proposed policy options and projected scenarios under each option

This study proposes the following four policy options to rationalize the saury fishery. The first option is “management change,” adding transferability to quota share (QS) and incentivizing inefficient fishers to sell their quota to more profitable fishers who are willing to pay more for the quota than the inefficient fishers would earn from the fishery. This management system is called ITQ (Individual Transferable Quota) management, which can improve the economic efficiency of the fishery by redirecting catch towards those who can earn the most profit and reduce the over-capacity of the fishery (Anderson et al., 2019). Under the current management of the saury fishery, the government (FAJ) renews the QS of individual vessels every year. Their quota is transferable during the fishing season with FAJ's approval, but QS and quota are reshuffled before the succeeding fishing season starts. Even though a vessel transfers all the quota it owns in one year, new QS and quota will be redistributed in the succeeding year. In the proposed ITQ option, in contrast, the government will no longer renew QS but allocate one-shot permanent QS to each vessel. Because QS becomes an asset, vessel owners can freely purchase QS from, or sell QS to, other saury fishers in the market. This option expects the number of vessels to decrease and the remaining vessels to become profitable.

The next two policy potions mobilize governmental budgets. The second option is "partial permit termination," terminating the permits of some vessels in exchange for providing one-shot relief or compensation to the vessel owners. This option resembles "buybacks," in which governments purchase fishing vessels, gear, and permits from fishers to reduce excess capacity, expecting the remaining fishers to increase their potential yield and profits (Squires, 2010; Cisneros-Montemayor et al., 2016). This analysis does not use the term "buybacks" because the permit granted to the saury fishery is not an asset of fishers, and the government does not intend to buy back the permit. Instead, "relief" (Demura, 2006) or "compensation" (Tanaka, 2017) would be more suitable for the Japanese context.

The third option is "income support," curtailing fishing effort by shortening the fishing period by a month in exchange for giving out income support to the vessel owners. Unlike the previous two options, this income support option attempts to reduce excess capacity by input control, i.e., shortening the fishing period, instead of cutting the number of vessels, expecting cost reduction combined with income support to make the net profits positive.

The fourth option, “diversification,” takes a different approach from the rest. It aims to increase revenue by issuing new permits for catching alternative species. The goal is to achieve positive net profits by combining alternative fishing opportunities with the saury fishery. This option, suggested by the study group (Table 5.2), is carefully examined in this analysis to determine its feasibility and potential benefits for the saury fishery.

Lastly, this analysis projects a future scenario under the status quo. The definition of the status quo in this analysis is that the government will keep the current operation without changing the management system, distributing any subsidies, or allowing fishers to catch alternative species.

5.4.1 Status Quo

Under the status quo scenario, vessel owners will exit the fishery in the order of catch potential if the total net profit of their size class is negative. The exit will continue until the total net profit of the size class in question becomes positive. From 2021 to 2023, the active vessels decreased from 125 to 109 (Nakayama et al., 2024). This option assumes that up to 10 vessels will exit in a single year, which can be described as:

$$N_{exit,t+1} - N_{exit,t} \leq 10 \tag{26}$$

t	2024	2025	2026	2027	2028	2029	2030
$P_{small,t}$	-1,046,938	-698,579	-352,162	39,466	-9,254	40,992	40,992
$P_{medium,t}$	-862,207	-937,991	-790,869	-666,231	-166,493	45,025	45,025
$P_{large,t}$	-203,671	252,395	167,883	289,507	421,539	543,163	543,163
$P_{total,t}$	-2,112,816	-1,384,175	-975,148	-337,258	245,792	629,180	629,180
$N_{small,t}$	34	27	19	11	11	10	10
$N_{medium,t}$	25	25	23	21	11	7	7
$N_{large,t}$	48	45	45	45	45	45	45
$N_{total,t}$	107	97	87	77	67	62	62

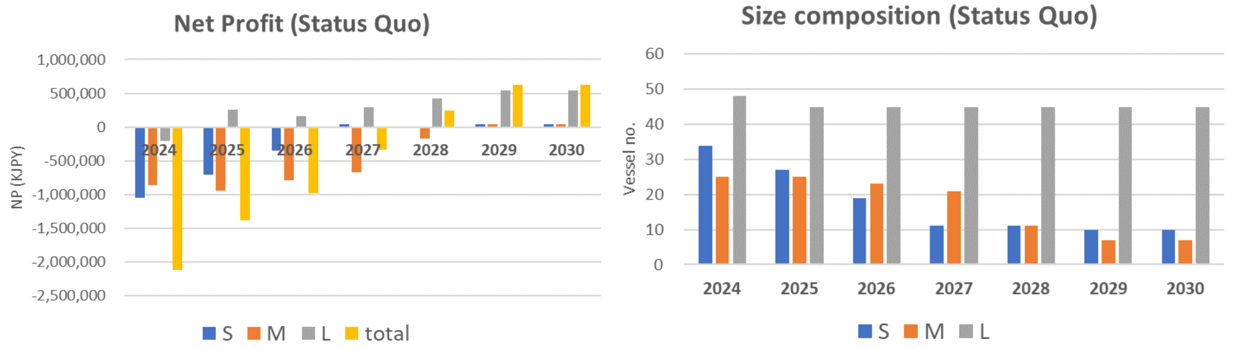


Figure 5.9. Projected scenario under the status quo.

Upper table shows calculated net profit (KJPY) and number of vessels for each size class from 2024 to 2030. Lower left is a timeseries of net profit. Lower right is a timeseries of vessel size composition.

Fig. 5.9 shows the result of the prediction for the status quo. Net profit in the small and medium size classes will remain negative until 2028. As a result, vessels in these size classes continue to exit, with the number becoming less than one-third from the original state. As the vessels decrease, the total net profit will recover.

5.4.2 Option 1: Management change

This option changes the management system so that inefficient fishers, i.e., vessels with low catch potential, will sell their quota to more profitable fishers, i.e., vessels with high catch potential, willing to pay more for the quota than the inefficient fishers would earn from the fishery. This model assumes that vessel owners only in the large-size class buy out QS from exiting fishers to increase their catch potential. Under this option, the aggregated catch potential for the large size class in year *t* can be described as follows:

$$H_{large,t} = \frac{\sum_{j=1,\dots,N_{large,t}} Catch_j + \sum_{k=1,\dots,N_{exit,t}} Catch_k}{\sum_{i=1,\dots,N_{total,t}} Catch_i} \quad \left(GT_j \geq 100\right) \tag{27}$$

Japan has no experience in implementing this ITQ management system. Hence, this model assumes that the management change requires one year of preparation and will be implemented after the end of the 2024 fishing season. Case studies from other countries demonstrate that quota transactions drive substantial structural changes (Anderson et al., 2019). For example, about 60% of Bering Sea crab vessels exited in the first year of ITQ implementation (NPFMC, 2017). In the case of British Columbia halibut fishery, active vessels decreased from 433 in 1991 to 182 in 2006 through consolidation after ITQ was introduced (Edward & Pinkerton, 2019). Introducing ITQ into the saury fishery will accelerate the exit because vessel owners with large deficits (small catch potential) are incentivized to leave the fishery immediately by selling their QS. In contrast, vessel owners in the large size class have an incentive to let other fishers sell out by purchasing their QS, expecting more share of landings from the fishery in the future. This scenario assumes that 20 vessels will exit annually in the first two years. As the deficits are solved, the exit speed will become slower during the next two years, and ten vessels will exit yearly. In the next two years, five vessels per year will exit. This assumption can be described as follows:

$$N_{exit,t+1} - N_{exit,t} = 20 \ (t = 2024, 2025) \tag{28}$$

$$N_{exit,t+1} - N_{exit,t} = 10 \ (t = 2026, 2027) \tag{29}$$

$$N_{exit,t+1} - N_{exit,t} = 5 \ (t = 2028, 2029) \tag{30}$$

t	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
$P_{small,t}$	-1,046,938	-425,840	30,041	-16,499	115,245	91,205	91,205
$P_{medium,t}$	-862,207	-990,077	-726,449	-187,433	-17,965	0	0
$P_{large,t}$	-203,671	636,186	992,911	1,267,799	1,357,366	1,938,632	2,575,927
$P_{total,t}$	-2,112,816	-779,731	296,503	1,063,867	1,454,646	2,029,837	2,667,132
$N_{small,t}$	34	20	7	7	2	2	2
$N_{medium,t}$	25	23	16	6	1	0	0
$N_{large,t}$	48	44	44	44	44	40	35
$N_{total,t}$	107	87	67	57	47	42	37

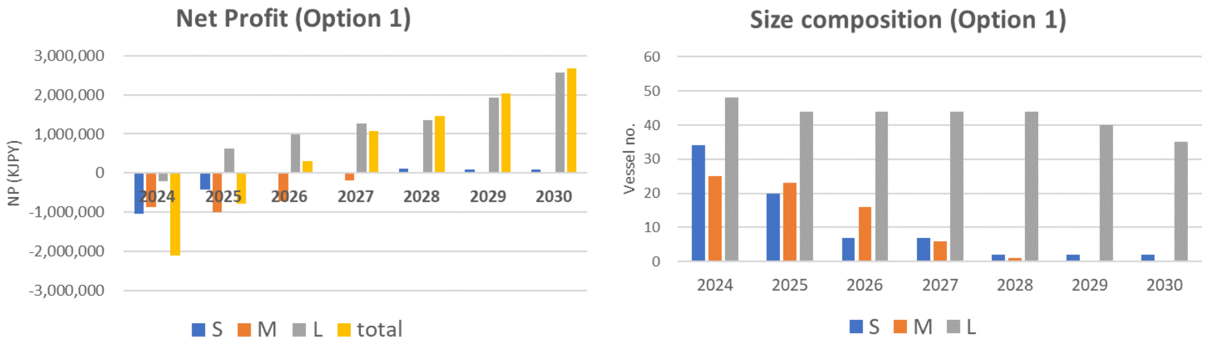


Figure 5.10. Projected scenario under option 1 (management change).

Upper table shows calculated net profit (KJPY) and number of vessels for each size class from 2024 to 2030. Lower left is a timeseries of net profit. Lower right is a time series of vessel size composition.

Fig. 5.10 shows the prediction for this option (management change). Total net profit will recover to positive in 2026 and continue to rise over time. On the other hand, the number of small and medium-sized vessels will continue to decrease, eventually disappearing altogether. The model results suggest consolidation will happen under this option, as in the past cases.

5.4.3 Option 2: Partial permit termination

In this option, the government terminates the permits of some vessels in exchange for providing one-shot relief to the vessel owners. A similar intervention, buybacks, generally adopt fixed-price buybacks or reverse auctions to determine how much budget the government offers and who accepts the offer (Squires, 2010). Previous cases in Japan were reductions of the number of vessels with compensation shared among the remaining fishers, in conjunction with relief provided by the government, when Japanese vessels had to retreat from foreign waters in the late 1970s and 1980s (Demura, 2006; Tanaka, 2017). Under the current fisheries restructuring scheme, the Japan Fisheries Association is supposed to mediate with the government and fishers' groups (FCAs) to carry out a vessel reduction program. If this option is implemented, the saury FCA may have an internal discussion to decide how many and which vessels will exit, and the Japan Fisheries Association may deliver its list to the government to request its approval. This model assumes that this process requires one year of preparation and will be implemented after the end of the 2024 fishing season. As for the number of exiting vessels, the saury industry is expected to request assistance for all the vessels with deficits by providing relief through permit termination. Hence, this model counts the vessels for each size class in the order of catch potential until the following conditions are all met:

$$P_{small,2025} \geq 0, P_{medium,2025} \geq 0, P_{large,2025} \geq 0 \tag{31}$$

The listed vessels will exit altogether before the 2025 fishing season starts.

t	2024	2025	2026	2027	2028	2029	2030
$P_{small,t}$	-1,046,938	88,159	88,159	88,159	88,159	88,159	88,159
$P_{medium,t}$	-862,207	22,333	22,333	22,333	22,333	22,333	22,333
$P_{large,t}$	-203,671	712,671	712,671	712,671	712,671	712,671	712,671
$P_{total,t}$	-2,112,816	823,163	823,163	823,163	823,163	823,163	823,163
$N_{small,t}$	34	8	8	8	8	8	8
$N_{medium,t}$	25	7	7	7	7	7	7
$N_{large,t}$	48	44	44	44	44	44	44
$N_{total,t}$	107	59	59	59	59	59	59

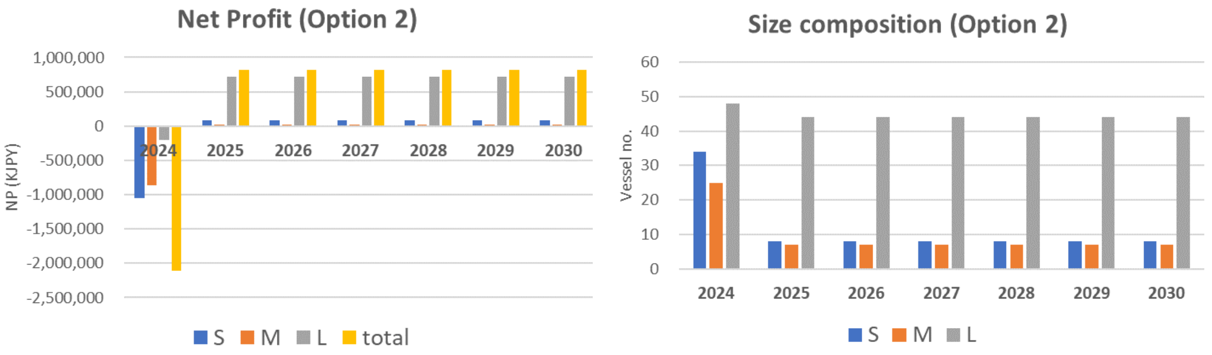


Figure 5.11. Projected scenario under option 2 (partial permit termination).

Upper table shows calculated net profit (KJPY) and number of vessels for each size class from 2024 to 2030. Lower left is a timeseries of net profit. Lower right is a timeseries of vessel size composition.

Fig. 5.11 shows the prediction for this option (partial permit termination). Total net profit will immediately recover to positive status in 2025 after implementation. About 50 vessels with deficits, mainly small and medium-sized vessels, will exit altogether through permit termination. Later, no vessel will exit because of its positive net profit.

In the past cases, the compensation shared with remaining fishers was based on expected future profit from the fishery, and the amount of government relief was based on costs necessary for the exit, e.g., vessel scrapping cost. Meanwhile, this principle was not applied to some cases where the fishery was already unprofitable, and a fixed amount of relief was offered (Demura, 2006). A recent case in Japan was the permit termination of the driftnet salmon fishery operating in the Russian EEZ, where 39 permits were terminated from 2016 to 2017 (Fisheries Agency of Japan, n.d.j). Because of the lack of remaining fishers, the exiting vessels received only governmental relief. When it comes to the saury fishery, it is already unprofitable, and some fishers will remain. Although it is uncertain what kind of relief or compensation scheme will be designed, this option assumes that the government and remaining fishers will share the cost of relief for the exiting fishers. In terms of calculating the total amount of relief, this study refers to the case of the driftnet salmon fishery as follows (Fisheries Agency of Japan, n.d.k):

$$\begin{aligned} Relief_{size} &= GearComp_{size} + LaborComp_{size} + RepairComp_{size} \\ &+ AdminComp_{size} + \frac{2}{3} ScrapCost_{size} \end{aligned} \tag{32}$$

The relief consists of gear cost compensation, labor cost compensation, vessel repair cost compensation, administrative cost compensation, and support for vessel scrapping cost, with all components specific to vessel size classes. For simplification, all exiting vessels are assumed to be scrapped so that those vessels will not re-enter the fishery or cause overfishing in other fisheries. Following the driftnet salmon fishery case, each compensation component can be described as follows:

$$GearComp_{large} = N_{exit,2025,size} \times GearPrice_{large} \times 0.4995 \tag{33}$$

$$\begin{aligned} LaborComp_{size} &= N_{exit,2025,size} \times Salary_{2024} \\ &\times \left\{4.96 + 1.16 \times \left(Crew_{size,2024} - 3\right)\right\} \times \left(Mon_{2024} \times 0.9 + 1.5\right) \end{aligned} \tag{34}$$

$$RepairComp_{size} = N_{exit,2025,size} \times RepairCost_{size} \tag{35}$$

$$AdminComp_{size} = (GearComp_{size} + LaborComp_{size} + RepairComp_{size}) \times 0.08 \tag{36}$$

where $N_{exit,t,size}$ is the number of vessels for each size class which exited before year t. Parameters $GearPrice_{size}$ and $RepairCost_{size}$ the averaged gear price and vessel repair cost for each size class, respectively. Vessel scrapping cost is dependent on vessel size in GT, and can be obtained as follows:

$$ScrapCost_{small} = UnitPrice_{small} \times \sum_{k=1,\ldots,N_{exit,small,2025}} GT_k \;\; (GT_k < 20) \tag{37}$$

$$ScrapCost_{medium} = UnitPrice_{medium} \times \sum_{k=1,\ldots,N_{exit,medium,2025}} GT_k \;\; (20 \leq GT_k < 100) \tag{38}$$

$$ScrapCost_{large} = UnitPrice_{large} \times \sum_{k=1,\ldots,N_{exit,large,2025}} GT_k \;\; (GT_k \geq 100) \tag{39}$$

Table 5.7. Parameters for calculating total amount of relief.

Parameters	**Value**	**Unit**	**Source**
$GearPrice_{large}$	6,475	KJPY	Business Plan
$GearPrice_{medium}$	5,188	KJPY	$0.8 \times GearPrice_{large}$
$GearPrice_{small}$	1,297	KJPY	$0.2 \times GearPrice_{large}$
$RepairCost_{large}$	12,000	KJPY	Business Plan
$RepairCost_{medium}$	9,600	KJPY	$0.8 \times RepairCost_{large}$
$RepairCost_{small}$	2,400	KJPY	$0.2 \times RepairCost_{large}$
$UnitPrice_{large}$	617,760	JPY/GT	The salmon driftnet case
$UnitPrice_{medium}$	439,560	JPY/GT	The salmon driftnet case
$UnitPrice_{small}$	463,320	JPY/GT	The salmon driftnet case

Note that parameters for labor cost compensation are the same as Table 5.3 and not shown in this table.

The parameter values are shown in Table 5.7. As for the relief cost share between the government and remaining fishers, this study follows the past fisheries restructuring scheme, which set the governmental share rate at four-ninths (Fisheries Agency of Japan, n.d.l). This analysis picks this ratio, and the amount of total relief borne by the government ($Relief_{govt}$) is described as:

$$Relief_{govt} = \frac{4}{9}\left(Relief_{small} + Relief_{medium} + Relief_{large}\right) \tag{40}$$

Table 5.8 This table shows the estimated total relief and cost distribution. How cost is allocated among the remaining fishers depends on internal discussion in the saury FCA. To help the remaining fishers pay the cost, a government-affiliated financial institution, Japan Finance Corporation (JFC), can provide a loan with a low interest rate (0.2 percent/year), a five-year deferral period, and a fifteen-year repayment period. This assumption is based on the actual loan program by JFC (Japan Finance Corporation, n.d). The estimated total annual interest (4,317 KJPY) is very small relative to the total expected profit from the fishery per year (823,163 KJPY). Also, the loan sum can be repaid in three years on condition of 823,163 KJPY of expected annual profit with an 8% discount rate. Hence, this cost distribution seems to be feasible enough.

Table 5.8. The total amount of relief to each size class (unit: KJPY) and cost distribution between the government and remaining fishers.

Size class	Total relief	Number of exited vessels	(per vessel)	Expediture (government)	Expediture (remaining fishers)	Number of remaining vessels
small	1,656,901	26	(63,727)	1,726,964	2,158,706	8
medium	1,471,820	18	(81,768)			7
large	756,949	4	(189,237)			44
total	3,885,670	52				59

Note that the number of exited vessels represents vessels which have their permit terminated and are qualified for receiving the relief.

5.4.4 Option 3: Income support

This option curtails fishing efforts by shortening the fishing period by a month (fishing effort is decreased by 20%) in exchange for giving out income support to the vessel owners, expecting cost reduction combined with income support to make the net profits positive. This intervention is assumed to be implemented swiftly from the 2024 fishing season and last five years until the 2028 fishing season. Some parameters under this option should be changed from the default in a way that the total landings and trips will decline by 20% in proportion to the length of the fishing period ($t = 2024{,}2025,\cdots,2028$):

$$Mon_t^* = 0.8 \times Mon_t = 4 \ \ (t = 2024{,}2025,\cdots,2028) \tag{41}$$

$$L_t^* = 0.8 \times L_t \ \ (t = 2024{,}2025,\cdots,2028) \tag{42}$$

$$Trip_{total,t}^* = 0.8 \times Trip_{total,t} \ \ (t = 2024{,}2025,\cdots,2028) \tag{43}$$

As a result, both the total revenues and costs will decrease. The loss of revenue is compensated by income supports calculated by the following equations:

$$Support_{t,size} = N_{size,t} \times UnitSupport_{size}$$

$$UnitSupport_{size} = Baseline_{size} \times 0.64 \times \frac{(Mon_t - Mon_t^*)}{Mon_t} \times \frac{2}{3} \times \frac{1}{N_{size,2024}} \tag{44}$$

$$Baseline_{size} = \frac{\left(R_{total,2021} + R_{total,2022} + R_{total,2023}\right)}{3} \times H_{size,2023} \tag{45}$$

where $Support_{size}$ is the sum of income support paid to all vessels in each size class. This calculation is followed by the past fisheries restructuring scheme (Fisheries Agency of Japan, n.d.l). This option assumes that the vessel owners will exit the fishery in the order of catch potential if the sum of total net profit of their size class and income support ($P^{*}_{t,size}$) is negative:

$$P^{*}_{t,size} = P_{t,size} + Support_{t,size} \;\; (t = 2024\ 2025, 2026, 2027, 2028)$$

$$P^{*}_{size,t} = P_{t,size} \;\; (t = 2029, 2030) \qquad (46)$$

The exit will continue until $P^{*}_{t,size}$ becomes positive. This option assumes that up to 10 vessels will exit in a single year (the same condition as Eq. (26)).

Table 5.9. Unit support (income support per vessel) and total support for each size class per year (KJPY).

UnitSupport	
$UnitSupport_{small}$	3,988
$UnitSupport_{medium}$	5,424
$UnitSupport_{large}$	13,183

t	**2024**	**2025**	**2026**	**2027**	**2028**	**total**
$Support_{t,small}$	135,592	99,700	63,808	63,808	23,928	386,836
$Support_{t,medium}$	135,600	130,176	124,752	70,512	70,512	531,552
$Support_{t,large}$	632,784	632,784	632,784	632,784	632,784	3,163,920
	903,976	862,660	821,344	767,104	727,224	4,082,308

Note that: total support diminishes over time as vessels with deficits exit, while the values of unit support are constant.

t	2024	2025	2026	2027	2028	2029	2030
$P^*_{small,t}$	-743,495	-370,589	-40,225	119,405	81,221	41,152	41,152
$P^*_{medium,t}$	-676,046	-657,565	-618,592	-445,703	-32,156	65,248	65,248
$P^*_{large,t}$	180,914	163,930	177,421	250,767	414,445	202,834	202,834
$P^*_{total,t}$	-1,238,627	-864,224	-481,396	-75,531	463,510	309,234	309,234
$N_{small,t}$	34	25	16	10	10	10	10
$N_{medium,t}$	25	24	23	19	9	6	6
$N_{large,t}$	48	48	48	48	48	48	48
$N_{total,t}$	107	97	87	77	67	64	64

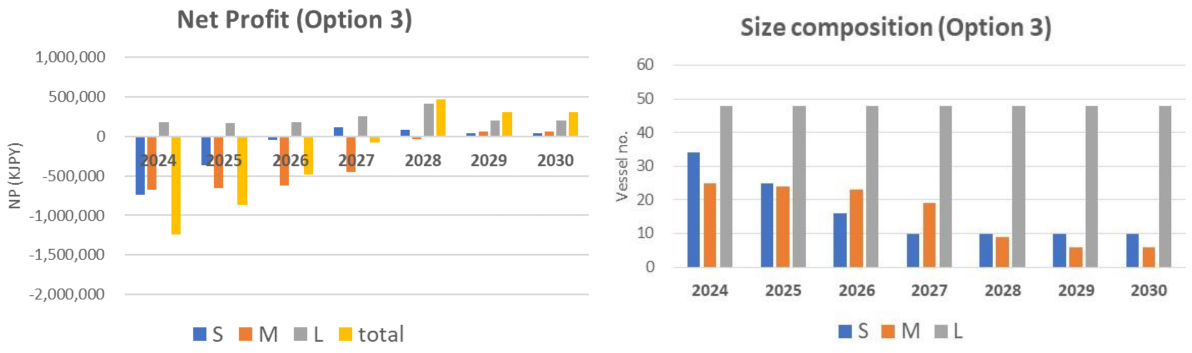


Figure 5.12. Projected scenario under option 3 (income support).

Upper table shows calculated net profit (KJPY) added to income support and number of vessels for each size class from 2024 to 2030. Lower left is a timeseries of net profit added to income support. Lower right is a timeseries of vessel size composition.

Table 5.9 shows the calculated income support. Fig. 5.12 shows the prediction for this option (income support). Note that some of the default parameters are replaced with Eqs. 41-43. Net profit in the small and medium size classes will remain negative until 2026 and 2028, respectively, despite income support. Vessels in these size classes continue to exit, resulting in an outcome similar to the status quo. The magnitude of deficits will be cushioned by income support relative to the status quo. The subsidy amount will be the highest for the large-size class (Table 5.9) because income support reflects previous years' revenues, and no large-sized vessel will exit in the scenario to fully receive the subsidy during the period. The prediction implies that not income support but fleet reduction will contribute to solving deficits. If a stock can recover with a curtailing fishing period, this option could work for recovering profits. However, if stock is not expected to recover soon regardless of fisheries management, like the situation of this saury fishery, this intervention will not address the root cause of the unprofitable fishery.

5.4.5 Option 4: Diversification

This option aims to increase revenue by issuing new permits for catching alternative species in order to make up for the revenue loss of the saury fishery. The targeted alternative species in this option is Japanese sardine (*Sardinops melanostictus*) for the following reasons. First, the abundance of Japanese Sardine Pacific Stock is currently high, and there is room for additional exploitation regardless of existing resource users. According to the latest stock assessment report issued by FRA, the current biomass is almost twice as much as the biomass achieving maximum sustainable yield (BMSY) because of continued successful recruitment. Second, sardine can be harvested in the same manner as catching saury, and this alternative fishing does not require fishers to replace their gear (i.e., stick-held dip-net). Actually, Hokkaido, Iwate, and Miyagi Prefecture have issued temporary permits for some saury fishers to catch sardines before or after the saury fishing season (for one or two months). This option assumes that all small and medium-sized vessels start catching sardines during the 2024 fishing season and continue the operation until 2030. One key condition is that large-sized vessels are not allowed to diversify to avoid conflicts between other resource users and overfishing.

Assuming that sardine fishing will happen for an additional month, some running cost parameters for small and medium-sized classes are replaced with new ones as follows:

$$Mon_t^* = 1.2 \times Mon_t = 6 \tag{47}$$

$$Cons_{small\,\&\,medium}^* = 1.2 \times Cons_{small\,\&\,medium} \tag{48}$$

$$Usage_{small\,\&\,medium}^* = 1.2 \times Usage_{small\,\&\,medium} \tag{49}$$

As for additional revenue from sardine fishing, this study refers to the existing temporary sardine fishing for small-sized saury fishers initiated by the local governments: Miyagi Prefecture, Iwate Prefecture, and Hokkaido. Using available data on these temporary fishing, the potential of sardine landings and prices are estimated (Table 5.10). The estimated revenue in 2024 is likely to be close to the revenue in 2023. Note that the total landings of Japanese Sardine Pacific Stock harvested by all fisheries in 2023 is 104.9 metric tons, implying that the additional landings by saury fishers would be a small fraction (less than 2%). Hence, this assumption is sufficiently realistic.

Table 5.10. Estimation of potential landings and price of alternative sardine fishing.

Place	Year	Landing [ton]	revenue (KJPY)	Price (JPY/10kg)	Source
Miyagi	2022-23	2,537 (a)	223,552	881 (d)	Miyagi Pref.
Iwate	2024	1,072 (b)	159,109	1,484 (e)	Ohfunato Fish Market
Hokkaido	2021	9,274	-	-	Hokkaido Govt.
Hokkaido (TAC)	2023	27,000 (c)	N/A	N/A	Hokkaido Govt.
Estimation	**2024**	**17,109**	**2,023,995**	**1,183**	

Source. Miyagi: Operated for 23 days from Dec. 2022 to Feb. 2023 (Miyagi Prefectural Government, 2023). Iwate: Landing data at Ohfunato Fish Market (a major fishing port for saury in Iwate) on January 2024 (Iwate Prefectural Government, n.d.). Price is obtained by revenue divided by landing. Hokkaido: Operated in June 2021. Only landing data is available. For 2023, landing data is unavailable but TAC for temporary fishing is available (Hokkaido Government, 2022b). Estimation: Landing is calculated by (a)+(b)+(c)/2. Price is calculated by ((d)+(e))/2. Revenue is landings times price.

This option assumes that the estimated landing and price will continue until 2030 as follows:

$$Rsard_t = 2{,}023{,}995 \ (t = 2024, 2025, 2026, 2027, 2028, 2029, 2030) \tag{50}$$

The total revenue from sardine in year *t* ($R_{sard,t}$) is assumed to be distributed to small and medium-sized classes in proportion to the number of vessels therein as follows:

$$Rsard_{small\,\&\,medium,t} = Rsard_t \times \frac{N_{small\,\&\,medium,t}}{N_{small,t} + N_{medium,t}} \tag{51}$$

Since the sardine landing is supplemental to the saury harvest, the total revenue for these two size classes is the sum of both revenue from saury and sardine. Hence, the total net profit for small and medium-sized classes in this potion can be obtained as follows:

$$P^*_{small\,\&\,medium,t} = R_{small\,\&\,medium,t} + Rsard_{small\,\&\,medium,t} - Cost^*_{small\,\&\,medium} \tag{52}$$

where $Cost^*_{size}$ is the total cost with some parameters replaced according to Eqs. 47-49. This option assumes that the vessel owners will exit the fishery in the order of catch potential until the net profit in the size class therein becomes positive. This option assumes that up to 10 vessels will exit in a single year (the same condition as Eq. (26)).

t	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
P^*_{small}	-388,444	-73,665	238,950	386,474	386,474	386,474	386,474
$P^*_{medium,t}$	-415,128	-390,708	-89,264	44,685	44,685	44,685	44,685
$P_{large,t}$	-203,671	252,395	167,883	207,671	207,671	207,671	207,671
$P_{total,t}$	-1,007,243	-211,978	317,569	638,830	638,830	638,830	638,830
$N_{small,t}$	34	27	19	19	19	19	19
$N_{medium,t}$	25	25	23	20	20	20	20
$N_{large,t}$	48	45	45	45	45	45	45
$N_{total,t}$	107	97	87	84	84	84	84

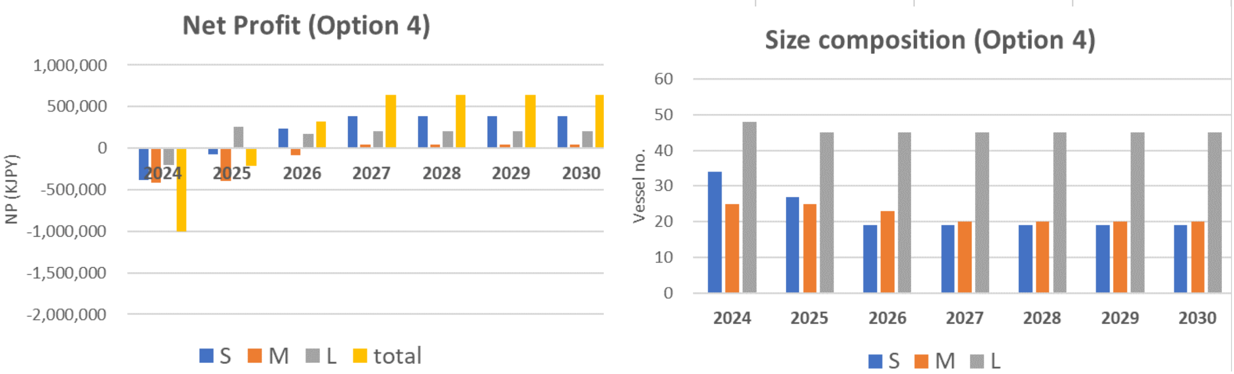


Figure 5.13. Projected scenario under option 4 (diversification).

Upper table shows calculated net profit (KJPY) added to income support and number of vessels for each size class from 2024 to 2030. Lower left is a timeseries of net profit added to income support. Lower right is a timeseries of vessel size composition.

Fig. 5.13 shows the prediction for this option (diversification). The total net profit from the entire fishery will become positive in 2026, with the largest profit in the small size class. The size composition shows that substantial number of small and medium-sized vessels can remain in the fishery in this option. This result demonstrates that supplemental revenue from sardine can make up the revenue loss of saury other things being equal.

5.5 Criteria and analysis

This policy analysis employs eight criteria to analyze the four policy options proposed in the previous section and the status quo. This section presents analysis of the following criteria: profit gain, impacts on the local community, cost of government, distributive equity, procedural equity, political feasibility, uncertainty, and duration.

5.5.1 Criterion 1: Profit gain

This criterion considers how much profit implementing the proposed policies will gain by introducing cumulative net profit in KJPY, defined as the sum of total net profit from the saury fishery from 2024 to 2030. In this regard, this criterion has something to do with the extent to which those policies will address the problem, “there is too little profit from the fisheries to sustain the livelihoods of all the current saury fishers.”

Policy	2024	2025	2026	2027	2028	2029	2030	Cumulative net profit
Status Quo	-2,112,816	-1,384,175	-975,148	-337,258	245,792	629,180	629,180	-3,305,245
1. Management change	-2,112,816	-779,731	296,503	1,063,867	1,454,646	2,029,837	2,667,132	**4,619,438**
2. Partial permit termination	-2,112,816	823,163	823,163	823,163	823,163	823,163	823,163	2,826,162
3. Income support	-1,238,627	-864,224	-481,396	-75,531	463,510	309,234	309,234	-1,577,800
4. Diversification	-1,007,243	-211,978	317,569	638,830	638,830	638,830	638,830	1,653,668

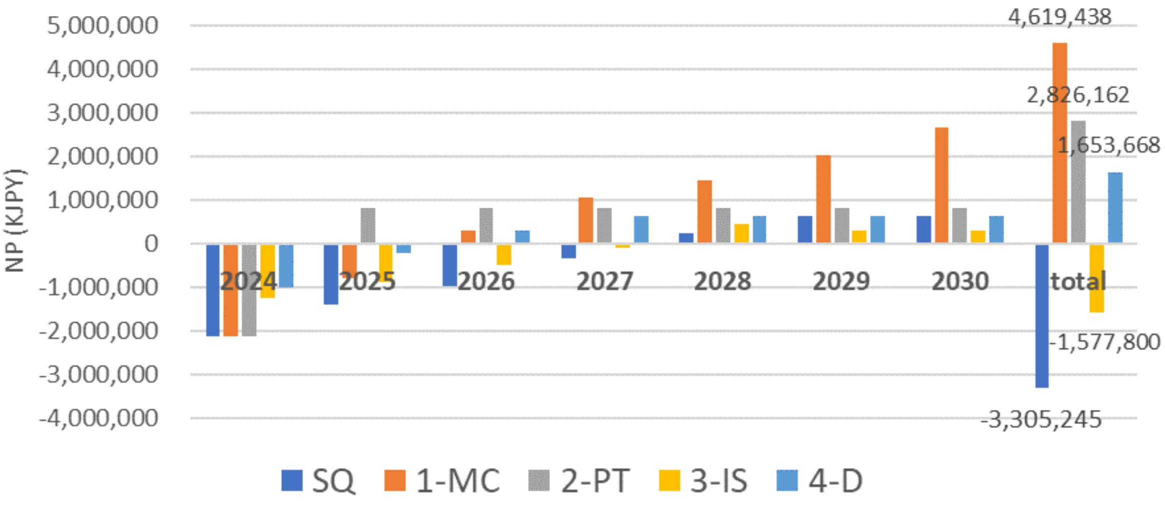


Figure 5.14. Time series of total net profit (KJPY) for each policy option.

SQ: Status quo, 1-MC: Management change (Policy 1), 2-PT: Partial permit termination (Policy 2), 3-IS: Income support (Policy 3), and 4-D: Diversification (Policy 4). Cumulative net profit is the sum of total net profit from 2024 to 2030.

Fig. 5.14 shows a time series of estimated total net profit for each policy option. Aside from the status quo, only the income support option expects a negative cumulative net profit, suggesting that subsidy can alleviate deficits but be unable to gain sufficient profits. On the other hand, the permanent quota option expects the largest profit gain because of consolidation. The partial permit termination option also expects a high cumulative net profit because the profit from the fishery will recover immediately after policy implementation. The diversification option expects the least deficits, moderate profit, and, consequently, moderate cumulative net profit.

5.5.2 Criterion 2: Impacts on local community

Any options above will entail the unemployment of crew members who were employed on exiting vessels. Laid off crew members will leave the community unless they can find alternative livelihoods there. This analysis introduces a scale (the most negative, negative, and the least negative) as a metric of impacts on the local community.

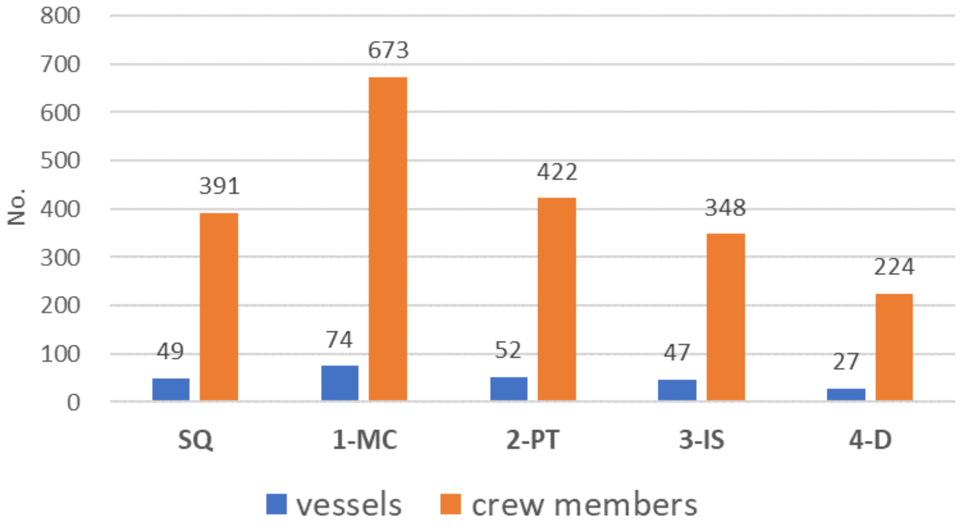


Figure 5.15. Estimated number of exiting vessels and crew members.

For each policy option. SQ: Status quo, 1-MC: Management change (Policy 1), 2-PT: Partial permit termination (Policy 2), 3-IS: Income support (Policy 3), and 4-D: Diversification (Policy 4).

Fig. 5.15 shows each option's estimated number of exiting vessels and crew members. The management change option will cause the most negative impacts on communities due to it having the highest unemployment level driven by consolidation. In contrast, the diversification option will have the least negative impacts, keeping the largest number of crews in the fishery among the proposed scenarios. The partial permit termination and income support options will cause the same negative impacts as the status quo regarding the unemployment level.

5.5.3 Criterion 3: Cost to Government

This criterion measures the total cost of implementing each policy to the central government of Japan in KJPY. The management change and diversification options do not require additional governmental budgets fundings. The partial permit termination option will cost an estimated 1,726,964 KJPY for relief to exiting fishers. The income support option necessitates budget funding for income support, costing 4,082,308 KJPY. While the former option subsidizes only exiting fishers and shares the cost with the remaining fishers, the latter option subsidizes all the remaining fishers for five years. As a result, the income support will cost more than twice as much as the permit termination.

5.5.4 Criterion 4: Distributive equity

This criterion gauges the extent to which the proposed policies equitably distribute benefits and costs among the saury fishers. This analysis discusses this equity criterion in terms of (A) the remaining fishers versus the exiting fishers and (B) among the three size classes by introducing a scale (high, medium, and low) as a metric of distributive equity.

As for discussion (A), the exiting fishers in the status quo scenario will suffer from deficits without support, whereas the remaining fishers can eventually recover profits. Because of this disparity, distributive equity of the status quo is considered low. Although the income support option will result in a similar outcome, this analysis concludes that its distributive equity is medium because the deficits of exiting fishers can be alleviated to some extent by income support before closing their business. Regarding the management change option, the exited fishers can make up for their deficits to some extent by selling their quota to the remaining fishers, albeit the quota prices are uncertain. Hence, this analysis concludes that the distributive equity of this option is medium. The partial permit termination is a highly equitable option because the exiting fishers can receive compensation from the government and the remaining fishers. The compensation amount is calculated so that the exited fishers can make up for the cost of closing the business. In contrast to the management change, the permit termination can secure sufficient compensation before implementation. The distributive equity of the diversification option is also high because the least fishers will exit under the scenario.

Policy ＼ Size class	**Small**	**Medium**	**Large**
Status Quo	-1,985,467	-3,333,751	2,013,981
1. Management change	-1,161,565	-2,784,128	8,565,178
2. Partial permit termination	-517,968	-728,220	4,072,344
3. Income support	-871,406	-2,299,570	1,593,120
4. Diversification	1,322,754	-716,368	1,047,336

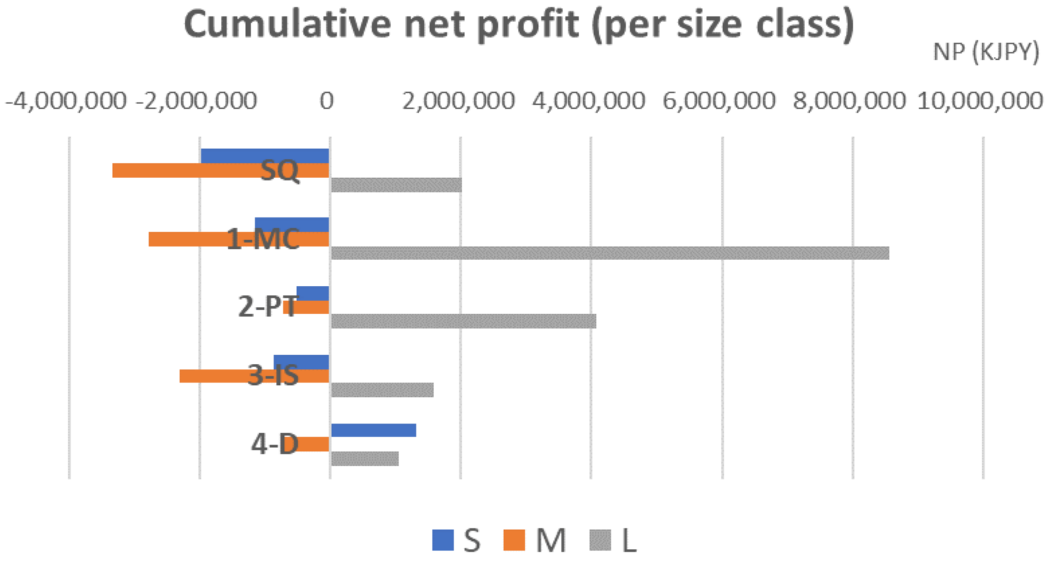


Figure 5.16. Cumulative net profit (KJPY) break down into size classes for each policy option. S: small, M: medium, and L:large size class. SQ: Status quo, 1-MC: Management change (Policy 1), 2-PT: Partial permit termination (Policy 2), 3-IS: Income support (Policy 3), and 4-D: Diversification (Policy 4).

As for discussion (B), Fig. 5.16 reveals that the status quo scenario will result in negative cumulative profits for the small and medium classes, whereas the large class will eventually become profitable. Large-sized vessels with high catch potential can have a higher share of revenue from the fishery. Regarding the small and medium-sized vessels, their cost exceeds the revenue due to lower catch, with the medium-sized vessels suffering more. Considering this gap, if an option expects a more favorable outcome for small and medium size classes than the status quo, the option can be seen as highly equitable. If a policy expects a broader disparity than the status quo, that will be inequitable. Regarding discussion (B), the distributive equity of the management change option is low because this consolidation scenario will end up with the widest disparity in favor of the large class. In contrast, the diversification option is highly equitable because this policy will enable small and medium-sized vessels to increase revenue by catching sardines, keeping a substantial number of vessels in the fishery. The permit termination and income support options subsidize fishers but do not intentionally differentiate the small and medium size classes from the large ones. Hence, the distributive equity of these two options is medium.

5.5.5 Criterion 5: Procedural equity

This criterion measures the extent to which the proposed policies give the saury fishers room for proactive decision-making on whether to exit or remain in the fishery by introducing a scale (high, medium, and low) as a metric of procedural equity.

In the income support scenario, whether fishers can remain or exit is “survival of the fittest,” which is the same as the status quo. Fishers with deficits will have no choice but to exit despite income support. Hence, this analysis concludes that the procedural equity of the income support option is low. The diversification option is similar in principle, because fishers are allowed alternative fishing. Therefore, its procedural equity is considered medium, better than the income support. On the other hand, the management change policy enables fishers to choose between selling their quota to exit or continuing the fishery. The permit termination option will also allow fishers to decide whether to remain or exit through internal discussions in the saury FCA. This analysis assesses the procedural equity of these two options as high.

5.5.6 Criterion 6: Political feasibility

This criterion measures the extent to which the proposed policies are accepted by the saury fishers and decision-makers, i.e., politicians and the Fishery Agency of Japan, by introducing a scale (high, medium, and low) as feasibility metric.

The management change option can be the least feasible because Japan has never implemented this type of ITQ management. Fishers may express concerns about consolidation driven by this policy, making decision-makers hesitant to carry out this option. In contrast, diversification will be the most feasible option because this option has already been suggested by the study group (Table 4.2). Although the diversification risks causing conflicts with other resource users, this option only allows small and medium-sized vessels to catch sardines, and the expected sardine catch will be limited to the current harvest level, minimizing the likelihood of conflicts. The permit termination and income support options may be acceptable to fishers because of the subsidy, whereas the governments will be cautious about having to mobilize budgetary-funding for compensation. In this regard, the political feasibility of these two options can be medium.

5.5.7 Criterion 7: Uncertainty

This criterion measures how much uncertainty is expected where the policy benefits reach the saury fishers by introducing a scale (high, medium, and low) as an uncertainty metric. The permit termination and income support options are less uncertain because the government can control the implementation. The amount of relief or income support is a priori in implementing those two policies. Regarding the management change, the number of quota transactions that will occur depends on market conditions, which can be predictable to some extent but entails uncertainty. The expected outcome of the diversification option is highly uncertain because of the uncertainty of the sardine stock. Pacific sardine stock is known to be highly volatile, driven by environmental conditions, and it is unpredictable if the current level of catch will continue until 2030.

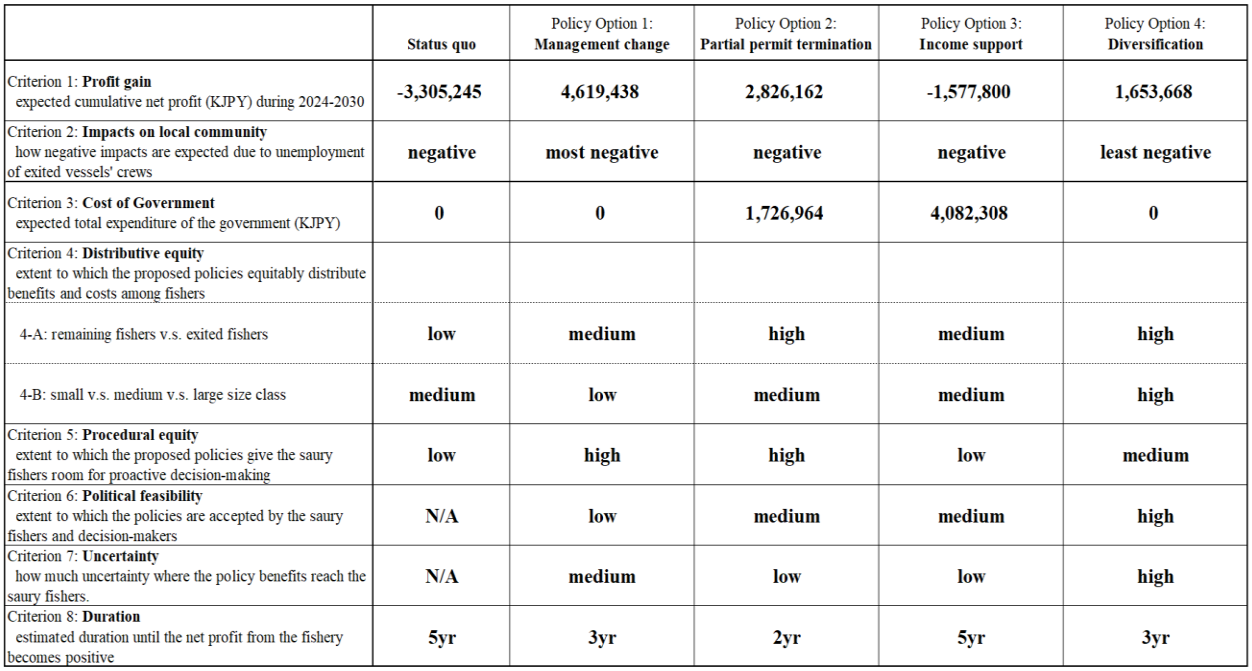
5.5.8 Criterion 8: Duration

This criterion measures the estimated duration until the net profit from the fishery becomes positive, attributed to the policy option. In principle, the earlier it happens, the better. According to Fig. 5.14, the total profit summing up all size classes will become positive the first in the permit termination option (in 2025), followed by the management change and diversification (in 2026), and the income support and the status quo (in 2028).

5.6 Tradeoffs among policy options

Table 5.9 is a policy matrix summarizing the policy analysis in the previous section. This section highlights the key trade-offs between the policy options using this matrix forrmat. First, the status quo is the worst scenario in terms of any criterion, underscoring the urgency for decision-makers to intervene.

Table 5.11. Policy matrix, summarizing the policy analysis in the section 5.5.



	Status quo	Policy Option 1: **Management change**	Policy Option 2: **Partial permit termination**	Policy Option 3: **Income support**	Policy Option 4: **Diversification**
Criterion 1: **Profit gain** expected cumulative net profit (KJPY) during 2024-2030	**-3,305,245**	**4,619,438**	**2,826,162**	**-1,577,800**	**1,653,668**
Criterion 2: **Impacts on local community** how negative impacts are expected due to unemployment of exited vessels' crews	**negative**	**most negative**	**negative**	**negative**	**least negative**
Criterion 3: **Cost of Government** expected total expenditure of the government (KJPY)	**0**	**0**	**1,726,964**	**4,082,308**	**0**
Criterion 4: **Distributive equity** extent to which the proposed policies equitably distribute benefits and costs among fishers					
4-A: remaining fishers v.s. exited fishers	**low**	**medium**	**high**	**medium**	**high**
4-B: small v.s. medium v.s. large size class	**medium**	**low**	**medium**	**medium**	**high**
Criterion 5: **Procedural equity** extent to which the proposed policies give the saury fishers room for proactive decision-making	**low**	**high**	**high**	**low**	**medium**
Criterion 6: **Political feasibility** extent to which the policies are accepted by the saury fishers and decision-makers	**N/A**	**low**	**medium**	**medium**	**high**
Criterion 7: **Uncertainty** how much uncertainty where the policy benefits reach the saury fishers.	**N/A**	**medium**	**low**	**low**	**high**
Criterion 8: **Duration** estimated duration until the net profit from the fishery becomes positive	**5yr**	**3yr**	**2yr**	**5yr**	**3yr**

The management change option will promise the highest profit gain for remaining fishers without additional governmental expenditure. However, its impacts on the community will be the most negative, causing the highest unemployment driven by consolidation. This option will likely completely reshape the fishery, leading to the survival of only large vessels. From an equity perspective, the disparity of cumulative net profit between large vessels and the others is the widest, although small and medium-sized vessels will get some money by selling their quota and exit of their own will. The political feasibility of this policy is also a challenge, given that Japan has no experience in implementing this type of management, i.e., ITQ, and fishers may have concerns about consolidation.

In the partial permit termination scenario, the total profit will become positive at the earliest among the four options, and the cumulative net profit will be high. Meanwhile, many crew members will leave the fishery after permit termination. Vessel owners can decide whether to remain or exit. Exiting fishers can receive compensation from the government and the remaining fishers, which means the burden of poor catch driven by climate change will be shared among the exiting fishers, remaining fishers, and the general public. In this regard, this option is highly equitable from the perspective of the exiting fishers, but it costs approximately 1.7 billion JPY to the government. The policy implementation is less uncertain under the direct control of the government.

The income support option expects a negative cumulative net profit and high level of unemployment due to many vessels going bankrupt. The profit recovery is the slowest among the four policies. Meanwhile, it costs the largest amount in terms of governmental expenditure. Overall, the performance of this option seems poor.

The diversification option expects an intermediate cumulative net profit. The impacts of unemployment on the community are the least because the largest number of vessels can remain in the fishery in this scenario. This is the only option where the cumulative net profit of small-sized vessels will become positive, thanks to the supportive policy for small and medium-sized classes. In addition to being highly equitable, this option costs no governmental expenditure and seems highly feasible. One caveat is the uncertainty of sardine stock status: Its successful outcome depends on whether the current level of sardine revenue can continue until 2030.

In conclusion, the diversification option will achieve profit recovery with the least negative impacts on the community in an equitable manner, requiring no governmental budgets funding. This policy analysis demonstrates that the study group’s suggestion, diversification, can be implementable for the saury fishery. However, the option is uncertain due to its dependence on volatile sardine stock. In contrast, permit termination is a less uncertain option. This policy expects high profit gain equitably, but it needs governmental budgets funding and will entail higher unemployment than the diversification. Meanwhile, this policy can be an effective alternative to the diversification policy. The management change option expects the highest profit gain without governmental budget funding, but this policy is inequitable due to consolidation, wiping out almost all small and medium-sized vessels from the fishery. The income support options expect poor performance with the lowest profit gain and high unemployment.

It should be emphasized that no matter what option decision-makers choose, some level of unemployment will be unavoidable. Therefore, it is of utmost importance to thoroughly consider alternative livelihoods for crew members of exiting vessels. Given their experience in the saury fishery, crew member positions in other offshore fisheries in the same region could be ideal. However, it is unlikely that other fisheries have the capacity to absorb the hundreds of unemployed crew members. Hence, alternative livelihoods and training for jobs other than capture fisheries should be considered. The FAJ Study Group suggests a transition to aquaculture, and some trial salmon farming projects have been launched in northern Japan, in which major ports of the saury fishery are located. Blue economies such as “umigyo,” i.e., tourism and other activities to attract people from urban areas and stimulate local economy, could also offer job opportunities.

Chapter 6. Conclusions

The adverse impacts of climate change on Japanese fisheries have been alarmingly apparent since 2010 in all sectors, from coastal fisheries and aquacultures to offshore fisheries. These impacts, such as catch declines, distribution changes, and mass mortalities, occur at an unprecedented level beyond the historical baseline, necessitating immediate post-incident financial relief to address the unanticipated economic damage. While effective in the short term, the current fisheries insurance scheme in Japan is not designed to subsidize a continuing or persistent revenue loss, highlighting the urgent need for additional policies.

Research to elucidate the mechanism of changes and impacts is essential to explore fundamental solutions. FRA gears its research plans toward climate change and adaptation, including innovations relevant to aquaculture, such as selective breeding of heat tolerant strains and developing alternatives to fish-meal-based feeds. The FAJ Study Group recommends accelerating data collection on the changing ocean environment and biological information of important fish stocks. Research capacity, prioritization, and resource allocation are topics worthy of discussion but are beyond the scope of this study.

It can take substantial time and research to elucidate the mechanisms of climate change impacts on fisheries. Also, it can be uncertain whether implementable solutions are identified even if the mechanisms are uncovered. In this regard, fisheries sectors must build resilience against adverse impacts to mitigate unavoidable damage. The Japanese government has already launched discussion platforms such as FAJ’s Study Group and MoE’s Regional Councils for adaptation to narrow down measures to build resilience. The key message of the Study Group’s recommendations is diversification. This strategy can be implemented for coastal fisheries because of its flexible management and operation as well as the ability to develop concerted actions among coastal fishers through FCAs. However, it is questionable if diversification can be feasible for offshore fisheries, especially ones relying on single species such as saury fisheries.

The ongoing “fisheries policy reform” underscores output control based on Maximum Sustainable Yield to recover declined stocks and achieve sustainable use. In so doing, the Study Group recommends to improve stock assessment and data collection. Although this policy is undoubtedly important as a fisheries management principle, policymakers should also consider the situation where a declining fish stock is unlikely to recover soon under climate change despite introducing robust catch limits. Notably, some stocks targeted by offshore fisheries, such as saury and flying squid are in such a situation now, and businesses involved in the fisheries are jeopardized due to their heavy reliance on saury and flying squid.

This study provides a policy approach to address this problem, using data sets of the North Pacific saury fishery. The analysis points to the need to rationalize the fishery, which means reducing fishing capacity to adjust to a low stock level driven by climate change. Four policy options are proposed: (1) management change (ITQ), (2) partial permit termination, (3) income support, and (4) diversification for consideration. Analysis of each option employing eight criteria is performed: (1) profit gain, (2) impacts on the local community, (3) cost to government, (4) distributive equity, (5) procedural equity, (6) political feasibility, (7) uncertainty, and (8) duration. Equity criteria are included because, unlike conventional overfishing issues, the current economic crisis of this fishery is not solely responsible for saury fishers, given that climate change is a significant driver. The policy analysis reveals trade-offs among policy options. For the offshore large-scale Pacific saury fishery, the ITQ option projects the highest profit gain but the most negative impacts on the local community and with the widest disparity among vessel size classes due to consolidation. The permit termination option results in high unemployment, but the economic burden of exiting fishers is shared with the government and the remaining fishers. Also, the profitability of the fishery will recover in the shortest time with less uncertainty, but a substantial amount of the government budget investment is required. The income support option requires the largest governmental expenditure to alleviate fishers' deficits, but it will end up with the lowest profit gain and a high level of unemployment. The diversification option expects no additional governmental budget and has the least negative impacts on local communities because of the fewest exiting fishers. Even smaller-scale vessels can remain in the fishery thanks to diversification, allowing for supplemental revenues from alternative fish (Japanese sardine). One caveat of this option is the uncertainty of sardine stock status.

The policy analysis results suggest the diversification or permit termination options, while the author hopes that stakeholders swiftly start communication using this policy analysis by adding or modifying policy options and criteria, if necessary, discuss key trade-offs among policy options, and implement the best option in an equitable manner.

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