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**Paper:**

# Impact on Fisheries in Contaminated Water Discharged from Nuclear Power and Reprocessing Plants: The Cases of La Hague Reprocessing Plant, Sellafield Nuclear Fuel Reprocessing Plant, and TEPCO Fukushima Daiichi Nuclear Power Plant

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**This paper statistically analyzes residents' understanding of problems related to radioactively contaminated water discharged from nuclear power and nuclear reprocessing plants. Moreover, this paper examines their impact on the surrounding fisheries by using the cases of La Hague, Sellafield, and Fukushima Daiichi Nuclear Power Plant. Survey data shows that more than 60% respondents disagree with the release of contaminated water, and this sentiment is particularly strong among both British and French respondents. Regarding seafood caught in the vicinity of the nuclear power and nuclear reprocessing plants, although British respondents noted that they hold it in high regard, many people do not purchase this seafood. In contrast, many Japanese respondents reported that they were less concerned, and thus, willingly purchase seafood caught off the coast of Fukushima Prefecture. In all three countries, many people did not trust government information on the release of contaminated water. Compensation to the affected people was provided by the central government, companies involved, and local governments, in that order. Japanese and British respondents reported higher expectation for compensation as compared to French respondents. Japanese and French respondents noted that they have knowledge of radioactive materials and contaminated water, and many of them purchased seafood caught in the vicinity of the nuclear power and reprocessing plants. British respondents were the most opposed to the release of contaminated water, whereas Japanese respondents were the least reliant on government information about the release of contaminated water. Finally, among those who trusted information from the government and retailers, French respondents were the least concerned about contamination. French respondents were also the least likely to expect any compensation for the fishermen affected by contamination. Both British and French residents around the affected plants expected the central government to compensate the affected fishermen, whereas those who did not reside around the affected plants did not expect the fishermen to be compensated. French respondents were more likely to expect compensation from the local governments; affluent respondents were more likely to expect the compensation to be funded by taxation, whereas less affluent respondents expected them to be funded by donations. Respondents who were more skeptical of government information wanted the companies involved to compensate the fishermen. British respondents reported a tendency for wanting the companies involved to provide this compensation, and did not support the concept of compensation provided through donations.**

**Keywords:** La Hague Reprocessing Plant, Sellafield Nuclear Fuel Reprocessing Plant, TEPCO Fukushima Daiichi Nuclear Power Plant, release of radioactively contaminated water, compensation for loss or damage

## 1. Introduction

On March 11, 2011, the Great East Japan Earthquake caused a devastating tsunami, which in turn caused a nuclear accident at TEPCO's Fukushima Daiichi Nuclear Power Station, thereby resulting in a core meltdown [1]. Water injected to cool the reactor, rainwater from a damaged building, and groundwater flowing from the mountain side to the coast flowed into the reactor building [2]. This water came into direct contact with the melted fuel and mixed with water containing radioactive materials accumulated inside the reactor building, thereby resulting in the collection of a considerable volume of contaminated water currently posing a major problem in processing, storage, and disposal [2]. This contaminated water is stored in on-site tanks, and radioactive material is being removed in stages to reduce the related risks [2]. Over 1 million tons of water that was used to cool the reactor is now stored in a separate huge tank [3]. The tank of contaminated water will be at full capacity by 2022, thus introducing the possibility that contaminated water will be released into the ocean [3]. Nuclear reprocessing plants worldwide remove 62 types of multi-nuclides (such as Cs) by using systems like the advanced liquid processing system (ALPS) equipment used at the Fukushima site; however, these systems cannot remove tritium [1]. Therefore, the water subsequently released continues to be called "contaminated water" by the media. Water scheduled to be released has ingredients comparable with those discharged by nuclear power plants and reprocessing facilities worldwide. Although this may sound drastic, ocean discharge of similarly contaminated water is a worldwide phenomenon. In particular, the La Hague reprocessing plant (to be referred to as "La Hague") releases approximately 1,700 trillion Bq of contaminated liquid annually, and the Sellafield Nuclear Fuel Reprocessing Plant (henceforth "Sellafield") releases approximately 1,540 trillion Bq of contaminated water annually. Comparing the volume of contaminated liquid released from both the reprocessing plants with that of liquid that may be released from Fukushima in 2022 (approximately 1,000 trillion Bq), it can be estimated that an enormous amount of contaminated water is released.

In the UK and France, there is widespread debate regarding a causal link between nuclear facilities and leukemia. There is also controversy surrounding the potential bioaccumulation of tritium in marine life, which is then passed on to the human population through the consumption of seafood. However, despite the existence of theories suggesting this phenomenon, definitive scientific consensus has yet to be reached regarding the causal link between nuclear reprocessing plants and leukemia, or regarding the effects of discharged tritium on marine life. The social context of Sellafield and La Hague will be examined in the following paragraphs.

The first incident in Europe of contaminated water being released from a nuclear reprocessing plant was the Windscale fire accident (October 10, 1957) in the Sellafield plant cluster. On November 1, 1983, Yorkshire TV broadcasted a documentary program called "Windscale: The Nuclear Laundry" [4]. This program highlighted the frequent occurrence of leukemia among children living near Sellafield, in the nearby village of Seascale [4]. This program was perceived as anti-nuclear, and thus, received a great deal of criticism and protest from Sellafield's owners, such as the British Nuclear Fuels Limited (BNFL) [5], and nuclear power proponents, which led to the topic becoming more controversial among the public. In response to the public outcry, the British government organized an Independent Advisory Group, headed by Black, to investigate the issue [6]. This group published its report in 1984, concluding that although a high incidence of leukemia was noted in the area, current scientific understanding could not link this phenomenon to the level of radiation emitted by Sellafield. The report also recommended that further research and investigation must be conducted regarding this issue [6]. In the following year, the British government set up the Committee on Medical Aspects of Radiation in the Environment (COMARE), with a wider and deeper remit to investigate the issue. Separate research led by Gardner [7], a member of the Black Committee, found an increased relative risk of leukemia and non-Hodgkin's lymphoma among children born around Sellafield, children of employees at Sellafield, as well as the children of mothers who had been exposed to high levels of radiation before becoming pregnant. However, Gray et al. [8] noted that despite the higher incidence of leukemia and non-Hodgkin's lymphoma among young people in the immediate vicinity, this was not exceptional to the wider area. A further study by Kinlen [9] confirmed this conclusion.

The position of BNFL [5] was that, since there were many other clusters of leukemia around the country, radioactive contamination had no direct connection to these cases of leukemia. However, the lawsuits from residents around Sellafield are increasing. In addition, the anti-nuclear movement in the UK has become more active, and demands for improved radiation exposure standards for facility workers have increased [10]. According to COMARE [11], the incidence of childhood leukemia occurred only in Seascale village for 40 years, from 1950 to 1990, and did not occur in other neighboring towns and villages [10].

La Hague has faced no significant protests, with the exception of some obstructions of unloading work by protestors [12]. Reasons for the lack of major protests here are as follows: (i) La Hague has not experienced any major incidents; (ii) the operators' careful engagement with the local community; and (iii) active public relations activities [12]. However, in 1997, the environmentalist Green Party (Les Verts) joined the coalition government of the Socialist Party (PS: Parti Socialiste) and the Communist Party (PCF: Parti Communiste Français). The activities of environmental groups, such as Greenpeace [13], increased around La Hague [12]. These activities included a discussion on the relationship between La Hague and childhood leukemia among the surrounding population. This discussion followed the publication of papers by Viel et al. [14] and Pobel and Viel [15]. Viel et al. [14] concluded that between 1978 and 1992, the incidence of childhood leukemia in areas surrounding and to the southeast of La Hague strongly suggested the occurrence of a cluster. Pobel and Viel [15] examined childhood leukemia among 27 patients aged 25 years and younger diagnosed between 1978 and 1993, as well as 192 people (acting as control participants) living within 35 km of La Hague. The relationship between personal, social, and other factors, and risk factors was investigated. They concluded that the use of local beaches by mothers and children and consumption of local seafood increased the risk of leukemia. On the other hand, the Nuclear Safety Authority (ASN) [16] and the operator Orano Cycle [17] have denied any link between emissions exposure from La Hague and increase in leukemia. Dousset [18] compared mortality from cancer in the Beaumont-Hague canton, where La Hague is located, with that of the rest of the Department of Manche. They concluded that no significant increase in leukemia mortality between 1970 and 1982 and mortality of all types of tumors between 1975 and 1982 [18] had been noted. Hattchouel et al. [19] examined the mortality rate of leukemia in 1985 among residents aged below 25 years living around 13 active nuclear facilities. They found that the number of leukemia deaths observed around the nuclear facility did not differ from the expected number of estimated deaths, based on the national mortality statistics, and thus concluded that no increased risk of leukemia was noted, regardless of age, sex, type of facility, or proximity to the facility [19].

To summarize the results of research focusing on Sellafield and La Hague, a conclusive consensus has yet to be drawn regarding the causal relationship between reprocessing plants and leukemia. However, food contamination by radionuclides has been a serious issue for Japanese consumers, producers, and policymakers. According to the results of monitoring inspections of fish caught off Fukushima between 2016 and 2018, no seafood exceeded the standard value of radioactive cesium content in food (100 Bq/kg) [20]. Voluntary inspection of the Fukushima Prefectural Federation of Fisheries Co-operative Associations (Fishing Cooperative) only exceeded the standard value in one case – a ray, the common skate (161 Bq) – and although the fishermen have emphasized its safety, the reputational damage to seafood caught in the vicinity of Fukushima has persisted [21]. However, in February 2020, restrictions on the sale of common skate as well as other marine products were lifted. The prefectural Fishering Cooperative began discussions in the autumn of 2020, with the aim to resume full-scale operations in multiple stages, starting from the spring of 2021 [22]. However, radioactive cesium exceeding the national standard value (100 Bq/kg) was detected for the first time in nearly two years in the black rockfish caught during test operations off the coast of Fukushima Prefecture in 2021, and on February 22, 2021, the Fishing Cooperative announced that shipments of black rockfish had been suspended until their safety could be confirmed [23]. In addition, the Fishing Cooperative has reported that market wholesalers are cautious about increasing stock and are, thus, unable to expand their catch due to worries that it will remain unsold [21]. In early 2020, TEPCO proposed a method for disposing decontaminated water from the Fukushima Daiichi Nuclear Power Plant. In response, the Fishing Cooperative stated its opposition about releasing contaminated water into the ocean and demanded that the water must continue to be stored on the shore until radioactivity in the treated water disappears [24]. Similarly, the Miyagi Prefectural Fisheries Cooperative Association petitioned Governor Yoshihiro Murai to request the national government to disallow the release of this water into the oceans [25]. Despite Fukushima Prefecture and Miyagi Prefecture opposing the release of this contaminated water, the Japanese government and TEPCO [1] have emphasized the safety of the water, similar to the British and French governments and their operators. However, Reiher [26] stated that Japanese people do not trust information from government agencies and the food industry, and highlighted the failure of the risk communication strategy of the government to restore public confidence. Similarly, Figueroa [27] emphasized the lack of a risk communication strategy, combined with management missteps and errors, thereby resulting in anxiety among Japanese people, as well as a general distrust of safety regulators and the nuclear industry. Shimura et al. [28] noted that although evacuation from the area and controlling food distribution is crucial for ensuring public safety, a comprehensive risk communication strategy is a key factor for successfully managing the situation. On April 13, 2021, the Japanese government approved a policy to release treated water containing radioactive materials, such as tritium, into the ocean after diluting it to a concentration below the national standard [29]. This policy highlights the importance of risk communication strategies in nuclear accidents.

This paper compares results of surveys conducted in these countries regarding the impact of contaminated water on surrounding fisheries. These surveys determine how respondents perceive the reputation of fisheries, in light of their proximity to nuclear power and nuclear reprocessing plants (henceforth collectively referred to as "nuclear facilities") discharging contaminated water into the ocean.

## 2. Methodology

### 2.1. Structure of the Paper

The structure of this paper is as follows: Section 2 describes the survey design, target area, collection method, research methodology, and analytical methodology.

Section 3 examines the knowledge of participants regarding radioactive material and contaminated water. We also examine the arguments for and against releasing contaminated water including tritium. In addition, purchasing behaviors related to seafood caught in the vicinity of nuclear facilities are analyzed.

Section 4 examines whether there is a connection between the survey respondents' position on the arguments for and against releasing contaminated water and their purchasing behavior. The relationship between purchasing behavior, position on the release of contaminated water, and personal attributes (such as age and sex) and whether or not (and how) fishing communities are compensated when contaminated water is released is statistically analyzed in this section.

Section 5 summarizes the issue of contaminated water discharged from nuclear facilities and its impact on surrounding fisheries.

**Table 1.** Tritium quality standards per country and facility.

| Country | Nuclear power stations/Nuclear fuel reprocessing plant | Type containment building | Liquid release [TBq] | Gas emissions [TBq] |
|---|---|---|---|---|
| Canada | Bruce A, B (2015) | CANDU | 892.0 | 1079.0 |
| | Darlington (2015) | CANDU | 241.0 | 254.0 |
| | Pickering (2015) | CANDU | 372.0 | 535.0 |
| United States | Three Mile Island (1990–1993) | PWR (Accidental furnaces) | 24.0 | – |
| | Callaway (2002) | PWR | 42.0 | – |
| | Diablo Canyon 1 (2002) | PWR | 51.0 | 11.0 |
| | Grand Gulf (2002) | BWR | 2.0 | 2.6 |
| | Brunswick (2002) | BWR | 0.2 | 4.3 |
| UK | Heysham (2015) | AGR | 390.0 | – |
| | Sizewell (2015) | PWR | 20.0 | – |
| | Sellafield (2015) | Nuclear reprocessing | 1,540.0 | 84.0 |
| France | Tricastin (2015) | PWR | 54.0 | |
| | La Hague (2015) | Nuclear reprocessing | 13,700.0 | 78.0 |
| Korea | Wolseong (2016) | CANDU | 17.0 | 119.0 |
| | Kori (2016) | PWR | 36.0 | 16.0 |
| Taiwan | Maanshan (2002) | PWR | 40 | 10.0 |
| China | Daya Bay (2002) | PWR | 42 | – |
| Japan | Fukushima Daiichi (2023–2053) | BWR | 860 | |
| | Tokai (1977–2007) | Nuclear reprocessing | 5,400 | |

Source: [30–34].
Note: (1) TBq = $10^{12}$ Bq. (2) CANDU = Canadian deuterium uranium, PWR = Pressurized Water Reactor, BWR = Boiling Water Reactor, AGR = Advanced Gas-cooled Reactor.

## 2.2. Comparison of Tritium Emissions, Distribution Regulations, and Testing at the Three Sites

### 2.2.1. Annual Tritium Emissions from Major Nuclear Facilities Worldwide

Before presenting the hypotheses examined in this paper, this section will explore annual tritium emissions and water quality standards of La Hague, Sellafield, and Fukushima nuclear power plants. This section will address how much tritium each site emits per year.

**Table 1** presents annual tritium emissions from major nuclear power facilities worldwide. First, the largest annual discharge of tritiated water is La Hague, with 13,700 TBq, which is greater than any other facility. La Hague is followed by Sellafield, which releases 1,540 TBq into the Irish Sea. In Canada, the combined liquid and gas emissions of Bruce A and B (with the highest gas emissions worldwide) is 1,971 TBq, higher than that of Sellafield. Both Darlington and Pickering release high levels of tritium in liquid and gas form.

The annual amount of liquid and gaseous tritium released from Fukushima prior to the accident was 2 TBq, which is less than half the amount released by Grand Gulf (4.6 TBq) and Brunswick (4.5 TBq) in the USA; this is the lowest tritium discharge of any facility.

There is 860 TBq tritiated water stored in tanks on the Fukushima site, and all of this water will be released by 2051 [35]. Between 2023 and 2051, 28.67 TBq will be released each year; this is less than the amount released by Daya Bay (42 TBq) in China, Maanshan (40 TBq) in Taiwan, or Kori (36 TBq) in Korea. The total amount released by the Tokai reprocessing plant in Japan over a 30-year period (1997–2007) was 5,400 TBq, or 180 TBq per year, and is over six times higher than the planned discharge from Fukushima after 2023.

To summarize, the planned discharge of tritium from Fukushima is not particularly high, compared with that of plants worldwide or historically. However, for many people, governments, and media in the region (specifically China, Korea, Taiwan, and the Japanese public), TEPCO is perceived as both the cause of the initial accident and a deliberate polluter of the ocean. The Fukushima accident was an "accidental release," as noted after the Windscale fire. La Hague has never experienced an accident on the scale of Fukushima (International Nuclear and Radiological Event Scale (INES) level 7) or Sellafield (INES level 5), with the worst incident being an INES level 3 silo fire in January 1981. The high levels of tritium discharged from La Hague is a "controlled release," which carries a different social meaning and response to that of an "accidental release." When testing the hypothesis, this difference in the meaning and potential response indicates that the results must be addressed with some caution.

### 2.2.2. Water Quality Standards for Each Country and Facility

The regulatory standards of each country and nuclear facility are then examined.

**Table 2** presents the drinking water quality standards for each country. Australia allows the highest tritium content (76,103 Bq/L). At first glance, Finland (30,000 Bq/L) appears to allow the second highest amount. However, water from Fukushima will be released using groundwater bypasses and other methods, with an operational target of 1,500 Bq/L. There are no drinking water standards in Japan, and the nearest equivalent is the wastewater standard of 60,000 Bq/L, thus, making Japan the second highest after Australia, and six times higher than the WHO standard.

The UK and France follow the OSPAR Convention [36] on drinking water standards, which sets a limit of 100 Bq/L. The EU standard is one fifteenth the operational standard set for Fukushima. France's effluent standard is 40,000 Bq/L, which is two thirds that of the Japanese standard. France strictly complies with the drinking water standard for tritiated water.

The EU conducts joint surveys to monitor the discharge of radioactive materials from each facility and the surrounding marine life and environment. For example, in France, ACRO [37] is accredited by ASN [16] to monitor the discharge of radioactive materials. ACRO works with local residents around La Hague and Gravelines (the largest nuclear power plant in Western Europe) [37]. According to ACRO, achieving zero radioactively in the North Atlantic will be a difficult task unless La Hague greatly reduces emissions into the Alderney Race [38].

**Table 2.** Tritium quality standards per country and institution.

| Country/Organization | Tritium limit for drinking water [Bq/L] | Effluent standard [Bq/L] |
|---|---|---|
| Australia | 76,103 | No standard value |
| Finland | 30,000 | |
| WHO | 10,000 | |
| Switzerland | 10,000 | |
| Russia | 7,700 | |
| Canada (Ontario) | 7,000 | |
| ODWAC proposed limits | 20 | |
| EU (European Union) | 100 | |
| France | | 40,000 |
| United States | 740 | 37,000 |
| California Public Health Goal (not enforceable) | 14.8 | |
| Japan | No standard value = Effluent standard | 60,000 |
| Operational targets for FDNPP (Groundwater bypass etc.) | | 1,500 |

Source: [30–32].
Note: (1) ODWAC = Ontario Drinking Water Advisory Council. (2) FDNPP = Fukushima Daiichi Nuclear Power Plant

The EU follows the OSPAR Convention, it has high drinking water standards and requires strict monitoring, whereas, Japan does not have such standards, nor any required marine surveillance. Thus, differences may be noted in the quality and reliability of data publicly available.

Next, three hypotheses are posited for testing, based on the method of tritium discharged, the amount discharged, and water quality standards.

## 2.3. Survey Design and Target Area, and Statistical Methodology

### 2.3.1. Hypothesis

This paper posits three hypotheses:

First null hypothesis $H_0$: "There is no difference between the three countries in the reasons given for or against supporting the release of contaminated water." The alternative hypothesis $H_1$: "The reasons for or against supporting the release of contaminated water differ between countries."

Second null hypothesis $H_0$: "There is no difference between the three countries in the respondents' purchasing behavior of seafood caught in the vicinity of nuclear facilities." The alternative hypothesis $H_1$: "The purchasing behavior of respondents for seafood caught in the vicinity of nuclear facilities varies between countries."

Third null hypothesis $H_0$: "There is no difference between respondents in the three countries regarding how they believe the affected fishermen and fishing communities should be compensated." The alternative hypothesis $H_1$: "Respondents in the three countries differ in how they believe fishermen and fishing communities should be compensated."

### 2.3.2. Survey Areas

**Figure 1** presents the locations of La Hague, Sellafield, and Fukushima Daiichi Nuclear Power Plant, as well as the survey sites (ArcGIS). Circles in **Fig. 1** indicate the locations of La Hague, Sellafield, and Fukushima Daiichi Nuclear Power Plant. In France, six survey areas are presented: the Basse-Normandie where La Hague is located, the adjacent Bretagne, Haute-Normandie facing the English Channel, Picardie, Nord-Pas-de-Calais, and Île de France. In the UK, the six regions of North West England where Sellafield is located, Northern Ireland facing the Irish Sea, Wales, Scotland, South West England, and Greater London were targeted. Castrillejo et al. [39] examined the behavior of radioactive materials in the ocean current released from La Hague and Sellafield, and used radiocarbon ($^{14}C$) as an example. Survey areas for the UK and France were selected based on this study.

Similarly, we targeted six regions in Japan: Fukushima Prefecture where the Fukushima Daiichi Nuclear Power Plant is located, Ibaraki Prefecture facing the Pacific Ocean, Miyagi Prefecture, Aomori Prefecture where the Rokkasho reprocessing plant is located, and Tokyo. Behrens et al. [40] simulated the movement of radioactive cesium ($^{137}Cs$) released from the Fukushima Daiichi Nuclear Power Plant in the Pacific Ocean; the study areas were selected based on the results of this research.

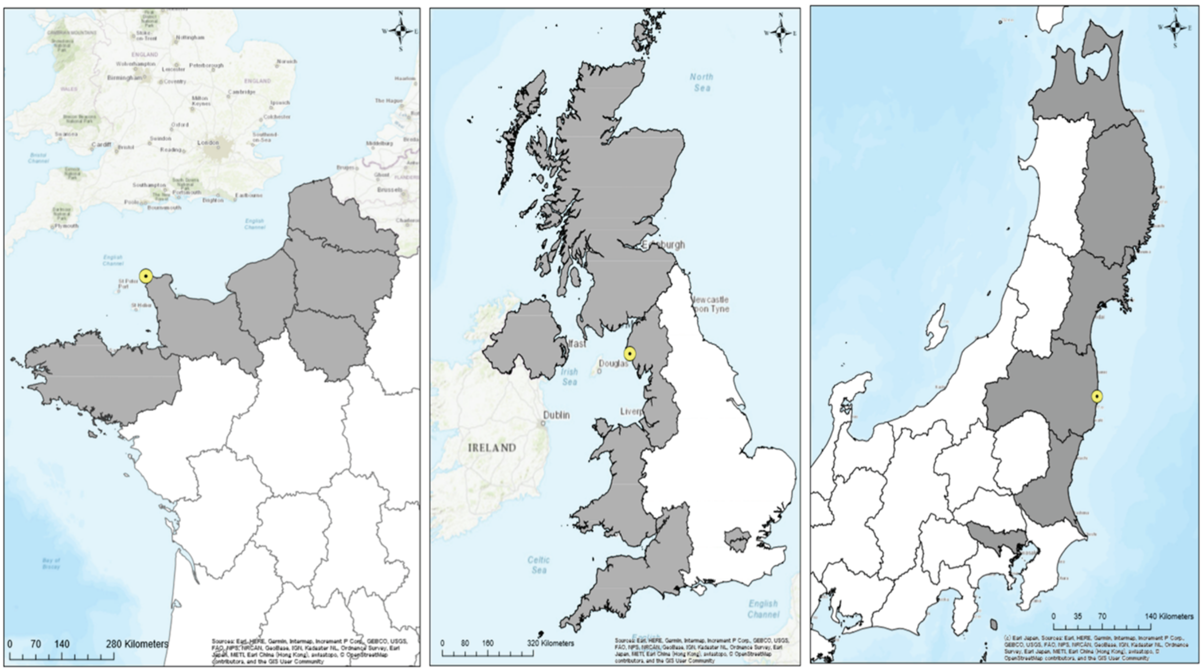
### 2.3.3. Aggregation Method

We created a web questionnaire on SurveyMonkey, and distributed and surveyed the questionnaire to the consumer panel provided by SurveyMonkey. The questionnaire language is Japanese in Japan and English in France and the UK.

Among the 310 respondents in France, 301 provided full responses. Among 309 respondents in England, 302 provided full responses. Moreover, among 306 respondents in Japan, 300 provided full responses. The response rate was 97.1% in France, 97.7% in the UK, and 98.0% in Japan. The aggregation period is June 1st (Monday) to 3rd (Wednesday), 2020 Japan time.[1]

For assembling the sample of respondents, the quota method was applied to match as best as possible the general population in terms of sex, age, and other factors. However, SurveyMonkey was not always able to derive adequate samples from regions wherein contaminated water is discharged, because their pool of respondents is concentrated in the denser population areas of Île de France, Greater London, and Tokyo. Therefore, the metropolitan areas of each country were set to 20% and the other five areas were 16% each. There are more respondents in the 20–40 age range, as well as more engineers and college graduates, compared with those found in the wider population.

1. Surveys were conducted over the course of three days, with the dates being June 1–2, 2020 in France, June 1, 2020 in the UK, and June 1–3, 2020 in Japan.




Source: Created from ArcGIS.
Note: ⊙ indicates the location of the La Hague Reprocessing Plant, Sellafield Nuclear Fuel Reprocessing Plant, and TEPCO Fukushima Daiichi Nuclear Power Station.

**Fig. 1.** Location of Ague Reprocessing Plant, Sellafield Nuclear Fuel Reprocessing Plant, and Tokyo Electric Power Fukushima Daiichi Nuclear Power and survey site.

#### 2.3.4. Comparison Method

First, a correspondence analysis is used to determine the relationship between contaminated water and knowledge of radioactive materials among respondents. Participants were asked to recall how many nuclear accidents they could remember, and about their knowledge of radioactive materials and contaminated water. The statistical means were calculated to draw comparisons between the different populations.

A statistical comparison is drawn using the responses derived when asked to consider the pros and cons of releasing contaminated water containing tritium.

The purchasing behavior of respondents and their impression of the quality of seafood caught in the vicinity of nuclear facilities is tested and compared. In addition, the differences among populations for the reasons driving their purchasing decisions were examined.

Finally, multiple comparisons are drawn to examine the statistical relations between recollection of nuclear accidents, knowledge of the release of radioactive materials and contaminated water, and perspectives regarding the pros and cons of releasing contaminated water.

### 2.4. Calculation Method

#### 2.4.1. Analysis of Reasons for Supporting or Opposing the Release of Contaminated Water

This section describes the estimation method for the ordinal logit model.

First, the ordinal logit model is estimated using "support for or opposition to releasing contaminated water" (see **Table 3**) as the dependent variable. The responses are scored as "oppose" = 1, "somewhat oppose" = 2, "unsure" = 3, "somewhat support" = 4, and "support" = 5.

12 arguments for (five) and against (seven), as well as nine individual attributes are applied as explanatory variables (see **Table 4**). The binary individual attributes are gender (male = 1, female = 0), country (France = 1, non-France = 0, UK = 1, non-UK = 0), household with children aged below 12 (present = 1). The presence or absence of a nuclear facility in their area was also included (present = 1, absent = 0).

Five continuous variables were applied: age bracket, number of household members, education level, income bracket, and distance from a nuclear facility. Age and income were bracketed, thus, an individual aged 45 years would fall into the 40–50-year-old bracket, and an income of 1.51 million yen would fall into the 1–2 million yen salary bracket. Educational attainment was scored from 1 for junior high school or equivalent to 6 for doctoral level.[2]

Using Google Earth, distance from the nuclear facility was introduced as an explanatory variable, represented by the distance between the two points from the facility to the capital city, the capital city of each region, the prefectural capital, and the capital of each region [41].[3]

2. Although there are other methods for measuring education by aggregating it into high school, junior college, and college graduates, and postgraduate completion dummies, we introduced scored discrete variables as proxies for years of education.
3. In this paper, we measured the distances between the facility to the capital city, the capital city and the prefectural capital of each region [42]. The measurement results showed that the distances from Google Earth [41] and orthogonal projection method differed only within

**Table 3.** Release of contaminated water.

| Item | Question / Response | "Oppose" | "Somewhat oppose" | "Unsure" | "Somewhat support" | "Support" | Average SD |
|---|---|---|---|---|---|---|---|
| Release of contaminated water into the ocean | Are you supportive of the current situation wherein tritium is not removed before the contaminated water is discharged? | 37.2% | 23.0% | 26.0% | 8.9% | 4.9% | 3.788 |
| | | 336 | 208 | 235 | 80 | 44 | 1.176 |

**Table 4.** Comparison of reasons given for supporting or opposing discharge of contaminated water (multiple answers allowed).

| Items | | All countries | | Japan | | UK | | France | | Comparison | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | count | % | count | % | count | % | count | % | JPN–GBR | JPN–FRA | GBR–FRA |
| Reasons for supporting | I believe that highly toxic substances, such as strontium-90 and iodine-129, will be removed. | 165 | 18.3% | 37 | 12.3% | 59 | 19.5% | 69 | 22.8% | −7.3% | −10.6%$^{*}$ | −3.3% |
| | It is inevitable that contaminated water will be discharged. | 132 | 14.6% | 37 | 12.3% | 40 | 13.2% | 55 | 18.2% | −1.0% | −6.0% | −5.0% |
| | Polluted water will quickly be diluted in the sea. | 100 | 11.1% | 26 | 8.6% | 36 | 11.9% | 38 | 12.6% | −3.3% | −4.0% | −0.7% |
| | The government has made it clear that tritiated water is not toxic. | 101 | 11.2% | 23 | 7.6% | 45 | 14.9% | 33 | 10.9% | −7.3% | −3.3% | 4.0% |
| | Other countries have also released polluted water into the ocean. | 64 | 7.1% | 21 | 7.0% | 21 | 7.0% | 22 | 7.3% | 0.0% | −0.3% | −0.3% |
| Reasons for opposing | Once polluted water is released, it will have a serious negative impact on neighboring fisheries. | 302 | 33.4% | 104 | 34.4% | 125 | 41.4% | 73 | 24.2% | −7.0% | 10.3%$^{*}$ | 17.2%$^{***}$ |
| | Radioactive substances that contaminate ocean life will also be released into the ocean. | 297 | 32.9% | 103 | 34.1% | 119 | 39.4% | 75 | 24.8% | −5.3% | 9.3%$^{*}$ | 14.6%$^{**}$ |
| | There is no guarantee that tritiated water is safe. | 277 | 30.7% | 83 | 27.5% | 129 | 42.7% | 65 | 21.5% | −15.2%$^{**}$ | 6.0% | 21.2%$^{***}$ |
| | The government is an unreliable source of trustworthy information. | 185 | 20.5% | 63 | 20.9% | 75 | 24.8% | 47 | 15.6% | −4.0% | 5.3% | 9.3% |
| | A huge amount of water, compared with that of other countries, will be discharged. | 176 | 19.5% | 55 | 18.2% | 87 | 28.8% | 34 | 11.3% | −10.6%$^{*}$ | 7.0% | 17.5%$^{**}$ |
| | Contaminated water should be stored in tanks until the technology for removing tritium from tritiated water is developed. | 175 | 19.4% | 43 | 14.2% | 93 | 30.8% | 39 | 12.9% | −16.6%$^{**}$ | 1.3% | 17.9%$^{**}$ |
| | There are no facilities to remove radioactive substances from contaminated water. | 169 | 18.7% | 79 | 26.2% | 61 | 20.2% | 29 | 9.6% | 6.0% | 16.6%$^{**}$ | 10.6% |
| | Other | 13 | 1.4% | 4 | 1.3% | 6 | 2.0% | 3 | 1.0% | −0.7% | 0.3% | 0.99% |

Note: $^{***}$, $^{**}$, and $^{*}$ indicate statistically significant differences at the 1%, 5%, and 10% levels, respectively (also applies to **Tables 5–7**).

### 2.4.2. Relationship Between Purchasing Behavior and Reasons for Not Purchasing Seafood Near Nuclear Facilities

To understand the degree to which the "purchasing behavior of seafood near nuclear facilities" (see **Table 8**) is related to the reasons for purchasing and not purchasing, the marginal effects are estimated using an ordinal logit model. The objective variables are scored as follows: "definitely will not buy" = 1, "reluctant to buy" = 2, "unsure" = 3, "buy a little less than usual" = 4, and "buy as usual" = 5.

In addition to the nine personal attributes mentioned in the previous section, the explanatory variables include the "reputation of seafood caught in the vicinity of a nuclear facility" (see **Table 5**) and "reasons for and against purchasing seafood caught in the vicinity of a nuclear facility" (see **Table 6**).

To estimate the ordinal logit model, categories of the dependent variable were combined when the differences between stages were not statistically significant or when the number of respondents was low. The estimation was conducted considering Akaike's Information Criterion (AIC) and likelihood ratio values, and only the best results have been presented. Each explanatory variable was estimated using the backward selection method, removing explanatory variables above the 20% significance level to ensure that only variables significant at the 1–10% significance level remained, until the best results were obtained.

The cut in **Tables 9–10** indicates the threshold variable, corresponding to $\Pr(y=1) = \Pr(\beta x < \text{cut1})$ and

the margin of error. Therefore, we used the distances from Google Earth, which can reliably start from the nuclear facility. Specifically, the distance from La Hague to Rennes (the capital city of Bretagne) is 172.65 km; from Sellafield to Edinburgh (the capital of Scotland) is 178.83 km; from Fukushima Daiichi Nuclear Power Plant to Sendai, Miyagi Prefecture, is 96.22 km.

**Table 5.** Comparison of reputation of seafood caught in the vicinity of nuclear facilities (multiple answers allowed).

| Items | All countries | | Japan | | UK | | France | | Comparison | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | count | % | count | % | count | % | count | % | JPN–GBR | JPN–FRA | GBR–FRA |
| No particular image | 232 | 25.7% | 90 | 29.8% | 68 | 22.5% | 74 | 24.5% | 7.3% | 5.3% | −2.0% |
| Good quality | 229 | 25.4% | 46 | 15.2% | 116 | 38.4% | 67 | 22.2% | −23.2%*** | −7.0% | 16.2%** |
| Fresh | 228 | 25.2% | 49 | 16.2% | 111 | 36.8% | 68 | 22.5% | −20.5%*** | −6.3% | 14.2%** |
| Delicious | 158 | 17.5% | 46 | 15.2% | 73 | 24.2% | 39 | 12.9% | −8.9% | 2.3% | 11.3%* |
| Area is famous for its product | 153 | 16.9% | 55 | 18.2% | 59 | 19.5% | 39 | 12.9% | −1.3% | 5.3% | 6.6% |
| Safe | 119 | 13.2% | 31 | 10.3% | 58 | 19.2% | 30 | 9.9% | −8.9% | 0.3% | 9.3% |
| Potentially dangerous to eat | 118 | 13.1% | 39 | 12.9% | 48 | 15.9% | 31 | 10.3% | −3.0% | 2.6% | 5.6% |
| Cheap | 96 | 10.6% | 38 | 12.6% | 29 | 9.6% | 29 | 9.6% | 3.0% | 3.0% | 0.0% |
| Recognizable/familiar fish | 96 | 10.6% | 12 | 4.0% | 55 | 18.2% | 29 | 9.6% | −14.2% | −5.6% | 8.6% |
| A strong brand | 64 | 7.1% | 8 | 2.6% | 34 | 11.3% | 22 | 7.3% | −8.6% | −4.6% | 4.0% |
| Availability | 63 | 7.0% | 26 | 8.6% | 16 | 5.3% | 21 | 7.0% | 3.3% | 1.7% | −1.7% |
| High concentration of radioactive substances | 62 | 6.9% | 34 | 11.3% | 16 | 5.3% | 12 | 4.0% | 6.0% | 7.3% | 1.3% |
| Advertising | 35 | 3.9% | 5 | 1.7% | 7 | 2.3% | 23 | 7.6% | −0.7% | −6.0% | −5.3% |
| Other | 8 | 0.9% | 5 | 1.7% | 2 | 0.7% | 1 | 0.3% | 1.0% | 1.3% | 0.3% |

$\Pr(y=2) = \Pr(\text{cut1} < \beta x < \text{cut2})$, where $y$ is the category of the dependent variable, $x$ is the explanatory variable, and $\beta$ is the parameter.

#### 2.4.3. Analysis of the Relationship Between Personal Attributes and Opinions About How Fishing Communities Should Be Compensated

We observed the objective variable of which organization should be compensating fishermen and fishing communities affected by contaminated water (see **Table 7**). Respondents were asked if they agreed whether compensation should be provided by the state, fishing companies, local government, through donations, or whether no compensation should be provided. In each case, agreement scored a 1, and disagreement scored a 0. However, there is a possibility of the error term correlating, because participants were able to provide more than one response. Therefore, we decided to post the final regression results with standard errors calculated by combining the covariance matrices estimated from the five probit regressions and the simultaneous sandwich/robust covariance matrix.

In addition to the nine personal attributes described above, a further explanatory variable scored on a 5-point scale is respondents' trust in government information about treated water discharged from nuclear facilities (see **Table 12**). Each explanatory variable was estimated using the backward selection method to ensure that only variables significant at the 1–10% level remained, until the best estimation results were obtained.

## 3. Survey Summary

In this section, results of the web-based survey are presented.

### 3.1. Sample Attributes

**Table 13** shows the sample attributes. First, observing the gender of respondents from the three countries, 43.9% respondents are male and 56.1% are female, with the largest cohort of females (64.5%) in France. A total of 40.1% of respondents in the three countries have children (or grandchildren) aged below 12 years at home, with only France showing a slight majority of respondents with children (51.5%). The predominant level of education in the three countries is university graduate. Household size in the three countries is 2.841, and is slightly higher in Japan (3.033). The average income of respondents was 4,873,000 yen, which is slightly higher in Japan (5,557,000 yen) and lower in France (3,819,000 yen). The percentage of respondents in metropolitan areas is approximately 20.0%, and 16% in the other areas, because the quota method was applied. In the UK, the number of retirees (12.3%) is higher, compared with that of the other two countries. The average age of the respondents was 42.4 years, which was not notably different among the three countries, and the age groups of individuals aged 30–39 years (28.5%), those aged 40–49 years (24.4%), those aged 20–29 years (17.3%), and those aged 50–59 years (16.3%) were predominant, whereas the number of individuals aged 40–49 years (30.0%) was slightly higher in Japan. The average distance from the nuclear facility to the regional capitals, and national capital cities is 232.0 km, but the distance is shorter in Japan (189.0 km), compared with France (251.5 km) and the UK (255.4 km).

### 3.2. Recollection of Nuclear Accidents, Knowledge of Radioactive Materials, and Contaminated Water

**Table 14** presents aggregate results of respondents from the three countries on how much they remember nuclear accidents and how much they know about radioactive materials and contaminated water. In this section, the

**Table 6.** Reasons for and against purchasing seafood from areas near nuclear facilities (multiple answers allowed).

| Items | | All countries | | Japan | | UK | | France | | Comparison | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | count | % | count | % | count | % | count | % | JPN–GBR | JPN–FRA | GBR–FRA |
| Reasons for buying | I think it's safe if it's in a shop. | 171 | 18.9% | 77 | 25.5% | 45 | 14.9% | 49 | 16.2% | 10.6%* | 9.3% | −1.3% |
| | I trust the assurances that pollution levels will not exceed the maximum limits set by the government. | 169 | 18.7% | 31 | 10.3% | 63 | 20.9% | 75 | 24.8% | −10.6% | −14.6%** | −4.0% |
| | It doesn't particularly bother me. | 154 | 17.1% | 101 | 33.4% | 27 | 8.9% | 26 | 8.6% | 24.5%*** | 24.8%*** | 0.3% |
| | I want to support local fishermen by purchasing local seafood. | 123 | 13.6% | 41 | 13.6% | 51 | 16.9% | 31 | 10.3% | −3.3% | 3.3% | 6.6% |
| | If the government is not restricting the sale of seafood, it must be safe. | 123 | 13.6% | 24 | 7.9% | 49 | 16.2% | 50 | 16.6% | −8.3% | −8.6% | −0.3% |
| | Because the government has declared the seafood to be safe. | 93 | 10.3% | 30 | 9.9% | 36 | 11.9% | 27 | 8.9% | −2.0% | 1.0% | 3.0% |
| | The government has declared that contaminated water will be diluted by seawater and will not affect the human body. | 62 | 6.9% | 10 | 3.3% | 25 | 8.3% | 27 | 8.9% | −5.0% | −5.6% | −0.7% |
| | I don't have young children. | 42 | 4.7% | 15 | 5.0% | 11 | 3.6% | 16 | 5.3% | 1.3% | −0.3% | −1.7% |
| Reasons for not buying | Polluted water is flowing into the ocean from the nuclear reprocessing plant site. | 193 | 21.4% | 52 | 17.2% | 102 | 33.8% | 39 | 12.9% | −16.6%** | 4.3% | 20.9%*** |
| | It is impossible to distinguish between fish with high and low bioconcentrations of radioactive materials. | 156 | 17.3% | 38 | 12.6% | 75 | 24.8% | 43 | 14.2% | −12.3%* | −1.7% | 10.6%* |
| | There is no guarantee that contaminated water is safe after treatment. | 149 | 16.5% | 38 | 12.6% | 75 | 24.8% | 36 | 11.9% | −12.3%* | 0.7% | 12.9%* |
| | I don't trust the safety assurances from the government or other authorities. | 144 | 15.9% | 36 | 11.9% | 73 | 24.2% | 35 | 11.6% | −12.3%* | 0.3% | 12.6%* |
| | Tests for radioactivity in seafood are not thorough or accurate enough. | 127 | 14.1% | 28 | 9.3% | 68 | 22.5% | 31 | 10.3% | −13.2%* | −1.0% | 12.3%* |
| | Seafood from other, safer areas are available. | 121 | 13.4% | 40 | 13.2% | 58 | 19.2% | 23 | 7.6% | −6.0% | 5.6% | 11.6%* |
| | I suspect there are high levels of bioaccumulation of radioactive materials in the food chain. | 115 | 12.7% | 25 | 8.3% | 62 | 20.5% | 28 | 9.3% | −12.3%* | −1.0% | 11.3%* |
| | I don't eat much fish anyway. | 100 | 11.1% | 24 | 7.9% | 40 | 13.2% | 36 | 11.9% | −5.3% | −4.0% | 1.3% |
| Other | | 14 | 1.6% | 5 | 1.7% | 7 | 2.3% | 2 | 0.7% | −0.7% | 1.0% | 1.7% |

**Table 7.** Who should be providing compensation to affected fishing communities (multiple answers allowed).

| Items | All countries | | Japan | | UK | | France | | Comparison | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | count | % | count | % | count | % | count | % | JPN–GBR | JPN–FRA | GBR–FRA |
| The central government should compensate. | 440 | 48.7% | 191 | 63.2% | 153 | 50.7% | 96 | 31.8% | 12.6%*** | 31.5%*** | 18.9%*** |
| The operators and parent companies should compensate. | 322 | 35.7% | 116 | 38.4% | 131 | 43.4% | 75 | 24.8% | −5.0% | 13.6%** | 18.5%*** |
| The local government should compensate. | 196 | 21.7% | 56 | 18.5% | 53 | 17.5% | 87 | 28.8% | 1.0% | −10.3%* | −11.3%* |
| No one should be compensated. | 96 | 10.6% | 16 | 5.3% | 32 | 10.6% | 48 | 15.9% | −5.3% | −10.6% | −5.3% |
| Donations should be collected. | 79 | 8.7% | 37 | 12.3% | 12 | 4.0% | 30 | 9.9% | 8.3% | 2.3% | −6.0% |
| Other | 10 | 1.1% | 4 | 1.3% | 3 | 1.0% | 3 | 1.0% | 0.3% | 0.3% | 0.0% |

**Table 8.** Purchasing behavior for seafood caught in the vicinity of a nuclear facility.

| Item | Question / Response | "Buy as usual" | "Buy a little less than usual" | "Unsure" | "Reluctant to buy" | "Definitely will not buy" | Average SD |
|---|---|---|---|---|---|---|---|
| Purchase of seafood from the vicinity of a nuclear facility | Would you buy seafood caught in the vicinity of a nuclear facility? | 17.6% | 21.8% | 32.3% | 17.2% | 11.1% | 3.177 |
| | | 159 | 197 | 292 | 155 | 100 | 1.228 |

**Table 9.** Relationship between arguments for or against and support or opposition to discharge of contaminated water.

| Variables | Arguments for or against release of contaminated water | | | "Support"/"Somewhat support" | | | "Unsure" | | | "Somewhat oppose" | | | "Oppose" | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value |
| For: It is inevitable that contaminated water will be discharged. | 0.470 | 0.176 | 0.008*** | 0.041 | 0.018 | 0.020** | 0.069 | 0.025 | 0.007*** | −0.010 | 0.009 | 0.248 | −0.100 | 0.035 | 0.004*** |
| For: Polluted water will quickly be diluted in the sea. | 0.882 | 0.196 | 0.000*** | 0.090 | 0.026 | 0.001*** | 0.122 | 0.024 | 0.000*** | −0.039 | 0.018 | 0.030** | −0.173 | 0.032 | 0.000*** |
| For: Other countries have also released polluted water into the ocean. | 0.710 | 0.245 | 0.004*** | 0.070 | 0.030 | 0.021** | 0.101 | 0.031 | 0.001*** | −0.028 | 0.020 | 0.154 | −0.142 | 0.001 | 0.001*** |
| Against: There are no facilities to remove radioactive substances from contaminated water. | −0.463 | 0.183 | 0.011** | −0.031 | 0.011 | 0.005*** | −0.067 | 0.026 | 0.009*** | −0.010 | 0.009 | 0.264 | 0.108 | 0.044 | 0.014** |
| Against: Radioactive substances that contaminate ocean life will also be released into the ocean. | −1.012 | 0.158 | 0.000*** | −0.068 | 0.011 | 0.000*** | −0.143 | 0.022 | 0.000*** | −0.024 | 0.012 | 0.039** | 0.235 | 0.037 | 0.000*** |
| Against: The government is an unreliable source of trustworthy information. | −0.777 | 0.192 | 0.000*** | −0.049 | 0.011 | 0.000*** | −0.110 | 0.025 | 0.000*** | −0.025 | 0.014 | 0.077* | 0.184 | 0.047 | 0.000*** |
| Against: There is no guarantee that tritiated water is safe. | −0.671 | 0.169 | 0.000*** | −0.046 | 0.011 | 0.000*** | −0.097 | 0.024 | 0.000*** | −0.013 | 0.009 | 0.153 | 0.156 | 0.040 | 0.000*** |
| Against: Contaminated water should be safely stored in tanks until the technology for removing tritium from tritiated water is developed. | −0.703 | 0.200 | 0.000*** | −0.045 | 0.011 | 0.000*** | −0.100 | 0.027 | 0.000*** | −0.021 | 0.013 | 0.115 | 0.166 | 0.049 | 0.001*** |
| Against: A huge amount of water, compared with that of other countries, will be discharged. | −0.423 | 0.199 | 0.033** | −0.029 | 0.012 | 0.019** | −0.062 | 0.028 | 0.029** | −0.008 | 0.009 | 0.346 | 0.099 | 0.048 | 0.038** |
| Income | −0.275 | 0.082 | 0.001*** | −0.021 | 0.006 | 0.001*** | −0.041 | 0.012 | 0.001*** | 0.000 | 0.003 | 0.918 | 0.062 | 0.018 | 0.001*** |
| Education | 0.162 | 0.055 | 0.003*** | 0.012 | 0.004 | 0.004*** | 0.024 | 0.008 | 0.004*** | 0.000 | 0.002 | 0.918 | −0.037 | 0.012 | 0.003*** |
| UK = 1 | −0.596 | 0.146 | 0.000*** | −0.042 | 0.010 | 0.000*** | −0.087 | 0.021 | 0.000*** | −0.009 | 0.007 | 0.211 | 0.138 | 0.034 | 0.000*** |
| cut1 | −1.442 | 0.221 | | | | | | | | | | | | | |
| cut2 | −0.131 | 0.214 | | | | | | | | | | | | | |
| cut3 | 1.609 | 0.224 | | | | | | | | | | | | | |
| Sample size | 903 | | | | | | | | | | | | | | |
| Likelihood ratio | −1024.5*** | | | | | | | | | | | | | | |
| AIC | 2079.1 | | | | | | | | | | | | | | |
| $\chi^2$ | 351.1 | | | | | | | | | | | | | | |
| pseudo $R^2$ | 0.146 | | | | | | | | | | | | | | |

Note: (1) ***, **, and * indicate statistical significance at 1%, 5%, and 10% levels, respectively (also applies to **Tables 10** and **11**). (2) Cut represents threshold values; cut1 is "unsure," cut2 is "somewhat support," and cut3 is "support." (3) As there were so few "support" and "somewhat support" responses (see **Table 3**), these were combined to improve the model. (4) The backwards selection method was applied to both reasons for and against (see **Table 4**) (excluding the response "other") until only variables significant at 1–10% remained (also applies to **Tables 10** and **11**).

**Table 10.** Relationship between purchasing behavior and reasons for and against purchasing seafood.

| Variables | Reasons for and against purchasing | | | "Definitely will not buy" | | | "Reluctant to buy" | | | "Unsure" | | | "Buy a little less than usual" | | | "Buy as usual" | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | coef. | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value |
| Safe | 0.790 | 0.208 | 0.000*** | −0.023 | 0.005 | 0.000*** | −0.074 | 0.017 | 0.000*** | −0.091 | 0.032 | 0.004*** | 0.108 | 0.026 | 0.000*** | 0.080 | 0.027 | 0.003*** |
| Delicious | 0.665 | 0.177 | 0.000*** | −0.021 | 0.005 | 0.000*** | −0.065 | 0.016 | 0.000*** | −0.070 | 0.024 | 0.004*** | 0.093 | 0.024 | 0.000*** | 0.063 | 0.020 | 0.002*** |
| Dangerous | −0.700 | 0.203 | 0.001*** | 0.034 | 0.013 | 0.008*** | 0.088 | 0.029 | 0.002*** | 0.019 | 0.010 | 0.061* | −0.095 | 0.026 | 0.000*** | −0.045 | 0.011 | 0.000*** |
| For: I trust the assurances that pollution levels will not exceed the maximum limits set by the government. | 1.249 | 0.174 | 0.000*** | −0.034 | 0.005 | 0.000*** | −0.111 | 0.014 | 0.000*** | −0.152 | 0.029 | 0.000*** | 0.159 | 0.020 | 0.000*** | 0.138 | 0.026 | 0.000*** |
| For: It doesn't particularly bother me. | 2.144 | 0.206 | 0.000*** | −0.049 | 0.007 | 0.000*** | −0.158 | 0.014 | 0.000*** | −0.283 | 0.033 | 0.000*** | 0.192 | 0.019 | 0.000*** | 0.298 | 0.042 | 0.000*** |
| For: I want to support local fishermen by purchasing local seafood. | 0.758 | 0.195 | 0.000*** | −0.022 | 0.005 | 0.000*** | −0.072 | 0.016 | 0.000*** | −0.086 | 0.029 | 0.004*** | 0.104 | 0.025 | 0.000*** | 0.076 | 0.024 | 0.002*** |
| For: If the government is not restricting the sale of seafood, it must be safe. | 0.762 | 0.194 | 0.000*** | −0.023 | 0.005 | 0.000*** | −0.072 | 0.016 | 0.000*** | −0.086 | 0.029 | 0.003*** | 0.105 | 0.025 | 0.000*** | 0.076 | 0.024 | 0.002*** |
| For: I think it's safe if it's in a shop. | 1.461 | 0.179 | 0.000*** | −0.039 | 0.006 | 0.000*** | −0.125 | 0.014 | 0.000*** | −0.182 | 0.031 | 0.000*** | 0.176 | 0.019 | 0.000*** | 0.170 | 0.029 | 0.000*** |
| Against: Polluted water is flowing into the ocean from nuclear facilities. | −1.069 | 0.180 | 0.000*** | 0.055 | 0.013 | 0.000*** | 0.135 | 0.026 | 0.000*** | 0.019 | 0.015 | 0.201 | −0.142 | 0.022 | 0.000*** | −0.067 | 0.011 | 0.000*** |
| Against: There is no guarantee that contaminated water is safe after treatment. | −0.473 | 0.197 | 0.016*** | 0.021 | 0.010 | 0.041** | 0.057 | 0.026 | 0.027** | 0.022 | 0.007 | 0.002** | −0.066 | 0.027 | 0.013** | −0.033 | 0.012 | 0.007** |
| Against: Tests for radioactivity in seafood are not thorough or accurate enough. | −0.719 | 0.201 | 0.000*** | 0.035 | 0.013 | 0.006*** | 0.090 | 0.028 | 0.001*** | 0.019 | 0.010 | 0.055* | −0.098 | 0.026 | 0.000*** | −0.046 | 0.011 | 0.000*** |
| Against: Seafood from other, safer areas are available. | −0.578 | 0.207 | 0.005*** | 0.027 | 0.012 | 0.024** | 0.071 | 0.028 | 0.011** | 0.021 | 0.007 | 0.005*** | −0.080 | 0.027 | 0.003*** | −0.039 | 0.012 | 0.001*** |
| Distance from nuclear facility | −0.259 | 0.125 | 0.039** | 0.010 | 0.005 | 0.044** | 0.029 | 0.014 | 0.040** | 0.019 | 0.010 | 0.054* | −0.037 | 0.018 | 0.041** | −0.021 | 0.010 | 0.042** |
| Family size | −0.098 | 0.047 | 0.036** | 0.004 | 0.002 | 0.040** | 0.011 | 0.005 | 0.037** | 0.007 | 0.004 | 0.051** | −0.014 | 0.007 | 0.038** | −0.008 | 0.004 | 0.038** |
| Income | 0.178 | 0.084 | 0.034** | −0.007 | 0.003 | 0.039** | −0.020 | 0.009 | 0.036** | −0.013 | 0.007 | 0.047** | 0.025 | 0.012 | 0.036** | 0.014 | 0.007 | 0.036** |
| France = 1 | 0.536 | 0.145 | 0.000*** | −0.019 | 0.005 | 0.000*** | −0.057 | 0.015 | 0.000*** | −0.047 | 0.016 | 0.003*** | 0.076 | 0.021 | 0.000*** | 0.046 | 0.014 | 0.001*** |
| cut1 | −3.720 | 0.174 | | | | | | | | | | | | | | | | |
| cut2 | −2.020 | 0.688 | | | | | | | | | | | | | | | | |
| cut3 | 0.169 | 0.685 | | | | | | | | | | | | | | | | |
| cut4 | 1.835 | 0.688 | | | | | | | | | | | | | | | | |
| Sample size | 903 | | | | | | | | | | | | | | | | | |
| Likelihood ratio | −1095.1*** | | | | | | | | | | | | | | | | | |
| AIC | 2230.1 | | | | | | | | | | | | | | | | | |
| $\chi^2$ | 607.8 | | | | | | | | | | | | | | | | | |
| pseudo $R^2$ | 0.217 | | | | | | | | | | | | | | | | | |

Note: cut1 to cut4 represent "Reluctant to buy" to "Buy as usual."

**Table 11.** Personal attributes as a factor in deciding position on compensation for fishing communities.

| Item | Central government should compensate | | | Industry stakeholders should compensate | | | Regional/local government should compensate | | |
|---|---|---|---|---|---|---|---|---|---|
| | coef. | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value |
| Reliability of government information | | | | −0.249 | 0.039 | 0.000$^{***}$ | | | |
| Distance from nuclear facility | −0.212 | 0.089 | 0.017$^{***}$ | | | | | | |
| Male = 1 | | | | 0.356 | 0.088 | 0.000$^{***}$ | | | |
| Children = 1 | | | | | | | 0.213 | 0.098 | 0.030$^{**}$ |
| Age | | | | | | | −0.010 | 0.004 | 0.005$^{***}$ |
| UK = 1 | −0.254 | 0.109 | 0.020$^{**}$ | 0.304 | 0.092 | 0.001$^{***}$ | | | |
| France = 1 | −0.702 | 0.113 | 0.000$^{***}$ | | | | 0.305 | 0.099 | 0.002$^{***}$ |
| Income | 0.135 | 0.055 | 0.014$^{**}$ | | | | | | |
| Family size | 1.238 | 0.458 | 0.007$^{***}$ | 0.074 | 0.125 | 0.551 | −0.564 | 0.171 | 0.001$^{***}$ |
| Sample size | 903 | | | 903 | | | 903 | | |
| Likelihood ratio | −588.8$^{***}$ | | | −553.9$^{***}$ | | | −458.3$^{***}$ | | |
| AIC | 1187.7 | | | 1115.9 | | | 924.6 | | |
| $\chi^2$ | 73.6 | | | 68.6 | | | 28.3 | | |
| pseudo $R^2$ | 0.1 | | | 0.1 | | | 0.0 | | |

| Item | Compensation through donation | | | No compensation necessary | | |
|---|---|---|---|---|---|---|
| | $dy/dx$ | Standard error | $p$-value | $dy/dx$ | Standard error | $p$-value |
| Reliability of government information | | | | 0.210 | 0.060 | 0.000$^{***}$ |
| Distance from nuclear facility | | | | | | |
| Male = 1 | | | | | | |
| Children = 1 | | | | | | |
| Age | | | | | | |
| UK = 1 | −0.488 | 0.148 | 0.001$^{***}$ | | | |
| France = 1 | | | | 0.312 | 0.119 | 0.009$^{***}$ |
| Income | −0.221 | 0.064 | 0.001$^{***}$ | | | |
| Family size | −0.963 | 0.103 | 0.000$^{***}$ | −2.018 | 0.199 | 0.000$^{***}$ |
| Sample size | 903 | | | 903 | | |
| Likelihood ratio | −256.1$^{***}$ | | | −290.5$^{***}$ | | |
| AIC | 518.1 | | | 587.1 | | |
| $\chi^2$ | 23.7 | | | 30.7 | | |
| pseudo $R^2$ | 0.0 | | | 0.1 | | |

Note: This regression consists of five probit regressions. However, the error terms may be correlated because respondents were able to select multiple responses (see **Table 6**), thus the covariance matrices were combined and the standard errors were calculated using a sandwich covariance estimator.

**Table 12.** Trust in government assurances on safety of decontaminated water.

| Item | Question / Response | "Very reliable" | "Somewhat reliable" | "Unsure" | "Not very reliable" | "Totally unreliable" | Average SD |
|---|---|---|---|---|---|---|---|
| Government assurances on safety of decontaminated water | How reliable do you find government assurances that decontaminated water from the nuclear facility is safe? | 8.9% | 22.1% | 32.2% | 23.8% | 13.0% | 2.901 |
| | | 80 | 200 | 291 | 215 | 117 | 1.151 |

combined responses of respondents from the three countries are compared, and they are examined in isolation in Section 3.8 below.

### 3.2.1. Recollection of Nuclear Accidents

First, survey results on the extent to which participants of the three countries could remember nuclear accidents are calculated. According to INES, only two accidents, Chernobyl and Fukushima, are classified as level 7, the highest ("major accident").[4]

When asked how much they knew about the Chernobyl accident, the most common answer was "know a little" (45.1%) followed by "know a lot" (23.6%), for a total of 68.7% respondents having a degree of awareness of the incident.

Similarly, when asked about the Fukushima accident,

4. The International Nuclear and Radiological Event Scale, or INES, [43] is a scale for evaluating nuclear accidents and failures and was developed by the IAEA [44] and the OECD/NEA (Organization for Economic Cooperation and Development) [45].

**Table 13.** Survey participants attributes ($n = 903$).

| Personal attributes | | All countries freq. | All countries % | Japan ($n = 300$) freq. | Japan % | France ($n = 301$) freq. | France % | UK ($n = 302$) freq. | UK % |
|---|---|---|---|---|---|---|---|---|---|
| Sex | Male | 396 | 43.9% | 141 | 47.0% | 107 | 35.5% | 148 | 49.0% |
| | Female | 507 | 56.1% | 159 | 53.0% | 194 | 64.5% | 154 | 51.0% |
| Education | Junior high | 27 | 3.0% | 13 | 4.3% | 12 | 4.0% | 2 | 0.7% |
| | Senior high | 220 | 24.4% | 100 | 33.3% | 43 | 14.3% | 77 | 25.5% |
| | College, etc. | 207 | 22.9% | 77 | 25.7% | 64 | 21.3% | 66 | 21.9% |
| | Undergraduate | 297 | 32.9% | 99 | 33.0% | 120 | 39.9% | 78 | 25.8% |
| | Graduate | 101 | 11.2% | 9 | 3.0% | 52 | 17.3% | 40 | 13.2% |
| | Post-graduate | 51 | 5.6% | 2 | 0.7% | 10 | 3.3% | 39 | 12.9% |
| Children | Present | 362 | 40.1% | 92 | 30.7% | 155 | 51.5% | 115 | 38.1% |
| | Absent | 541 | 59.9% | 208 | 69.3% | 146 | 48.5% | 187 | 61.9 % |
| Household members | average/SD | 2.841 | 1.376 | 3.033 | 1.472 | 2.757 | 1.318 | 2.732 | 1.319 |
| Annual income | under ¥1 million | 64 | 7.1% | 28 | 9.3% | 26 | 8.6% | 10 | 3.3% |
| | ¥1.01 m–2 m | 86 | 9.5% | 11 | 3.7% | 39 | 13.0% | 36 | 11.9% |
| | ¥2.01 m–3 m | 132 | 14.6% | 35 | 11.7% | 64 | 21.3% | 33 | 10.9% |
| | ¥3.01 m–4 m | 155 | 17.2% | 41 | 13.7% | 61 | 20.3% | 53 | 17.5% |
| | ¥4.01 m–5 m | 127 | 14.1% | 47 | 15.7% | 42 | 14.0% | 38 | 12.6% |
| | ¥5.01 m–6 m | 96 | 10.6% | 31 | 10.3% | 25 | 8.3% | 40 | 13.2% |
| | ¥6.01 m–7 m | 82 | 9.1% | 33 | 11.0% | 18 | 6.0% | 31 | 10.3% |
| | ¥7.01 m–8 m | 43 | 4.8% | 17 | 5.7% | 7 | 2.3% | 19 | 6.3% |
| | ¥8.01 m–9 m | 26 | 2.9% | 12 | 4.0% | 6 | 2.0% | 8 | 2.6% |
| | ¥9.01 m–10 m | 24 | 2.7% | 12 | 4.0% | 4 | 1.3% | 8 | 2.6% |
| | ¥10.01 m–11 m | 19 | 2.1% | 11 | 3.7% | 1 | 0.3% | 7 | 2.3% |
| | ¥11.01 m–12 m | 7 | 0.8% | 2 | 0.7% | 3 | 1.0% | 2 | 0.7% |
| | ¥12.01 m–13 m | 8 | 0.9% | 3 | 1.0% | 2 | 0.7% | 3 | 1.0% |
| | ¥13.01 m–14 m | 3 | 0.3% | 2 | 0.7% | 0 | 0.0% | 1 | 0.3% |
| | ¥14.01 m–15 m | 8 | 0.9% | 5 | 1.7% | 1 | 0.3% | 2 | 0.7% |
| | ¥15.01 m–16 m | 4 | 0.4% | 3 | 1.0% | 0 | 0.0% | 1 | 0.3% |
| | ¥16.01 m–17 m | 3 | 0.3% | 0 | 0.0% | 0 | 0.0% | 3 | 1.0% |
| | ¥17.01 m–18 m | 4 | 0.4% | 0 | 0.0% | 2 | 0.7% | 2 | 0.7% |
| | ¥18.01 m–19 m | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| | ¥19.01 m–20 m | 1 | 0.1% | 0 | 0.0% | 0 | 0.0% | 1 | 0.3% |
| | over ¥20 million | 11 | 1.2% | 7 | 2.3% | 0 | 0.0% | 4 | 1.3% |
| | Average/SD | 487.3 | 355.5 | 555.7 | 396.6 | 381.9 | 261.4 | 524.5 | 370.3 |
| Age | Under 19 | 17 | 1.9% | 9 | 3.0% | 5 | 1.7% | 3 | 1.0% |
| | 20–29 | 156 | 17.3% | 50 | 16.7% | 60 | 19.9% | 46 | 15.2% |
| | 30–39 | 257 | 28.5% | 79 | 26.3% | 94 | 31.2% | 84 | 27.8% |
| | 40–49 | 220 | 24.4% | 90 | 30.0% | 65 | 21.6% | 65 | 21.5% |
| | 50–59 | 147 | 16.3% | 46 | 15.3% | 48 | 15.9% | 53 | 17.5% |
| | 60–69 | 76 | 8.4% | 19 | 6.3% | 25 | 8.3% | 32 | 10.6% |
| | Over 70 | 30 | 3.3% | 7 | 2.3% | 4 | 1.3% | 19 | 6.3% |
| | average/SD | 42.4 | 13.7 | 41.6 | 13.1 | 41.0 | 13.1 | 44.6 | 14.7 |
| Region | Tokyo\|Paris\|London | 181 | 20.0% | 62 | 20.7% | 65 | 21.6% | 54 | 17.9% |
| | Fukushima\|Basse-Normandie\|North West England | 143 | 15.8% | 47 | 15.7% | 45 | 15.0% | 51 | 16.9% |
| | Miyagi\|Bretagne\|Northern Ireland | 152 | 16.8% | 51 | 17.0% | 51 | 16.9% | 50 | 16.6% |
| | Ibaraki\|Haute-Normandie\|Scotland | 150 | 16.6% | 48 | 16.0% | 52 | 17.3% | 50 | 16.6% |
| | Iwate\|Picardie\|South West England | 133 | 14.7% | 44 | 14.7% | 41 | 13.6% | 48 | 15.9% |
| | Aomori\|Nord-Pas-de-Calais\|Wales | 144 | 15.9% | 48 | 16.0% | 47 | 15.6% | 49 | 16.2% |
| | Average distance from a facility/SD | 232.0 | 102.5 | 189.0 | 105.8 | 251.5 | 84.1 | 255.4 | 102.8 |
| Occupation | General office worker | 179 | 19.8% | 48 | 16.0% | 55 | 18.3% | 76 | 25.2% |
| | Public employee | 94 | 10.4% | 18 | 6.0% | 44 | 14.6% | 32 | 10.6% |
| | Factory | 48 | 5.3% | 22 | 7.3% | 12 | 4.0% | 14 | 4.6% |
| | Engineer/specialist | 52 | 5.8% | 12 | 4.0% | 26 | 8.6% | 14 | 4.6% |
| | Self-employed | 58 | 6.4% | 13 | 4.3% | 27 | 9.0% | 18 | 6.0% |
| | Agriculture/fisheries | 12 | 1.3% | 8 | 2.7% | 1 | 0.3% | 3 | 1.0% |
| | Homemaker | 50 | 5.5% | 39 | 13.0% | 4 | 1.3% | 7 | 2.3% |
| | Student | 42 | 4.7% | 15 | 5.0% | 19 | 6.3% | 8 | 2.6% |
| | Health worker | 30 | 3.3% | 16 | 5.3% | 11 | 3.7% | 3 | 1.0% |
| | Education | 44 | 4.9% | 11 | 3.7% | 18 | 6.0% | 15 | 5.0% |
| | Sales and marketing | 50 | 5.5% | 29 | 9.7% | 7 | 2.3% | 14 | 4.6% |
| | Distribution | 23 | 2.5% | 11 | 3.7% | 4 | 1.3% | 8 | 2.6% |
| | Social work | 28 | 3.1% | 7 | 2.3% | 8 | 2.7% | 13 | 4.3% |
| | Retired | 69 | 7.6% | 10 | 3.3% | 22 | 7.3% | 37 | 12.3% |
| | Unemployed | 65 | 7.2% | 17 | 5.7% | 31 | 10.3% | 17 | 5.6% |
| | Incapacitated/off work | 25 | 2.8% | 8 | 2.7% | 4 | 1.3% | 13 | 4.3% |
| | Service industry | 14 | 1.6% | 6 | 2.0% | 5 | 1.7% | 5 | 1.7% |
| | Other | 20 | 2.2% | 10 | 3.3% | 3 | 1.0% | 5 | 1.7% |

Source: Compiled from SurveyMonkey survey results.
Note: (1) Children are defined as those who are in junior high school or younger. (2) Average and standard deviation (SD) of age and income are calculated using class values. (3) Average distance/SD from nuclear power plants and nuclear processing facilities are estimated using Google Earth, calculated as a straight-line from the Fukushima Daiichi Nuclear Power Plant to Tokyo, a straight-line from La Hague to Paris, and as a straight line from Sellafield to London, and also as a straight line from each facility to the capitals of each surveyed region.

**Table 14.** Knowledge of nuclear accidents, radioactive material, and contaminated water.

| Items | | Question / Response | "Know well" | "Know a little" | "Unable to say" | "Don't know well" | "Don't know at all" | Average SD |
|---|---|---|---|---|---|---|---|---|
| Knowledge of nuclear accidents | Chernobyl | Do you know about the 1986 Chernobyl nuclear power plant accident? | 23.6% | 45.1% | 17.3% | 8.9% | 5.2% | 3.730 |
| | | | 213 | 407 | 156 | 80 | 47 | 1.077 |
| | Fukushima | Do you know about the Fukushima Daiichi Nuclear Power Plant accident in Japan? | 33.0% | 34.3% | 15.4% | 10.9% | 6.4% | 3.766 |
| | | | 298 | 310 | 139 | 98 | 58 | 1.201 |
| | Recollection of accidents in nuclear facilities | Do you know about accidents in nuclear facilities and manufacturing facilities? | 15.4% | 28.7% | 18.4% | 18.5% | 19.0% | 3.029 |
| | | | 139 | 259 | 166 | 167 | 172 | 1.360 |
| Knowledge of radioactive materials | Radioactive cesium | Do you know about radioactive cesium? | 12.5% | 30.7% | 18.2% | 20.5% | 18.2% | 2.989 |
| | | | 113 | 277 | 164 | 185 | 164 | 1.319 |
| | Radioactive iodine | Do you know about radioactive iodine? | 10.4% | 32.6% | 18.7% | 20.6% | 17.7% | 2.973 |
| | | | 94 | 294 | 169 | 186 | 160 | 1.288 |
| | Tritium | Do you know about tritium? | 8.4% | 23.6% | 19.2% | 21.9% | 26.9% | 2.647 |
| | | | 76 | 213 | 173 | 198 | 243 | 1.321 |
| Knowledge of contaminated water | Release of tritium from nuclear facilities | Do you know about the quantities of tritium being emitted from nuclear power plants into the sea? | 10.6% | 22.9% | 18.5% | 22.1% | 25.8% | 2.704 |
| | | | 96 | 207 | 167 | 200 | 233 | 1.350 |
| | Radioactive materials in water | Do you know about contaminated water containing radioactive materials other than tritium? | 10.6% | 25.6% | 16.9% | 23.1% | 23.7% | 2.763 |
| | | | 96 | 231 | 153 | 209 | 214 | 1.344 |
| | Tritium and reprocessing plants | Do you know about the far higher levels of tritium released from nuclear reprocessing plants, compared with that of nuclear power plants? | 7.3% | 19.2% | 20.5% | 24.4% | 28.7% | 2.520 |
| | | | 66 | 173 | 185 | 220 | 259 | 1.283 |
| | Removal of tritium | Do you know that nuclear facilities release water containing tritium without the necessary equipment to completely remove tritium from the water? | 9.3% | 18.9% | 22.6% | 17.8% | 31.3% | 2.570 |
| | | | 84 | 171 | 204 | 161 | 283 | 1.346 |
| | Bioaccumulation of radioactive materials | Do you know that contaminated water may also release bioaccumulative radioactive materials, such as iodine-129, into the ocean? | 8.4% | 26.4% | 21.2% | 17.5% | 26.6% | 2.725 |
| | | | 76 | 238 | 191 | 158 | 240 | 1.328 |
| | Contaminated water around nuclear facilities | Do you know about the contaminated water around nuclear facilities? | 15.0% | 25.9% | 19.7% | 13.7% | 25.7% | 2.907 |
| | | | 135 | 234 | 178 | 124 | 232 | 1.420 |
| | Release of contaminated water | Do you know your country releases large amounts of contaminated water into the ocean? | 9.6% | 20.7% | 19.6% | 20.4% | 29.7% | 2.602 |
| | | | 87 | 187 | 177 | 184 | 268 | 1.352 |

Note: The average given is the average of the question items scored using the 5-level Likert scale (applies to **Tables 3**, **8**, and **12**).

most respondents knew either a little (34.3%) and slightly less knew a lot (33%), for a total of 67.3% respondents indicating a degree of awareness about the Fukushima accident.

The Windscale fire was a Level 5 accident according to the INES (an "accident with wider consequences"), which is the same level as the Three Mile Island nuclear power plant accident (USA). The loss of power at La Hague (April 15, 1980) is classified as a Level 3 ("serious incident").[5] The Tokai-mura JCO criticality accident (September 30, 1999) is classified as Level 4 ("accident with local consequences") under INES.

We asked respondents whether they knew about other accidents at nuclear facilities in general. The majority of the respondents knew a little about it (28.7%), but the number of those who knew it well (15.4%) was less than that for the major nuclear accidents.

### 3.2.2. Knowledge of Radioactive Materials

The following is a summary of the respondents' stated knowledge of radioactive materials.

In the event of a nuclear power plant accident, radioactive cesium ($^{134}$Cs, $^{137}$Cs) is discharged, and respondents were asked whether they were aware about this. Most respondents knew a little about it (30.7%), followed by those who did not know much at all (20.5%).

5. Among nuclear accidents that have occurred in France, French people remembered the fire accident at the Cattenom nuclear power plant (2013), followed by the uranium effluent spill at Tricastin nuclear power plant (2008) [46]. On the other hand, the loss of power at La Hague in 1980 was the third most remembered accident [46], thereby suggesting that despite the fact that this incident occurred 30 years before the survey, it was a memorable accident for French people.

Similarly, radioactive iodine ($^{131}$I and $^{133}$I) is also released during nuclear accidents, but it is $^{131}$I that adversely affects the thyroid gland [47, 48]. When asked whether or not they "knew about radioactive iodine," most knew a little about it (32.6%), followed by those who did not know much at all (20.6%).

Tritium is a radioactive isotope of hydrogen ($^{3}$H), which naturally occurs in small amounts, but has been produced in large quantities in nuclear tests and in nuclear power plants, and has been widely dispersed around the world. When asked whether or not they knew about tritium, many people reported that they knew a little bit about tritium (23.6%), but the largest number of people knew nothing about it (26.9%), and the third largest group did not know much about it (20.6%).

#### 3.2.3. Knowledge of Contaminated Water

The survey also asked about respondents' knowledge of contaminated water.

First, the annual tritium discharge into the ocean from nuclear power plants all over Japan has reached approximately 380 trillion Bq per year [49]. Nuclear power plants release large amounts of tritiated water, even under normal circumstances. Respondents were asked if they were "aware of the large amount of tritium released in the vicinity of nuclear power plants;" regardless of whether there had been an accident or not. A total of 47.9% respondents answered in the negative, with 25.8% responding "don't know at all" and 22.1% responding "don't know much."

Second, contaminated water discharged from nuclear power and reprocessing plants contains not only tritium, but also radioactive substances, such as $^{90}$Sr and $^{129}$I, which is produced by the fission of uranium and plutonium [13]. When asked if they knew of radioactive substances other than tritium being released, 46.8% respondents did not know about it, including those who said they did not know at all (23.7%) and those who said they did not know much (23.1%).

The amount of radioactive material released into the air and sea by nuclear reprocessing plans per day is more than a year's worth (1 trillion Bq) released through nuclear power generation [13]. When asked about the large quantities of tritium in areas surrounding nuclear facilities, 53.1% respondents reported that they had no knowledge (28.7%) nor did not know much about it (24.4%).

Tritium is a special radionuclide with the ability to easily enter the life cycle, but the complex nature of its interactions with the environment have yet to be fully understood [50]. Although there are many theories, scholars have yet to reach concrete scientific consensus. Tritium has been released into the oceans at 100 times higher than other materials, such as cesium and iodine, under the belief that it has no concentration effect on marine life [51]. We asked respondents how aware they were of tritium being released into the ocean. A total of 31.3% respondents were completely unaware and 17.8% were somewhat unaware (a total of 49.1%).

Most radioactive materials discharged in liquid form from nuclear fuel reprocessing plants into the ocean are not susceptible to bioaccumulation, but $^{129}$I can be bioaccumulated in seaweed [52]. Therefore, seaweed around the nuclear reprocessing plant is contaminated with radioactive material, and bivalves that eat this seaweed can also experience the bioaccumulation of radioactive material, as reported by a study in the Bristol Channel [52]. When asked if they knew that bioaccumulative radioactive materials, such as iodine-129, were also released into the ocean, many respondents reported that they knew a little about it (26.4%), but the largest group knew nothing at all (26.6%).

La Hague receives approximately half of the world's spent nuclear fuel from nuclear reactors (light water reactors) [53]. Many British citizens do not eat fish-and-chips from the Irish Sea because of the problem of contaminated water flowing out of Sellafield into the Irish Sea [54]. Therefore, many respondents are aware that the release of contaminated water from the Fukushima Daiichi nuclear power plant into the ocean is imminent [3]. Respondents were asked if they were aware of the problem of contaminated water in the ocean around nuclear facilities, and the most common response was "I know a little about it" (25.9%), followed by "I don't know at all" (25.7%).

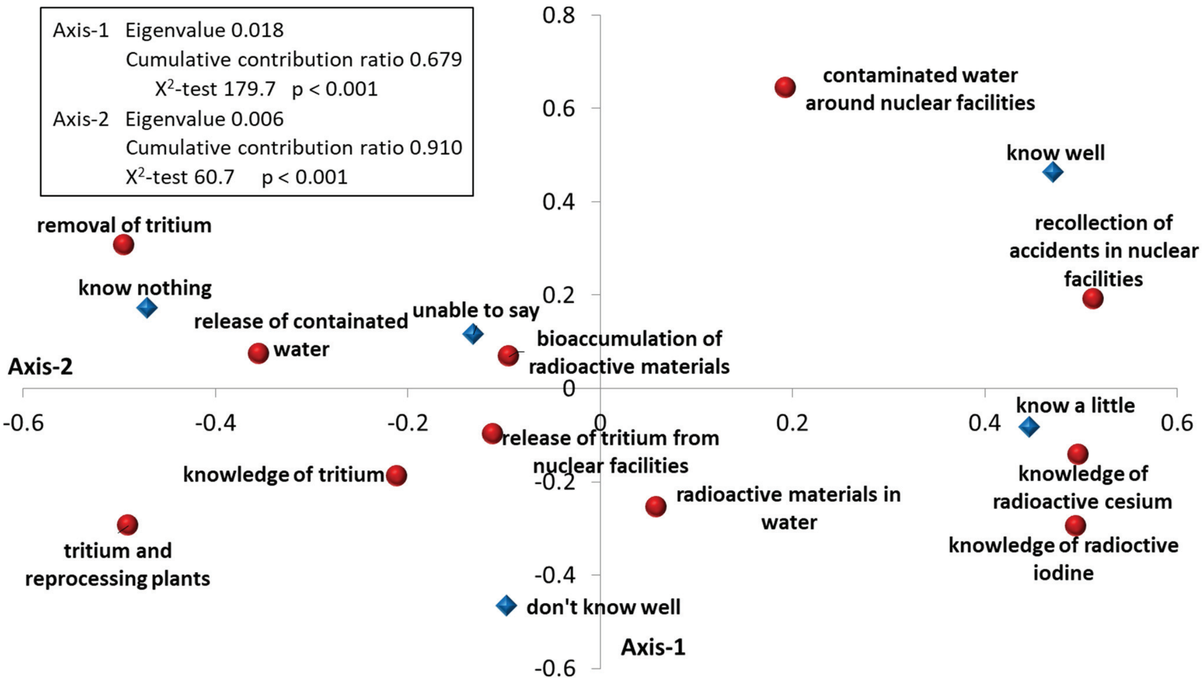
Finally, we asked respondents if they were aware that their local nuclear facilities were currently releasing, and will continue to release large quantities of contaminated water. A total of 49.7% respondents reported that they either did not know much (20.4%) or knew nothing (29.7%) about it.

### 3.3. Relationship Between Knowledge of Radioactive Materials and Knowledge of Contaminated Water

A correspondence analysis was conducted to illustrate the relationship between knowledge of radioactive materials with that of contaminated water. This analysis visualizes the relationship between the categories by using a map. Categories located closer together on the map are relatively more closely-related, and conversely, those located further apart are less related.

**Figure 2** illustrates the analysis results of the association between knowledge of radioactive materials and that of contaminated water. The vertical axis (the first axis) is concentrated within the range of 0.8 to $-0.6$, and the horizontal axis (the second axis) is within the range of 0.6 to $-0.6$, meaning the values are very similar. The first axis explains 67.9%, and 91.0% when the second axis is included, and the $p$-values of the $\chi^2$ tests (tests of significance of inter-row and inter-column differences, and tests of significance of residuals) for the first and second axes are at the level of less than 1% for both the first and second axes, thereby indicating that the axes are statistically meaningful. The first axis shows a high or low rating of the contaminated water problem, and the second axis shows a high or low rating of the Likert scale ("know well" to "not know at all").

In the top right quadrant, "contaminated water around nuclear facilities" and "recollection of accidents in nu-




Source: Data collected from SurveyMonkey.

**Fig. 2.** Correspondence analysis of radioactive material and of contaminated water.

clear facilities" are found with "know well." In the top left quadrant "bioaccumulation of radioactive materials," and "unable to say" are closely located, as well as the "removal of tritium" and "not know at all." In the bottom left quadrant, "knowledge of tritium," "release of tritium from nuclear facilities," and "don't know well." In the bottom right quadrant, "radioactive cesium," "radioactive iodine," and "know a little" are all closely located.

This analysis shows that respondents in each of the three countries were aware of the problems of contaminated water around nuclear facilities, and of the accidents at the nuclear processing facilities and fuel manufacturers themselves, but respondents were not aware of the lack of facilities to remove tritiated water, and of the fact that large amounts of contaminated water are discharged in their countries.

### 3.4. Comparing Recollection of Nuclear Accidents, Knowledge of Radioactive Materials, and Radioactive Contamination

**Table 15** presents the results of multiple comparisons of recollection of nuclear accidents, knowledge of radioactive materials, and radioactive contamination, as well as estimates of $t$-tests for tritium release and release of contaminated water.

#### 3.4.1. Tukey Test Results for Recollection of Nuclear Accidents, Knowledge of Radioactive Materials, and Radioactive Contamination

Statistically significant difference is not found between memories of the Chernobyl accident (3.730) and the Fukushima Daiichi accident (3.766). However, recollections of both Chernobyl and Fukushima are significantly higher than that of other accidents (3.029) at a significance level of 1% or higher.

Regarding knowledge of radioactive substances, no statistically significant difference is noted between the knowledge of radioactive cesium (2.989) and radioactive iodine (2.973). One the other hand, both are significantly higher than knowledge about tritium (2.647).

Regarding radioactive contamination, knowledge of the problem of ocean discharge and bioaccumulation (2.725) is significantly higher than that of the lack of tritium decontamination equipment (2.570). Similarly, knowledge of high levels of radioactive material in the sea (2.763) is higher, compared with the issue of tritium decontamination equipment. On the other hand, statistically significant difference is not noted between knowledge of contaminated water and that of bioaccumulation.

To summarize, recollection of major accidents are more significant, compared with memories of accidents at other nuclear facilities. Knowledge of cesium and radioactive iodine was higher, compared with that of tritium, and the lack of tritium decontamination equipment is less known, compared with the issues of high levels of ocean contamination and bioaccumulation.

#### 3.4.2. Results for the Test of the Difference in the Population Mean ($t$-Test)

Knowledge that tritium is released from nuclear facilities (2.704) is significantly higher, compared with knowledge that large amounts of tritium can be found in the surrounding environment (2.520).

**Table 15.** Comparisons of recollection of nuclear accidents, knowledge of radioactive materials, and radioactive contamination (Tukey test), and $t$-test for tritium release and contaminated water discharge.

| | Items | Nuclear accident 1 | Nuclear accident 2 | Significance 1 | Significance 2 | Difference (1–2) | $p$-value |
|---|---|---|---|---|---|---|---|
| Tukey Tests | Recollection of nuclear accidents | Chernobyl | Fukushima | 3.730 | 3.766 | 0.037 | 0.800 |
| | | Chernobyl | Accidents at nuclear facilities | 3.730 | 3.029 | 0.701 | 0.000*** |
| | | Fukushima | Accidents at nuclear facilities | 3.766 | 3.029 | 0.738 | 0.000*** |
| | Item | Radioactive material 1 | Radioactive material 2 | Significance 1 | Significance 2 | Difference (1–2) | $p$-value |
| | Knowledge of radioactive materials | Cesium | Iodine | 2.973 | 0.016 | 0.966 | 0.966 |
| | | Cesium | Tritium | 2.647 | 0.342 | 0.000 | 0.000*** |
| | | Iodine | Tritium | 2.647 | 0.327 | 0.000 | 0.000*** |
| | Item | Release 1 | Release 2 | Significance 1 | Significance 2 | Difference (1–2) | $p$-value |
| | Release of radioactive material | Lack of equipment to remove tritium | Bioaccumulation | 2.570 | 2.725 | 0.155 | 0.037** |
| | | Lack of equipment to remove tritium | Radioactive material in the oceans | 2.570 | 2.763 | 0.193 | 0.006*** |
| | | Bioaccumulation | Radioactive material in the oceans | 2.725 | 2.763 | 0.038 | 0.822 |
| $t$-tests | Item | Release of tritium 1 | Release of tritium 2 | Significance 1 | Significance 2 | Difference (1–2) | $p$-value |
| | Release of tritium | Tritium present near nuclear facilities | Presence of large quantities of tritium near nuclear facilities | 2.704 | 2.520 | 0.184 | 0.003*** |
| | Item | Contaminated 1 | Contaminated 2 | Significance 1 | Significance 2 | Difference (1–2) | $p$-value |
| | Release of contaminated water | Release of contaminated water into the ocean | Large quantities of tritium being released | 2.907 | 2.602 | 0.305 | 0.000*** |

Note: *** and ** indicate statistically significant differences in the mean at the 1% and 5% levels.

Knowledge of water contamination from nuclear facilities (2.907) is significantly higher, compared with knowledge of large amounts of contaminated water being released (2.602).

Therefore, although respondents are aware of the release of tritium from nuclear facilities, they are unaware of the extent of it. Similarly, they are aware of the issue of contaminated seawater, but not how much contaminated water is being released.

## 3.5. Discharge of Contaminated Water

### 3.5.1. Support for/Opposition to the Discharge of Tritiated Water

As mentioned above, although most radioactive materials in contaminated water are removed using complex water purification systems, tritium is not removed. Although there are reports of attempts to develop methods and equipment for fully removing tritium, thus far nothing has been introduced to the market. Therefore, treated water (tritiated water) is known by the media as contaminated water. This is the most widely used term, thus we have used it in this survey and paper.

**Table 3** presents the aggregated results about whether the respondents agreed with the discharge of contaminated water in the current situation wherein tritium has not been removed. The results show that 60.2% of respondents who "oppose" (37.2%) and "somewhat oppose" (23.0%) were unaware about it. When the total of those who "somewhat support" (8.9%) and "support" (4.9%) were added together, only 13.8% respondents agreed with the proposal.

To summarize, many respondents opposed the discharge of tritiated water even after most radioactive substances had been removed, because it would impact surrounding fisheries and the purchasing behavior of consumers. In addition, many respondents appeared to resent the failure of authorities to fully disclose the release of contaminated water, thus 60% respondents opposed the release of tritiated water, despite having little knowledge of tritium.

### 3.5.2. Reasons for Supporting/Opposing Discharge of Contaminated Water

Respondents were allowed to select multiple reasons for supporting or opposing the discharge of contaminated water into the ocean.

**Table 4** presents the results for each country, as well as a comparison between countries.

Observing the top three reasons for supporting the discharge of tritiated water, the most common reason provided was that "highly toxic radioactive materials, such as strontium-90 and iodine-129, will be removed" (18.3%). Cross-country comparison showed a significant difference (10.6%) between France (22.8%) and Japan (12.3%). French respondents were more likely, compared with the Japanese respondents, to argue that contaminants would be removed before being discharged into the ocean.

The next most common reasons were "it is inevitable that contaminated water will be discharged" (14.6%) and "polluted water will quickly be diluted in the sea" (11.1%).

On the other hand, the most common reason given for opposing the discharge of contaminated water was that "once polluted water is released, it will have a serious negative impact on neighboring fisheries" (33.4%). This reason was not significantly different between Japan (34.4%) and the UK (41.4%) (a difference of 7.0%), but there was a significant difference between France (24.2%) and the UK (a difference of 17.2%), as well as between France and Japan (a difference of 10.3%). Similarly, for the reason "radioactive substances that contaminate ocean life will also be released to the ocean" (32.9% for all countries), the differences between France (24.8%) and the UK (39.4%) (a difference of 14.6%) and between France and Japan (34.1%) (a difference of 9.3%) were significant. British and Japanese respondents are more likely than French respondents to argue that contaminated water will have a significantly negative impact on neighboring fisheries and will release radioactive materials into the ocean, thereby resulting in bioaccumulation.

For the reason that "there is no guarantee that tritiated water is safe" (30.7%), a significant difference was noted between Japan (27.5%) and the UK (42.7%) (a difference of 15.2%), and between France (21.5%) and the UK (a difference of 21.2%). Similarly, a significant difference was noted between Japan (18.2%) and the UK (28.8%) (a difference of 10.6%) on the number of respondents giving the reason "a huge amount of polluted water, even when compared to other countries, will be discharged" (19.5% for all countries), and between France (11.3%) and the UK (a difference of 17.5%). British respondents (30.8%) also showed significant differences to French (17.8%) and Japanese (16.6%) respondents for the reason "contaminated water should be safely stored in tanks until the technology for removing tritium water is developed" (19.4% for all countries). British respondents were more concerned about the safety of discharged water containing tritium and the amount of contaminated water being discharged, and are thus more likely to believe the contaminated water should be held in storage.

These findings suggest that French respondents are supportive of discharging water they believe has been sufficiently decontaminated, whereas British and Japanese respondents are more reluctant to trust the efficacy of the process, with the British being the more skeptical.

### 3.6. Impact on the Reputation and Purchase of Seafood Caught Near Nuclear Facilities

#### 3.6.1. Impact of Nuclear Facilities on Seafood Purchasing Behavior

**Table 8** presents the results of the question about whether knowing seafood has been caught in the vicinity of a nuclear facility has any impact on the purchasing behavior of respondents. The largest group was undecided (32.3%). However, those purchasing as usual (17.6%) or at a reduced rate (21.8%) made up 39.4% of all respondents, as opposed to the 28.3% who were either reluctant (17.2%) or would definitely not buy (11.1%) seafood they knew was caught near a nuclear facility.

#### 3.6.2. Impact of Nuclear Facilities on the Reputation of Seafood

**Table 5** presents the impact of nuclear facilities on the reputation of seafood caught in the area, and compares the reasons suggested by respondents from each country.

First, the largest number of respondents (25.7%) reported that they had no particular image of fisheries located near nuclear facilities, followed by "good quality" (25.4%), "fresh" (25.2%), "delicious" (17.5%), "area is famous" (16.9%), and "safe" (13.2%). The image of fisheries was primarily positive. However, few respondents believed that it was dangerous to eat (13.1%), and that the concentration of radioactive material was high (6.9%).

When comparing the reputation of quality, the UK (38.4%) significantly differed from that of Japan (15.2%, a difference of 23.2%) and France (22.6%, a difference of 6.2%). Similarly, in terms of freshness, a significant difference was noted between the UK (36.8%) and Japan (16.2%, with a difference of 20.5%) and between the UK and France (22.5%, with a difference of 14.2%). Among the three countries, British respondents had stronger positive perceptions of the quality and freshness of seafood caught in the vicinity of a nuclear facility (for the UK, the Irish Sea, wherein Sellafield discharges its water).

A significant difference (11.3%) was noted between British (24.2%) and French (12.9%) respondents, in terms of the taste of the seafood they perceived to be delicious. British respondents perceived the taste of seafood from the Irish Sea to be good.

#### 3.6.3. Reasons for Purchasing Behavior of Seafood Caught in the Vicinity of Nuclear Facilities

**Table 6** presents the reasons for purchasing or not purchasing seafood, and compares the reasons provided by respondents in each country.

First, the most common reason for purchasing is "I think it is safe if it is in a shop" (18.9%). The next most common reasons are "I trust assurances that the pollution levels will not exceed the maximum set by the government" (18.7%), "It doesn't particularly bother me" (17.1%), "I want to support local fishermen by buying local seafood," and "If the government is not restricting the sale of seafood, it must be safe" (13.6%).

Cross-country comparison of the reasons for buying seafood indicates significance differences at the 10% level between Japan (25.5%) and the UK (14.9%) for "I think it is safe if it is in a shop" (a difference of 10.6%), thereby suggesting that Japanese respondents felt more secure about buying fish found in supermarkets and from fishmongers.[6] There was a similar significance difference for the response "it doesn't particularly bother me" between Japanese (33.4%) and British (8.9%, a difference of 24.5%) respondents, as well as French respondents (8.6%, a difference of 24.8%). This finding suggests that among Japanese participants willing to buy seafood, where it was caught is either unimportant or they believe that it is safe enough not to worry about it.[7]

The most common reasons for not purchasing seafood are "polluted water is flowing into the ocean from nuclear facilities" (21.4%), followed by "it is impossible to distinguish between fish with high and low levels of bioaccumulation of radioactive materials" (17.3%) and "there is no guarantee that the treated contaminated water is safe" (16.3%), "I don't trust assurances by the government or authorities" (15.9%), followed by "tests for radioactivity in seafood are not thorough or accurate enough" (14.1%).

The first five items and the response "I suspect there are high levels of bioaccumulation of radioactive materials in the food chain" (12.7%), have statistically significant differences between Japan and the UK, and between the UK and France. A significant difference was noted (11.6%) between the UK (19.2%) and France (7.6%) for the reason that "seafood from other, safer areas are available" (13.4% for all countries). These findings suggest that British respondents, despite perceiving seafood from the Irish Sea to be of good quality and freshness, are reluctant to purchase it.

## 3.7. Reliability of Government Information on Treatment of Contaminated Water, and Compensation for Fishing Communities

### 3.7.1. Reliability of Government Information on Treatment of Contaminated Water

**Table 12** presents the responses derived when respondents were asked how reliable they found government reassurances that the decontamination process is thorough and safe. The most common response was "unsure" (32.2%). The proportion of those who found the government to be untrustworthy was 36.8% (23.8% for "not very reliable" and 13.0% for "totally unreliable"), whereas the proportion of those who trusted government assurances was 31.0% (22.1% for "somewhat reliable" and 8.9% for "very reliable"), thereby suggesting a fairly even division between those trusting, not trusting, and unsure.

6. The authors of this paper have investigated the reasons behind the failure of the general public to take measures against consuming agricultural products from areas surrounding the Fukushima and Chernobyl accidents. Nakamura et al. found that 25.3% respondents in Japan [47] and 19.7% in Ukraine [48] perceived that if agricultural products are sold in a store, they can be considered safe.
7. The surveys mentioned in Note 6 found that 30.8% Japanese respondents [47] and 40.7% of Ukrainian respondents [48] were not concerned about the harmful effects of potential contamination in agricultural products.

### 3.7.2. Compensation for Fishing Communities and Cross-Country Comparison

**Table 7** presents the responses derived when respondents were asked who should compensate the fishing communities affected by the impact of contaminated water on fisheries and their livelihood and health.

Most respondents believed that the central government should pay compensation (48.7%). The second most common answer was that "operators and parent companies should compensate" (35.7%), followed by "the local government should compensate" (21.7%).

A marked and statistically significant difference is noted between countries regarding whether the central government should compensate, with Japan at 63.2%, the UK at 50.7%, and France at 31.8%. A significant difference is also noted between Japan (38.4%), the UK (43.4%), and France (24.8%), in terms of those who believe that the fishing industry should be providing compensation. In terms of whether local governments should compensate, a significant difference was noted between France (24.8%) and Japan (18.5%), and France and the UK (17.5%).

Respondents from Japan and the UK tended to expect the central government and fishing industry to help the affected fishing communities, whereas French respondents tended to perceive the issue as the responsibility of local governments.

## 3.8. Comparing the Recollection of Nuclear Accidents, Knowledge of Radioactive Materials and Contaminated Water Discharge, and Respondents' Support or Opposition

**Table 16** presents a comparison of recollections of nuclear accidents, knowledge of radioactive material and contaminated water discharge, and the opinions of respondents on releasing contaminated water.

First, recollection of the Chernobyl accident was significantly higher among British respondents (3.874), compared with Japanese (3.670) and French (3.645) respondents at a significance level of 1–5%. However, this was likely caused by the popularity of the TV mini-drama "Chernobyl," [55] produced by HBO (USA) and Sky UK (UK) from May 6 to June 3, 2019 (and coincidentally, the survey was released on the June 1, 2019).

Next, Japanese respondents had a much better recollection of the Fukushima accident and were also more aware of accidents at other nuclear facilities, compared with their British and French counterparts. Knowledge of water contamination being released from nuclear facilities was highest among Japanese respondents, followed by French and British respondents. In Europe, there is awareness about the problem of contaminated water in Japan [56], as well as emergency closure of the Monju reactor on December 21, 2016 [57], and the diminishing need for nuclear reprocessing plants [58], but memories of the Fukushima accident and its wider implications are notably more vivid and immediate in Japan.

**Table 16.** Comparing recollection of nuclear accidents, knowledge of radioactive materials and contamination, and respondents' opinions (Tukey test).

| Items | Country 1 | Country 2 | Mean 1 | Mean 2 | Difference (1–2) | *p*-value |
|---|---|---|---|---|---|---|
| Recollection of Chernobyl | Japan | UK | 3.670 | 3.874 | 0.204 | 0.052* |
| | Japan | France | 3.670 | 3.645 | 0.025 | 0.954 |
| | UK | France | 3.874 | 3.645 | 0.230 | 0.024** |
| Recollection of Fukushima | Japan | UK | 4.273 | 3.447 | 0.826 | 0.000*** |
| | Japan | France | 4.273 | 3.581 | 0.692 | 0.000*** |
| | UK | France | 3.447 | 3.581 | 0.134 | 0.321 |
| Recollection of other nuclear accidents | Japan | UK | 3.340 | 2.795 | 0.545 | 0.000*** |
| | Japan | France | 3.340 | 2.953 | 0.387 | 0.001*** |
| | UK | France | 2.795 | 2.953 | 0.159 | 0.315 |
| Knowledge of radioactive cesium | Japan | UK | 3.233 | 2.553 | 0.680 | 0.000*** |
| | Japan | France | 3.233 | 3.183 | 0.051 | 0.879 |
| | UK | France | 2.553 | 3.183 | 0.630 | 0.000*** |
| Knowledge of radioactive iodine | Japan | UK | 3.070 | 2.725 | 0.345 | 0.003*** |
| | Japan | France | 3.070 | 3.126 | 0.056 | 0.852 |
| | UK | France | 2.725 | 3.126 | 0.401 | 0.000*** |
| Knowledge of tritium | Japan | UK | 2.763 | 2.281 | 0.482 | 0.000*** |
| | Japan | France | 2.763 | 2.897 | 0.134 | 0.416 |
| | UK | France | 2.281 | 2.897 | 0.616 | 0.000*** |
| Knowledge of tritium in the environment | Japan | UK | 2.860 | 2.305 | 0.555 | 0.000*** |
| | Japan | France | 2.860 | 2.950 | 0.090 | 0.680 |
| | UK | France | 2.305 | 2.950 | 0.646 | 0.000*** |
| Knowledge of contaminated water | Japan | UK | 2.870 | 2.550 | 0.320 | 0.009*** |
| | Japan | France | 2.870 | 2.870 | 0.000 | 1.000 |
| | UK | France | 2.550 | 2.870 | 0.321 | 0.009*** |
| Knowledge of large quantities of cesium around nuclear facilities | Japan | UK | 2.507 | 2.291 | 0.215 | 0.095* |
| | Japan | France | 2.507 | 2.764 | 0.257 | 0.035** |
| | UK | France | 2.291 | 2.764 | 0.473 | 0.000*** |
| Knowledge of lack of decontamination capacity | Japan | UK | 2.530 | 2.182 | 0.348 | 0.003*** |
| | Japan | France | 2.530 | 3.000 | 0.470 | 0.000*** |
| | UK | France | 2.182 | 3.000 | 0.818 | 0.000*** |
| Knowledge of bioaccumulation in the ocean | Japan | UK | 2.723 | 2.401 | 0.323 | 0.007*** |
| | Japan | France | 2.723 | 3.053 | 0.330 | 0.006*** |
| | UK | France | 2.401 | 3.053 | 0.652 | 0.000*** |
| Knowledge of contaminated water being released into the ocean | Japan | UK | 3.617 | 2.152 | 1.464 | 0.000*** |
| | Japan | France | 3.617 | 2.957 | 0.660 | 0.000*** |
| | UK | France | 2.152 | 2.957 | 0.804 | 0.000*** |
| Knowledge of large amount being released by own country | Japan | UK | 2.490 | 2.348 | 0.142 | 0.387 |
| | Japan | France | 2.490 | 2.970 | 0.480 | 0.000*** |
| | UK | France | 2.348 | 2.970 | 0.622 | 0.000*** |
| For or against releasing contaminated water | Japan | UK | 3.773 | 4.132 | 0.359 | 0.000*** |
| | Japan | France | 3.773 | 3.458 | 0.315 | 0.002*** |
| | UK | France | 4.132 | 3.458 | 0.674 | 0.000*** |
| Purchasing behavior | Japan | UK | 3.313 | 2.921 | 0.393 | 0.000*** |
| | Japan | France | 3.313 | 3.299 | 0.014 | 0.989 |
| | UK | France | 2.921 | 3.299 | 0.378 | 0.000*** |
| Trust in government assurances | Japan | UK | 2.513 | 2.914 | 0.401 | 0.000*** |
| | Japan | France | 2.513 | 3.276 | 0.762 | 0.000*** |
| | UK | France | 2.914 | 3.276 | 0.362 | 0.000*** |

Note: ***, **, and * indicate the mean difference is statistically significant at the 1%, 5%, and 10% levels, respectively.

Knowledge of radioactive materials (such as radioactive cesium, radioactive iodine, and tritium) and knowledge of contaminated water (such as tritium released in the vicinity of nuclear facilities and radioactive materials in contaminated water) was significantly higher among Japanese and French respondents, compared with British respondents (at a 1% level of significance). Japanese and French respondents were also significantly more likely than British respondents to purchase seafood caught in the vicinity of nuclear facilities.

Furthermore, knowledge of contaminated water, such as the large amounts of tritium released from nuclear facilities, lack of decontamination capacity, and the issue of bioaccumulation in the oceans, was significantly higher in France, Japan, and the UK, in that order. On the other hand, British respondents showed more opposition to the release of contaminated water, followed by Japanese and French respondents.

Finally, French respondents showed more trust in the reliability of government pronouncements on contaminated water, followed by British and Japanese respondents, in that order. Japanese respondents proved to be significantly more skeptical of their government, compared with participants from other countries.

To summarize, the findings show that (1) Japanese and French people share knowledge of radioactive substances; (2) looking at individual countries, Japanese people remember the accident in Fukushima and are aware of the problem of contaminated water, and do not trust government information; (3) British people remember the accident at Chernobyl; and (4) in addition to their generally high level of knowledge of radioactive materials, French respondents are also well-informed about tritiated water, in particular. Moreover, French respondents showed higher levels of trust toward government pronouncements.

## 4. Results

In this section, using the method described in Section 2.5, results obtained from the ordinal logit model and binomial probit model are presented.

### 4.1. Relationship Between Support and Opposition Toward the Discharge of Contaminated Water, and the Reasons Given

**Table 9** presents results of the calculations and marginal effects on the association between participants' support for or opposition toward releasing contaminated water, and the reasons they provide for adopting their respective positions. The results show that the pseudo-$R^2$ is as low as 0.146, but the likelihood ratio test with the null hypothesis of zero regression coefficients is rejected by the model.

#### 4.1.1. Regression Analysis

Observing the reasons for supporting the release of contaminated water, the coefficients for the following reasons are positive: "It is inevitable that contaminated water will be discharged" (0.470) and "polluted water will quickly be diluted in the sea" (0.882).

In contrast, the reasons against were as follows: "There are no facilities to remove radioactive substances from contaminated water" (−0.463), "radioactive materials that contaminate ocean life will be released into the ocean" (−1.012), "the government is an unreliable source of trustworthy information" (−0.777), "there is no guarantee that tritiated water is safe" (−0.671), "contaminated water should be safely stored" (−0.703), and "a huge amount of contaminated water, compared with that of other countries, will be released" (−0.423).

On the other hand, the coefficients on income (−0.275) and the UK (−0.596) were negative, with those earning lower incomes and UK respondents opposing the discharge of polluted water. Conversely, the coefficient for education (0.162) was positive, and those with higher levels of education were more likely to be in favor of discharging polluted water.

#### 4.1.2. Marginal Effects

To determine results of the marginal effects, four marginal effects, ranging from "support/somewhat support" to "oppose," were calculated.[8] The calculated marginal effect of "oppose" is the highest, thus we will focus on this.

First, the most influential reason opposing the discharge of contaminated water is concern about bioaccumulation (0.235). The second reason is distrust of government information (0.184), followed by the argument that the contaminated water should be stored until a safe method of disposal can be found (0.166). This was followed by the concern that tritiated water is unsafe (0.156), and the lack of facilities to remove contaminants from water (0.108). Being a British person was also a factor in opposing the discharge of contaminated water (−0.138).

On the other hand, the most influential reason in support of discharging contaminated water was that it would quickly become diluted in the ocean (−0.173).

### 4.2. Relationship Between Purchasing Behavior and Reasons for and Against Buying Seafood

**Table 10** examines the relationship between reasons for buying or not buying seafood from areas in the vicinity of nuclear facilities, their relevance, and the marginal effects.

#### 4.2.1. Regression Coefficient

The coefficients for "safe" (0.790) and "delicious" (0.665) are positive for the purchase of seafood caught in the vicinity of nuclear facilities. On the other hand, the coefficient "dangerous" (−0.700) has a negative impact.

The reasons given in support of purchasing seafood are: trust in assurance by the government (1.249); a general lack of concern (2.144); desire to support local fishermen (0.758); belief that the government will not allow unsafe seafood to be sold (0.758); and belief that shops would not sell it if it was dangerous (1.461).

On the other hand, the reasons against buying seafood are that contaminated water is flowing into the ocean (−1.069), concerns that the treated water is unsafe (−0.473); fear that decontamination tests and measures are insufficient (−0.719); and belief that seafood caught in other areas is safer (−0.578).

The coefficients for distance from a nuclear facility (−0.259) and household size (−0.098) are both negative, thereby suggesting that those living closer to the facility

8. There were relatively fewer "support" and "somewhat support" responses (see **Table 3**), and the combined model minimized the AIC, thus we combined the two to make four measures.

and those with smaller families do not purchase seafood caught in the vicinity of nuclear facilities. However, the coefficients for income (0.178) and France (0.536) are positive, thereby suggesting those with higher incomes and residents of France are more likely to buy seafood.

#### 4.2.2. Marginal Effects

For the marginal effects, we calculated five marginal effects, ranging from "definitely will not buy" to "buy as usual."

The strongest marginal effect for those willing to "buy as usual" or "buy only a little less" was that they did not particularly care (0.298 and 0.192, respectively). This was followed by the belief that it must be safe if the shops sell it (0.170 and 0.176), followed by trust in government assurances on levels of contamination (0.138 and 0.159). Being French also had a marginal effect on purchasing behavior (0.046 and 0.076).

Two factors that are important for those who would purchase a little less than usual was their belief that the government would restrict the sale of such seafood if it were dangerous, and a desire to help local fishermen (0.105 and 0.104, respectively). The marginal effects for safe (0.108) and delicious (0.093) were also high.

In contrast, those who were reluctant to purchase contaminated water being released from nuclear facilities (0.135) and inadequate testing and safety measures taken by the authorities (0.090).

### 4.3. Relationship Between Personal Attributes and Position on Compensation for Affected Communities

**Table 11** presents the statistical relationships between individual attributes and respondents' positions on who should compensate the fishermen and fishing communities affected by the discharge of contaminated water.

Respondents who perceived that the government should cover the compensation costs tended to live closer to nuclear facilities (−0.212), and tended to have higher income (0.135). Unlike Japanese respondents, the British (−0.254) and French (−0.702) respondents did not perceive that the state should pay for this compensation.

Those who perceived that regional or local governments should pay for compensation were those who had children (0.213), those who were younger (−0.010), and those who resided in France (0.305).

In addition, those who perceived that fishery companies should cover the compensation tended to have less faith in government information about contamination (−0.249). Simultaneously, those who believed that the companies should compensate tended to be male (0.336) and British (0.304).

Those who believed that donations should be raised for compensation tended to have lower incomes (−0.221) and also resided in the UK (−0.488).

Finally, those who perceived that compensation was unnecessary were those who with more trust in the reliability of government information about contaminated water (0.210) and those who resided in France (0.312).

## 5. Conclusions

### 5.1. Results

In this paper, the issues of contaminated water discharged from nuclear facilities and the impact on fisheries have been statistically analyzed in the cases of La Hague, Sellafield, and Fukushima Daiichi Nuclear Power Plant. The following points can be highlighted.

First, regarding nuclear accidents, respondents residing in the vicinity of the accident site had more information about that specific accident, compared with accidents at other nuclear facilities. Respondents were more aware of radioactive cesium and iodine, compared with tritium. They were aware of decontaminated water being released into the ocean, but not about the lack of equipment to remove tritium from the water. Furthermore, they were unaware that larger amounts of tritium were released from nuclear reprocessing plants, compared with nuclear power plants, and were generally unaware about the extent of the release of contaminated water in their own country.

Second, more than 60% respondents opposed the discharge of water contaminated with tritium, although a relatively large number of respondents in France are in favor of the discharge of contaminated water. On the other hand, more participants in the UK are against the discharge of contaminated water, compared with their counterparts in Japan and France.

On the issue of seafood caught in the vicinity of nuclear facilities, in the UK, the sea off the Sellafield coast is perceived as rich in high-quality seafood. However, many respondents were reluctant to purchase this seafood due to concerns about contamination. On the other hand, many participants in Japan perceived seafood caught off the coast of Fukushima Prefecture to be safe, as long as it is available in the shops, and indicated little concern for any dangers posed.

In addition, the number of respondents who did not trust government information on the discharge of contaminated water was slightly higher, compared with those who trusted it. Respondents perceived that compensation for the affected communities should be paid for by the government, fishery companies, and local governments, in this order of preference. Japanese and British respondents were more likely to support compensation, compared with French respondents.

Japanese respondents showed the highest knowledge of nuclear accidents. Japanese and French respondents had more knowledge of radioactive materials and contaminated water, and many of them purchased seafood caught in the vicinity of nuclear facilities. British respondents were the most opposed to the discharge of contaminated water, but Japanese people were the least trusting toward information regarding contaminated water from their government.

Finally, although British respondents were opposed to the discharge of contaminated water, those who trusted information from the government and retail outlets did not mind purchasing seafood. French respondents, in particular, were the least concerned. Even in the event of contaminated water being released, those who trusted assurances from their government, along with French respondents, did not believe that fishermen or their communities should be compensated. However, those living closer to a nuclear facility believed that the state should pay compensation. On the other hand, British and French respondents did not perceive the state compensating the fishermen as a necessity. However, some French people perceived that regional or local governments should foot the bill. Those with high incomes believed that the state should compensate the fishermen using taxes, and those with low incomes favored compensation through the collection of donations. Those who did not trust government information believed that companies should compensate fishermen, and British respondents believed that the companies involved should compensate fishermen, instead of relying on donations.

### 5.2. Discussion

In this section, the three hypotheses are re-examined in light of the regression analysis results.

The first null hypothesis – "There is no difference between the three countries in the reasons given for or against supporting the release of contaminated water" – can be rejected because British respondents tended to oppose the discharge of contaminated water into the Irish Sea, particularly when informed that tritium has not been removed from the contaminated water. Although the opposition was not as high as expected, statistically significant differences are noted between the three countries.

The second null hypothesis – "There is no difference between the three countries in the respondents' purchasing behavior of seafood caught in the vicinity of nuclear facilities" – can also be rejected because British and Japanese respondents showed notably higher reluctance to purchase seafood, compared with French respondents. The French government and plant operator have been actively providing safety information to residents around La Hague, which has reassured them, and they are, thus, able to purchase locally caught fish without concern.

The third null hypothesis – "There is no difference between the respondents in the three countries as to who they think should compensate affected fishermen and fishing communities" – can be rejected because there are wide variations between the three countries regarding whether and how compensation should be paid. Japanese respondents indicated that compensation should be provided by the central government, whereas British respondents indicated that compensation should be provided by the fisheries industry, and French respondents indicated that either local governments should pay the compensation, or no compensation should be provided.

### 5.3. Future Challenges and Recommendations for Fukushima

In this study, the problem of contaminated water discharged from nuclear power plants and reprocessing plants was statistically analyzed, and the impact this has had on fisheries in the vicinity.

Japan is about to discharge large amounts of contaminated water into the ocean; however, thus far, this plan is not on the scale of Sellafield and La Hague. British respondents are strongly opposed to the discharge of contaminated water and do not purchase seafood from the area wherein Sellafield discharges its contaminated water; this finding is slightly different from that of Japanese and French respondents. Immediately after the Fukushima accident, untreated contaminated water flowed into the surrounding rivers and sea; however, treated water is currently not being discharged. In La Hague, although treated water is released, no radioactive substances are noted. The Windscale accident led to vast amounts of untreated water flowing into the sea, and Sellafield continues to regularly release treated water. British respondents' reluctance to purchase fish from the Sellafield area may be due to the "accidental release" nature of the discharge. This finding suggests that after 2023 and the release of significant amounts of decontaminated water, people will also be reluctant to buy marine produce caught in the vicinity of Fukushima Prefecture.

The study results provide an important takeaway for Japanese authorities. Japanese respondents showed the least trust in government information and pronouncements about contaminated water, and were also the most likely to expect the national government to compensate the affected fishing communities. Summarizing differing responses from the three countries indicates that the differing nature of the nuclear facilities is not a significant factor, instead it is the fact that Fukushima and Sellafield experienced serious and high-profile accidents, whereas La Hague has not. Although the quantity of tritiated water released around Fukushima is not so high, when compared with similar facilities worldwide, the fact that it is due to an accident, combined with the lack of trust in TEPCO, raises awareness about this incident, and the possibility that a similar accidental release may occur again in the future. British and Japanese respondents perceived it the duty of the state or nuclear industry to compensate fishermen for damage to their livelihoods, whereas French respondents perceived compensation as unnecessary. The Japanese government has decided that TEPCO will compensate for any reputational damage to marine products from the area [59]. Many UK respondents expressed concern for the accidental and controlled release of contaminated water into the sea. Starting from 2023, with the release of treated water into the sea, many Fukushima fishermen may seek compensation from the government and TEPCO.

In contrast, although the quantity of tritiated water released from La Hague is higher than that of any other facility, this is a "controlled release" that adheres to the

OSPAR Convention, and is accompanied by strict, regular, and public monitoring. Combined with the absence of any serious accidents, this means that public confidence is high and people are willing to buy locally caught marine produce.

Japanese authorities can benefit from following the French example of providing clear lines of communication and involvement of the local community in monitoring radiation. This may result in higher trust and willingness to purchase locally caught seafood.

However, a weakness and limitation of this paper is that it is comparing responses from areas affected by discharge from nuclear power plants with those from nuclear reprocessing plants, where the quantity of discharge is notably higher.

The French government conducts oceanographic surveys to monitor the release of radioactive materials, controls drinking water standards, and regularly publishes information on treated water. However, the situation at Fukushima more closely resembles the situation at Sellafield, instead of that at La Hague. Future research may examine how the British government has conducted oceanographic research and the measures taken against harmful rumors. The British government's handling of problems surrounding Sellafield may provide a useful lesson for the Japanese government in its handling of problems faced by Fukushima and its fishing industry.

On the other hand, Japanese and French respondents had a higher level of knowledge of radioactive materials and contaminated water, compared with British participants. Future studies may examine whether the knowledge of radioactive materials and contaminated water affects the purchasing behavior of seafood caught in the vicinity of nuclear facilities.

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