Journal of Environmental Radioactivity 151 (2016) 136–143

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Short communication

Assessment of the effectiveness of the post-Fukushima food monitoring campaign in the first year after the nuclear accident: A hypothesis

Georg Steinhauser [a, b, *]

[a] Colorado State University, Environmental and Radiological Health Sciences, Fort Collins, CO 80523, United States
[b] Leibniz Universität Hannover, Institute of Radioeology and Radiation Protection, 30419 Hannover, Germany

A R T I C L E I N F O

Article history:
Received 7 June 2015
Received in revised form
1 September 2015
Accepted 13 September 2015
Available online 8 October 2015

Keywords:
Fukushima nuclear accident
Radioactive fallout
Food monitoring
Food safety
Radiocesium
Internal exposure
Regulatory limit
Cattle

A B S T R A C T

The purpose of this study was to assess whether or not the food monitoring campaign after the Fukushima nuclear accident has been successful in reducing the number of above-limit-food from reaching the consumers. The hypothesis of this study is that the fraction of "post-market" food can be used for this purpose, when the post-market fraction in the above-limit (p′) items is compared to the post-market fraction in the entity of food items (p) that have been screened for radionuclides (^{134}Cs and ^{137}Cs). Indeed the post-market fraction in most vegetarian produce decreased significantly in the above-limit food items ($p'/p < 1$), indicating a high efficiency of the monitoring campaign. For tea, however, the analysis reveals a low efficiency of the campaign ($p'/p \approx 1$). For beef, the fraction of post-market-foods within the above-limit samples was much higher than the respective fraction in the entity of measured samples ($p'/p > 1$), indicating a much lower effectiveness of the monitoring action for beef. The author speculates that, by following the governmental monitoring manual (which gives "meat" only second priority), the sudden exceedances caught the monitoring agencies unprepared and triggered a much higher density monitoring of beef with the delay of several weeks. Even then, many above limit items reached the market (mainly because the monitoring during this period had focused on the post-market). Therefore, it is likely that some above-limit beef has been consumed by the public. For other meat products, the fraction of post-market samples was very low, which does not allow for the validation of the effectiveness of the monitoring campaign. Overall, the monitoring seemed to have been more effective for vegetarian produce than for meat.

1. Introduction

Internal exposure caused by intake of contaminated foods is a major threat to human health after nuclear accidents (Hamada and Ogino, 2012; Travnikova et al., 2001). Depending on the type of food, the effective half-lives of ^{137}Cs can be in the range of several years (Merz et al., 2015a) and, therefore, will be health relevant for many years to come after an accident. Consequently, monitoring of food has been treated with high priority by the Japanese authorities in the aftermath of the Fukushima nuclear accident (March 11, 2011). They ordered the radioanalysis of hundreds of thousands of food items to secure food safety. In our previous publication, we briefly outlined the main characteristics of the food monitoring program and some radioecological aspects of the enormous data set that has been compiled by the Japanese government (Merz et al., 2015b) and potential problems from underestimating ^{90}Sr concentrations in food which is one of the understudied radionuclides after Fukushima (Steinhauser, 2014). We concluded that it seems very unlikely that more than very few members of the public in Japan exceeded the maximum permissible additional internal exposure of 1 mSv/year. However, in a discussion of that article, *Science* rightfully stated that "a significant quantity of the vegetable foods initially exceeded the limits" (Normile, 2015). *Science* also mentioned that "nongovernmental watchdog groups have reported finding items on grocery store shelves that exceed the limit" (Normile, 2015). These findings fuel the public concern in Japan about food safety and makes (at least some) people wonder how

* Corresponding author. Leibniz Universität Hannover, Institute of Radioeology and Radiation Protection, 30419 Hannover, Germany.
E-mail addresses: georg.steinhauser@colostate.edu, georg.steinhauser@ati.ac.at, steinhauser@irs.uni-hannover.de.

http://dx.doi.org/10.1016/j.jenvrad.2015.09.013
0265-931X/

effective the food monitoring campaign has been, if above-limit food items still make it onto the shelves of grocery stores.

The intrinsic nature of random sampling, of course, can only employ statistical methods to quantify probabilities (Seto and Uriu, 2015), but never prevent singular above-limit food items from reaching the shelves. It is very difficult, however, to communicate the associated risks to the public. Only when the entity of a food product is measured prior to reaching the markets, absolute safety can be reached. This level of safety has been impressively accomplished in the monitoring of rice in Japan following the Fukushima accident (Nihei et al., 2015). Such comprehensive monitoring campaigns, however, cannot be employed for more perishable food, such as meat or vegetables. Instead, Japanese scholars have used food duplicate studies to assess the true exposure by analyzing the duplicates of foods that have been collected by selected participants of these studies (Harada et al., 2012), or purchased by researchers (Koizumi et al., 2012). In these duplicate studies, participants have prepared one identical extra meal of everything they ate over the duration of the survey. This duplicate has been measured to assess the participant's internal exposure. Finally, whole-body measurements have been performed on large numbers of citizens of Fukushima Prefecture, reflecting the uptake of radiocesium (^{134}Cs and ^{137}Cs) (Hayano et al., 2013). All the studies mentioned found relatively low exposure to radionuclides through intake of contaminated foods. In this study, we attempt the first assessment of the effectiveness of the monitoring campaign in terms of reducing the number of above-limit foods from being consumed by members of the public. For this objective, the information contained in the governmental monitoring data set (Merz et al., 2015b; Ministry of Health Labour and Welfare (MHLW), 2014) was harnessed. The general approach was to use the data that are already at hand rather than launching another measurement campaign, which naturally would have been a major logistical and financial endeavor.

2. Materials and methods

In the immense data set compiled by the MHLW (Merz et al., 2015b; Ministry of Health Labour and Welfare (MHLW), 2014), the analyzed food items were categorized in three “market-categories”: namely “pre-market”, “post-market” or “not specified”. Pre-market items were obtained directly at the producers, farmers etc., whereas post-market items were bought in grocer's shops, supermarkets or the like. “Not specified” could be any of the other two market categories or anything in between the main two market categories. The radiocesium data set used in this study ranges from March 11, 2011 to Mach 31, 2012 and covers all Japanese prefectures.

The key hypothesis of this study was that the ratios of post-market items to the entity of samples measured can be used to assess the effectiveness of the Fukushima food monitoring campaign.

Let N be the number of all samples of one food category, and p the fraction of post-market samples, so that the number of post-market items equals pN. Let N′ be the number of samples which exceed the limit, and p′ the fraction of post market samples exceeding the regulatory limits, consequently p′N′ being the number of post-market samples exceeding the limit. If the fraction of post-market food items amongst above-limit foods (p′) was lower than the fraction of post-market foods in the total number of samples of the respective food category (p), so that the following condition is fulfilled: $p'/p < 1$, the monitoring campaign has effectively removed above-limit foods from the market and thus protected the consumer. The same scenario could also be described as follows: The probability, within all samples, that a sample exceeds the limit, is prob(C > limit; all) = N′/N. For post market samples, this probability is prob(C > limit; post-market)=(p′N′)/(pN). If the latter probability is lower than the former, monitoring has been successful. The ratio of these probabilities equals

$$\frac{(p'N'/pN)}{(N'/N)} = \frac{p'}{p}$$

and thus is identical to the aforementioned ratio.

If the fraction of post-market foods amongst above-limit food remains unchanged when compared with the fraction of post-market items in the total number of samples of a certain food category ($p'/p \approx 1$), it may indicate that the food monitoring program has lacked effectiveness to a certain degree and failed to prevent above-limit foods from reaching the shelves of the market (Scenario 1 in Fig. 1). In case $p'/p < 1$, as described above, the food monitoring campaign has effectively worked and reduced the number of above-limit foods reaching the grocery stores (Scenario 2 in Fig. 1). In case the increase of the fraction of post-market items that are above the regulatory limit is observed compared with the post-market fraction in all monitored items ($p'/p > 1$) (Scenario 3 in Fig. 1), this may indicate some other mechanisms that require further investigation. It can be assumed that food inspectors purchase post-market samples in competition with regular consumers. They therefore reflect the fraction of foods in the monitoring campaign that has reached the market and represent food that has been consumed by members of the public. The distribution of radiocesium measured in post-market food samples hence can be assumed the same as the one in food which has actually been consumed.

In this study, focus has been on radiocesium (^{134}Cs and ^{137}Cs) contaminations in the main food categories vegetables (including algae), mushrooms, fruits and berries, beef, wild boar meat, tea leaves and tea products, as well as other animal products (including chicken meat, eggs, and game). The half-lives of ^{134}Cs and ^{137}Cs are 2.07 y and 30.08 y, respectively.

2.1. Choice of the metric

The metric of p′/p has been chosen because customers, for obvious reasons, will focus on post-market foods only, as they appear within reach of the customer's consumption. It probably provides little relief to the customer knowing that hundreds or thousands of samples have been “caught” in the pre-market, exceeding the limits. The only thing concerned customers will be interested in, is how many effectively made it into the shelves. This is why the author believes that p′/p is a more intuitive metric than others, as is compares the fractions of food samples sampled in the grocery stores to those exceeding the limits in the grocery stores. For example, it will provide a certain degree of relief, if customers realize that for a certain type of food, 20% of this type of food have been sampled in stores, but only 0.5% of samples of this food type exceeding the limits were found in the shelves. However, there are also other potentially useful metrics, such as a direct comparison between the fraction of above-limit contaminated items in the pre-market (pre′) and the post-market (p′/pre′), which will be briefly discussed as well.

3. Results and discussion

Prior to studying the market fractions, the nature and characteristics of above-limit foods need to be identified. For an overview, Fig. 2 summarizes the average activity concentration (a) and number (b) of above-limit food items in the main food categories that have been targeted for this study. The regulatory limit for these

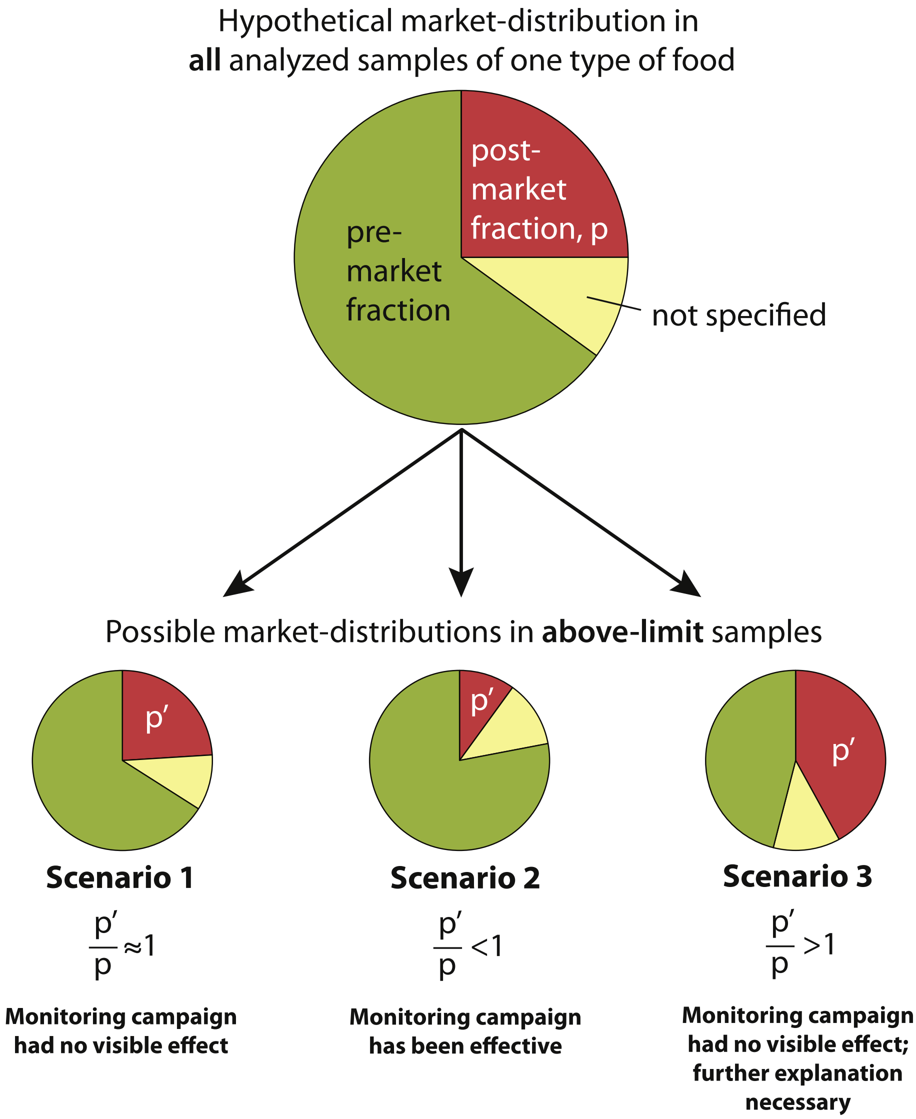

Fig. 1. Explanation of the metric p′/p and all three scenarios possibly observable in a food monitoring campaign.

types of foods was 500 Bq·kg^{-1} in the period of observation (March 11, 2011 until March 31, 2012) (Merz et al., 2013). As of April 1, 2012, the regulatory limit for these types of food was set to 100 Bq kg^{-1}. The figure shows the dynamics of activity buildup both in terms of average activity (Fig. 2a) but also in terms of numbers of samples exceeding the limits (Fig. 2b). In the initial phase (March–June) after the accident, it was mainly vegetables that caused exceedances. By summer 2011 (July, August), it was mainly beef that caused exceedances. In late summer (September) to fall (October–November) tea as well as mushrooms (including dried mushrooms) and wild boar meat became the most significant above-limit food categories. In September 2011, the average activity concentrations in the above-limit mushrooms and boar samples reached a maximum (Fig. 2a). From winter 2011 to spring 2012, meat of wild boars and mushrooms dominated the above-limit items.

Fig. 3 summarizes the effectiveness of the food monitoring campaign in the following food categories: *Asian black bear*, *wild boar*, *game and other meats*, *fruits & berries*, *algae*, (dried) *mushrooms*, *above-ground vegetables*, *below-ground vegetables*, *beef* and *tea* (thus following the systematics previously introduced (Merz et al., 2015b)). The light bars indicate the percentage in the total number of samples measured (N) and distinguishes in the above-mentioned market-categories (green, pre-market; yellow, not specified; red, post-market). The market fractions of above-limit food items (N′) in each food category are depicted directly next to the market fractions representing the total number of food items-bar in darker colors. The values of the ratios p′/p for each food type investigated herein, together with other numerical key information are summarized in Table 1.

One important aspect of the food monitoring is the priority of various food items that had to be measured. Japanese authorities (Ministry of Health Labour and Welfare (MHLW), 2002) published a manual according to which the priorities of certain food items for measurement have been defined for the case of a nuclear accident. The manual lists seven food categories (1. grains, 2. fruits, 3. vegetables, 4. seaweed, 5. seafood, 6. dairy products, 7. others) to be measured in the "first stage" in response to an emergency. The manual also states that the samples should be obtained/bought from the source (corresponding to the "pre-market" category). In the "second stage", the "others" are further partitioned into potatoes, beans, mushrooms, meats, eggs and "others" (total of 12 categories). The manual recommends collecting samples in the "second stage" from the market (post-market), but even in this

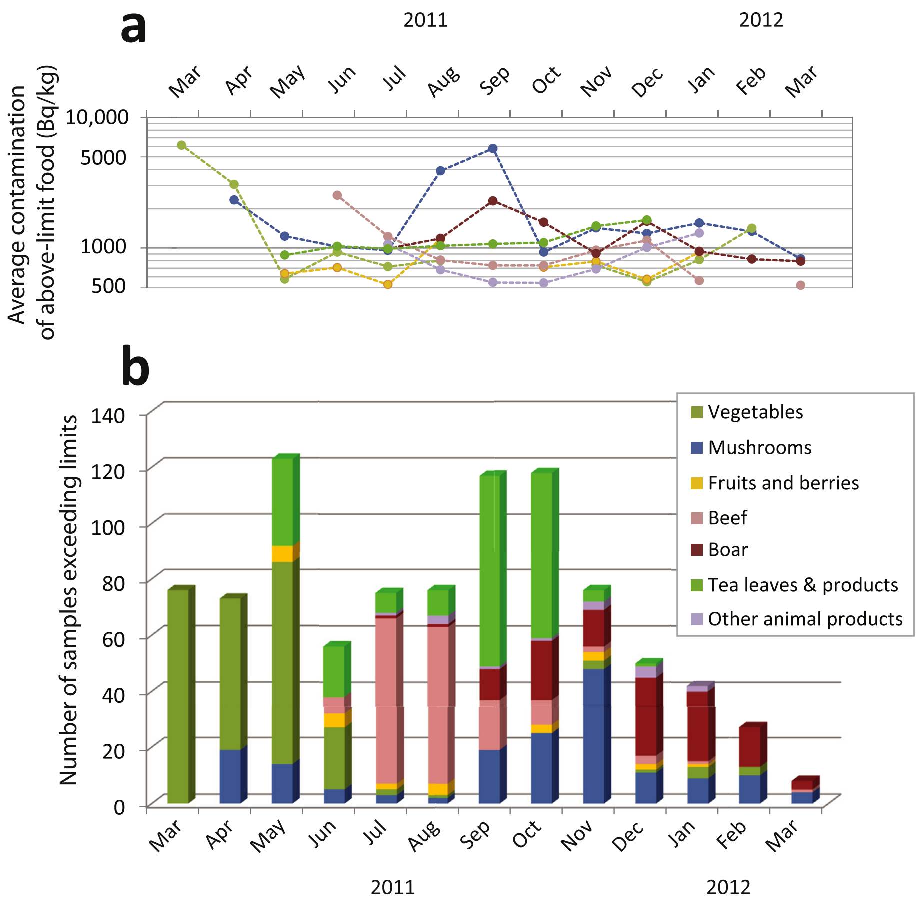

Fig. 2. Average radiocesium activity concentration (monthly averages) of above-limit food (a) and month-wise number of exceedances of the regulatory limits per food category (b).

case, local products are to be obtained/purchased from the source (pre-market). This makes the time aspect very important for the assessment of the effectiveness of the monitoring program.

The analysis of Fig. 3 discloses several interesting aspects that reveal the effectiveness of the food monitoring campaign but also shows intrinsic problems of the campaign. One problem for this study was that, according to the aforementioned manual (Ministry of Health Labour and Welfare (MHLW), 2002), the monitoring of some food categories focuses solely (or almost exclusively) on the pre-market but ignored any post-market monitoring that could be used to validate the effectiveness of the campaign. However, this is not entire line with the priorities listed. *Meats*, for example, should be measured in the second stage and hence have a significant post-market fraction. However, this is not the case for the categories *asian black bear* (0% post-market) or *game etc.* (0.8% post-market) which have been sampled predominantly on the pre-market. This is even more problematic with sentinel species such as radiocesium-accumulating *wild boars* (Tanoi et al., 2015; Steinhauser and Saey, 2015): only 1 of 344 samples in the category *wild boar meat* was categorized as post-market. With these food categories, it is hence not surprising that the number of above-limit food items in the post-market category (p′N′) was zero.

The monitoring of the vegetarian categories *fruits & berries*, *algae*, *mushrooms*, *above ground vegetables* and *below ground vegetables* had been done with much higher fraction in the post-market. Here, the comparison of total number of samples measured and samples above limit illustrates a high efficiency of the monitoring campaign. The fraction of post-market items was always much lower in the above-limit category than in the total number of samples measured (see Fig. 3). It is noteworthy, however, that the fraction of “not specified” food items was always greater in above-limit foods when compared to the entity of samples measured. This can partly be explained by a very low overall fraction of foods exceeding the limits: a small absolute number in exceedances was observed in *fruits & berries* (26 out of 3541) or *algae* (8 out of 230 samples), with a relatively high fraction belonging to the not-specified-category. It may well be that it was pure coincidence that more of the exceedances belonged to the not-specified-category. This could make the not-specified-category appear over-represented in above-limit foods and thus potentially indicating higher risk as the not-specified-category could also include post-market foods. The very low total number of exceedances, however, indicates an overall low risk. Similarly, the 11.1% of post-market foods exceeding the limits in the category of *below-ground vegetables* exceeding the limit should not be overestimated as the absolute number of above-limit *below-ground vegetables* was as low as 9 samples and the 11.1% correspond to 1 sample. Only 9 out of 2939 samples exceeded the limits in this food category.

The analysis in Fig. 3 seems to indicate that the monitoring has not been effective in the category of *tea & tea products*. The post-market fraction of tea has been 5.6% (131 out of 2344 samples) for all tea samples measured. Amongst tea samples that exceeded the limits, however, 9.1% belonged to the post-market category (18 out of 197), thus making $p'/p = 1.6$. In any case, the p'/p ratio of 1.6 ± 0.9 is not significantly >1, which makes tea a $p'/p \approx 1$ scenario (Scenario 1 in Fig. 1). There are several possible explanations for this observation. Either, Japanese authorities have not accounted properly for the translocation of radiocesium into the newly grown tea leaves after foliar uptake (by older leaves), thus making tea a highly radiocesium-accumulating sentinel plant

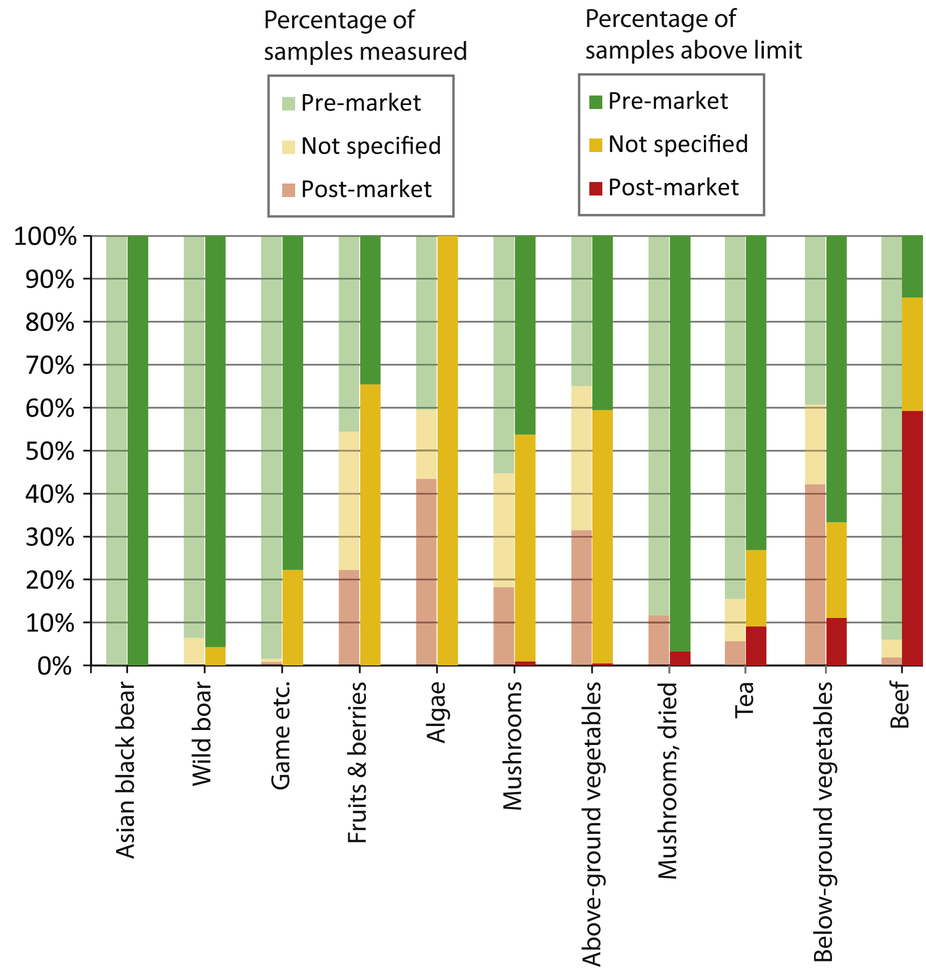

Fig. 3. Direct comparison of the main food categories with their respective market-fractions. The light-colored columns depict the entity of the measured samples, whereas the dark-colored columns illustrate the fraction of above-limit food items. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1
Summary of the numbers and percentages of samples measured and of samples exceeding the regulatory limit (500 Bq/kg) in the course of the post-Fukushima food monitoring campaign in Japan (March 11, 2011–March 31, 2012). Uncertainties of p′/p are standard deviations from Poisson distribution and are given at a confidence interval of 95% (k = 2).

Category	Pre-market			Not specified			Post-market			Total			Post-market fractions		
	Total	Above-limit	Fraction	Total	Above-limit	Fraction	Total	Above-limit	Fraction	N	N′	Fraction	p	p′	p′/p
Asian black bear	46	7	15.2%	0	0		0	0		46	7	15.2%	0	0	
Wild boar	322	112	34.8%	21	5	23.8%	1	0	0.0%	344	117	34.0%	0.003	0	0
Game etc.	239	7	2.9%	2	2	100.0%	2	0	0.0%	243	9	3.7%	0.008	0	0
Fruits and berries	1616	9	0.6%	1137	17	1.5%	788	0	0.0%	3541	26	0.7%	0.22	0	0
Algae	93	0	0.0%	37	8	21.6%	100	0	0.0%	230	8	3.5%	0.44	0	0
Mushrooms	1245	50	4.0%	597	57	9.5%	411	1	0.2%	2253	108	4.8%	0.18	0.009	0.05 ± 0.1
Above-ground vegetables	3326	77	2.3%	3182	112	3.5%	2991	1	0.0%	9499	190	2.0%	0.32	0.005	0.02 ± 0.03
Mushrooms, dried	250	59	23.6%	0	0		33	2	6.1%	283	61	21.6%	0.12	0.033	0.3 ± 0.4
Tea & tea products	1981	144	7.3%	232	35	15.1%	131	18	13.7%	2344	197	8.4%	0.056	0.091	1.6 ± 0.9
Below-ground vegetables	1155	6	0.5%	544	2	0.4%	1240	1	0.1%	2939	9	0.3%	0.42	0.11	0.3 ± 0.6
Beef	84,177	22	0.0%	3729	40	1.1%	1598	90	5.6%	89,504	152	0.2%	0.018	0.59	33 ± 9

(Shiraki et al., 2013), or tea has (rightfully) been regarded as a supplementary food item that contributes little to the overall food consumption, thus making tea a food item of lower priority. In both cases, little governmental action would have been taken to effectively keep above limit tea from reaching the market. In any case, what makes tea a low-priority food item, is not only that a low amount of tea is actually consumed by tea drinkers (one also needs to consider the dilution of small amounts of tea leaves in rather large volumes of water); a previous study also showed that a minimum of 30% of radiocesium remains unextracted inside the tea leaves during the brewing procedure (Tagami et al., 2012). Finally, also logistical and agricultural reasons may be responsible for the p′/p ratio of 1.6 ± 0.9. It seems plausible that the pre-market samples of tea have included fresh tea leaves whereas post-market samples have probably been predominantly dried tea leaves. It also seems possible that pre-market samples and post-market samples have originated from different regions, which would thwart the applicability of the method presented herein. In any case, the proposed metric p′/p addresses the potential problem of the effectiveness of the monitoring of tea, whereas the alternative metric p′/pre′ = 0.13 ± 0.03 does not indicate any potential problem.

Lastly, monitoring of *beef* revealed a different picture that could be interpreted as a lack of effectiveness. Of 89,504 beef samples measured in the first year after the accident, 1598 (1.8%) samples have been obtained from the post-market. Unfortunately, of the 152 beef samples exceeding the regulatory limits, 90 samples (59.2%) belonged to the post-marked category, thus making p′/p = 33 ± 9, which is significantly >1 and hence corresponds to Scenario 3 from Fig. 1. This incongruity calls for a more in-depth analysis.

However, the time aspect is not considered in this parameter as it summarizes all data of the first year. Fig. 4 shows the chronological development of p′/p observed in beef on a monthly basis. Since the number of samples measured per month is naturally much smaller, the uncertainties in this approach (95% confidence interval) increase; partly even into negative numerical values (which cannot be displayed in a logarithmic scale but are indicated by the dashed error bars in Fig. 4). The figure shows that only months 6 (2011-8-11 until 2011-9-10) and 8 (2011-11-11 until 2011-12-10) had p′/p ratios significantly >1.

In Fig. 5, the time aspect of sampling and monitoring of beef is illustrated. Fig. 5a displays the monitoring in the three market categories in a linear graph. Below-limit samples are shown in green, samples exceeding the regulatory limit in red. Fig. 5a indicates that the very first exceedances were observed in the post-market category in June 2011, hence triggering a wave of measurements from mid-July onwards. These findings explain why the governmental focus has shifted from other meats such as chicken or pork (with hundreds of samples being measured in the first year) to beef (with tens of thousands samples being measured).

Fig. 5b adds the sum radiocesium activities to this information. It appears that beef samples have remained well below the regulatory limits for a rather long time after the accident. They hence initially did not raise much concern and consequently triggered very little monitoring efforts, until (possibly by coincidence) some above-limit samples were found in the post-market in mid-June. Our data suggest that the resulting pre-market campaign was initiated too late to effectively catch above-limit items and ban them from the market in summer 2011. The majority of pre-market samples measured after mid-July was well below the regulatory limit; however, still a considerable number of post-market beef samples exceeded the limits until November 2011. After November 2011, the number of exceedances was greatly reduced. Although Fig. 5b suggests that only four post-market samples were taken after December 2011, Fig. 5a reveals that in fact much more post-market samples were actually taken, but did not exhibit any detectable radiocesium concentrations (hence not resulting in a respective data point in Fig. 5b). It is interesting to note that after approximately October 2011, no more samples were characterized as "not specified." This is a great improvement for the reliability of the data thereafter.

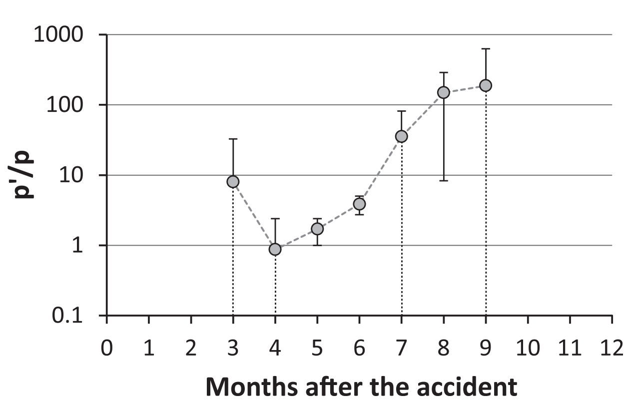

Fig. 4. Development of p′/p in beef over the first year after the Fukushima accident on a monthly basis.

In our previous paper (Merz et al., 2015b), we had concluded that monitoring of meat outside Fukushima Prefecture has commenced with significant delay. The present analysis, however, suggests that also in Fukushima Prefecture, by following the instructions of the governmental food manual (Ministry of Health Labour and Welfare (MHLW), 2002), monitoring for beef received little attention until several exceedances in post-market samples had been observed. It then took the authorities several weeks (and tens of thousands of samples) to intercept the stream of above-limit beef from reaching the market. Until this point of success had been reached, a high priority had been on post-market-monitoring to remove above-limit beef that had already been in the production stream and could not be identified in the pre-market, as shown in Fig. 6. Although in the first year after the accident, the total number of pre-market beef samples exceeded the number of post-market beef samples by a factor of 53, the number of post-market beef samples temporally exceeded the number of pre-market beef samples between July 20, 2011 and August 18, 2011. It is very likely that this focus on the post-market had been triggered by the first exceedance which was found in the post-market. This unusual focus on the post-market is equivalent to the bias that has been made in the choice of samples that led to the unusual and unexpected p′/p > 1 (Scenario 3 in Fig. 1). This bias is most likely the reason for the p′/p ratios in months 5 (July 11 until August 10) and 6 (August 11 until September 10) after the accident (Fig. 4) being ≥1 or significantly >1, respectively.

The method of calculating the ratio p′/p could be a useful tool to provide insight on the effectiveness of food monitoring. However, the detailed analysis on the beef monitoring shows that this tool is not necessarily sufficient by itself. For example, it depends on a completely randomized sampling regime, where pre- and post-market samples originate from the same agricultural areas and not further bias is introduced (e.g., predominantly dried tea leaves in the post-market category vs. fresh tea leaves in the pre-market category).

Alternative metrics such as the comparison between the fraction of above-limit contaminated items in the pre- and the post-market successfully identified the problems of beef (p′/pre′ = 4 ± 1), but failed to address the potential problem of tea, by pretending effectiveness of the monitoring campaign through p′/pre′ = 0.13 ± 0.03. In any case, the alternative metric p′/pre′ rightfully identified the monitoring of all other food categories as successful, just like p′/p did. The sole focus of p′/pre′ on above-limit samples (while disregarding the entity of the samples measured) appears to be disadvantageous compared with p′/p.

Again, it is necessary to emphasize that the method of using p′/p is highly vulnerable to biases that are introduced in the course of the monitoring campaign. It would be a prerequisite for the absolute reliability and applicability of p′/p that the samples of the pre-market and the post-market originated not only from the same regions, but also have been produced at the same time etc. Also the fractions of items from the pre- and post-market had to be constant over the period of observation. Nevertheless, the metric p′/p still works in addressing problematic food categories and problems in the monitoring, despite all biases, as could be shown herein.

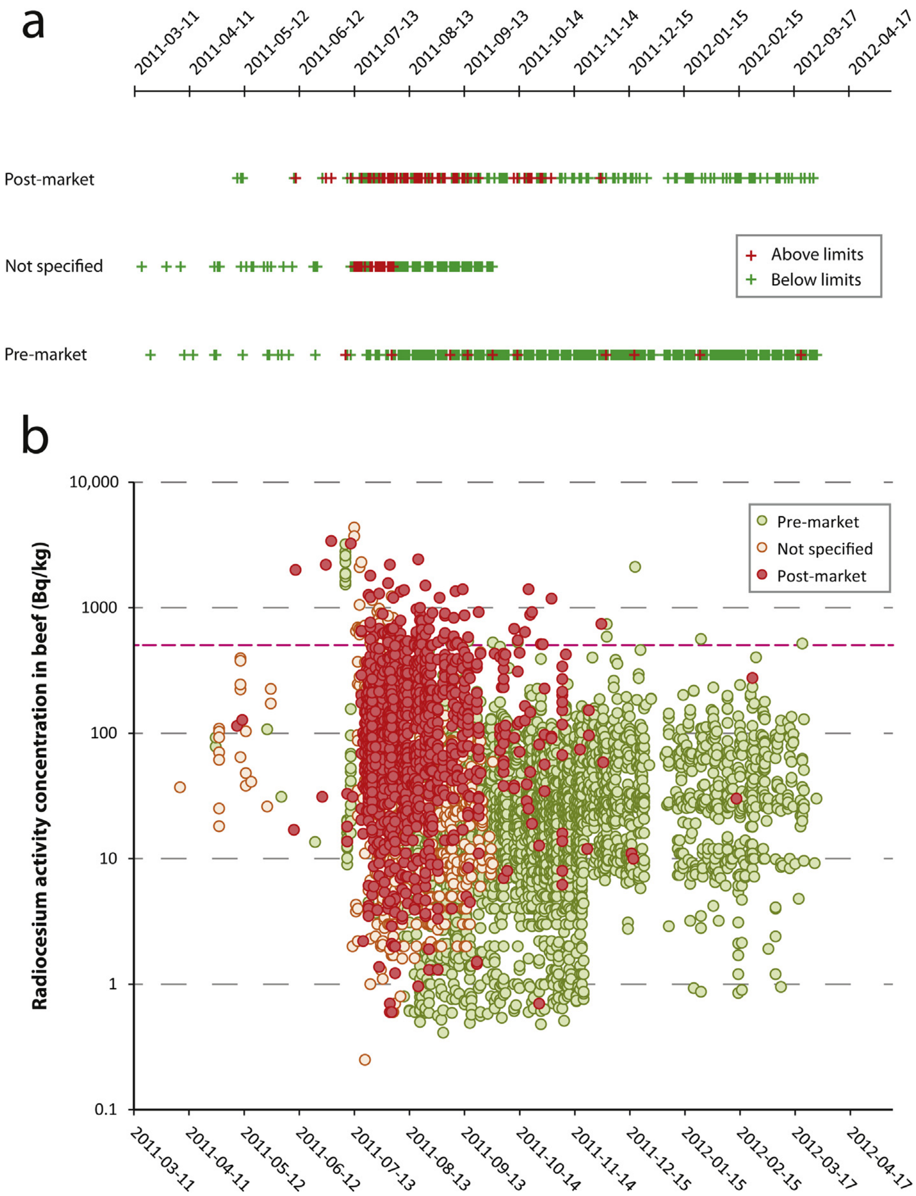

Fig. 5. Illustration of the monitoring density in beef in the three market-categories (a), with green crosses for below-limit samples and red crosses for above-limit samples. Radiocesium ($^{134}Cs + ^{137}Cs$) activity concentrations in beef (b), with green symbols for pre-market samples, yellow symbols for not-specified-samples and red symbols for post-market samples. The magenta dotted line indicates the regulatory limit of 500 $Bq \cdot kg^{-1}$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Conclusion

In summary, analysis of post-market food items reveals that only relatively few post-market samples exceeded the limits, with the notable exception of beef (and tea). All food types (with the exception of tea and beef) had a p′/p ratio that was significantly smaller than 1, thus indicating effectiveness of the Japanese food monitoring campaign. The first beef samples exceeding the limits were obtained from the post-market, and even though these findings triggered a massive monitoring campaign, it took these governmental measures several months to effectively and successfully exclude above-limit beef from hitting the market. It seems that the time delay in the production of beef between slaughtering and appearance of the beef in the grocery stores (at least in part) caused the delay of the success of the monitoring action. Another problem was the very low number of post-market samples in several food categories such as Asian black bear, wild boar, and game. This fact makes it impossible to assess the effectiveness of the monitoring campaign in these food categories. It can be concluded that the monitoring of meats was generally slightly less effective (or at least somewhat more problematic) than the monitoring of vegetarian produce which has been extremely successful.

The data analysis also revealed the problem of the uncertainty that has been induced by the measurement of samples that have not been categorized as “pre-market” or “post-market”. The uncertainty caused by this “not-specified”-category makes a comprehensive analysis of the data difficult. Measurement of “not specified” food thwarts the statistical analysis and certainly did not exhibit the most efficient use of radiation detector capacities. Unfortunately, it seems that the necessary information on the market categories has not always been recorded in the early phase after the accident. For beef, it is worth noting that it took until the end of September 2011 (more than 6 months after the accident) for the

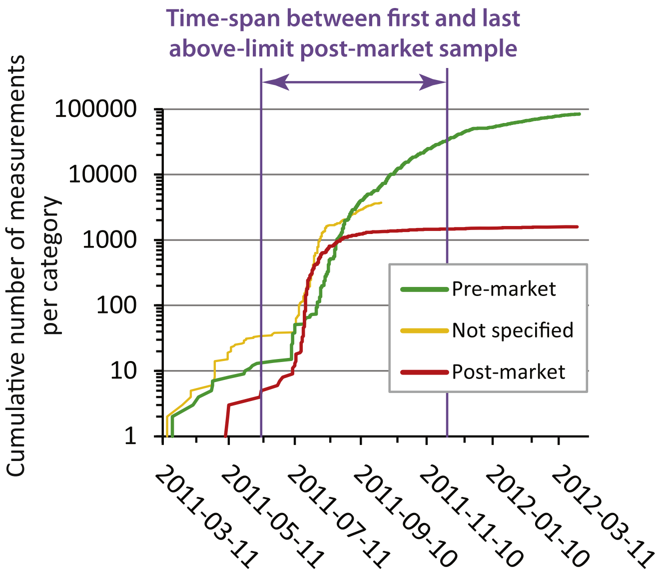

Fig. 6. Comparison of the temporal development of the changing focus on the market-categories in the monitoring of beef by comparison of the cumulative number of measurements per category vs. date.

"not-specified"-category to disappear from the data base and to be replaced by a more accurate attribution of the samples into the "pre-market" and "post-market" categories. In case of future nuclear accidents, this lesson of the need for accurate attribution into market-categories should be learned from Fukushima.

Acknowledgments

The author thanks Alexander Brandl and Peter Bossew for insightful and inspiring discussions on this topic. This study was supported by Grant Number T42OH009229-07 from CDC NIOSH Mountain and Plains Education and Research Center. Its contents are solely the responsibility of the author and do not necessarily represent the official views of the CDC NIOSH and MAP ERC. The author also gratefully acknowledges funding by the US Nuclear Regulatory Commission (NRC), grant number NRC-HQ-12-G-38-0044.

References

Hamada, N., Ogino, H., 2012. Food safety regulations: what we learned from the Fukushima nuclear accident. J. Environ. Radioact. 111, 83–99.

Harada, K.H., Fujii, Y., Adachi, A., Tsukidate, A., Asai, F., Koizumi, A., 2012. Dietary intake of radiocesium in adult residents in Fukushima prefecture and neighboring regions after the Fukushima nuclear power plant accident: 24-h food-duplicate survey in December 2011. Environ. Sci. Technol. 47, 2520–2526.

Hayano, R.S., Tsubokura, M., Miyazaki, M., Satou, H., Sato, K., Sakuma, Y., 2013. Internal radiocesium contamination of adults and children in Fukushima 7 to 20 months after the Fukushima NPP accident as measured by extensive whole-body-counter survey. Proc. Jpn. Acad. Ser. B 89, 157–163.

Koizumi, A., Harada, K.H., Niisoe, T., Adachi, A., Fujii, Y., Hitomi, T., et al., 2012. Preliminary assessment of ecological exposure of adult residents in Fukushima Prefecture to radioactive cesium through ingestion and inhalation. Environ. Health Prev. Med. 17, 292–298.

Merz, S., Steinhauser, G., Hamada, N., 2013. Anthropogenic radionuclides in Japanese food: environmental and legal implications. Environ. Sci. Technol. 47, 1248–1256.

Merz, S., Shozugawa, K., Steinhauser, G., 2015a. Effective and ecological half-lives of ^{90}Sr and ^{137}Cs observed in wheat and rice in Japan. J. Radioanal. Nucl. Chem. http://dx.doi.org/10.1007/s10967-015-4352-6 (in press).

Merz, S., Shozugawa, K., Steinhauser, G., 2015b. Analysis of Japanese radionuclide monitoring data of food before and after the Fukushima nuclear accident. Environ. Sci. Technol. 49, 2875–2885.

Ministry of Health Labour and Welfare (MHLW), 2002. A Manual for Measuring Radioactivity in Foodstuff in an Emergency (In Japanese). http://www.mhlw.go.jp/stf/houdou/2r9852000001558e-img/2r98520000015cfn.pdf. Accessed: June 2015.

Ministry of Health Labour and Welfare (MHLW), 2014. Levels of Radioactive Contaminants in Foods Tested in Respective Prefectures. http://www.mhlw.go.jp/english/topics/2011eq/index_food_radioactive.html. Accessed: September 2014.

Nihei, N., Tanoi, K., Nakanishi, T.M., 2015. Inspections of radiocesium concentration levels in rice from Fukushima Prefecture after the Fukushima Dai-ichi Nuclear Power Plant accident. Sci. Rep. 5.

Normile, D., 2015. Food Supply Was Protected after Fukushima, Study Finds. http://news.sciencemag.org/asiapacific/2015/03/food-supply-was-protected-after-fukushima-study-finds. Accessed: June 2015.

Seto, M., Uriu, K., 2015. Sample size allocation for food item radiation monitoring and safety inspection. Risk Anal. 35, 409–422.

Shiraki, Y., Takeda, A., Okamoto, P., 2013. Translocation of radioactive cesium in Tea Nursery stocks and its distribution in the branches and trunks of the matured Tea Bush. Tea Res. J. 115, 11–19 (in Japanese).

Steinhauser, G., 2014. Fukushima's forgotten radionuclides: a review of the understudied radioactive emissions. Environ. Sci. Technol. 48, 4649–4663.

Steinhauser, G., Saey, P.R.J., 2015. ^{137}Cs in the meat of wild boars: a comparison of the impacts of Chernobyl and Fukushima. J. Radioanal. Nucl. Chem. http://dx.doi.org/10.1007/s10967-015-4417-6 (in press).

Tagami, K., Uchida, S., Ishii, N., 2012. Extractability of radiocesium from processed green tea leaves with hot water: the first emergent tea leaves harvested after TEPCO's Fukushima Daiichi Nuclear Power Plant accident. J. Radioanal. Nucl. Chem. 292, 243–247.

Tanoi, K., Uchida, K., Doi, C., Nihei, N., Hirose, A., Kobayashi, N.I., et al., 2015. Investigation of radiocesium distribution in organs of wild boar grown in Iitate, Fukushima after the Fukushima Daiichi nuclear power plant accident. J. Radioanal. Nucl. Chem. http://dx.doi.org/10.1007/s10967-015-4233-z (in press).

Travnikova, I.G., Bruk, G.J., Shutov, V.N., Bazjukin, A.B., Balonov, M.I., Rahola, T., et al., 2001. Contribution of different foodstuffs to the internal exposure of rural inhabitants in Russia after the chernobyl accident. Radiat. Prot. Dosim. 93, 331–339.