Contamination of Japanese foodstuffs following the Fukushima accident

Since March 2011, the Japanese Ministry of Health, Labour and Welfare (MHLW) has regularly published the radionuclide measurement results of foodstuffs produced in Japan on its website[1]. The IRSN has systematically analysed all information concerning foodstuffs as and when it became available.

Summary 2015-2016:

Between March 2015 and February 2016, over 270,000 samples were analysed across the whole of Japan. These analyses primarily concern foodstuffs from animal sources (≈86%), agriculture (≈10%), dairy production (≈1%), game (≈0.2%) and other foodstuffs (≈3%). Overall, activities measured in these foodstuffs are declining, and this decrease can be attributed to the radioactive decay of the radionuclides, various natural processes (caesium migration into the soils, reduction in its bioavailability...) but also to different anthropogenic measures such as soil decontamination, use of potassic fertilisers reducing the transfer of radiocaesiums[2], changes in farming practices and even a stop to farming in certain areas.

Over this period, less than 0.1% of the measurement results exceed the Maximum Permissible Levels (MPLs)[3] to be marketed. These are mainly (≈58%) game meat (wild boar, bear, venison) and certain specific foodstuffs (≈36%). These MPL exceedances are not confined to the Fukushima prefecture, and also widely affect the prefectures of Miyagi, Gunma, Tochigi and Nagano.

With very few exceptions, measurement results of samples from agriculture or livestock farming no longer exceed these levels.

In 2015, despite the notable reduction in activity measured in agricultural production in the Fukushima prefecture, and the low percentage of measurement results exceeding the MPLs of 100 Bq/kg, the agricultural sector registered a significant decrease in demand, leading to overproduction and a fall in prices. Sale prices of foodstuffs produced in the Fukushima prefecture remain, for the most part, below those coming from other prefectures and below 2010 prices. As a result, farmers' incomes have fallen dramatically, and led to 20,000 of them ceasing their activity. Only a few products benefiting from a strong brand image, such as asparagus, have got back to sales prices equivalent to or higher than in 2010.

[1] http://www.mhlw.go.jp/english/topics/2011eq/index_food_radioactive.html
[2] These radiocaesiums are caesium-134 and caesium-137.
[3] Maximum Permissible Levels for marketing (MPLs): 2000 Bq/kg fresh weight for iodine-131 and 500 Bq/kg fresh weight for radiocaesium (134+137) up until March 2012, then 100 Bq/kg fresh weight.

Reminder of the situation in 2011

The highest levels of contamination in foodstuffs were reached immediately following the radioactive deposits, and affected vegetable foodstuffs whose leaves collected said deposits. At the end of this winter of 2011, only some market gardening production was in progress, in particular leaf vegetables (spinach, lettuce, cabbage...). In the non-evacuated zones most affected by radioactive fallout (notably Iitate-mura and Kawamata-machi, evacuated from April onwards), the massic activity of these highly-sensitive foodstuffs reached several tens of thousands of Bq/kg in iodine-131 or radiocaesiums (134 and 137). This contamination then rapidly decreased, by 100 to 1,000 times in two to three months. For iodine-131, this reduction is linked to radioactive decay; for radiocaesiums, it is mainly due to plant growth.

The majority of the main crops were at a very early stage of development at the time of the radioactive deposits. Most of the orchard trees were neither in leaf nor in flower. Grain crops were either sprouting (therefore a long way from grain formation) or had not yet been planted, such as rice. The plants were therefore only directly affected by radioactive fallout on a small scale, if at all. Their later contamination occurred via the soil through re-suspension, root transfer or irrigation (in the case of rice). For these reasons, the contamination of the region's main crops was moderate with regard to the scale of the radioactive deposits.

The contamination of meat and dairy products was limited due to the practice - which is current in Japan - of feeding animals with imported fodder stored under shelter whilst awaiting its distribution. If cows from the most contaminated non-evacuated territories (such as Iitate or Kawamata) had consumed local herbage, the radiocaesium content of their milk would have exceeded 100,000 Bq/L, whereas the maximum observed activities remained 50 to 100 times lower, only very rarely exceeding 1,000 Bq/L. These activities then quickly decreased, including in the most affected zones: less than 100 Bq/L from April 2011 onwards and, with only a few exceptions, less than 10 Bq/L from June 2011. Again, due to the consumption of imported fodder, meat contamination - which reached its peak during summer 2011 due to a more progressive transfer of caesium - was also moderate. Nevertheless, the massic activity of some meat from cattle fed with fodder stored outside at the time of the deposits reached levels of several thousand Bq/kg fresh weight during July 2011. The destruction of such fodder imposed by the authorities, followed by the decision to set the permissible radiocaesium level in fodder to 300 Bq/kg dry weight, enabled the progressive control of the radiocaesium content of livestock meat. With regard to other livestock products, the analyses carried out on chicken meat and eggs only rarely quantified or detected traces of iodine-131 or radiocaesiums, which is consistent with the fact that food consumed by these animals is often comprised of cereal derivatives harvested the previous summer, and therefore prior to the accident. The same applies to pork meat and offal even if, only very occasionally, activities reaching 100 or even 200 Bq/kg fresh weight were observed.

Figure 1 shows that, due to the date of the accident and this practice of importing fodder, the number of analysed samples of agricultural and livestock foodstuffs exceeding the marketable levels (different shades of blue) has, since 2011, been very low with regard to the total number of samples

analysed. This number is highest in the Fukushima prefecture (dark blue), followed by the prefectures of Miyagi and Iwate to the north, Tochigi, Gunma and Nagano to the south and south-west. The fact that it reached the most distant prefectures (Gunma, Nagano and Iwate) is linked to snow and rainfall, particularly during the night of 15-16 March 2011, which led to more significant radioactive deposits. The contamination of foodstuffs produced in the other prefectures only rarely exceeded the marketable limits (sky blue and white on the maps), if at all. In the Fukushima prefecture, only 2.8% of the samples analysed in 2011 exceeded the marketable standard. Most often, the activities measured were even more than 5 times lower than these standards.

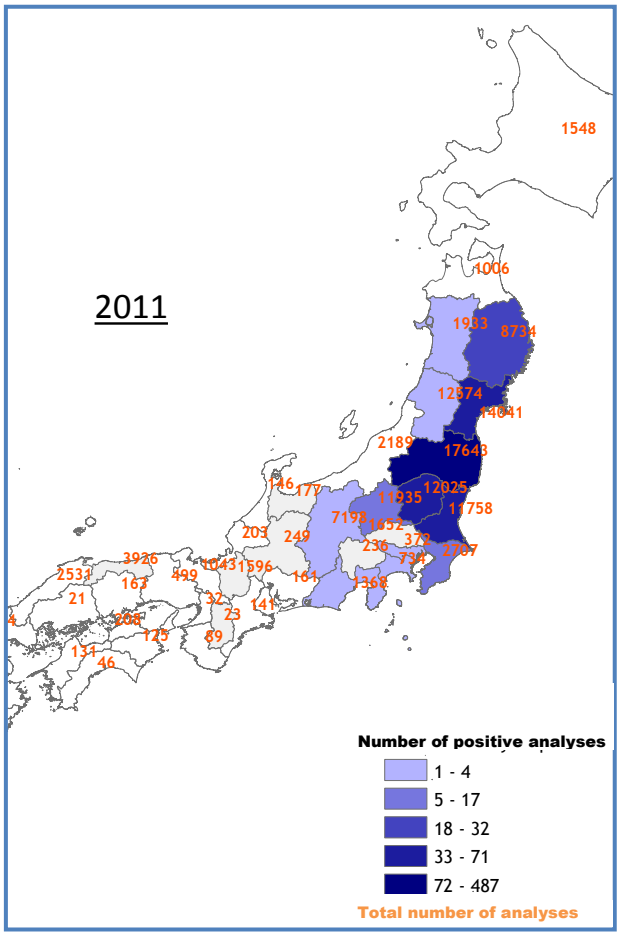

Figure 1: Number of analyses of foodstuffs from agricultural production and livestock exceeding the Maximum Permissible Levels for their marketing in 2011 (2000 Bq/kg for iodine-131 and 500 Bq/kg for radiocaesium).

The contamination of agricultural and livestock production therefore remained, on the whole, well below the marketable standards of 500 Bq/kg fresh weight for radiocaesiums and 2,000 Bq/kg fresh weight for iodine-131, including within the Fukushima prefecture.

In the case of vegetable foodstuffs, besides the leaf vegetables discussed previously, cases exceeding the standard mainly concerned Japanese apricots, early fruit harvested from the end of May onwards whose radiocaesium activity reached several hundred Bq/kg fresh weight, as well as plants that come into bud early but bear fruit later, such as kiwis or persimmon (figure 2), and dried fruit[4]. Trees and shrubs that do not lose their leaves in winter did however intercept radioactive deposits on a more significant level: this was the case for bamboo (figure 7), tea plants and certain citrus fruits (yusus in particular). The contamination of bamboo shoots and tea leaves therefore reached several thousand Bq/kg fresh weight at the most affected sites.

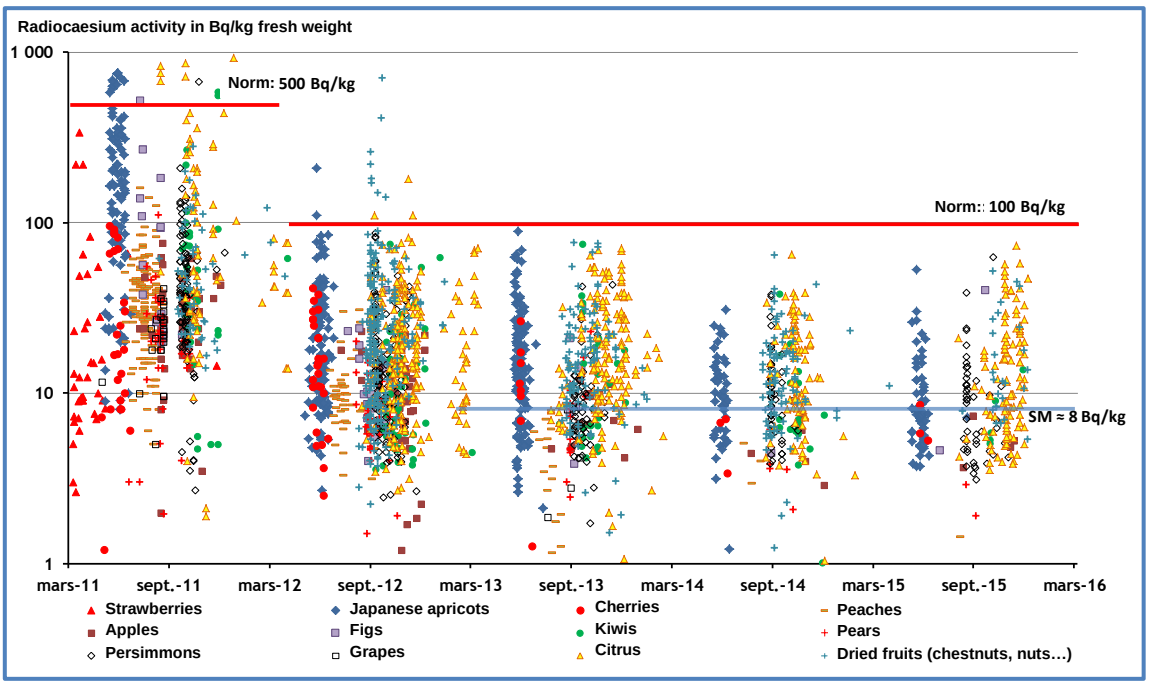

Figure 2: Radiocaesium activity (Bq/kg fresh weight), above the measurement thresholds[5], in samples of successive harvests of fruit produced across all prefectures.

Most Japanese foodstuffs were therefore relatively spared due to the date of the accident, and it is important to underline that, if the accident had occurred three or four months later, many 2011 harvests - fruit and cereal in particular - would have reached extremely high contamination levels comparable to those observed in leaf vegetables or bamboo shoots.

[4]Apart from their low water content, which proportionately increases massic activity, dried fruits often have a high potassium content. As caesium is a chemical analogue of potassium, its concentration is also higher.
[5]The fact that caesium activity is below the measurement threshold signifies that it was too low to be measured. The measurement threshold is not fixed, and depends on measurement conditions: type of apparatus, duration of the measurement, type and weight of the sample measured. For this report, the term "measurement threshold" thus defined has been chosen over other more technical terms having a particular signification for specialists, such as "decision threshold" or "limit of detection".

More precisely, figure 3 shows that in 2011, even in the Fukushima prefecture, the number of samples of vegetable foodstuffs, milk and livestock meat exceeding the levels was low: 3%, 2.7% et 0.9% respectively.

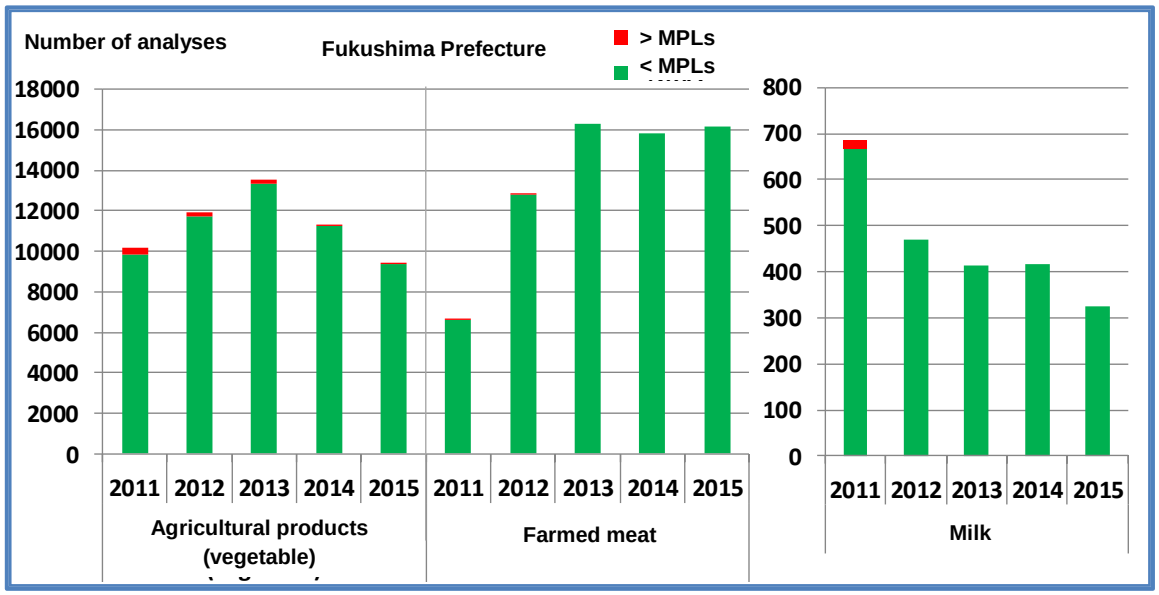

Figure 3: Number of analyses of samples of foodstuffs produced in the Fukushima prefecture over (and respectively under) the marketable standards: 2000 Bq/kg for iodine-131, 500 Bq/kg for radiocaesium up until March 2012, then 100 Bq/kg.

Since summer 2011, following the disappearance of iodine-131 through radioactive decay and the rapid decline in radiocaesium contamination of market garden vegetables, milk and meat for the reasons mentioned previously, contamination levels of agricultural and livestock foodstuffs have continued to decrease. For all foodstuffs, part of this decrease is linked to the radioactive decay of caesium-134 which, over five years, lost 80%[6] of its activity. However, for the main part, the reasons behind this decrease vary according to the type of production and are explained later.

Evolution since 2012

From 2012 onwards, and with only very few exceptions, exceedances of the new Japanese limit of 100 Bq/kg fresh weight only affected:

- wild foodstuffs (game, seasonal mushrooms) or those cultivated in a natural environment (e.g. shiitake mushrooms),
- plant-based foodstuffs that were in leaf in March 2011 at the time of the radioactive fallout: bamboo shoots, tea leaves, aralia and koshiabura shoots, ostrich ferns...
- some agricultural foodstuffs (vegetables) grown in areas located on the outskirts of the evacuated zone, notably rice, buckwheat, soya beans and kidney beans.

In 2015, with only a few exceptions, the foodstuffs exceeding the MPLs only concerned the first two categories.

[6] This 80% fall in caesium-134 in five years is reflected in a reduction of almost 46% in the totalled activities of the two caesiums, 134 and 137.

Consequently, in order to better summarise the contamination levels of agricultural and livestock production, it is more relevant, on the one hand, to present the activity measured and its evolution over the five years and, on the other hand, to present the number of samples for which the radiocaesium content was too low to be measured; i.e. below the measurement thresholds (MTs) applied[4].

As the contamination of livestock products can be controlled everywhere via that of the fodder, no livestock foodstuffs have exceeded the limit of 100 Bq/kg fresh weight in radiocaesiums since mid-2012, including in the most affected areas. Caesium content is even predominantly lower than the measurement thresholds applied by the Japanese, which are themselves 4 to 20 times below the marketable level.

The graphs in figure 4 concern samples of meat, milk and eggs produced exclusively in Date, Fukushima-shi[7], Kawamata, Katsurao, Kori, Minamisoma and Naraha.

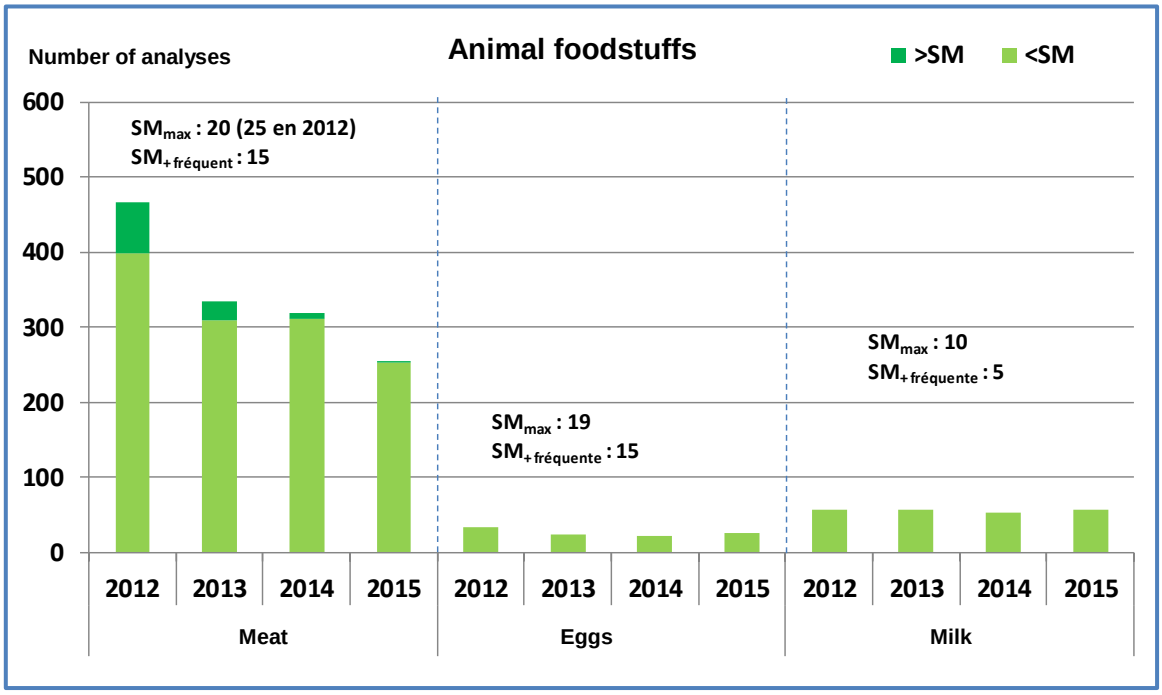

Figure 4: Number of analyses of samples of animal foodstuffs produced in Date, Fukushima-shi, Kawamata, Katsurao, Kori, Minamisoma and Naraha, over (respectively under) the measurement thresholds (SM) indicated.

These graphs show that since 2012 the radiocaesium content of milk and eggs is lower than the measurement thresholds (<MT in light green): always lower at 10 or 19 Bq/kg respectively (maximum measurement thresholds) and most often lower at 5 or 15 Bq/kg respectively (most frequent measurement thresholds). In the case of meats, of the 254 samples from these sites analysed in 2015, radiocaesium activity could only be quantified once, at around 8 Bq/kg fresh weight (>MT in dark green).

[7] Shi signifies that this refers to the town of Fukushima and not the whole prefecture.

Figure 5 shows that, even for vegetables produced in the aforementioned locations, radiocaesium content was, for the most part, below 20 Bq/kg fresh weight (highest measurement threshold), or 9 Bq/kg fresh weight (most frequent measurement threshold), i.e. 10 times below the limit. The highest activity was measured in varieties of cabbage (29 Bq/kg fresh weight), spinach (52 Bq/kg fresh weight) and broccoli (62 Bq/kg fresh weight). These levels, most often below 9 Bq/kg fresh weight, are entirely consistent with the underlying radiocaesium contamination of the soils due to root absorption and the deposit of re-suspended soil dust on leaves. It is likely that this contamination of vegetables will decrease only slowly from now on.

The contamination of successive crops of orchard fruits is directly linked to the contamination of the 2011 harvest and to the stage of development of the trees in March 2011. Figures 2, 5 and 6 show that, each year, Japanese apricots, kiwis and persimmon, as well as dried fruit (chestnuts, walnuts, ginkgo nuts) present the highest caesium content. Contrary to vegetables or the main annual crops, this contamination of the 2012-2015 harvests does not result from transfer through the soil but from a remanence of tree contamination since March 2011. The proportion of radioactive deposits intercepted by trees at this time, despite being so low due to the time of year, was in part maintained by the ligneous parts of the tree, from which it is transferred to new harvests. Even if it is difficult to know if the decrease observed will continue at this pace, it is possible, due to the progressive exhaustion of activity "stored" in the tree, that this contamination is even less frequently measurable (< MT) in harvests over the coming years, including in those areas most affected by radioactive deposits. Figure 5 therefore shows that this decrease at the most affected sites can also be observed in the number of analyses returning results above the measurement thresholds; for fresh fruit, this fell from 85% in 2012 to around 40% in 2014-2015. Moreover, it must be noted that these activities are effectively the highest of all those shown in figure 2 for all prefectures.

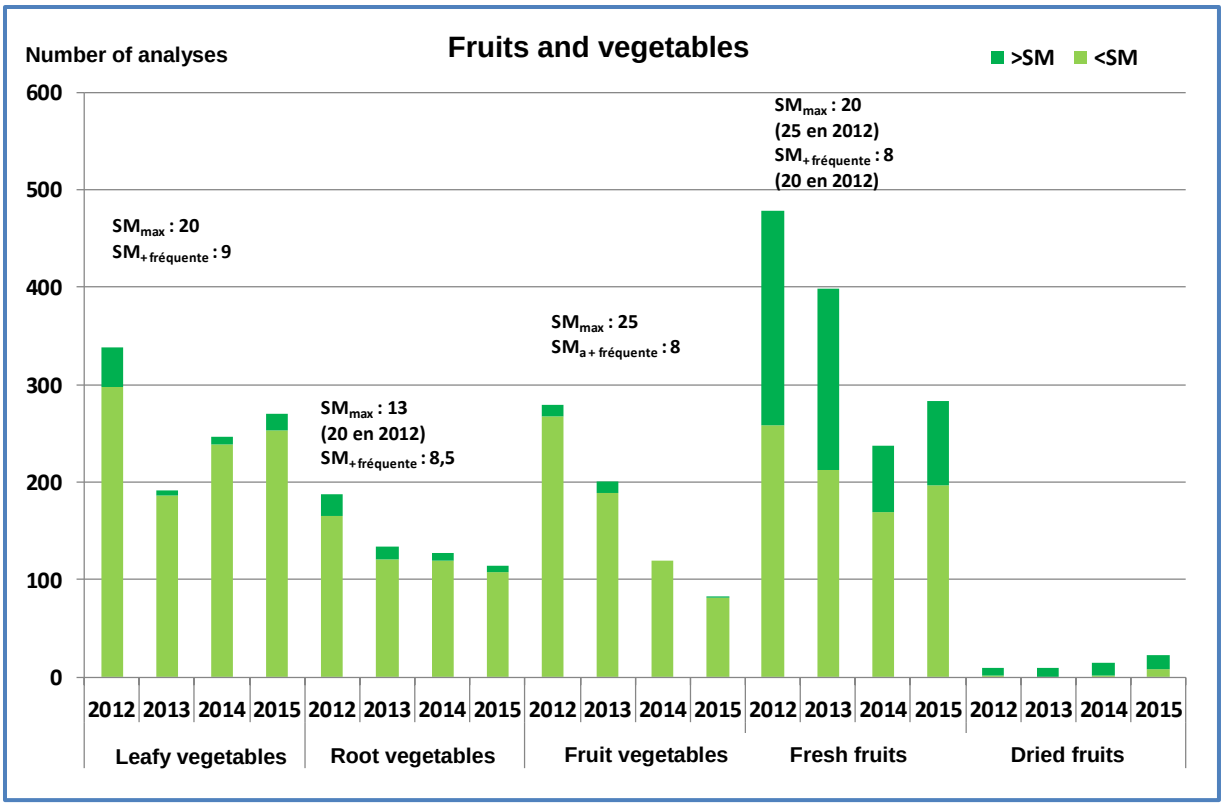

Figure 5: Number of analyses of samples of vegetables and fruit produced in Date, Fukushima-shi, Kawamata, Katsurao, Kori, Minamisoma and Naraha, over (respectively under) the measurement thresholds (SM) indicated.

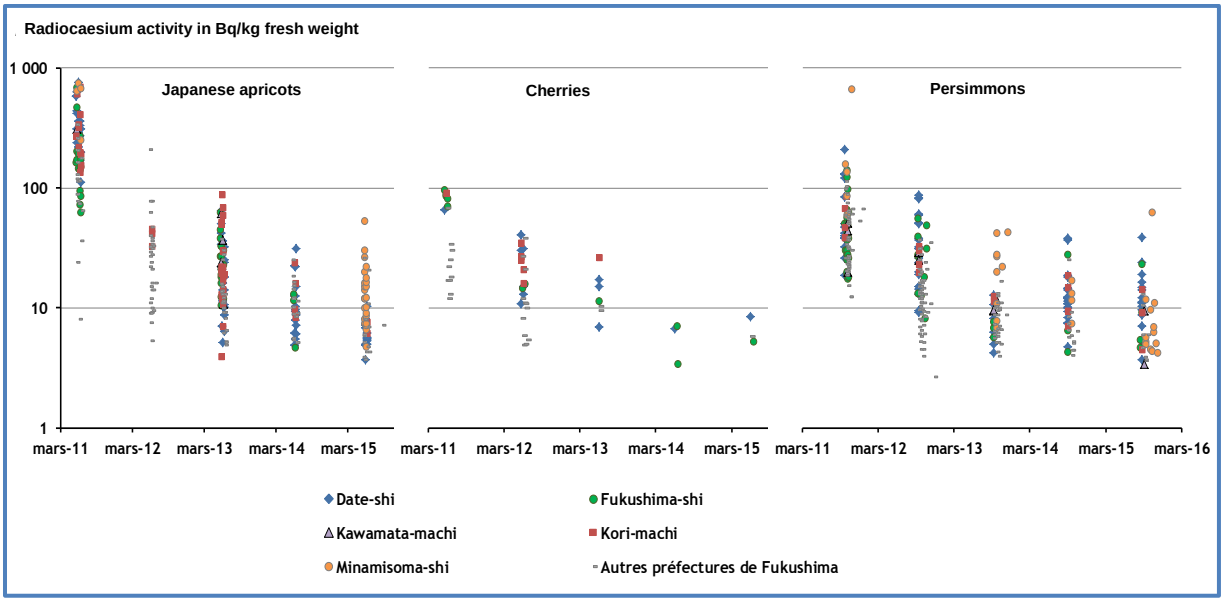

Figure 6: Radiocaesium activity (Bq/kg fresh weight), over the measurement thresholds, in samples from successive harvests of Japanese apricots, cherries and persimmon produced in Date, Fukushima-shi, Kawamata, Kori and Minamisoma.

This remanence of the initial contamination in trees and shrubs exists *a fortiori*, for those in leaf at the time of the radioactive deposits in March 2011, such as tea bushes, bamboo and citrus fruits (notably yusus and mandarins).

Figure 7 therefore shows a reduction in activity in bamboo shoots similar to that observed in fruits, but with a higher overall level of contamination. This level of activity is higher because the measurements shown on this diagram do not come from the most affected sites in the Fukushima prefecture but from several prefectures. It is likely that these foodstuffs, liable to exceed marketable levels, are no longer produced in the zones where deposits were the highest, or are only produced by way of specific measures (for example new plants) enabling compliance with standards.

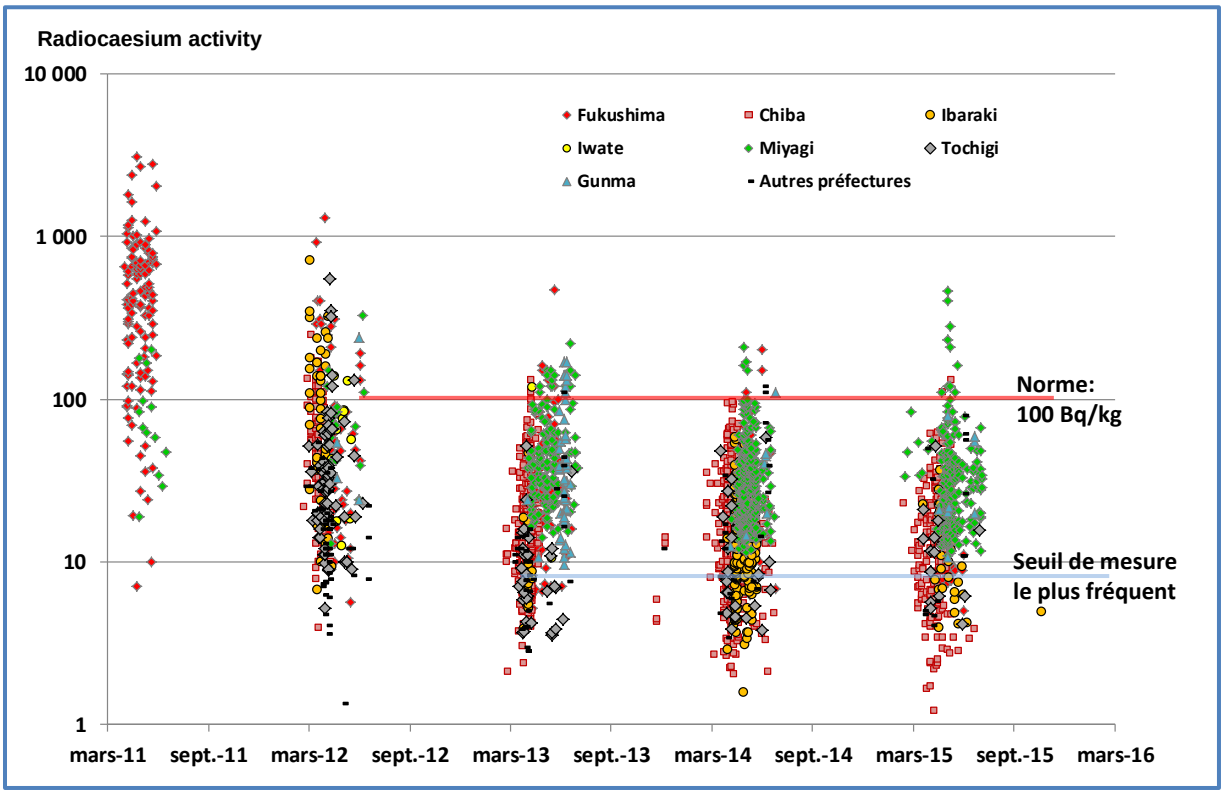

Figure 7: Radiocaesium activity (Bq/kg fresh weight), above the measurement thresholds in samples from successive harvests of bamboo shoots in several prefectures.

The evolution since 2011 of the contamination of the main cereal crops (wheat, barley, rice) and pulses (kidney beans, soya, buckwheat) varies greatly depending on the species. The radiocaesium content of wheat and barley, as expected, declined from 2012 onwards, for the most part below 10 Bq/kg fresh weight, i.e. less than a tenth of the marketable limit, including in the non-evacuated and most-affected areas (figure 8). In 2015, around 1,300 measurements were carried out on rice in Japan, 14 were above the the measurement thresholds including two measurements above the MPLs (measurement thresholds between 1 and 25 Bq/kg fresh weight; the most frequent measurement threshold being 10 Bq/kg fresh weight). In the Fukushima prefecture, 18 measurements were carried out, with seven being above the measurement thresholds including the two measurements above the MPLs. The small number of measurements carried out on rice produced in the Fukushima prefecture demonstrates, in all likelihood, the abandonment of this crop in areas where activity in this foodstuff can still be significant, due to the flooding of paddy fields that leads to a transfer of radiocaesium from the water to the leaves in addition to root transfer.

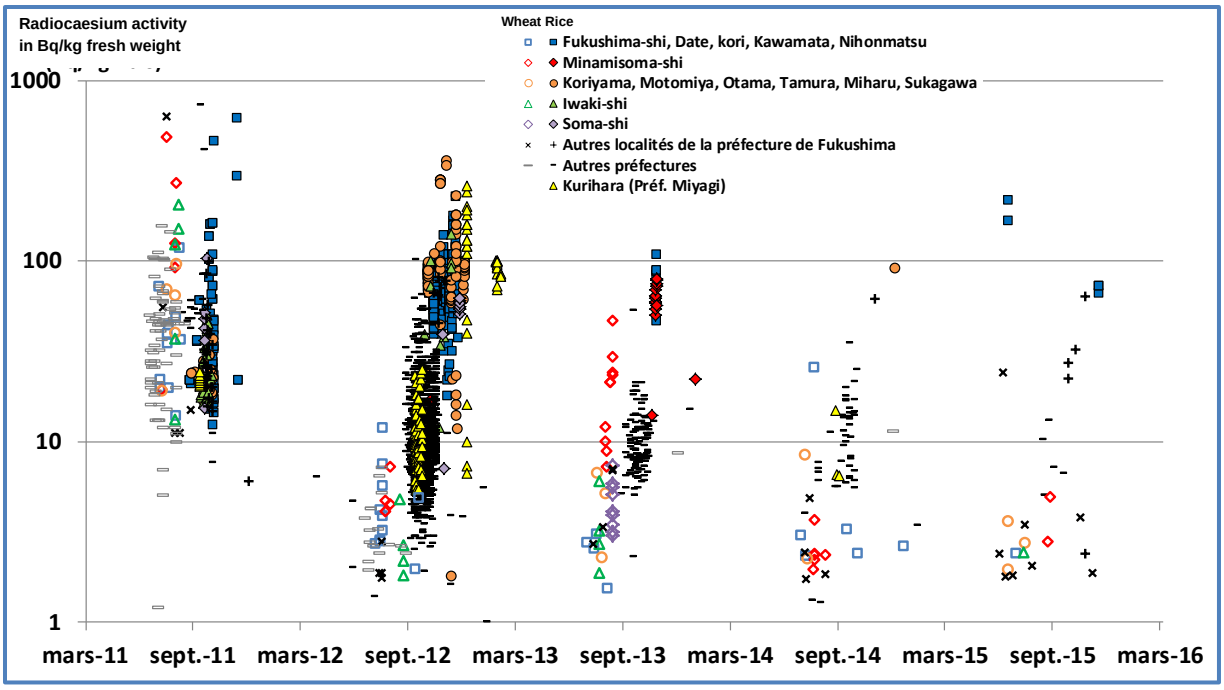

Figure 8: Radiocaesium activity above the measurement thresholds, in samples from successive harvests of wheat and rice (Bq/kg fresh weight).

The decrease observed for wheat and barley was expected due to a contamination that was exclusively linked to that of the soil from the 2012 harvest onwards. In the case of soya, this transfer via the soil is more significant than for cereals and its contamination fell only relatively slightly between the harvests of 2012 and 2015. In 2015, around 2,300 measurements were carried out on soya, almost 90% of which were in the Fukushima prefecture; three-quarters of the measurement results were below the measurement thresholds (≈ 10 Bq/kg fresh weight). The significant activity measured lies between 1 and 30 Bq/kg fresh weight outside the Fukushima prefecture, and between 3 and 120 Bq/kg fresh weight within the Fukushima prefecture (two activities are over the MPLs: 110 and 120 Bq/kg fresh weight). The results for the 2015 buckwheat harvest confirm the trend observed in 2014 of a decrease in measured activity. 90% of the results are now below the measurement thresholds (around 10 Bq/kg fresh weight); activity over these thresholds lies between 2 and 20 Bq/kg fresh weight with one activity of 76 Bq/kg fresh weight in the Miyagi prefecture and one of 130 Bq/kg fresh weight exceeding the MPL in the Iwate prefecture. It is not possible to determine the role of agricultural land decontamination measures or specific measures aimed at reducing radiocaesium content (use of potassic fertilisers for example) in this overall observed decrease.

The Chernobyl accident had demonstrated that forest products such as mushrooms and game can reach high contamination levels that only decrease slowly over the years. Fukushima has confirmed this characteristic, extending it to plant-based shoots consumed in Japan (aralia and koshiabura shoots, ostrich ferns) and to cultivated mushrooms (shiitakes). From autumn 2011 onwards, game meat (wild boar, venison, black bear, pheasant, water fowl) and seasonal mushrooms frequently

exceeded 100 Bq/kg fresh weight, more occasionally 1,000 Bq/kg fresh weight, in several prefectures (Fukushima, Tochigi, Gunma...) (see figures 9, 10 and 11 for game). In the case of wild boar meat, values above 10,000 Bq/kg fresh weight were still observed in 2015 in the most affected sites in the Fukushima prefecture. The downward trend over the four years seems quite weak, in part due to the radioactive decay of caesium-134.

For these natural or semi-natural products likely to frequently exceed the marketable standards, including in prefectures other than Fukushima, the measurement results also reproduce the evolution in hunting and harvesting practices. If game is still hunted in the non-evacuated and most-affected zones, samples of seasonal mushrooms or plant shoots (aralia, koshiabura, ferns...), reputed for their very high activity, now only rarely come from these areas, and provide information about contamination levels at sites further away from the Fukushima prefecture and in other prefectures. In the same way, of the numerous species of mushrooms consumed in Japan, the most radiologically-sensitive are being progressively identified and picked less, and therefore measured less. It is therefore difficult to comment on the results in terms of levels of activity and trends. In 2015, of the 1,700 mushroom samples analysed, the activity measured is mainly (75%) below the measurement thresholds (measurement thresholds between 2 and 25 Bq/kg fresh weight). Nevertheless, the most sensitive species still show levels of between 120 and 900 Bq/kg fresh weight, and this activity can be reached more than 100 km from the most affected zones. Very few measurements (fewer than 2%) have been carried out on species identified since 2011 as being the most sensitive (weeping milk cap, gypsy mushroom, saffron milk cap,...). These species, that are now well-identified, are picked less. Nevertheless, in October-November 2015, gypsy mushrooms presenting an activity of 460 to 590 Bq/kg fresh weight were picked in the Yamanashi prefecture. Activity measured in wild plants (aralia, koshiabura, ferns..) is also, on the whole, below the measurement thresholds (≈75%). The highest activity measured reaches almost 700 Bq/kg fresh weight in the prefectures of Miyagi and Nagano, almost 400 Bq/kg fresh weight in the Iwate prefecture, and around 300 Bq/kg fresh weight in Fukushima prefecture.

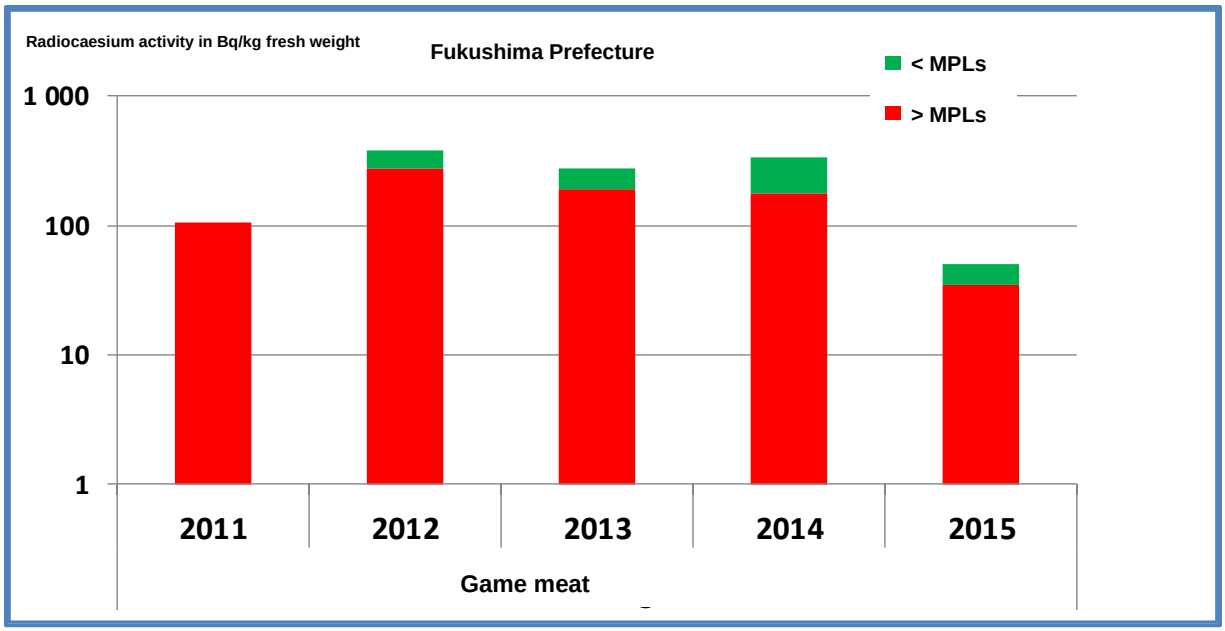

Figure 9: Number of analyses of samples of game meat hunted in the prefecture of Fukushima that are above (respectively below) the marketable limit: 500 Bq/kg for radiocaesium up until March 2012, then 100 Bq/kg.

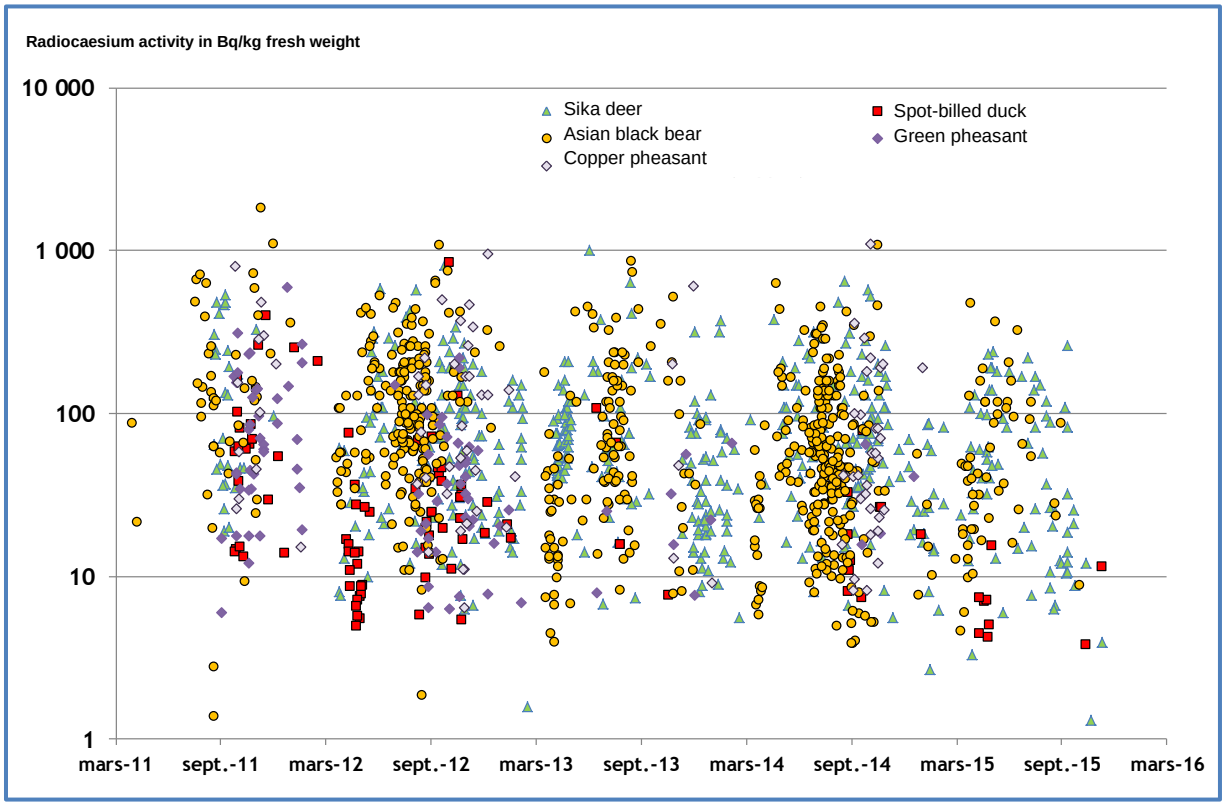

Figure 10: Massic activity in radiocaesium, above the measurement thresholds, measured in samples of game meat from all prefectures.

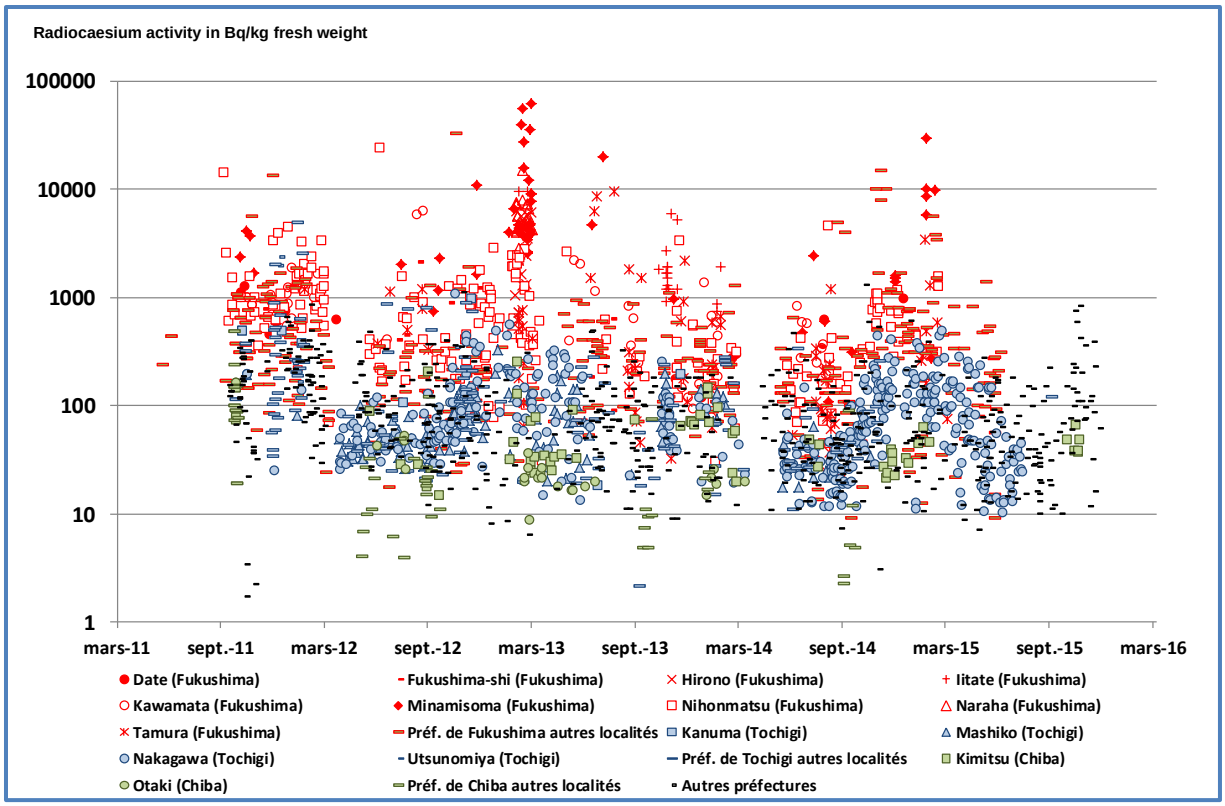

Figure 11: Massic activity in radiocaesium, above the measurement thresholds, in samples of wild boar meat from all prefectures.

Finally, measurements carried out on "shiitakes" demonstrate the efforts made by producers of this mushroom, of which the number of analyses (≈3,000 in 2015) reflects its importance in Japan. As its Japanese name indicates, the shiitake (also known in English as the oak mushroom) grows on wood. In Japan, it is traditionally grown in the undergrowth: cut sections of branches are sown and placed on props. From 2011, its radiocaesium content reached several hundred Bq/kg fresh weight and exceeded 1,000 Bq/kg fresh weight in the Fukushima prefecture (figure 12), notably in the most affected sites of Date, Kawamata, Soma and Kawauchi (figure 13). The year after, probably following specific measures, shiitake contamination fell to around 10 Bq/kg fresh weight at these locations. In 2012, the highest activity was measured in the prefectures of Gunma, Tochigi, Iwate, Miyagi and Chiba, in particular at the sites of Chiba-shi, Ichinoseki and Oshu (figure 13). As was the case the previous year in Fukushima, measures were taken and, since 2013, radiocaesium content at these sites has also been around 10 Bq/kg and up to 100 Bq/kg at other locations within these prefectures. At sites such as Chiba-shi and Futtsu-shi, the radiocaesium content of shiitakes, initially lower, only decreased slightly over the years and, following a slow natural evolution, is today among the highest. During 2015, of almost 3,000 measurements carried out on shiitakes, almost half were below the measurement thresholds (from 1 to 25 Bq/kg fresh weight). Activity measured across all prefectures lies between 1 and 97 Bq/kg fresh weight.

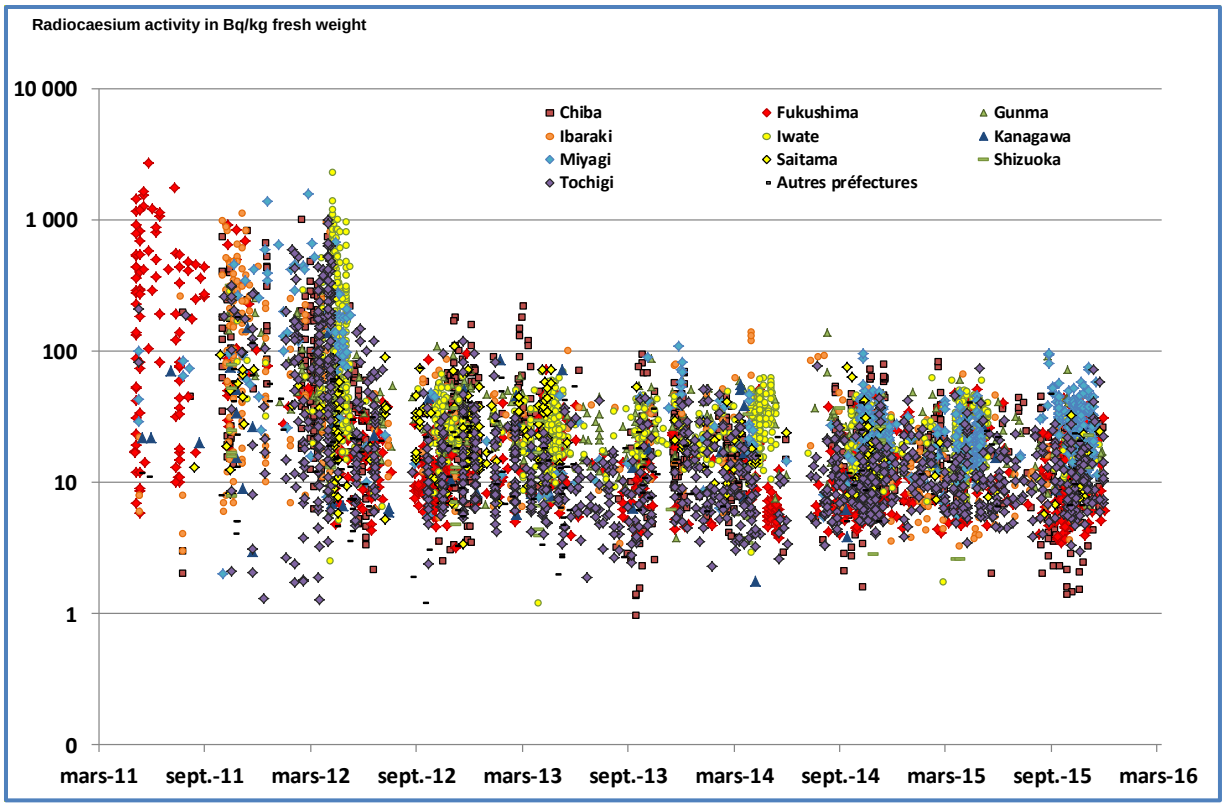

Figure 12: Massic activity in radiocaesium, above the measurement thresholds, in samples of shiitakes from all prefectures.

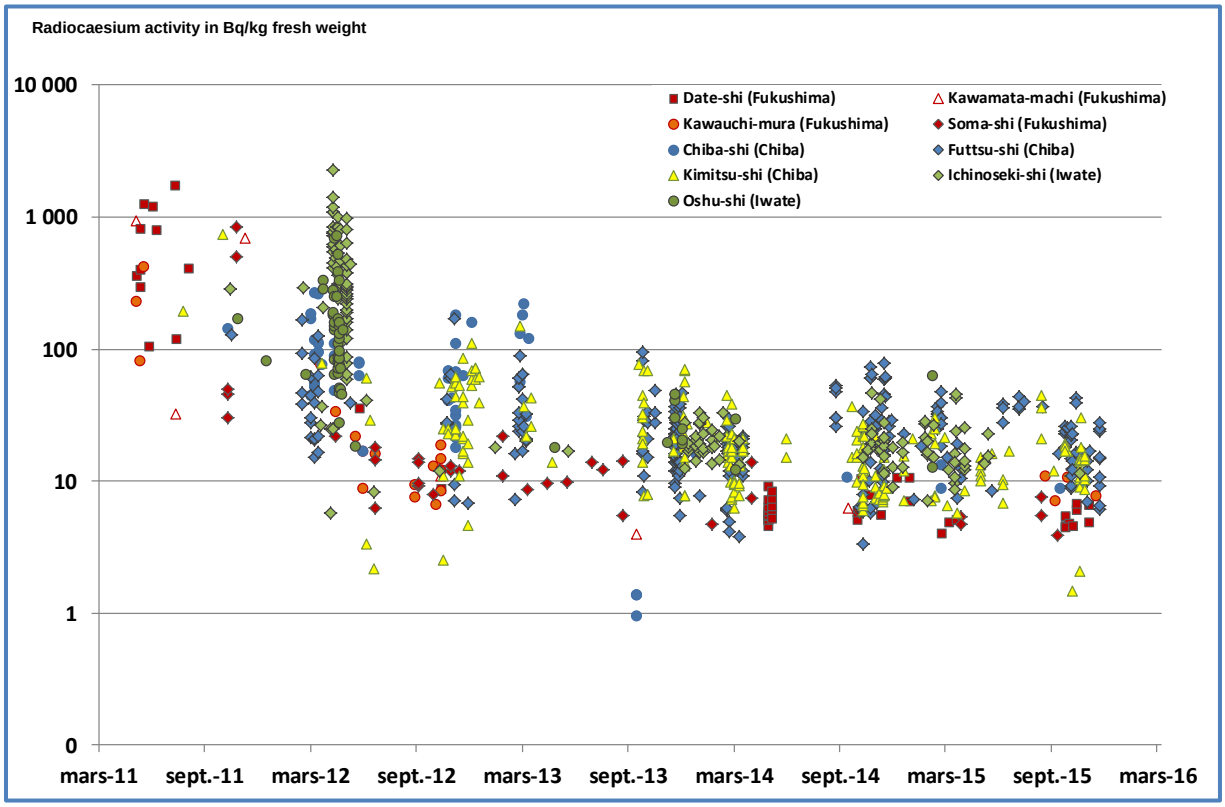

Figure 13: Massic activity in radiocaesium, above the measurement thresholds, in samples of shiitakes from a selection of sites.