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Need for Systematic Statistical Tools for Decision-Making in Radioactively Contaminated Areas

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Although four years have passed since Japan's Fukushima Daiichi Nuclear Power Plant accident in Japan, which resulted from the major earthquake and subsequent tsunami on 11 March 2011, serious problems influencing human livelihoods and well-being remain. Of great concern are the continued restrictions on the distribution of radioactively contaminated foods in Fukushima and other prefectures. The Japanese government has applied a regulatory limit of 100 Bq/kg for radioactive cesium; this limit is very strict for radionuclide content in products and is about four to ten times lower than those in most countries.[1] National and regional Japanese institutions have run extensive food monitoring programs; when samples exceeding the regulatory limit are found, distribution and consumption of the products are banned very quickly.[2] As of December 2015, this monitoring had resulted in ongoing restrictions on the distributions of 78 agricultural food items, 50 fisheries food items, and 25 wild-animal meat items in 14 prefectures. Although the current monitoring program ensures high levels of food safety,[3,4] once a distribution is restricted, that restriction is not canceled quickly, even when further samples testing shows levels below the regulatory limit. This affects the livelihoods of local farmers, fishermen, and others.

A prominent example can be found in the Lake Kasumigaura watershed, approximately 160 km southwest of the Fukushima Daiichi plant, where the distribution of crucian carp (*Carassius auratus*) and Japanese eel (*Anguilla japonica*) —both important fisheries products—was restricted on 14 April and 7 May 2012, respectively (Figure 1). Although the total radiocesium activity (i.e., ^{134}Cs and ^{137}Cs) in crucian carp fell below the regulatory limit at about the beginning of 2013, the restriction on crucian carp distribution was not canceled until 24 March 2015 (Figure 1). Likewise, the current radiocesium level in Japanese eel has fallen substantially below the regulatory limit, but the restriction on distribution has not yet been canceled.

These delayed decisions are not due to poor data; there is a vast database showing long-term trends in radioactivity levels in food products.[3] Instead, one of the main reasons is a lack of statistical tools to support decision-making. The most fundamental requirement for cancellation of distribution restrictions is that monitoring results must fall below the regulatory limit "in a stable manner".[2] There is, however, no scientific or statistical framework for deciding whether this requirement is fulfilled; in current practice, decision-makers are compelled to decide on the basis of whether the samples show levels substantially below half the regulatory limit (i.e., 50 Bq/kg). Thus, there is currently a gap between "the regulatory limit" and "the practically applied limit," leading to unnecessary delays in restriction cancellations.

To bridge the gap, we suggest that systematic statistical tools or frameworks should be used. A method of predicting the probability of samples exceeding the regulatory limit would be practically relevant into helping to decide on when to lift distribution restrictions. In several fields of environmental science, such as water quality and biological monitoring, equivalence (or inequivalence) tests have been applied to evaluate compliance with regulatory criteria.[5] Equivalence tests can be based on a null hypothesis that a parameter estimate is either outside (inequivalence hypothesis) or inside (equivalence hypothesis) an equivalence region. Alternatively, Bayesian or bootstrap methods are more powerful when uncertainty exists in radioactivity concentration dynamics or observation processes. To our knowledge, these statistical approaches have been rarely applied in radioecological research fields. Because any statistical implementation requires deep scientific understanding, interdisciplinary collaboration is needed to develop more relevant tools for addressing the probability of exceeding the regulatory limit. To better support decision-makers or practitioners, the development of simple, flexible and user-friendly statistical tools is also desirable.

We believe that incorporating statistical tools and frameworks into management strategies in radioactively contaminated areas would not only accelerate restoration of the

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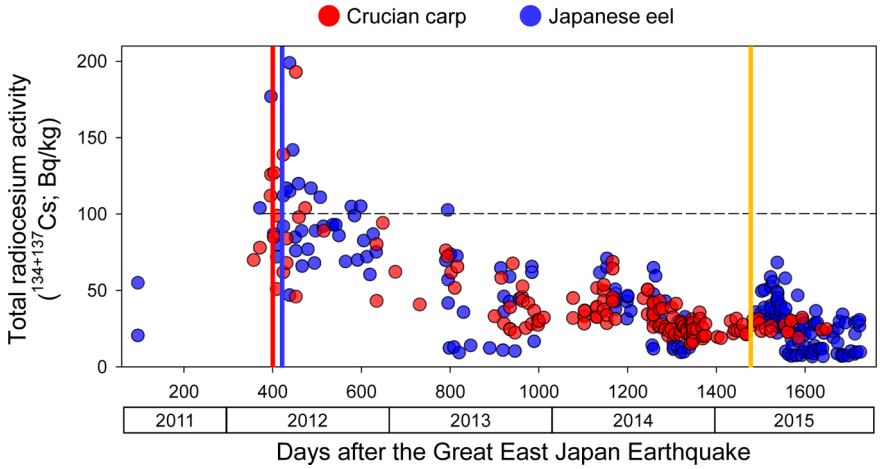

Figure 1. Temporal changes in radiocesium activity in crucian carp and eel in the Lake Kasumigaura watershed. Broken line indicates the regulatory limit. Red and blue lines, dates of implementation of distribution restrictions of crucian carp and eel, respectively; orange line, date of cancellation of distribution restriction of crucian carp.

livelihoods of local farmers, fishermen, and other food producers, but would also improve consumer confidence in the inspection process and safety levels by providing supporting scientific information.

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