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Understanding Fukushima through Butterfly Biology: Academic Freedom for Scientists and the Public

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The impacts of the Great East Japan Earthquake on people living in the Tohoku and Kanto districts and on Japanese society in general were, in many ways, beyond description. The earthquake and the accompanying tsunami destroyed many cities along the east coast of the Tohoku and Kanto districts. However, an additional long-lasting disaster was the nuclear pollution caused by the collapse of the Fukushima Dai-ichi Nuclear Power Plant (NPP). This event was the second worst nuclear accident in the world, next to the Chernobyl accident. At the time of the collapse of the Fukushima Dai-ichi NPP, Japanese government and TEPCO (Tokyo Electric Power Company) could not evacuate people efficiently from the area around the NPP, in part because they did not want to release information on the disaster. From the outset, it appeared that the Japanese government and TEPCO were making every conceivable effort to save the nuclear industry (but not to help people living in Fukushima and vicinity) and to minimize the financial damage and negative publicity resulting from this accident. To achieve their goals, the authorities concealed information that would have put them in a worse position if it had been released. This governmental behavior is not unexpected; similar behavior was seen in the former Soviet Union at the Chernobyl accident. This is understandable in the sense that nuclear policy is strategically sensitive and is involved with making a nation strong militarily and economically. Such restriction of information for political reasons in connection with the governmental alignment with the nuclear industry is, in my opinion, the worst aspect of the use of nuclear energy to produce electricity in any country. Withholding important information hampers the public from making democratic decisions, and it violates the people's right to know and scientists' academic freedom.

When the shock of the Great East Japan Earthquake hit the country, we were studying butterflies "peacefully" at the University of the Ryukyus, Okinawa, Japan. (I wrote "peacefully", but Okinawa is the place where the worst ground battle took place between the United States and Japan during World War II, with a massive number of deaths of Okinawan people. Okinawa was formally under United States control from soon after the end of the war until 1972. Even

now, most US military bases in Japan are located on Okinawa.) One of our favorite butterflies is the pale grass blue, which is the most abundant butterfly in Japan (including Okinawa but excluding Hokkaido). Although I was trained in olfactory neurobiology at Columbia University, New York, I had been interested in butterfly biology as an amateur lepidopterologist and butterfly physiologist since I was a little child. Thus, I have had a strong interest in using Japanese butterflies for molecular physiological studies. Immediately after returning to Japan from the University of Cambridge, U.K., more than a decade ago, I started working on the pale grass blue butterfly at Kanagawa University and then at the University of the Ryukyus.

Originally, I focused on the pale grass blue butterfly from developmental and evolutionary perspectives, i.e., how wing color patterns are determined, constructed, and changed over time, and this is still an important core topic in my laboratory. We have established the standard rearing method for this species. Our methodology was published in 2010, approximately one year before the NPP accident (Hiyama et al., 2010). In this modest but important accomplishment and also in subsequent studies of this butterfly, my student Atsuki Hiyama was a major player. The idea that this butterfly may be useful for environmental monitoring accompanied our previous evolutionary study on this butterfly at the northern margin of its range (Otaki et al., 2010; Hiyama et al., 2012a). Fortunately, this research was appreciated by highly respected and prominent evolutionary biologists (Buckley et al., 2010).

When the Fukushima nuclear accident occurred, I believe that everyone felt deeply sorry for people who lived in highly polluted areas. At the same time, everyone was thinking of ways in which they could help. Shortly after the accident, one graduate student of mine, Chiyo Nohara, felt that she wanted to do something. She and A.H. together discussed the possibility of using the pale grass blue. In a regular lab meeting, they proposed to me that the pale grass blue might be used to examine the possible biological impacts of the Fukushima nuclear accident. I agreed instantly because that was what I had been thinking about and because there seemed to be no technical difficulty associated with this project. The technical problems of rearing the butterfly had already been solved by A.H.. Moreover, active students' proposals based on high motivations are my priority for deciding on research directions in our laboratory. We are not in a research institute, but we are in a university.

As expected, we received a variety of opinions, comments, and advice on this matter from other students in our laboratory and from other professors in our university even before starting this research. Many of them discouraged us. Some worried about us because radioactive materials are hazardous to health. Some worried that our research might annoy people living in the polluted areas, the nuclear power industry, and Japanese government, implying that the research would politically dangerous. However, over and above theses considerations, we were terrified by the pollution itself and by the continuing release of radioactive materials. We are also terrified by the possibility of additional earthquakes and further breaches of the NPP. However, we convinced ourselves that we as scientists should contribute to something that provides biological truth on this issue.

We soon noticed that we had to collect the first-voltine butterflies that will emerge at the beginning of May 2011. Otherwise, we might miss the real impact of the pollution. The first-voltine individuals were overwintering larvae at the time of the collapse. Most surely, they received massive doses externally. In April, larvae eat new leaves for growth. Therefore, they surely ate radioactive materials on the surface of leaves and inside leaves, resulting in internal exposures. They then pupated and eclosed at the beginning of May. We had to catch them!

At that point, I did not know that insects had been characterized as being highly resistant to radiation. A professor who formerly worked at the National Institute of Radiological Sciences advised us that our research plan would be futile, because insects are generally highly resistant to radiation. I thought it over and considered readings on the topic that had been suggested but I came to the conclusion that such a "common sense" conclusion in radiation biology was not supported by solid experimental evidence. As a lepidopterologist, I know that the pale grass blue is quite resilient to environmental stress on the population, but it is also highly sensitive to environmental changes at the individual level. Moreover, if we could not detect anything abnormal after a thorough examination, this would be welcome news for the public because it might mean that the pollution level could be safe, at least for this butterfly.

At that point, we also thought that many ecologists and other biologists in Japan would study the biological impacts of this accident because this issue is probably the single most important one in the Japanese ecosystem. In retrospect, a very limited number of laboratories studied this aspect of the Fukushima nuclear accident. In a sense, this is surprising, but in a different sense, this is not unexpected. Most of us are "professional" scientists who live on a particular research topic defined by a study field. I believe that science should be driven, at least partly, by "social demands for knowledge" *sensu lato*. (People worldwide wanted to know what really occurred in Fukushima.) In short, the Fukushima accident revealed a very discouraging fact; most scientists today in Japan do not care much about their social responsibility except for doing their institutionalized research.

Luckily, another graduate student, Seira Kinjo, agreed with us and joined us to work on this project. We had no financial support, but we at least had sufficient human resources. We made a detailed plan for our fieldwork, which would last for a week. When these three graduate students of mine (A.H., C.N., and S.K.) and I entered the polluted areas to collect butterflies approximately two months after the accident, the overall radioactivity was still very high, and highways were physically wavy in some areas. However, we managed to complete our first mission, which covered Tokyo, Ibaraki Prefecture (Tsukuba, Mito, and Takahagi), Fukushima Prefecture (Iwaki, Hirono, Koriyama, Motomiya, and Fukushima), and Miyagi Prefecture (Shiroishi). We subsequently performed several experiments (i.e., morphological examination of the collected butterflies, morphological and physiological examinations of the next generation of butterflies, an internal exposure experiment, and an external exposure experiment) to show the correlation and causality of the NPP accident in relationship to observations of morphological abnormalities and deaths in the butterfly. These experiments were primarily based on the concept that we would reproduce, in the laboratory, what might have occurred in the field. We have been studying butterfly color pattern evolution with this approach. That is, we have been trying to reproduce evolutionary changes in the laboratory at the phenotypic level using *Vanessa*, *Junonia*, and *Zizeeria* butterflies. We have applied this approach to this case of environmental pollution by radioactive materials. We also completed our second mission in September 2011 to obtain information that would allow the results for May and September 2011 to be compared. We published our results without delay on August 9, 2012 in a new open access journal, *Scientific Reports* (Hiyama et al., 2012b) to allow free access to our article and contribute to the understanding of the biological status of Fukushima. Coincidentally, the date of publication was the anniversary of the A-bomb attack on Nagasaki. (I am originally from Nagasaki.)

Immediately after the publication of this paper, we received a massive number of responses from media, scientists, and the public worldwide. The paper has now 331,433 page views as of March 28, 2015. Some scientists criticized us politely, pointing out some points that we could not

demonstrate in the paper. I appreciate their comments. However, other responses were sharp criticisms that lacked any scientific basis. Most likely, these critics firmly believe that nothing biological should happen because of the Fukushima NPP accident. Some of them appear to have read the paper intelligently and to have understood what wepresented, but they still tried to discredit the paper by offering trivial or non-scientific criticisms. The critics likely followed a program of attacking any suggestions that appeared to oppose ideas about the use of nuclear energy. Because free discussion is the core idea in science, I believe that personal attacks in science are inappropriate. Scientific discussion in this sense requires love of others in addition to love of truth. In other words, open discussion is the heart of science, and such discussion should not be personal or political, at least ideally. Otherwise, open discussion would be impossible. Open discussion on Fukushima seems to be rather difficult now.

Fortunately, we received many appreciations from international media. The BBC was the very first to e-mail me and covered our story, at least on the Internet and worldwide radio. I was particularly surprised to know that a French newspaper, *Le Monde*, and a French popular science magazine, *Science & Vie*, covered our story extensively, given that France is promoting the use of nuclear energy. It was like the experience of a great difference between a fully developed self-governed nation (i.e., France) and an immature nation that is always influenced by other international pressures (i.e., Japan). I simply believe that politics must be built on open knowledge, whether it is for or against nuclear reactors.

At the end of 2012, *Nature* announced its high-scoring papers based on the Altmetrics framework. To our real surprise, our paper was ranked top in the world (Noorden, 2012). I believe that it is a good idea to evaluate papers in terms of multiple aspects, in addition to the conventional impact factors, and in that sense, I welcomed the Altmetric score. In 2013, I presented our results in the Society for Molecular Biology and Evolution in Chicago. *Nature* covered our story in the news section (Callaway, 2013). Above all, we were generously helped and encouraged by some researchers who logically understand our research (e.g., Møller and Mousseau, 2013; Akimoto, 2014).

I note two peculiar aspects of radiation biology. It appears that the basic philosophy of biology is not understood well in this field. (This criticism may only apply to a handful of radiation biologists.) First, in science in general, it is quite difficult to prove “nothing happened”. To prove this proposition, the experimental system should be well defined and investigated thoroughly. Simple failure and rough investigations almost always result in “no results” or “nothing happened”. On the other hand, it is relatively easy to disprove “nothing happened”, because all one has to do is to find anything that happened. Second, there are many simulation studies in radiation biology, and such studies are considered “facts” in this field. In general, biologists are notoriously unconvinced by simulation and other theoretical studies. This is because any simulation may be correct but may be incorrect. That is, any kind of phenomena can be simulated. To be sure, simulations themselves are admissible and often very important, but they should be treated as simulations, not as facts.

Nuclear policy is one of the most important types of policy for any modern nation. The Manhattan Project during World War II was a component of the defense effort against Nazi Germany, and numerous nuclear bombs have been produced since then. The nuclear materials are also intended for “peaceful purposes” to justify the development of the nuclear power technologies. Richard Feynman, who was involved in the Manhattan Project and was a Nobel laureate in physics, has stated in a critical essay that nuclear power plants are just enormous machines for boiling water.

It is well known that Japan is the only nation in history to be attacked with atomic bombs, and Hiroshima and Nagasaki are famous. Officially, Japan cannot have nuclear bombs on its soil due to a constitutional ban. Therefore, the Japanese government has made many efforts to build and maintain nuclear power plants (instead of producing nuclear bombs explicitly) throughout the nation and, furthermore, to advocate the absolute safety of nuclear power, although Japan has frequent earthquakes. In my opinion, Japan has numerous time bombs waiting to go off that will be triggered by earthquakes or volcanic activity in the future. In this sense, the Fukushima Dai-ichi NPP is just the first bomb to be triggered.

In retrospect, we contributed to the knowledge of what really occurred at Fukushima. Our work had the chance to be highlighted because other scientists are so frightened that they ignored the public demand for knowledge. Many more scientists should have become involved in this issue because it was potentially a great accident that might have shaken the entire nation. (Most radioactive materials were dispersed to the Pacific Ocean, and Tokyo was not heavily polluted. We should recognize that Japan was simply lucky; an unlucky situation could have destroyed Tokyo and Japan almost entirely.) Science and technology should not lose the core value that all stems from academic freedom and open discussion. Science should not be used to restrict people's view of life. Rather, science should open up a new world for people.

We are making further progress on this issue now. We responded to comments from all over the world in a correspondence paper (Hiyama et al., 2013). We discussed philosophical aspects of this issue (Taira et al., 2014). We reported how genetic mutants resemble Fukushima aberrations (Iwata et al., 2013). We further evaluated the impacts of ingested radioactive materials for two generations (Nohara et al., 2014a, b). We reported the spatiotemporal dynamics of the impact from 2011 to 2013 (Hiyama et al., 2015). Luckily, we now have a very supportive graduate student from Okinawa, Wataru Taira, who has a good knowledge of butterflies. We also have a few more graduate students, Mayo Iwasaki from Tochigi, Ko Sakauchi from Fukushima, and Masaki Iwata from Miyagi. They are from the Tohoku and Kanto districts. However, I do not know how far we can go in this line of research. We have a very limited financial ability and workforce. University of the Ryukyus was built by the United States when Okinawa was still a part of it, and the University is now one of the local national universities. It seems that the Japanese government is now making a major step toward minimizing the financial ability and academic freedom of local national universities. Please watch us to see how far we can defend academic freedom in Okinawa and Japan in this early phase of the 21st century.

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