

Overview of Open Biodiversity Data around the Fukushima Disaster Area and the Nuclear Power Plants in Japan

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Abstract

Examining the comprehensive impacts of the nuclear accidents in Fukushima on biodiversity continues to be a challenge. Data availability may be one problem. Previous studies have used hardly any ecological data from before the accidents. Furthermore, raw data from the previous studies have been not adequately released for re-analysis and integration into new analyses. To examine the current status and problems with open biodiversity data and monitoring systems related with nuclear plants, we surveyed (1) datasets registered in GBIF (the Global Biodiversity Information Facility) around the Fukushima evacuation zone (including the “difficult to return zone,” Fig. 1) and (2) monitoring sites of the Monitoring Sites 1000 Project and JaLTER (Japan Long-Term Ecological Research Network) around Japan’s nuclear power plants. The GBIF database shows that few datasets on wild organisms exist covering periods both before and after the Fukushima accident around the evacuation zone, except on birds. The present monitoring sites near the nuclear power plants are shown mainly to target wild birds and sites targeting other taxa are limited. In addition, the monitoring surveys have been highly dependent on citizen scientists. To enhance biodiversity data availability in preparation for evaluating impacts of nuclear emergencies, it would be desirable to improve monitoring systems and technologies for integrating monitoring by citizen scientists in normal times with monitoring by scientists belonging to institutes in times of emergency.

Key words : citizen science, ecology, monitoring, nuclear power plant, open science

1. Introduction

The Fukushima Daiichi nuclear power plant (FDNPP) accident in 2011 following the Great East Japan Earthquake and Tsunami resulted in increased radiation levels over a large area owing to radioactive materials released from the FDNPP. Many studies have examined the ecological and biological impacts of that radiation on biodiversity from the genetic to the population level (Tamaoki, 2016; UNSCEAR, 2017). Some studies have suggested remarkable negative effects on wild plants and animals (e.g., Hiyama et al., 2012; Møller et al., 2012, 2013; Akimoto, 2014; Ochiai et al., 2014; Watanabe et al., 2015; Horiguchi et al., 2016), while others have not (e.g., Matsushima et al., 2015; Yoshioka et al., 2015; Okano et al., 2016; Lyons et al., 2020). It is difficult to explain some of the remarkable negative results only from direct radiation dose effects considering the spatial distribution of the air dose in the disaster area (Garnier-Laplace et al., 2011; UNSCEAR, 2017). Wild organisms and environments not only interact with each

other in complicated ways, but can also be affected by interruption of anthropogenic activities as a result of evacuation orders (Yoshioka et al., 2015; Lyons et al., 2020). Although United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (2017) concluded that any radiation effects would have been constrained to a limited area and that the potential for effects on biota beyond that area was insignificant, the long-term impacts of the nuclear disaster on biodiversity and ecosystems remain to be seen.

One difficulty in evaluating the impacts on biodiversity may be limited availability of data. First, studies based on data covering periods both before and after the accident are limited. Murase et al. (2015) compared the data on reproductive performance of the goshawk *Accipiter gentilis* before and after the Fukushima accident and suggested that the reproductive rate was negatively affected by the radiation doses. The study site, however, was more than 100 km from the FDNPP and the air dose rate was quite low (0.27–0.85 μSv/h) compared to the derived consideration reference

level (DCRL) for birds: 0.1–1 mGy/day by International Commission on Radiological Protection (ICRP, 2008). Please note that the air dose rate measured using a dosimeter (TERRA-P, Sparing-Vist Center, Lviv, Ukraine) in Murase *et al.* (2015) was considered to correspond to a gamma-ray dose equivalent rate and we assumed that $1\mu\text{Sv} \div 1\mu\text{Gy}$ (Morishita, 2007). Comparing data around the FDNPP and the evacuation zone before and after the accidents would provide more comprehensive inferences on the direct and indirect effects of the radiation. Although no one desires a nuclear accident, preparation in advance for evaluating the impact is desirable.

The second problem with data availability is openness and transparency of the data. The biological impacts of the nuclear accidents are of interest not only to scientists in multiple fields, but also to citizens. Among scientists, lack of underlying data makes appropriate interpretation difficult (Beresford *et al.*, 2012). Citizens have become skeptical of science and technology as a result of the nuclear accident (Ministry of Education, Culture, Sports, Science and Technology, Japan, 2012). To meet their expectations with limited information, accumulating and sharing raw data in the most open and transparent manner as possible would be helpful. In addition, considering serious nuclear accidents have been relatively infrequent (e.g., the Fukushima accident happened about 25 years after that in Chernobyl.) and the impacts can continue for a long time, contacting corresponding authors of papers on past accidents is not always easy. Sharing data in an open manner (e.g., using data repositories) would be desirable for integrating past data and novel data. Therefore, the concept of open science and citizen science (Silvertown, 2009) would be suitable as a research theme (Fukasawa *et al.*, 2017a).

Out of 20 papers on the biological and ecological impacts of the Fukushima accident that Tamaoki (2016) reviewed, however, only two papers (Murase *et al.*, 2015 and Yoshioka *et al.*, 2015) published the raw data they had used for statistical analysis, which is a basic component of ecological research (Økland, 2007). After 2016, some research groups that had reported remarkable results immediately after the accident published related studies presenting raw analyzed data (Morelli *et al.*, 2017; Hiyama *et al.*, 2017; Akimoto *et al.*, 2018), but that's not always the case (e.g., Hayama *et al.*, 2017; Møller & Mousseau, 2019). Thus, open data has not been a standard assumption under this research theme.

Interdisciplinarity may be one reason open data have been uncommon in this area. Differences in the culture of data sharing and access between different disciplines, and the lack of obvious, public, community repositories can pose a significant barrier to public data deposition (*Nature Research*, 2016). Nevertheless, leading scientific journals are working to improve the situation. *Nature Research* (2019) stated that sharing of data in earth, space

and environmental sciences will be required through data repositories at *Nature* and the related *Nature Research* journal; and *Scientific Data*, a nature research group journal for data papers, will be updating its list of recommended data repositories to help authors from these fields comply with these new policies. This movement may encourage researchers studying environmental impacts of radiation to publish their raw data as well.

As matters stand, there is room for improvement in data availability and openness in research on the biological and ecological impacts of the nuclear accident. To improve the situation from the viewpoint of ecologists, we have published ecological datasets collected inside and around the Fukushima evacuation zone in the form of data papers (Fukasawa *et al.*, 2016; Fukasawa *et al.*, 2017b; Ishiniwa *et al.*, 2019; Yoshioka *et al.*, 2020). Likewise, compiling open data collected in the past regardless of the FDNPP may be useful for evaluating the impact of the accident. Furthermore, current ecological monitoring systems not related to the nuclear disaster could potentially play an important role in evaluating the ecological risks of nuclear accidents in the future. In this paper, we examine open data and related projects regarding the distribution and population dynamics of wild organisms that can potentially play a role in biodiversity monitoring in the event of nuclear accidents via two approaches: (i) datasets collected around the FDNPP and registered in GBIF (the Global Biodiversity Information Facility), which is one of the largest world-wide platforms for open data on biodiversity, are examined, and (ii) monitoring sites around nuclear power plants in Japan and the monitoring targets of the “Monitoring Sites 1000 Project,” a national project for monitoring biodiversity, are examined as indicators of preparation for future emergencies. Based on these results, the characteristics and limitations of data availability on biodiversity data in Japan from the viewpoint of nuclear accidents are discussed.

2. GBIF Data around the FDNPP

GBIF is an international network and research infrastructure funded by governments around the world and aimed at providing anyone, anywhere, open access to data about all types of life on Earth (GBIF, 2020). Through the GBIF website, datasets on biological specimens and species distribution data registered by research institutes and scientists worldwide are available for free. Using the filter function of the website, we extracted datasets within a rectangular area enclosing the evacuation zone of Fukushima registered through June 30, 2020 (Fig. 1, GBIF.org, 2020). The latitudes and longitudes of the corners of the area are (N37.2402°, E140.61826°), (N37.2402°, E141.04526°), (N37.76172°, E141.04526°), (N37.76172°, E140.61826°). Please note that the filter function on the GBIF web site is able to

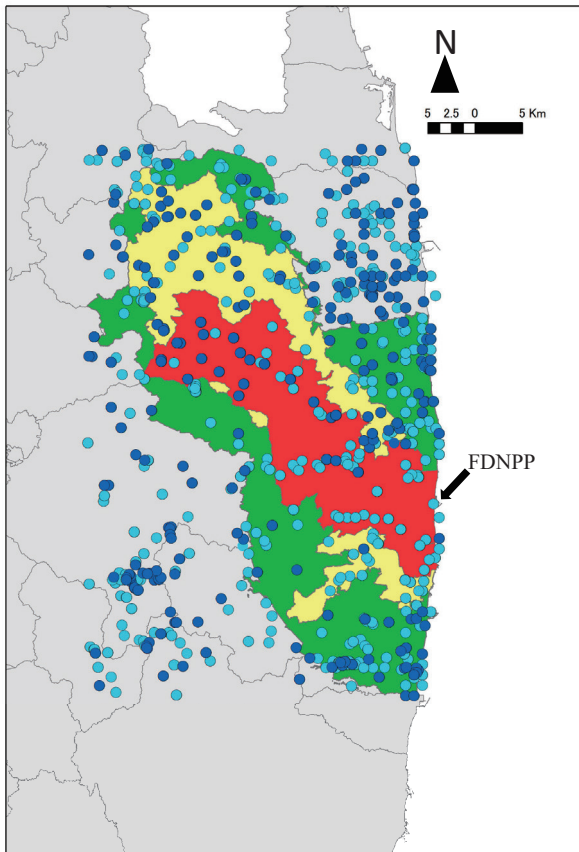


Fig. 1 Spatial distribution of ecological data registered in GBIF (Global Biodiversity Information Facility) near the FDNPP (Fukushima Daiichi nuclear power plant) through 30th June 2020. The sky blue circles and deeper blue circles show locations where the data were obtained before and after 2011, respectively. The latitudes and longitudes of the corners of the data-extracted area are (N37.2402°, E140.61826°), (N37.2402°, E141.04526°), (N37.76172°, E141.04526°) and (N37.76172°, E140.61826°). Please note that GBIF data outside the region were not extracted. The background map was obtained from National Land Numerical Information (Ministry of Land, Infrastructure, Transport and Tourism, 2014). The green, yellow and red zones correspond to the “areas preparing for the lifting of the evacuation order,” “restricted residential areas” and “areas to which it is difficult to return” sub-zones, respectively. The evacuation zone classification was based on conditions in October 2013 (Cabinet Office, Government of Japan, 2013).

extract only simple polygonal regions.

Based on “occurrences” (records of when and where a species existed, used as a unit in GBIF data), 75,556 occurrence records were extracted. Among them, however, 137 records lacked information on the year of sampling. Most of data had been obtained after 2011 (only 2,891 occurrence records had been obtained before 2011, see Fig. 2 also) and consisted of birds (Fig. 3). Actually, a large part of the data set on birds was obtained by NIES (National Institute for Environmental Studies, Japan) for monitoring the evacuation zone starting from 2014 (Fukasawa et al., 2016; Fukasawa et al., 2017b; Fig. 4). Excluding avian and mammalian data sets obtained by NIES for its biodiversity monitoring project after the accident (66,226 and 5,267 records, respectively), the volume of the remaining data decreased to about 5%. The remaining data consisted mainly of data on waterfowl populations and plant specimens (Fig. 3(c)). The waterfowl population data were based on a continuous census conducted by the Ministry of the Environment, Japan, and the abundance data were also published through the national government’s website (Biodiversity Center of Japan, 2020a). Thus, the dataset may give some inferences through ecological analysis. On the other hand, the dataset on plant specimens was obtained in the context of natural history and most of the data had been obtained before the accident. Several assumptions are needed and additional data may be required to analyze the dataset from an ecological viewpoint. The specimen data do not always show that the species were absent or rare in locations where specimens were not recorded. There are some ecological analysis methods for presence-only data such as Maxent (Phillips et al., 2006), so inferences of the results should be carefully conducted. Results of such an analysis will be biased due to spatial heterogeneity of the monitoring effort. Anyway, the taxa in the species distribution data available from GBIF are highly biased toward birds as matters stand. In particular, data before the nuclear accident are limited conspicuously.

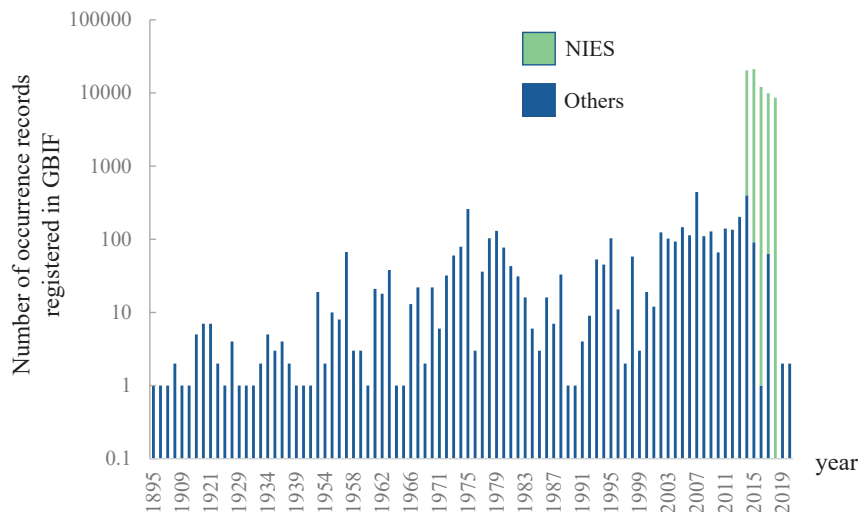


Fig. 2 Number of GBIF occurrence records registered by NIES (National Institute for Environmental Studies, Japan) and other institutes near the FDNPP per year as of 30 June 2020.

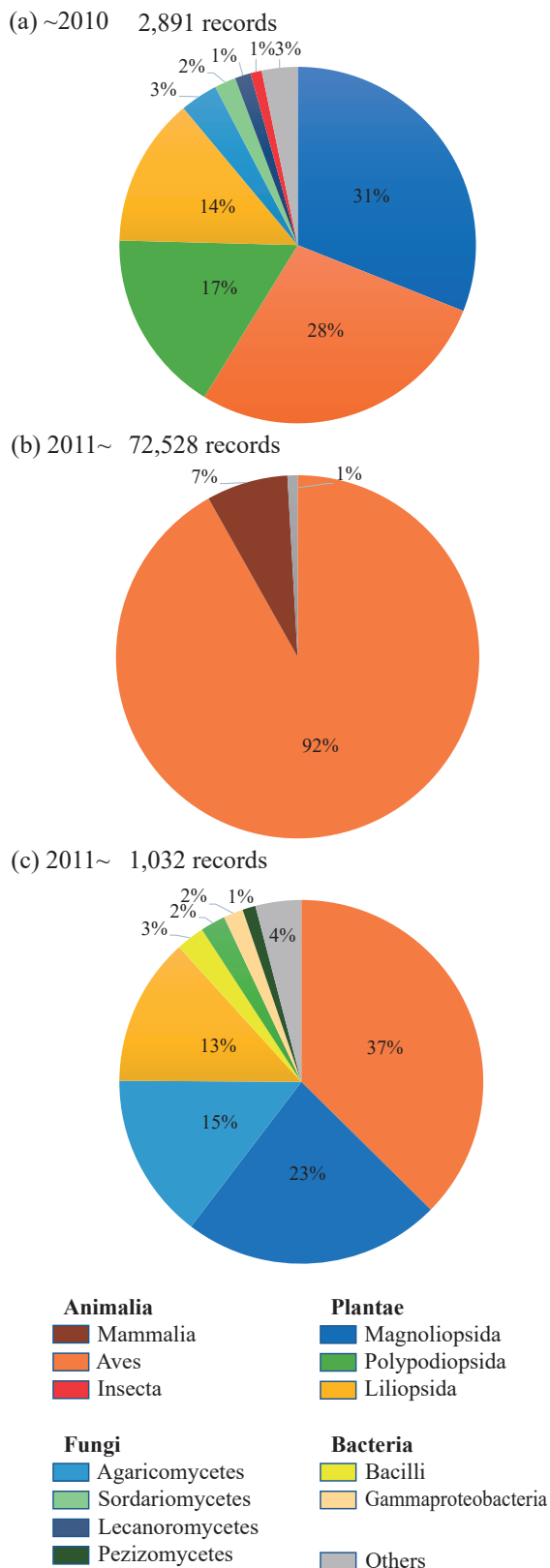


Fig. 3 Proportions of GBIF occurrence records of each taxon (class) near the FDNPP (a) through 2010, and (b) from 2011. Occurrence records from 2011 other than datasets from NIES (Aves: 66,226 records, Mammalia: 5,267 records, Insecta: three records, respectively) are also shown (c). In each graph, taxa accounting for less than 1% are summed under “Others.”

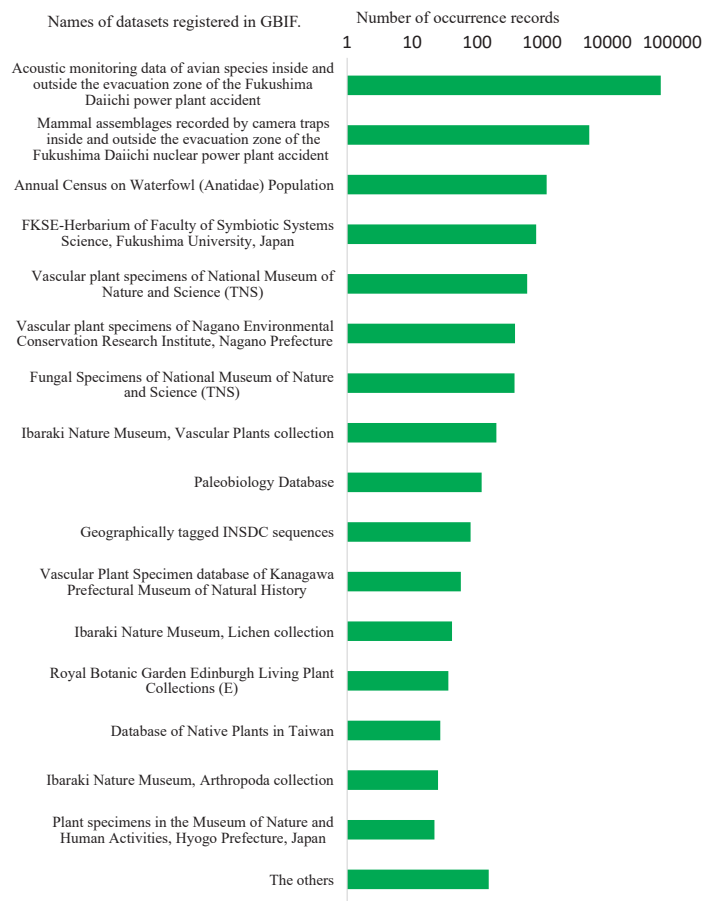


Fig. 4 Names of datasets containing GBIF data near the FDNPP and numbers of occurrence records included. The first and second largest dataset correspond to data published by Fukasawa *et al.* (2017b) and Fukasawa *et al.* (2016), respectively.

3. Ecological Monitoring Sites around the Nuclear Plants in Japan

Including decommissioned plants such as the FDNPP, there are 17 nuclear plant location points in Japan as of 2020 (Table 1). Although no nuclear accident should ever happen again, the existing biodiversity monitoring systems around the nuclear power plants are expected to be useful in evaluating the status of biodiversity and ecosystems at normal times and the data from them to contribute to analysis of changes in status if nuclear emergencies should happen.

The Monitoring Sites 1000 Project is a long-term nationwide project for monitoring biodiversity and ecosystems that has been conducted by the Ministry of the Environment, Japan since 2003 (Watanabe *et al.*, 2012; Kobori *et al.*, 2015). To cover Japan's wide variety of ecosystems, the monitoring data are collected not only by scientists belonging to research institutes, but also trained citizen scientists associated with the Wild Bird Society of Japan and the NACS-J (Biodiversity Center of Japan, 2019, 2020b). In long-term and broad-area biodiversity monitoring projects, citizens' cooperation has often

Table 1 The existing nuclear power plants in Japan (including decommissioned plants) and “Monitoring Sites 1000 Project” sites, important for monitoring the current status of the ecosystems around the nuclear plants. The terrestrial area within 30 km of each nuclear power plant is based on Ministry of Land, Infrastructure, Transport and Tourism, Japan (2014) and calculated using ArcGIS 10.2 (ESRI Inc.). The land area of Japan overall is based on Geospatial Information Authority of Japan (2020).

Nuclear power plant	Prefecture	Monitoring Sites 1000 within 20km (focal ecosystem)	Monitoring Sites 1000 within 20–30km (focal ecosystem)	The number of sites per terrestrial area within 30 km (sites/km ²)
Tomari	Hokkaido	n.a.	Nakoma (rural area)	5.26×10^{-4}
Higashidori	Aomori	n.a.	Mutsuyokohama (forest and grassland)	6.82×10^{-3}
			North coast of Shimokita peninsula (lake and wetland)	
			Obuchinuma (lake and wetland)	
			North part of Mutsu bay (lake and wetland)	
			Takasegawa-Mutsuogawara port (tidal flat)	
			Bentenjima (small islet)	
Onagawa	Miyagi	Ashijima (small islet)	Monomiishiyama forest road (forest and grassland)	6.40×10^{-3}
			Downstream of Kyu-Kitakami River (forest and grassland)	
			Haden-ya (rural area)	
			Shizugawa (seaweed bed)	
Fukushima Daiichi	Fukushima	n.a.	Hirusone-Ohatake forest road (forest and grassland)	7.19×10^{-4}
Fukushima Daini	Fukushima	n.a.	Hirusone-Ohatake forest road (forest and grassland)	1.44×10^{-3}
			Estuary of Natsui River (tidal flat)	
Tokai & Tokai Daini	Ibaraki	Nomekawahama (rural area)	Tanodairasandou (forest and grassland)	2.59×10^{-3}
		Ibaraki-kenminnomori (forest and grassland)	Hinuma (lake and wetland)	
Kashiwazaki Kariwa	Niigata	Koshijihara hill (rural area)	Tsukioka forest road (forest and grassland)	1.96×10^{-3}
		Kashiwazaki-yumenomori park (rural area)		
Shiga	Ishikawa	Besshodake (forest and grassland)	Tokinofurusato-Notomaruyama (rural area)	3.28×10^{-3}
		Ochigata (lake and wetland)	Chirihama (tidal flat)	
Tsuruga	Fukui	Nosaka-ikoinomori (forest and grassland)	Sanriyama (forest and grassland)	1.83×10^{-3}
			Kuroko forest road for Mikuniyama (forest and grassland)	
Mihama	Fukui	Nosaka-ikoinomori (forest and grassland)	Kuroko forest road for Mikuniyama (forest and grassland)	1.33×10^{-3}
Ohi	Fukui	n.a.	Ashiu (forest and grassland)	2.06×10^{-3}
			Ashiukamitani (forest and grassland)	
			Kanmurijima & Kutsujima (small islet)	
Takahama	Fukui	Kanmurijima & Kutsujima (small islet)	Ashiu (forest and grassland)	1.31×10^{-3}
Hamaoka	Shizuoka	Ogasayama (forest and grassland)	Oigawachofujimori-Yaizushitajiri (tidal flat)	4.35×10^{-3}
		Omaezaki coast (sandy shore)		
		Sagara coast (sandy shore)		
Shimane	Shimane	Lake Nakaumi (lake and wetland)	Hoshikamiyama (forest and grassland)	4.55×10^{-3}
		Lake Shinji (lake and wetland)	Esturay of Iinashi River (tidal flat)	
		Esturay of Hii River (lake and wetland)		
		Sada River (tidal flat)		
Ikata	Ehime	Suwazaki-shizenkyuorin (forest and grassland)	Dogadani-tonbonosato (rural area)	3.79×10^{-3}
		Sanctuary-donguri (rural area)		
Genkai	Saga	n.a.	Ochi (forest and grassland)	9.96×10^{-4}
Sendai	Kagoshima	Shibisan (forest and grassland)	Urushinosatoyama (rural area)	1.65×10^{-3}
Mean $\pm$ SD				$2.68 \times 10^{-3} \pm 1.90 \times 10^{-3}$
Number of sites in Japan (24 June 2020)				1,014
Land area of Japan overall (sites/km ²)				377,975.21
Density of monitoring sites in Japan (sites/km ²)				2.68×10^{-3}

played quite an important role (Silvertown, 2009; Bonney et al., 2009). The compiled dataset has been available from the project’s website and partly from the GBIF website, though some parts of the dataset are closed (e.g., data on species at risk from poaching and over-exploitation). Because this project aims to detect degradation of ecosystems at early stages through long-term continuous monitoring, the dataset is expected to contribute to evaluation of the state of biodiversity around nuclear plants now and in the future.

Here, we examine the spatial distribution of the monitoring sites (Fig. 5; Table 1; Table 2) based on the project’s website (Monitoring Site 1000 Project, 2020). We extracted the geographic coordinates of the

representative points of each monitoring site from the list on the website and examined whether the monitoring sites were included within a 20-km radius of a nuclear power plant using ArcGIS 10.2 (ESRI Inc.). The geographic coordinates of nuclear power plants were obtained from the National Land Numerical Information (Ministry of Land, Infrastructure, Transport and Tourism, 2013). We adopted the distance of 20 km here because the area within the 20 km of the FDNPP was declared a temporary evacuation zone in Fukushima when information on the spatial distribution of air radiation doses was inadequate. Considering that the values of coordinates of the monitoring sites on the website were relatively rough (about 0.01–0.1 degrees), we also

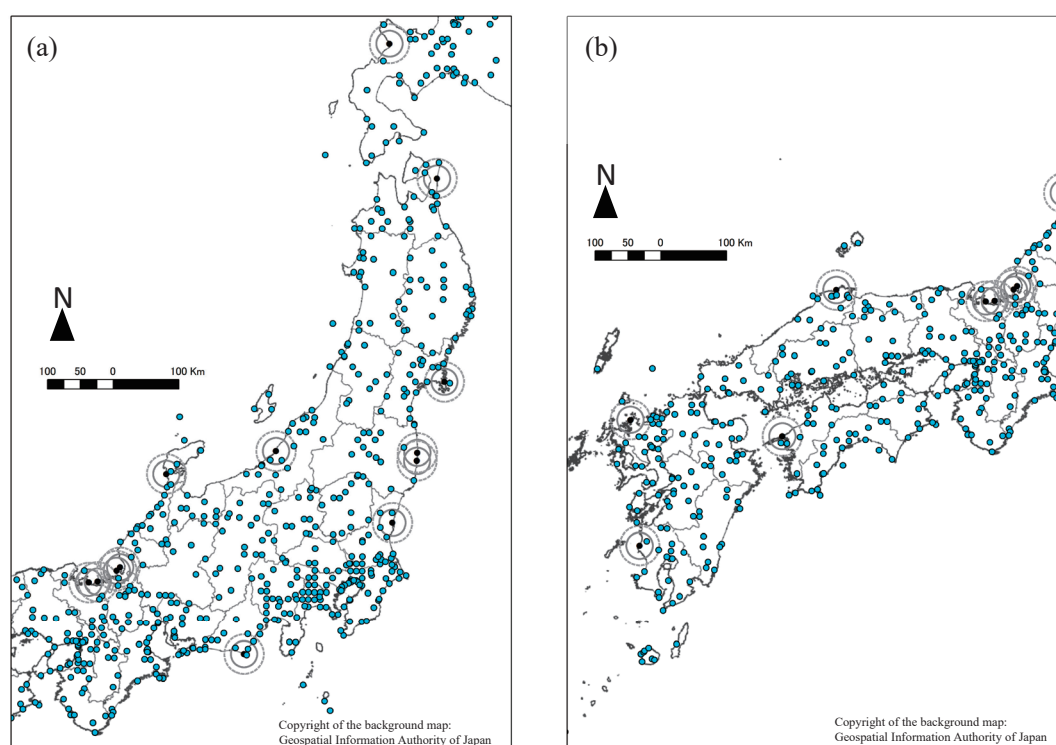


Fig. 5 Spatial distribution of the monitoring points of the Monitoring Sites 1000 Project and nuclear power plants in the (a) eastern and (b) western part of Japan, respectively. The blue points indicate representative points of each monitoring site. The black points indicate nuclear power plants. The circles of solid and dotted grey lines indicate the areas within a 20 km and 30 km radius from the nuclear plant, respectively.

Table 2 Relationships between focal ecosystems and monitoring targets (surveyed indicators) in the Monitoring Sites 1000 Projects. Please note that only cases within 30 km of a nuclear plant are shown.

Focal ecosystem	Monitoring target	Remarks
Forest and grassland	Terrestrial birds, Vegetation	In addition, ground-dwelling beetles, litter and tree growth have also been surveyed in “Ashiu,” which is one of the core sites for forest monitoring. Targeting indicators of traditional agricultural landscapes in Japan, the so called “ <i>satoyama</i> .” Usually, more than one from the nine targets is surveyed by citizen scientists (see Table 3). In the core sites, multiple indicators are surveyed (only the “Urushinosatoyama” site in Kagoshima Pref. is a core site for rural area monitoring within 30 km of a nuclear power plant).
Rural area	Flora	
	Water environment	
	Vegetation (Anthropogenic impacts)	
	Birds	
	Large-middle size mammals	
Lake and wetland	Harvest mouse <i>Micromys minutus</i>	At “Shinjiko” and “Nakaumi,” plankton, benthos and vegetation have been surveyed. At the other sites within 30 km of a nuclear plant, waterfowl has been surveyed.
	Frogs	
	Butterflies	
	Fireflies	
	Waterfowl	
	Plankton, Benthos, Vegetation	
Sandy shore	Turtles	
Tidal flat	Shorebirds	
Seaweed bed	Seaweed vegetation, Benthos	
Small islet	Seabirds	

examined areas within 30 km of each nuclear power plant as a buffer. In addition, areas 30 km from nuclear power plants usually correspond to “Urgent Protective Action Planning Zones” based on Japan’s Nuclear Emergency Response Guidelines (Nuclear Regulation Authority, 2019), in which precautionary sheltering and emergency monitoring of environmental radiation levels are required under nuclear emergency situations.

As a result, all nuclear power plants in Japan (including decommissioned plants) are located within

30 km of one or another of the monitoring sites, though six of the 17 nuclear power plants have no corresponding monitoring sites within 20 km. In particular, the number of monitoring sites in Hokkaido and Kyushu (Saga and Kagoshima prefectures) is likely to be small. The number of the monitoring sites near the nuclear power plants in Fukushima Prefecture is also small (three sites in total within 30 km). However, the mean density of sites within the 30 km zone (site number per terrestrial area) was 2.68×10^{-3} sites/km², almost equivalent to the site number

Table 3 Monitoring targets of rural (*satoyama*) sites of the Monitoring Sites 1000 Project near nuclear power plants, based on Biodiversity Center of Japan (2019).

Monitoring sites	Flora	Water environment	Vegetation	Birds	Large-middle size mammals	Harvest mouse	Frogs	Butterflies	Fireflies
Nakoma	○			○					
Haden-ya	○		○	○	○		○		○
Namekawahama	○	○	○	○					
Koshijihara hill	○		○	○					○
Kashiwazaki-yumenomori park	○			○					
Tokinofurusato-Notomaruyama	○						○		○
Sanctuary-donguri	○		○	○	○			○	○
Dogadani-tonbonosato		○					○		
Urushinosatoyama	○			○	○		○		○

per land area of Japan overall (Table 1).

Considering focal ecosystems and monitoring targets, most sites have targeted birds (Tables 1 and 2). In addition, these bird monitoring surveys have been conducted by citizen scientists. Therefore, citizen science is essential to monitoring the current status of biodiversity and ecosystems around nuclear plants. Sites surveying taxa other than birds are quite scarce. Although the sites focusing on rural areas (so-called *satoyama*, a traditional heterogeneous agricultural landscape of Japan; Takeuchi, 2001; Kadoya & Washitani, 2011) have mainly surveyed flora as well as birds, the total number of these sites is less than 10 (Table 3). There are even fewer sites surveying mammals, frogs or insects.

Furthermore, we also examined JaLTER (Japan Long-Term Ecological Research Network) monitoring sites near the nuclear plants. JaLTER was established in November 2006 to provide scientific knowledge contributing to conservation, advancement and sustainability of the environment, ecosystem services, productivity and biodiversity for society by conducting long-term and interdisciplinary research in ecological science including human dimensions (JaLTER, 2020a). This scientific network became an official member of the ILTER (International Long-Term Ecological Research) project (Ohte et al., 2012), which along with GBIF plays an important role in ecological data archiving (Osawa et al., 2013). Monitoring of the sites has been mainly conducted by scientists belonging to research institutes (JaLTER, 2020b) and the datasets have been available from a database called JaLTER Metacat (JaLTER, 2020c). The 61 representative points of the JaLTER sites were extracted from a Google Maps map. The Ashiu Forest Research Station was located within 30 km of the Oi nuclear power plant, while the Maizuru Fisheries Research Station was located within 20 km of the Takahama nuclear power plant and within 30 km of the Oi nuclear power plant. The Lake Shinji and Lake Nakaumi sites were located within 20 km of the Shimane nuclear plant. The locations and associated institutes of the JaLTER site in Ashiu, Lake Shinji and Lake Nakaumi overlapped to some extent with the sites of the Monitoring Sites 1000 Project. Therefore, JaLTER's sites

may not adequately complement the Monitoring Site 1000 Project's.

4. Discussion

In this study, we have obtained an overview of the ecological monitoring data/sites around Japan's nuclear plants that could play an important role owing to their availability. The results suggest that datasets on bird dynamics are relatively abundant, while datasets on other taxa are inadequate. In addition, the datasets on birds have been collected by not only researchers, but also citizen scientists from NGOs such as the Wild Bird Society of Japan and NACS-J (Biodiversity Center of Japan, 2019, 2020b), though research institutes such as NIES play an important role in publishing data around the Fukushima evacuation zone. The waterfowl census data conducted by the Ministry of the Environment, Japan and registered in GBIF have also been based on considerable cooperation from environmental organizations such as the Wild Bird Society of Japan (Ministry of the Environment, Japan, 2020a). Therefore, availability of open biodiversity data is highly dependent on taxa, and interest among citizens will be important.

The caveat here is that our overview is not a complete review of open biodiversity datasets near nuclear power plants. We may have overlooked other freely available ecological datasets and long-term monitoring sites which were not registered in GBIF or the Monitoring Sites 1000 Projects, respectively. In addition, the datasets from these projects cannot cover certain types of biodiversity components. For example, detailed information on endangered species has usually not been released by these projects to avoid poaching and overexploitation. In addition, data based on hunting and fishing (i.e., economically important data) which have been compiled by national or local governments (or related organizations) are often not released. Some databases have been released, but not adequately integrated into these world-wide projects (e.g., Ministry of Land, Infrastructure, Transport and Tourism, 2007). Furthermore, it goes without saying that the biodiversity datasets and monitoring sites have not usually conducted

surveys assuming nuclear accidents. Data and samples on internal exposure or mutation have not been monitored, though part of the data followed by preserved samples or specimens may make it possible to examine these biological effects later. Nevertheless, the biodiversity status should be rapidly assessed in emergent situations and easily available datasets representing normal situations will be required for comparison. GBIF and the Monitoring Sites 1000 Project are convenient and readily accessible to researchers and citizens. The open data provided by them will be important for rapid assessment of the status and dynamics of biodiversity.

From the viewpoint of improving preparation for future emergencies, what is needed is not only to maintain the current monitoring system, but also to provide a system for encouraging surveys of taxa diversity. Of course, the available manpower is usually limited, so indicator taxa should be well considered. If monitoring taxa other than birds is difficult, we should know how birds, which have often been assumed to be a good indicator of biodiversity (Greenwood, 2007), indicate or surrogate the status of other taxa in the event of nuclear accidents. Promoting registration of long-term data collected by local governments to GBIF or other available platforms may relieve the bias in monitored taxa in open biodiversity data. In principal, construction of nuclear power plants must accompany environmental surveys based on the Environmental Impact Assessment Act and the data associated with surrounding biodiversity should have been collected, though only summarized results were published for a limited period of time under the current system (Ministry of the Environment, 2020b). Furthermore, as our review shows, enhancing and maintaining participation of citizen scientists in ecological monitoring will be essential. The problem is that if a nuclear disaster happens, the citizens will not be able to collect data around the nuclear plants as before the accident. Therefore, methodology for follow-up of citizen scientists by scientists belonging to research institutes will also be important. In the case of the Fukushima accident, NIES has been conducting acoustic bird surveys using voice recorders and has set up opportunities to share their recordings of bird songs with local bird watchers (Fukasawa *et al.*, 2017a). To prepare for future nuclear emergencies (or other disasters with movement restricted long term) appropriately and sustainably, a hybrid of surveys by citizen scientists and automated digital devices may be key. Ideally, a scheme that integrates monitoring by citizen scientists in normal times and that by scientists belonging to institutes in emergency times should be established from the viewpoint of both technologies and systems.

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