Chapter 7
Environmental Monitoring with Indicator Plants for Air Pollutants in Asia

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Abstract Air pollution is a regional issue in Asia. To assess air pollution levels and their actual impacts on plants, environmental monitoring using indicator plants has been conducted since the 1970s. In particular, in Japan, during the 1970s/1980s when air pollution levels were relatively high, various kinds of indicator plants were used for monitoring air pollution. Some vascular plants, such as morning glory and petunia, were used as indicator plants for monitoring the pollution of photochemical oxidants (Ox), including O_3 and peroxyacetyl nitrate (PAN). In the middle of the 1970s, nationwide surveys using morning glory revealed Ox pollution in 37 of the 47 prefectures in Japan. Epiphytes, such as bryophytes and lichens, were used as bio-indicators for SO_2 pollution. The "epiphyte desert" observed in urban and industrial areas showed severe SO_2 pollution in large cities in Japan during the 1970s. An improvement in the distribution of epiphytes resulted in reduced SO_2 pollution in Japan during the 1980s. Similar environmental monitoring using bryophytes and lichens as bio-indicators was conducted in other Asian countries. Common tree species, such as cedar, can also be used as indicator plants for environmental monitoring. Further application of such monitoring in Asian countries should be promoted.

Keywords Morning glory • Petunia • Bryophyte • Lichen • Cedar

7.1 Introduction

Air pollution is a regional issue in Asia because the emission levels of various pollutants remain high in the region. According to Ohara et al. (2007), emissions increased rapidly from 1980 to 2003, by 28 % for black carbon (BC), 30 % for organic carbon (OC), 108 % for non-methane volatile organic compounds (NMVOCs), 119 % for sulfur dioxide (SO_2), and 176 % for nitrogen oxides (NO_X).

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Although the emission of SO_2 in China peaked in 2006 before declining thereafter, the emissions of BC and OC were still increasing as of 2010 (Lu et al. 2011). Air pollution, as well as being a human health issue, is a serious threat to plants in Asia.

Many cases of environmental pollution in the past were discovered due to abnormal changes in trees and crops near smelters, thermal power plants, and oil petrochemical complexes (Kuno and Ohashi 1993a). Moreover, some types of plants are very sensitive to environmental changes, including air pollution. Therefore, air pollution monitoring using indicator plants (or bio-indicators), such as some sensitive vascular plants, bryophytes, and lichens, has been utilized to evaluate pollution levels and/or actual impacts on plants. This chapter introduces the past and current issues related to the application of indicator plants for monitoring air pollutants.

7.2 Japanese Experience in the Application of Indicator Plants

SO_2 emissions in Japan significantly increased during the 1950s/1960s with rapid industrialization, peaked in 1969, and then rapidly decreased, according to the emissions inventory performed by Smith et al. (2011). In Japan, the Basic Law for Environmental Pollution Control and the Air Pollution Control Law were enacted in 1967 and 1968, respectively. Environmental quality standards (EQSs) were also established based on these laws, although damage to humans and plants by photochemical oxidants was still being reported in the Tokyo metropolitan area during the summer of 1970. Concentrations of primary pollutants, such as SO_2 and CO, rapidly decreased during the 1970s/1980s after the implementation of regulations for the total pollution loads of SO_X and NO_X in 1974 and 1981, respectively. However, emissions of NO_2 and photochemical oxidants (Ox) remained steady (Wakamatsu et al. 2013). In the 1970s/1980s, when the air concentrations of pollutants were still relatively high, various kinds of indicator plants were used for monitoring air pollution in Japan.

Kuno and Ohashi (1993a) reviewed indicator plants used for air pollution assessments and classified the methods of application of indicator plants into four categories:

1. Use of native/living plants in target areas: e.g., spatial distribution of tree decline symptoms, foliar discoloration, and other indicators in relation to air pollutant concentrations. Chemical analysis of pollutants absorbed in plant bodies and tree-ring analysis are also useful to assess chronic or long-term effects of air pollutants.
2. Replacement of indicator plants in target areas: e.g., visible foliar injuries to sensitive plants are compared in various locations.
3. Use of (open-top) chambers: e.g., in addition to visible foliar injuries, suppression of growth and yield reduction can be evaluated using filtered and non-filtered chambers.

4. Observations of the succession of plant groups: e.g., the species composition or density of mosses is examined in relation to air pollutant concentrations and then succession can be discussed to assess the long-term effects of air pollution.

Kuno and Ohashi (1993a) compiled data on the sensitivity of plant species to Ox, such as O_3 and peroxyacetyl nitrate (PAN); Japanese morning glory, petunia, tobacco, spinach, chickweed, kidney bean, and rice were listed as the plants most sensitive to Ox. These plants were injured by daily maximum values of approximately 80–100 ppb, although the sensitivities were different in various cultivars even within the same plant species. Many authors (e.g. Hatta and Terakado 1975; Nouchi and Aoki 1979) have reported morning glory (*Pharbitis nil* var Scarlett O'Hara) as a useful indicator plant for Ox. The review by Kuno and Ohashi (1993b), based on nationwide surveys conducted from 1974 to 1976, reported that visible foliar injuries to morning glory were observed in 37 of the 47prefectures of Japan. In addition, high concentrations of Ox above the EQS levels (60 ppb for 1-h value) were suggested in these prefectures. As for petunia, which is sensitive to PAN, Nouchi et al. (1984) reported that the percentage of visible foliar injuries in a sensitive cultivar (White ensign) escalated with an increase in the daily maximum concentration or daily dose of PAN. This finding was based on surveys conducted in Yurakucho, Tokyo, from 1976 to 1983. By using both the sensitive (White ensign) and tolerant (Blue ensign) cultivars, Nouchi et al. (1984) clarified that PAN pollution occurred at five representative locations (Ohme, Yohga, Shakujii, Yurakucho, and Adachi) in Tokyo in the late spring and autumn in 1982 and 1983. They also pointed out that cultivars with different sensitivities would be useful to estimate concentration levels of PAN. The national/regional assessments of air pollution discussed above were conducted by placing indicator plants in target areas and observing visible foliar injuries that were classified as category (2) above.

As for category (3), Izuta et al. (1988) studied the effects of ambient air on the growth of radish (*Raphanus sativus* L. cv. Comet) in Tokyo by using small open-top chambers. Their studies verified that the leaf area of cotyledons could be used as an indicator for the effects of O_3. Other studies using open-top chambers are introduced in other chapters of this book. In addition to higher plants, bryophytes are also used for the chamber method, since bryophytes, such as mosses, are sensitive to air pollution. Taoda (1973) developed a pair of filtered/non-filtered small open-top chambers using bryophytes and named the instrument the "bryo-meter". According to the study of an application of the "bryo-meter" using a moss species (*Marchantia polymorpha*) around the Kashima industrial district carried out by Yokobori (1978), the phytotoxicity, based on the growth rate of the bryophyte, was severe in the leeward direction from pollution sources. This finding corresponded to findings on the concentrations of air pollutants such as SO_2 and Ox. Shimizu et al. (1988) improved the bryo-meter system and used a different moss species (*Plagiomnium maximoviczii* (Lindb.) Kop.). They suggested that the species were sensitive to mixed gaseous pollutants, including 0.05 ppm of SO_2, 0.1 ppm of NO_2, and 0.07 ppm of O_3, and they noted that the system could be used for assessing atmospheric environments in urban areas of Japan.

As for categories (1) and (4) above, the following sections introduce the relevant studies in detail.

7.3 Bryophyte and Lichen Communities

Bryophytes have historically been used as indicator plants for air pollution in Japan. Taoda (1972) used epiphytic bryophytes on broad-leaved trees for assessing air pollution in Tokyo. He found an "epiphyte desert", in which no epiphytic bryophyte was observed in industrial areas around Tokyo Bay where SO_2 concentrations were over 0.05 ppm. He also pointed out that the Tokyo metropolitan area could be classified into five zones based on the number of bryophyte species that increased with the decline of SO_2 concentration levels. On the other hand, Taoda (1996) examined the effects of simulated acid rain on epiphytic bryophytes and reported that no correlation was found between distribution patterns of the species in the polluted area of Tokyo and tolerance to the acidity of the simulated rainwater. Mitsugi et al. (1978) used the Index of Atmospheric Purity (IAP: De Sloover and LeBlanc 1968), which was calculated from the frequency, coverage, density, and fertility of epiphytic bryophyte and lichen species, for assessing air pollution in Hyogo Prefecture, in the Kansai region of Japan. Multiple regression analysis showed that the combined effects of SO_2 and the soluble components of rainwater explained the IAP values. In their study, concentrations of heavy metals, such as Cu^{2+} and Mn^{2+}, had significant effects on the IAP values (Mitsugi et al. 1978). Mitsugi (1994) developed another index, the Evaluation Index of Air Quality (EIAQ), based on the number of epiphytic bryophyte species and their dominance scale. He classified the area of Hyogo prefecture into five zones, from Zone 0 (highly disturbed zone: epiphyte desert) around Kobe city along the Seto Inland Sea to Zone IV (undisturbed zone) in 1988; most of the area was classified as Zone III (quasi-normal zone). He also pointed out that the EIAQ values were better than those in 1975/1976 due to the reduction of SO_2 (and probably Ox) concentrations, especially in the industrial area near the sea. Omura and Murata (1984) assessed improvements in air pollution levels from 1978/1979 to 1982 by using modified IAP values (IAP*) in industrial areas in Fukuoka prefecture. They reported that the IAP* values were generally larger in 1982 than in 1978/1979, a finding which corresponded well to the reduction of SO_2 concentrations during that period. Thus, environmental monitoring using epiphytic bryophytes (and lichens) showed improvements in air pollution in the industrial areas of Hyogo and Fukuoka prefectures. Umezu (1978) applied the Braun-Blanquet method, based on phytosociology, to identify associations of epiphytic bryophytes and lichens in the industrial area around Ube city in Yamaguchi Prefecture. They classified the area into five zones according to the normal environmental degree, based on the species composition and their richness, which corresponded well to SO_2 concentrations.

As shown in the studies above, lichens were also used together with bryophytes for assessing air pollution. Since lichens are not plants but are composite organisms of algae (and/or cyanobacteria) and fungi, they should be called "bio-indicators." Nakagawa and Kobayashi (1990) classified Hyogo prefecture into six zones according to the upgraded IAP values, which were calculated based on the coverage of lichen species and their sensitivities to SO_2. The map of the upgraded IAP values reflected the pollution level in the area, from the lichen desert in the industrial area near the sea to the normal zone in the clean inland area. They also pointed out that two indicator species, *Parmelia tinctorum* (currently reclassified as *Parmotrema* *tinctorum*) and *Parmelia caperata* (currently reclassified as *Flavoparmelia caperata*), could be used for the rough evaluation of pollution levels. The usefulness of *P. tinctorum* as a bio-indicator for SO_2 air pollution had already been suggested by Sugiyama et al. (1976), who surveyed the distribution of the species on tombstones in the cemeteries of Buddhist temples in five cities in Japan; namely, Sendai, Tokyo, Fuji, Shizuoka, and Yokkaichi, from 1972 to 1974. They reported that the species were absent in the area where SO_2 concentrations were higher than 0.020 ppm. Ohmura et al. (2008) resurveyed the distribution of *P. tinctorum* in Shizuoka city in 1978, 1994, and 2003. They found that the lichen desert observed in 1972 near the port areas had shrunk in 1978 with a decrease in SO_2 concentrations. However, a new lichen desert appeared in 1978 near the crossing point of the Tomei Expressway and Japan National Route 1. This desert expanded along Route 1 until 2003. Although the new lichen desert did not show clear correlation with pollutants, such as NO, NO_2, and NO_X, the effects of increasing traffic, including air pollutants, drought conditions, high temperatures, etc., might affect the lichen species (Ohmura et al. 2008). The studies on bryophytes and lichens in Japan are summarized in Table 7.1. Almost

Table 7.1 Spatial assessment of air pollution using distribution of bryophytes and lichens as bio-indicators

Area, prefecture	Year	Biological indicator	Evaluation method or index	Reference
Tokyo	1969–1971	Epiphytic bryophyte	By number and abundance	Taoda (1972)
Hyogo	1975/1976	Epiphytic bryophytes and lichens	Index of Atmospheric Purity (IAP)	Mitsugi et al. (1978)
	1988 (partly compared with 1975/1976)	Epiphytic bryophytes	Evaluation Index of Air Quality (EIAQ)	Mitsugi (1994)
Ube city, Yamaguchi	1972–1976	Epiphytic bryophytes and lichens	Braun-Blanquet method based on phytosociology	Umezu (1978)
Omuta and Kitakyushu cities, Fukuoka	1978/1979 and 1982	Epiphytic bryophytes and lichens	Modified IAP (IAP*, as the mean of the top four values among the IAP values of five neighboring plots)	Omura and Murata (1984)
Hyogo	1984–1988	Epiphytic lichens	Upgraded IAP (based on coverage and sensitivity to SO_2 of lichens)	Nakagawa and Kobayashi (1990)
Sendai, Tokyo, Fuji, Shizuoka, and Yokkaichi	1972–1974	Lichen (*Parmotrema tinctorum*) on tombstones in the cemeteries of Buddhist temples	Presence or absence of species	Sugiyama et al. (1976)
Shimizu city, Shizuoka	1978, 1993, 2003	Lichen (*Parmotrema tinctorum*)	Presence or absence of the species	Ohmura et al. (2008)

all these studies were conducted in the 1970s/1980s, when SO_2 concentrations were still high. The current SO_2 concentration level in Japan is significantly lower than it was in the 1970s/1980s. However, lichens, such as *P. tinctorum*, may reflect changes in some more general atmospheric conditions, as suggested by Ohmura et al. (2008). Therefore, similar long-term surveys should be conducted to assess the improvement (or deterioration) of bryophyte and/or lichen communities in Japan.

The use of lichen communities as bio-indicators for air pollution was also applied in other Asian countries, including Hong Kong (Thrower 1980), Republic of Korea (Ahn et al. 2011), and Thailand (Saipunkaew et al. 2007). Thrower (1980) surveyed Hong Kong in the late 1970s in cooperation with secondary school students and classified the area into four zones based on the shapes of lichen species, including crustose, foliose, and fruticose lichens. Lichen deserts were found near power stations and industrial areas, and the distribution of crustose, foliose, and fruticose lichens was related to topography as well as the distance from major pollution sources (Thrower 1980). In Seoul, Ahn et al. (2011) compared the distribution of epiphytic macrolichens in 2010 with recorded data from 1975. They reported that the change in lichen distribution for that 35-year period was related to concentrations of air pollutants, such as SO_2, NO_2, and O_3, and the species richness tended to increase with distance from the city center. They also pointed out that the appearance of nitrophilic species might reflect increases of NO_2 concentrations. In northern Thailand, the distribution of epiphytic macrolichens corresponded to population density and was related to particulate matter less than 10 μm in diameter (PM_{10}), rather than SO_2, based on surveys in 2002 and 2004 (Saipunkaew et al. 2007). Therefore, not only the effects of SO_2 but also the effects of other pollutants, such as NO_2 (and/or nitrogen [N] deposition), and PM, should be taken into consideration as possible factors regulating lichen communities. In fact, in Europe and the United States, the relationship between the distribution of lichens and N deposition has been discussed recently, and critical N loads for lichen communities were proposed (e.g. Giordani et al. 2014).

7.4 Chemical Analysis of Bryophytes and Lichens

The studies discussed in the previous section assessed the effects of air pollution according to observations of bryophyte and lichen communities. In addition to field observations, some studies utilized chemical analysis of bryophytes and lichens to elucidate more direct relationships with pollution. Kobayashi et al. (1986) assessed atmospheric mercury (Hg) pollution around a steelworks facility in Hyogo prefecture in western Japan by using epiphytic lichens (*P. tinctorum*). They reported that the Hg concentration in lichen thallus decreased with the distance from the steelworks facility and noted that the Hg concentration in the thallus was significantly correlated with the level of atmospheric Hg. Moreover, Kobayashi and Nakagawa (1990) showed that the Hg concentration was positively correlated with the S concentration in lichen thallus, while a similar correlation was observed in atmospheric concentrations of

Hg. They pointed out that the Hg concentration could be used as an indicator of air pollution, since the upgraded IAP values (Nakagawa and Kobayashi 1990) were negatively correlated with the concentration of Hg. Nogami et al. (1987) suggested the Hg concentration in a moss species (*Bryum argenteum* Hedw.) could also be an indicator, based on surveys undertaken in 1986 in Okayama city in western Japan. They reported that the Hg concentration in the moss body was significantly correlated with the concentration of antimony (Sb; which showed a high enrichment factor), and was mainly derived from anthropogenic sources. They also pointed out that the moss species had an advantage over the sensitive lichen species, such as *P. tinctorum*, for assessing the conditions of air pollution over a wide area, since *P. tinctorum* could not be found in the industrial and urban areas (Nogami et al. 1987). Ishibashi et al. (1982) compared heavy metal concentrations in epiphytic moss bodies in three polluted areas, near a zinc smelter and cement factories, with concentrations in three control areas. They reported that cadmium (Cd), zinc (Zn), and/or lead (Pb) concentrations in the epiphytic moss bodies were significantly higher in the polluted areas than in the control areas. The heavy metal concentrations in moss bodies decreased with the distance from the zinc smelter (Ishibashi et al. 1982).

In addition to elemental analysis, isotopic analyses of epilithic mosses have also been applied to assess the atmospheric deposition of N and S in southwest China; e.g., the N isotopic ratio ($\delta^{15}N$) has been used for the assessment of N deposition (Liu et al. 2008), the S isotopic ratio ($\delta^{34}S$) for the assessment of S deposition (Liu et al. 2009), and the carbon isotopic ratio ($\delta^{13}C$) for the assessment of N deposition (Liu et al. 2010). In these cases, epilithic lichens, which live on rocks in open fields, were used for assessing the deposition of these elements, since the effects of the substratum could be regarded as negligible.

7.5 Use of Common Tree Species as Bio-indicators

This chapter has mainly concentrated on the use of sensitive plant and epiphyte species as bio-indicators. However, native/living plants in target areas can also be used as indicator plants, as Kuno and Ohashi (1993a) suggested (category 1 in Sect. 7.2). Common tree species, such as pine and cedar, are extensively planted for afforestation. Some of these trees could be used as bio-indicators, even if they are not as sensitive to air pollution as bryophytes and lichens. By using trees, not only can the current condition of air pollution be assessed but also the past condition or chronological change over time can be assessed. Several studies traced past air pollution conditions by utilizing tree rings. Katoh et al. (1988a) detected signs of air pollution effects from the ring width of Japanese cedar (*Cryptomeria japonica*) in Fukui prefecture. Conspicuous inhibition of growth in the species was observed within approximately an 8-km radius of the power station, and annual mean concentrations of SO_2 and NO_2 were closely related to the tree growth (Katoh et al. 1988b). Kawamura et al. (2006) analyzed sulfur isotopic ratio ($\delta^{34}S$) values in the tree rings of *C. japonica* and Japanese cypress (*Chamaecyparis obtusa*) collected in Fukuoka prefecture. They found that the profile of the $\delta^{34}S$ values significantly decreased in the 1960s/1970s, when high SO_2 concentrations were recorded, and increased gradually thereafter. Ishida et al. (2015) also analyzed tree rings of *C. japonica*, collected from stumps near Nagoya. They found a similar profile with lower $\delta^{34}S$ values in the 1960s/1970s. The profile was significantly correlated with anthropogenic SO_2 emissions in Japan. In contrast to tree rings, the outer bark, which is exposed to atmospheric concentrations, may reflect current air pollution conditions. In China, Kuang et al. (2007) clarified heavy metal pollution near a Pb-Zn smelter in Qujiang, Guangdong province, by analyzing the heavy metal concentrations in the outer bark of trees. Satake et al. (1996) clarified the progression of Pb pollution due to leaded gasoline used rom 1949 to 1987 in Japan – by comparing Pb concentrations in the outer bark and "bark pocket." The bark pocket is the outer bark from the past left within tree rings during the injury-repair process, and it preserves historical environmental information. Thus, the past and current conditions of air pollution have been clarified by using the tree rings and/or bark of these tree species.

The leaves/needles of these tree species have also been used as bio-indicators for air pollution. Sase et al. (1998a, b) clarified changes in the carbon and oxygen concentrations and carbon/oxygen (C/O) ratios in epicuticular wax in *C. japonica* due to natural and anthropogenic environmental factors. The amount of wax was higher both with the decrease of the C/O ratio caused by exposure to volcanic gas in Osorezan, Aomori prefecture in northern Japan (Sase et al. 1998a) and with the air pollutants from an electrochemical plant in Yakushima Island in southern Japan (Sase et al. 1998b). Takamatsu et al. (2000) analyzed heavy metals in the particulate matter strongly adsorbed on the leaf surfaces of *C. japonica* collected from Kanto and Tohoku, in eastern Japan, and Yakushima Island. They showed that Sb concentrations in the leaf-surface particles were correlated with population density, and NO_X and could be a good indicator of air pollution. Leaf surfaces can trap air pollutants effectively and may reflect air pollution conditions. Therefore, utilization of the leaf surface condition as a bio-indicator for air pollution should also be promoted.

7.6 Summary and Future Perspectives

Environmental monitoring, using indicator plants to assess air pollution levels and actual impacts on plants in Japan and other countries, has been conducted since the 1970s. In particular, in Japan, during the 1970s/1980s when air pollution levels were relatively high, various kinds of indicator plants and approaches were applied for monitoring air pollution. A list of sensitive plant species and the relevant air pollutants has been compiled in Japan. Some vascular plants, such as Japanese morning glory and petunia, were used as indicator plants for pollution by photochemical oxidants (Ox) including O_3 and PAN. Epiphytes, such as bryophytes and lichens, were also used as bio-indicators, for SO_2 pollution. Similar environmental monitoring using bio-indicators, such as bryophytes and lichens, was conducted in other Asian countries. Not only the sensitive plant species noted above but also common tree species, such as cedar, can be utilized as bio-indicators by performing analyses of their bark, tree rings, and leaf surface conditions.

With the development of an emission inventory for pollutants, and with simulations using chemical-transport models, the current and past conditions of air pollution may be reproduced precisely. However, the actual conditions for plants, and their reactions, should be proven in the field. Environmental monitoring using indicator plants is a strong tool for showing actual ecological conditions. Various approaches can be considered, as shown in this chapter. Further application in Asian countries should be promoted.

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