Recolonization of *Parmotrema tinctorum* (Parmeliaceae, Lichenized Ascomycota) in the Urban Area of Kanagawa Prefecture, Japan

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Abstract The distribution of *Parmotrema tinctorum*, known as an excellent bioindicator of air pollution, was examined in Kanagawa Prefecture, Japan, by comparing data from 2005–2007 with that from 2022. Field investigations were conducted in cemeteries and parks at 140 sites in 2005–2007 and at 128 sites in 2022. In 2005–2007, a large gap in the distribution of this species was observed in urban areas with higher concentrations of NO, NO₂ and SPM likely due to automobile exhaust emissions. In 2022, the recolonization of *P. tinctorum* was observed at six sites, and one new growth site was confirmed within the gap area of 2005–2007. The recolonization in the urban area is considered to be related to the significant improvement in air quality, due to the strict regulation of exhaust gas from diesel engines implemented since 2003 in and around Tokyo, including Kanagawa Prefecture. Similar phenomena of recolonization of *P. tinctorum* have also been reported within Tokyo, supporting this conclusion.

Keywords: air pollution, bioindicator, lichen, nitrogen oxide, nitrogen dioxide, urban areas.

Introduction

Parmotrema tinctorum (Nyl.) Hale (Parmeliaceae, lichenized Ascomycota) (Fig. 1) is one of the excellent bioindicators of air pollution, and this lichen species is known to decline when the annual average concentration of sulfur dioxide (SO₂) reached or exceeded 0.02 ppm (Sugiyama *et al.*, 1976). Following the enactment of the Pollution Control Basic Act in 1967, significant improvements in air quality especially on SO₂ concentration were observed within industrial areas in Japan. However, air pollution from automobile exhaust emissions emerged as a concern due to the increase in automobile traffic, a problem that persisted throughout the latter half of the 20th century. Accompanying the changes in sources of air pollution, it was observed that *P. tinctorum* recolonized in industrial area where the annual average concentration of SO₂ was previously 0.04 ppm or more in 1972 and drastically reduced to 0.01 ppm or less after 1979 (Ohmura *et al.*, 2008). However, it disappeared along a major road with heavy traffic where the annual average concentrations of nitrogen monoxide (NO) and nitrogen dioxide (NO₂) were higher than other area (Ohmura *et al.*, 2008).

In 2003, strict exhaust gas regulations for diesel vehicles were implemented in Tokyo and adjacent prefectures. This led to a further significant improvement in air pollution caused by automobile exhaust emissions. Following this, the recolonizations of *P. tinctorum* in Tokyo have

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Fig. 1. *Parmotrema tinctorum*, discovered in Atsugi City in 2022, was previously absent from the site in 2005.

been confirmed in areas where it had previously been absent (Ohmura *et al.*, 2012, 2014; Ohmura and Sugimoto, 2019).

Kanagawa Prefecture, which borders Tokyo to the west, has the second largest population in Japan. The eastern part of the prefecture features densely populated cities such as Kawasaki and Yokohama. In contrast, the western region is mountainous, with landmarks like Tanzawa Mountains (1673 m elev.) in the north-west and Hakone Volcano (1438 m elev.) in the southwest. Consequently, the high volume of automobile traffic once led to significant air pollution in the populated cities, especially before the exhaust gas regulations were implemented in 2003 (data for the related air pollutants such as NO, NO₂, SO₂, suspended particulate matter [SPM], oxidant [OX], and non-methane hydrocarbons [NMHC] are available at the website of National Institute for Environmental Studies: https://tenbou.nies.go.jp/gis/). In such polluted areas where average of annual concentration of NO_2 was ≥ 0.024 ppm, Parmotrema tinctorum has not been found by the investigations conducted in 2005-2007 (Minami, 1993; Takeda and Aihara, 2008). However, the air pollution was drastically improved as the result of the exhaust

gas regulations. For example, in 2005, the annual average concentration of SO_2 was 0.007 ppm in Kawasaki City and 0.009 ppm in Yokohama City, and by 2020, these values had decreased to 0.001 ppm in Kawasaki City and 0.003 ppm in Yokohama City. Similarly, in 2005, the annual average concentration of NO₂ was 0.046 ppm in Kawasaki City and 0.040 ppm in Yokohama City, and by 2020, these values had decreased to 0.024 ppm in Kawasaki City and 0.021 ppm in Yokohama City.

The aim of this study is to investigate the distribution of *P. tinctorum* in Kanagawa Prefecture in 2022, following the improvement of air quality since the previous investigation of the species carried out in 2005–2007.

Material and Methods

Field investigations were conducted in cemeteries and parks at 140 sites in 2005-2007 and at 128 sites in 2022 (Table 1). While Takeda and Aihara (2008) presented foundational distribution results and genetic data on the symbionts of P. tinctorum using data largely collected and examined by the last author of the current study, this study offers updated distribution data, along with the voucher specimens (Fig. 2, Table 1, https://doi.org/10.57400/data. Appendix S1, bnmnsbot.24717576). Of the 128 sites surveyed in 2022, 126 sites were investigated in 2005-2007. The remaining sites were not surveyed due to temple renovations or time constraints. The confirmed individuals were photographed in the field. For each site, up to five specimens of partial thallus were collected as vouchers. The diameter of the thallus was measured using ImageJ (Schneider et al., 2012) based on the field photo. All voucher specimens are housed in the herbarium of National Museum of Nature and Science (TNS), Tsukuba, Japan (Appendix S1).

Data on air pollutants within the prefecture was sourced from the annual average values of various measured substances (NO, NO₂, SPM, SO₂, OX, and NMHC) obtained from the National Institute for Environmental Studies

Recolonization of Parmotrema tinctorum in Kanagawa

Locality (Japan, Kanagawa Pref.)	Place	Elevation (m)	Latitude	Longitude	2005	2022
Ashigarashimo-gun	Manazuru-misaki Point	50	N35.1419	E139.1596		
0 0	Ohayashi Tenbo Park	38	N35.1424	E139.1506		
	Manyo Park	138	N35.1450	E139.0705		
	Hakone Shrine	744	N35.2034	E139.0254	\bigcirc	
	Kowakudani	624	N35.2369	E139.0471	0	0
	Manpuku-ji Temple	730	N35.1884	E139.0262	\bigcirc	Õ
Ashigarakami-gun	Hokisugi Park	465	N35.4584	E139.0614	_	
	Seitoku-ji Temple	38	N35.3256	E139.1279		
	Tanzawako Memorial Museum	330	N35.4147	E139.0428		
	Yadoriki, Matsuda-machi	286	N35.4018	E139.1376		
	Fukusyo-in Temple	272	N35.3919	E139.1392		
	Ryogi-dera Temple	108	N35.3333	E139.1674		
	Tenjin-sha Shrine	79	N35.3316	E139.1657	\bigcirc	
	Gosyo-hachimangu Shrine	46	N35.3230	E139.2196		
	Kouou-in Temple	62	N35.3206	E139.2138		
Minamiashigara-city	Ashigara Shrine	161	N35.3327	E139.0811		
	Kano Community Center	30	N35.3070	E139.1092		
	Saijo-ji Temple	330	N35.3026	E139.0763		
	Nioh-mon Gate	109	N35.3124	E139.0944		
Odawara-city	Terayama Shrine	69	N35.2024	E139.1368	\bigcirc	_
	Akezawa Cemetery	53	N35.3099	E139.2173		
	Odawara Castle Park	20	N35.2513	E139.1542	\bigcirc	
	Jogan-ji Temple	16	N35.2877	E139.1678		
	Mishima Shrine	16	N35.2908	E139.1699	\bigcirc	
	Ishibashi	408	N35.2192	E139.1162		
	Sobi-inari Shrine	33	N35.3211	E139.1359	\bigcirc	\bigcirc
	Hayakawa	390	N35.2218	E139.1140		
	Kaizo-ji Temple	33	N35.2417	E139.1425		
	Shinpuku-ji Temple	18	N35.2374	E139.1431		
	Hachiman Shrine	10	N35.2156	E139.1409		
Aiko-gun	Miyagase Lake	265	N35.5252	E139.2249	\bigcirc	
a 11 1	Kezo-in Temple	156	N35.4673	E139.2838		
Sagamihara-city	Kanuma Park	116	N35.5665	E139.3917	\bigotimes	Q
	Chosho-ji Temple	32	N35.4944	E139.3876	\bigotimes	Q
	Isurubeshimo Park	32	N35.4940	E139.3881	\bigotimes	0
	Komorebi-no-mori	101	N35.5384	E139.4082	\bigcirc	
	Chotuku-ji Temple	282	N35.6220	E139.1931	\bigotimes	Q
	Hofuku-ji Temple	180	N35.6052	E139.2212	\bigotimes	
	Zashu ii Temple	277	N35.03/9	E139.2030	X	
	Zosnu-ji tempie	243	N35.0195	E139.1408	Ő	
	Chasha ii Tamula	1033	N33.4932	E139.0772	Š	$\overline{\bigcirc}$
	Komyo ii Tomple	390	N33.3438	E139.1249	Š	
	Romyo-ji Temple	233	N35.5054	E139.2303		
	Zongyo ii Tomple	291	N35.3377	E139.1830		
	Deitau ii Temple	212	N35.0227	E139.2034		
	Tovo ii Tomplo	200	N25 5200	E139.2107		
	Solahin ii Tomplo	293	N35.5590	E139.2120		Ő
	Shoran ji Tampla	200	N35.5450	E139.2101		
	Renio in Temple	200	N35 5872	E139.1077	ĕ	
	lisso in Temple	292 191	N35 5044	E130 2420	Ĕ	-
	Ontake Shrine	101	N35 6722	E137.2439 E130 1510	-	
Hadano-city	Shirasasa-inari Shrina	110	N35 3650	E139.1510		ĕ
riadano-eny	Chuo-kodomo Park	120	N35 3787	E139.2104	Ĕ	ĕ
	Congenyama Park	242	N35 3719	E139.2004		-
Isehara-city	Jongenyama ratk Isebara-dajijngu Shrine	242 40	N35 2007	E137.2432 E130 2055	\bigcirc	
15011010-011y	Oyama-ahuri Shrine	390	N35.4276	E139.2446	ĕ	ĕ

Table 1. Investigated sites. *Parmotrema tinctorum*: \bigcirc = present, \bigcirc = absent

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Table 1. Continued

Naka-gun Oiso-joyama Park 36 N53.310 E139.2112 — Asama Shrine 26 N53.3110 E139.2112 — Asama Shrine 124 N53.2904 E139.2110 ● Atsugi-city Shosski-ji Temple 142 N53.2904 E139.2510 ● Hiratsuka-city Shosski-ji Temple 142 N53.4006 E139.3652 ● Hiratsuka-city Matsukage Park 4 N53.32616 E139.3452 ● Matsuka-ge Park 4 N53.3364 E139.3452 ● ● Syonan-datra 165 N53.3108 E139.3492 ● ● Shonan-kaigan Park 7 N53.3364 E139.3493 ● ● Shonan-kaigan Park 7 N53.3166 E139.3493 ● ● Hiosci-ji Temple 25 N53.3166 E139.3493 ● ● Shonan-kaigan Park 7 N53.3166 E139.3493 ● ● Hossciji Temple 13 N53.	Locality (Japan, Kanagawa Pref.)	Place	Elevation (m)	Latitude	Longitude	2005	2022
Myoda-ji Temple 26 N55.110 E139.2517 • Asugi-city Azamayama Park 113 N52.2990 E139.2517 • Atsugi-city Shooski-ji Temple 142 N55.010 E139.2597 • Rensho-ji Temple 142 N55.010 E139.2597 • • Hiratsuka-city Matsukage Park 4 N55.3216 E139.3050 • Hiratsuka-cito 5 N55.3217 E139.3459 • • Shoonan-dariga 165 N55.3188 E139.3459 • - Suvabe Shrine 8 N55.3466 E139.2518 • • Shoonan-kaigan Park 7 N55.3366 E139.2518 • • Hossinj Temple 64 N55.3476 E139.2518 • • Ebina-city Yayoi Shrine 45 N55.3466 E139.2518 • • Komyo-ji Temple 11 N55.4277 E139.3791 • • • • •	Naka-gun	Oiso-joyama Park	36	N35.3055	E139.2903		
Asama Shrine 124 N35.2990 E139.2510 • Atsugi-city Shoseki-ji Temple 142 N35.2990 • • Atsugi-city Shoseki-ji Temple 49 N35.4006 E139.3685 • Hiratsuka-city Matsukage Park 4 N35.3216 E139.3482 • Matsumi-cho 5 N35.3217 E139.3482 • • Syonan-daira 165 N35.3108 E139.3312 • • Suvabe Shrine 8 N35.3364 E139.3490 • • Suvabe Shrine 7 N35.3188 E139.3490 • • Shonan-kaigan Park 7 N35.3186 E139.3497 • • Hosci-ji Temple 64 N35.4474 E139.2497 • • Ebina-city Yayoi Shrine 45 N35.4613 E139.3497 • • Hokar-ji Temple 13 N35.4275 E139.3790 • • • Lina-city	-	Myodai-ji Temple	26	N35.3110	E139.3112		
Azamayam Park 113 N55.200 E139.2502 ● Atsugi-city Shoseki-ji Temple 142 N55.010 E139.2992 ● Hiratsuka-city Matsukage Park 4 N55.202 ● ● Hiratsuka-city Matsukage Park 4 N55.203 E139.3474 ○ Syonan-daira 165 N55.3198 E139.3538 ○ ● Swade Shrine 8 N55.3464 E139.3538 ○ ● Shonan-kaiga Park 7 N55.3464 E139.3538 ○ ● Shonan-kaiga Park 7 N55.3464 E139.3494 ○ ● Shonan-kaiga Park 7 N55.3464 E139.3494 ○ ● Jido-hiroba Park 7 N55.3466 E139.2518 ● ● Ebina-city Yayoi Shrine 45 N55.4616 E139.3787 ○ ● Hokan-ji Temple 13 N55.4237 E139.3791 ○ ● ● Komyo-ji Temple		Asama Shrine	124	N35.2994	E139.2517		
Atsagi-city Shoesk-ji Temple 142 N35,5010 E193,2992 • Hiratsuka-city Matsumon Temple 113 N35,4716 E193,3050 • Hiratsuka-city Matsumon Temple 113 N35,4716 E193,3050 • Hiratsuka-city Matsumi-cho 5 N35,3217 E193,3482 • Syonan-diara 165 N35,3186 E139,3312 • • Swabe Shrine 8 N35,3466 E139,3312 • • Tosaka Cemetery 9 N35,3366 E139,3494 • • Hirsteixka-Hachiman-gu Shrine 7 N35,3166 E139,3494 • • Hosei-ji Temple 25 N35,3466 E139,3497 • • Hosei-ji Temple 11 N35,427 E139,3791 • • Hokan-ji Temple 11 N35,427 E139,3791 • • Zama-city Zama Park 48 N35,4205 E139,3791 • •		Azumayama Park	113	N35.2990	E139.2510		
Rensho-ji Temple 49 N53, 4806 E119, 3050 Hiratsuka-city Matsulage Park 4 N35, 3216 E139, 3474 Matsumi-cho 5 N35, 3217 E139, 3474 0 Syonan-daira 165 N35, 3217 E139, 3474 0 Syonan-daira 165 N35, 3136 E139, 3312 0 Tosaka Cemetery 9 N35, 3466 E139, 33312 0 Hiratsuka-Hachiman-gu Shrine 7 N35, 3166 E139, 3334 0 0 Jido-hiroba Park 5 N35, 3166 E139, 3384 0 0 Hosci-ji Temple 64 N35, 4477 E139, 3494 0 0 Hokan-ji Temple 13 N35, 4257 E139, 3787 0 0 Mishimasha Temple 11 N35, 4237 E139, 3791 0 0 Zama-city Zama Park 48 N35, 4933 E139, 3991 0 0 Lipasaki-city Takasuna-ryokuchi Park 9 N35, 3256 E139, 4971	Atsugi-city	Shoseki-ji Temple	142	N35.5010	E139.2992	•	Ó
Iiyama-kamon Temple 113 N35.4716 E193.0305 Image of the status of		Rensho-ii Temple	49	N35.4806	E139.3685	õ	ŏ
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Edma-city Tayon Smine 4-5 N3.1-4013 E139.4000 0 Mishimasha Temple 11 N35.4237 E139.3787 0 Myoso-ji Temple 11 N35.4237 E139.3791 0 Zama-city Zama Park 48 N35.4231 E139.3791 0 Zama-city Zama Park 48 N35.4235 E139.3901 0 Zama-city Zama Shrine 48 N35.4933 E139.3920 0 Chigasaki-city Takasuna-ryokuchi Park 9 N35.3256 E139.4071 0 Fujisawa-city Takasuna-ryokuchi Park 9 N35.3256 E139.4711 0 Yugvo-ji Temple 5 N35.3403 E139.4711 0 0 Yugvo-ji Temple 10 N35.3403 E139.4711 0 0 Yugvo-ji Temple 10 N35.3403 E139.4313 0 0 Yugvo-ji Temple 10 N35.316 E139.4313 0 0 Yugvo-ji Temple 18 N35.202 E139.4313 0 0 Yuko-ji Temple 18 <td>Ehina aitu</td> <td>Voyoi Shrino</td> <td>25</td> <td>N25 4612</td> <td>E139.2007</td> <td>ŏ</td> <td>ĕ</td>	Ehina aitu	Voyoi Shrino	25	N25 4612	E139.2007	ŏ	ĕ
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Inokan-ji Temple 11 N35.4243 E139.3791 Image: Nashed State		Mishimasha Temple	13	N35.4237	E139.3/8/	X	X
Myoso-Ji Temple 12 N35.4295 E139.3791 Image: Construent in the image: Construent		Hokan-ji Temple	11	N35.4234	E139.3/91	\otimes	\bigotimes
Zama-city Zama Park 48 17 N53-492 E139.3942 Zama-city Sochu-ji Temple 34 N35.4912 E139.3942 Zama Shrine 48 N35.4913 E139.3901 Zama Shrine 48 N35.4933 E139.3929 Chigasaki-city Takasuma-ryokuchi Park 9 N35.3256 E139.4056 Fujisawa-city Nanatsugi Shrine 25 N35.4075 E139.4711 Honshin-ji Temple 5 N35.3273 E139.4711 Honshin-ji Temple 25 N35.3483 E139.4892 Oba-Joshi Park 43 N35.3620 E139.4056 Guba-Joshi Park 43 N35.3620 E139.4513 Hosen-ji Temple 10 N35.3116 E139.4892 Yokosuka-city Shogo-ji Temple 18 N35.3116 E139.4895 Yokosuka-city Shogo-ji Temple 4 N35.2215 E139.6091 Fukukon-ji Temple 18 N35.3116 E139.4895 Yokosuka-city Shogo-ji Temple 18 N35.215 E139.6091 Fukukon-ji Temple 18 N35.215 E139.6091 Fukukon-ji Temple 37 N35.2609 E139.6001 Jigen-ji Temple 37 N35.2609 E139.6262 Sairai-ji Temple 63 N35.4908 E139.5295 Fukusen-ji Temple 63 N35.4908 E139.5295 Fukusen-ji Temple 43 N35.4807 E139.5295 Fukusen-ji Temple 30 N35.4807 E139.5295 Fukusen-ji Temple 30 N35.4807 E139.5295 Fukusen-ji Temple 30 N35.4807 E139.5295 Shirare Park 45 N35.4486 E139.5312 Moho-shizen Park 45 N35.4486 E139.5312 Myoho-ji Temple 30 N35.4302 E139.5481 Kosyoo-ji Temple 30 N35.4302 E139.5481 Kosyoo-ji Temple 30 N35.4302 E139.5481 Kosyoo-ji Temple 30 N35.4458 E139.5481 Kosyoo-ji Temple 30 N35.4458 E139.5481 Kosyo-ji Temple 30 N35.4424 E139.5045 Seya Citizen Forest 80 N35.4778 E139.6044 Mitsuzawa Park 39 N35.4426 E139.4839 Nogeyama Park 39 N35.4426 E139.4839 Kododaya Park 39 N35.4426 E139.4839 Kitsuike Park 45 N35.4426 E139.4839 Kitsuike Park 45 N35.4426 E139.4839 Kitsuike Park 45 N35.4426 E139.584 Kodogaya Park 52 N35.4438 E139.6610 Kitsuike Park 52 N35.4454 E139.5844 Kitsuike Park 52 N35.4454 E139.5844 Kitsuike Park 52 N35.4454 E139.5844		Myoso-ji Temple	12	N35.4243	E139.3/91	\otimes	\bigotimes
Zama-city Zama Park 48 N55.4912 E139.3920 Sochu-ji Temple 34 N35.4933 E139.3901 Chigasaki-city Takasuna-ryokuchi Park 9 N35.2256 E139.4056 Fujisawa-city Nanatugi Shrine 25 N35.4075 E139.4711 Yugyo-ji Temple 25 N35.3273 E139.4711 Oba-Joshi Park 43 N35.3620 E139.4513 Yokosuka-city Shogo-ji Temple 10 N35.3116 E139.4513 Yokosuka-city Shogo-ji Temple 18 N35.202 E139.6091 <t< td=""><td>-</td><td>Ebina Sports Park</td><td>1/</td><td>N35.4295</td><td>E139.3/90</td><td>8</td><td></td></t<>	-	Ebina Sports Park	1/	N35.4295	E139.3/90	8	
Sochu-ji Temple 34 N55.4930 E139.3901 Image: Chigasaki-city Fujisawa-city Takasuna-ryokuchi Park 9 N35.3256 E139.4056 Image: Chigasaki-city Fujisawa-city Nanatsugi Shrine 25 N35.4075 E139.4741 Image: Chigasaki-city Yugyo-ji Temple 5 N35.3273 E139.4711 Image: Chigasaki-city Yugyo-ji Temple 25 N35.3483 E139.4892 Image: Chigasaki-city Yugyo-ji Temple 10 N35.316 E139.4892 Image: Chigasaki-city Yokosuka-city Shogo-ji Temple 10 N35.208 E139.6435 Image: Chigasaki-city Yokosuka-city Shogo-ji Temple 4 N35.216 E139.6345 Image: Chigasaki-city Yokosuka-city Shogo-ji Temple 18 N35.212 E139.6345 Image: Chigasaki-city Yokosuka-city Shogo-ji Temple 18 N35.2212 E139.6626 Image: Chigasaki-city Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5425 Is39.5480 Is39.5480 Is39	Zama-city	Zama Park	48	N35.4912	E139.3942	g	
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Fujisawa-city Nanatsugi Shrine 25 N35.4075 E139.4741 • Honshin-ji Temple 5 N35.3273 E139.4711 • • Yugyo-ji Temple 25 N35.3273 E139.4892 • • Oba-Joshi Park 43 N35.3260 E139.4513 • • Ryuko-ji Temple 10 N35.3116 E139.4530 • • Ryuko-ji Temple 18 N35.116 E139.4530 • • Yokosuka-city Shogo-ji Temple 4 N35.2208 E139.6971 • • Honju-ji Temple 18 N35.215 E139.6345 • • • Honju-ji Temple 18 N35.215 E139.6345 • • • Hodiku-ji Temple 37 N35.2692 E139.6601 •	Chigasaki-city	Takasuna-ryokuchi Park	9	N35.3256	E139.4056		
Honshin-ji Temple 5 N35.3273 E139.4711 • Yugyo-ji Temple 25 N35.3483 E139.4892 • Oba-Joshi Park 43 N35.3620 E139.4513 • Hosen-ji Temple 10 N35.316 E139.4530 • Ryuko-ji Temple 18 N35.316 E139.4530 • Yokosuka-city Shogo-ji Temple 4 N35.2252 E139.6091 • Fukuhon-ji Temple 18 N35.2252 E139.6345 • • Hofuku-ji Temple 15 N35.2270 E139.6601 • • Jigen-ji Temple 35 N35.2692 E139.6601 • • Jigen-ji Temple 35 N35.2702 E139.6626 • • Yokohama-city Seirai-ji Temple 50 N35.4807 E139.513 • Kodomo-shizen Park 85 N35.4486 E139.5317 • • Minami-honjyuku Park 70 N35.4593 E139.5481 • • Kosyo-ji Temple 30 N35.4302 E139.5481 •	Fujisawa-city	Nanatsugi Shrine	25	N35.4075	E139.4741		
Yugyo-ji Temple 25 N35.3483 E139.4892 • Oba-Joshi Park 43 N35.3620 E139.4530 • Hosen-ji Temple 10 N35.3116 E139.4530 • Ryuko-ji Temple 18 N35.3116 E139.4530 • Yokosuka-city Shogo-ji Temple 4 N35.2208 E139.6091 • Honju-ji Temple 18 N35.2215 E139.6091 • • Honju-ji Temple 18 N35.2215 E139.6091 • • Hofuku-ji Temple 15 N35.215 E139.6345 • • Jigen-ji Temple 37 N35.2692 E139.6601 • • Jigen-ji Temple 50 N35.4807 E139.513 • • Yokohama-city Seirai-ji Temple 63 N35.4908 E139.5113 • • Yokohama-city Seirai-ji Temple 70 N35.4807 E139.5382 • • Yokohama-city Sihrane Park 85 N35.4486 E139.5133 • • • Yokohama		Honshin-ji Temple	5	N35.3273	E139.4711	\bigcirc	
Oba-Joshi Park 43 N35.3620 E139.4513 • Hosen-ji Temple 10 N35.3316 E139.4513 • • Yokosuka-city Shogo-ji Temple 18 N35.2316 E139.4513 • • Yokosuka-city Shogo-ji Temple 18 N35.2308 E139.6971 • • Hofuku-ji Temple 20 N35.2252 E139.6091 • • • Hofuku-ji Temple 15 N35.3184 E139.6252 •		Yugyo-ji Temple	25	N35.3483	E139.4892		
Hosen-ji Temple 10 N35.3316 E139.4530 Yokosuka-city Shogo-ji Temple 18 N35.3116 E139.4895 Yokosuka-city Shogo-ji Temple 4 N35.2308 E139.6091 Fukuhon-ji Temple 20 N35.2252 E139.6091 Honju-ji Temple 15 N35.215 E139.6610 Sairai-ji Temple 37 N35.2692 E139.6601 Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5295 Yokohama-city Seirai-ji Temple 63 N35.4908 E139.5317 Yokohama-city Seirai-ji Temple 34 N35.3998 E139.5317 Yokohama-city Seirai-ji Temple 34 N35.4806 E139.5317 Yokohama-city Seirai-ji Temple 34 N35.4808 E139.5317 Kodomo-shizen Park 45 N35.4806 E139.5317 Minami-honjyuku Park 70 N35.4806 E139.5382		Oba-Joshi Park	43	N35.3620	E139.4513		
Ryuko-ji Temple 18 N35.3116 E139.4895 • Yokosuka-city Shogo-ji Temple 4 N35.2308 E139.6971 • Fukuhon-ji Temple 20 N35.2252 E139.6091 • • Honju-ji Temple 18 N35.2215 E139.6345 • • Hofuku-ji Temple 15 N35.3184 E139.6622 • • Sairai-ji Temple 37 N35.2692 E139.6601 • • Jigen-ji Temple 35 N35.2702 E139.6626 • • Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5295 • • Yokohama-city Seirai-ji Temple 63 N35.4908 E139.5113 • • Yokohama-city Seirai-ji Temple 63 N35.4807 E139.5382 • • Yokohama-city Seirai-ji Temple 34 N35.4807 E139.5382 • • Minami-honjyuku Park 70 N35.4825 E139.5481 • • • • • • • • <		Hosen-ji Temple	10	N35.3316	E139.4530	Q	Q
Yokosuka-city Shogo-ji Temple 4 N35.2308 E139.6971 • Fukuhon-ji Temple 20 N35.2252 E139.6091 • Honju-ji Temple 18 N35.2215 E139.6345 • Hofuku-ji Temple 15 N35.3184 E139.6252 • Sairai-ji Temple 37 N35.2692 E139.6601 • Jigen-ji Temple 35 N35.2702 E139.6626 • Yokohama-city Seirai-ji Temple 63 N35.4908 E139.5113 • Kodomo-shizen Park 85 N35.4486 E139.5382 • • Minami-honjyuku Park 70 N35.4593 E139.5481 • • Kosyo-ji Temple 34 N35.3998 E139.5481 • • Misuzawa Park 47 N35.4302 E139.5403 • • Myoho-ji Temple 30 N35.4302 E139.5403 • • Misuzawa Park 37 N35.4702 E139.5045 • • Bugen-ji Temple 20 N35.4720 E139.5045 •		Ryuko-ji Temple	18	N35.3116	E139.4895	0	
Fukuhon-ji Temple 20 N35.2252 E139.6091 • Honju-ji Temple 18 N35.2215 E139.6345 • Hofuku-ji Temple 15 N35.3184 E139.6345 • Sairai-ji Temple 37 N35.2692 E139.6601 • Jigen-ji Temple 35 N35.2702 E139.6626 • Yokohama-city Seirai-ji Temple 63 N35.4807 E139.5113 • Kodomo-shizen Park 85 N35.4486 E139.5137 • • Minami-honjyuku Park 70 N35.4825 E139.5481 • • Kosyo-ji Temple 34 N35.3998 E139.5481 • • Myoho-ji Temple 30 N35.4302 • • • Myoho-ji Temple 30 N35.4720 E139.5403 • • Jonen-ji Temple 73 N35.3846 E139.5043 • • Myoho-ji Temple 22 N35.4720 E139.6022 • • Myoho-ji Temple 22 N35.4757 E139.6021 • • <td>Yokosuka-city</td> <td>Shogo-ji Temple</td> <td>4</td> <td>N35.2308</td> <td>E139.6971</td> <td></td> <td></td>	Yokosuka-city	Shogo-ji Temple	4	N35.2308	E139.6971		
Honju-ji Temple 18 N35.2215 E139.6345 • Hofuku-ji Temple 15 N35.3184 E139.6252 • Sairai-ji Temple 37 N35.2692 E139.6601 • Jigen-ji Temple 35 N35.2702 E139.6626 • Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5295 • Kodomo-shizen Park 85 N35.4407 E139.5317 • • Minami-honjyuku Park 70 N35.4593 E139.5382 • • Shirane Park 45 N35.4425 E139.5481 • • Myoho-ji Temple 30 N35.4302 E139.5430 • • Myoho-ji Temple 30 N35.4302 E139.5444 • • Mitsuzawa Park 37 N35.3846 E139.5664 • • Mitsuzawa Park 37 N35.4720 E139.6046 • • Okubohara Park 50 N35.4727 E139.6046 • • Okubohara Park 50 N35.4469 E139.4977 •		Fukuhon-ji Temple	20	N35.2252	E139.6091		
Hofuku-ji Temple 15 N35.3184 E139.6252 • Sairai-ji Temple 37 N35.2692 E139.6601 • Jigen-ji Temple 35 N35.2702 E139.6626 • Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5295 • Fukusen-ji Temple 63 N35.4908 E139.5317 • • Kodomo-shizen Park 85 N35.4593 E139.5382 • • Minami-honjyuku Park 70 N35.4593 E139.5481 • • Kosyo-ji Temple 34 N35.3998 E139.5291 • • Myoho-ji Temple 30 N35.4802 E139.5403 • • Jonen-ji Temple 73 N35.3846 E139.5664 • • Mitsuzawa Park 37 N35.4720 E139.6042 • • Bugen-ji Temple 22 N35.4757 E139.6046 • • Okubohara Park 50 N35.4424 E139.5045 • • Choten-ji Temple 60 N35.4424 E139.4		Honju-ji Temple	18	N35.2215	E139.6345		
Sairai-ji Temple 37 N35.2692 E139.6601		Hofuku-ji Temple	15	N35.3184	E139.6252		
Jigen-ji Temple 35 N35.2702 E139.6626 Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5295 Fukusen-ji Temple 63 N35.4908 E139.5113 Kodomo-shizen Park 85 N35.4486 E139.5317 Minami-honjyuku Park 70 N35.4593 E139.5382 Shirane Park 45 N35.4486 E139.5481 Kosyo-ji Temple 34 N35.3998 E139.5291 Myoho-ji Temple 30 N35.4702 E139.5403 Jonen-ji Temple 73 N35.3846 E139.5664 Mitsuzawa Park 37 N35.4720 E139.6022 Bugen-ji Temple 73 N35.4720 E139.6046 Okubohara Park 50 N35.4728 E139.4977 Choten-ji Temple 60 N35.4731 E139.4858 Nogeyama Park 39		Sairai-ji Temple	37	N35.2692	E139.6601	\bigcirc	\bigcirc
Yokohama-city Seirai-ji Temple 50 N35.4807 E139.5295 Fukusen-ji Temple 63 N35.4908 E139.5113 Kodomo-shizen Park 85 N35.4486 E139.5317 Minami-honjyuku Park 70 N35.4593 E139.5382 Shirane Park 45 N35.4825 E139.5481 Kosyo-ji Temple 34 N35.3998 E139.5291 Myoho-ji Temple 30 N35.4302 E139.5403 Jonen-ji Temple 73 N35.3466 E139.5664 Mitsuzawa Park 37 N35.4720 E139.6022 Bugen-ji Temple 22 N35.4757 E139.6046 Okubohara Park 50 N35.4424 E139.5045		Jigen-ji Temple	35	N35.2702	E139.6626	\bigcirc	\bigcirc
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Kodomo-shizen Park 85 N35.4486 E139.5317 Minami-honjyuku Park 70 N35.4593 E139.5382 Shirane Park 45 N35.4825 E139.5481 Kosyo-ji Temple 34 N35.3998 E139.5291 • Myoho-ji Temple 30 N35.4302 E139.5403 Jonen-ji Temple 73 N35.3846 E139.5664 • Mitsuzawa Park 37 N35.4720 E139.6022 Bugen-ji Temple 22 N35.4757 E139.6046 • Okubohara Park 50 N35.4424 E139.5045 Seya Citizen Forest 80 N35.4798 E139.4977 Choten-ji Temple 60 N35.4469 E139.4858 Nogeyama Park 39 N35.4469 E139.4893 Chofuku-ji Temple 35 N35.4126 E139.4893 Negishi Shinrin Park 45 N35.4247 E139.6355 Negishi Shinrin Park 52 N35.4545		Fukusen-ji Temple	63	N35.4908	E139.5113	\bigcirc	\bigcirc
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Kosyo-ji Temple 34 N35.3998 E139.5291 • Myoho-ji Temple 30 N35.4302 E139.5403 • Jonen-ji Temple 73 N35.3846 E139.5664 • Mitsuzawa Park 37 N35.4720 E139.6022 • Bugen-ji Temple 22 N35.4757 E139.6046 • Okubohara Park 50 N35.4424 E139.5045 • Seya Citizen Forest 80 N35.4798 E139.4977 • Choten-ji Temple 60 N35.4731 E139.4858 • Nogeyama Park 39 N35.4469 E139.4858 • Chofuku-ji Temple 60 N35.4731 E139.4858 • Nogeyama Park 39 N35.4469 E139.4893 • Izumi-chuo Park 35 N35.4133 E139.4893 • Negishi Shinrin Park 45 N35.4247 E139.6355 • Mitsuike Park 20 N35.5228 E139.6610 • Hodogaya Park 52 N35.4545 E139.5864 • Sho		Shirane Park	45	N35.4825	E139.5481	\bigcirc	\bigcirc
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Mitsuzawa Park 37 N35.4720 E139.6022 Bugen-ji Temple 22 N35.4757 E139.6046 • Okubohara Park 50 N35.4424 E139.5045 • Seya Citizen Forest 80 N35.4798 E139.4977 • Choten-ji Temple 60 N35.4731 E139.4858 • Nogeyama Park 39 N35.4469 E139.6231 • Chofuku-ji Temple 35 N35.4133 E139.4893 • Izumi-chuo Park 35 N35.4126 E139.4897 • Negishi Shinrin Park 45 N35.4247 E139.6355 • Mitsuike Park 20 N35.5228 E139.6610 • Hodogaya Park 52 N35.4545 E139.5864 • Shofuku-in Temple 9 N35.4632 E139.5824 •		Jonen-ji Temple	73	N35.3846	E139.5664		
Bugen-ji Temple 22 N35.4757 E139.6046 • Okubohara Park 50 N35.4424 E139.5045 • Seya Citizen Forest 80 N35.4798 E139.4977 • Choten-ji Temple 60 N35.4731 E139.4858 • Nogeyama Park 39 N35.4469 E139.6231 • Chofuku-ji Temple 35 N35.4133 E139.4893 • Izumi-chuo Park 35 N35.4126 E139.4897 • Negishi Shinrin Park 45 N35.4247 E139.6355 • Mitsuike Park 20 N35.4252 E139.6610 • Hodogaya Park 52 N35.4545 E139.5864 • Shofuku-in Temple 9 N35.4632 E139.5824 •		Mitsuzawa Park	37	N35.4720	E139.6022	\bigcirc	\bigcirc
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Seya Citizen Forest 80 N35.4798 E139.4977 O Choten-ji Temple 60 N35.4731 E139.4858 O Nogeyama Park 39 N35.4469 E139.6231 O Chofuku-ji Temple 35 N35.4133 E139.4893 O Izumi-chuo Park 35 N35.4126 E139.4897 O Negishi Shinrin Park 45 N35.4247 E139.6355 O Mitsuike Park 20 N35.5228 E139.6610 O Hodogaya Park 52 N35.4545 E139.5864 ● Shofuku-in Temple 9 N35.4632 E139.5824 O		Okubohara Park	50	N35.4424	E139.5045	Ō	Ō
Choten-ji Temple 60 N35.4731 E139.4858 O Nogeyama Park 39 N35.4469 E139.6231 O Chofuku-ji Temple 35 N35.4133 E139.4893 O Izumi-chuo Park 35 N35.4126 E139.4897 O Negishi Shinrin Park 45 N35.4247 E139.6355 O Mitsuike Park 20 N35.5228 E139.6610 O Hodogaya Park 52 N35.4545 E139.5864 • Shofuku-in Temple 9 N35.4632 E139.5824 O		Seya Citizen Forest	80	N35.4798	E139.4977	Ō	Ō
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Shofuku-in Temple 9 N35.4632 E139.5824 \bigcirc		Hodogaya Park	52	N35.4545	E139.5864	ŏ	ĕ
		Shofuku-in Temple	9	N35.4632	E139.5824	ŏ	õ

Locality (Japan, Kanagawa Pref.)	Place	Elevation (m)	Latitude	Longitude	2005	2022
	Tokiwa Cemetery	31	N35.4676	E139.5890	0	0
	Tokiwa Park	41	N35.4701	E139.5902	\bigcirc	\bigcirc
	Choen-ji Temple	49	N35.5141	E139.5275	\bigcirc	\bigcirc
	Nakamaru Park	54	N35.5164	E139.5021	\bigcirc	\bigcirc
	Meotozaka Park	71	N35.5108	E139.5042	\bigcirc	\bigcirc
	Kirigaoka Park	58	N35.5135	E139.5021	\bigcirc	\bigcirc
Kamakura-city	Joju-in Temple, 1-chome	34	N35.3093	E139.5313		
-	Joju-in Temple, 2-chome	40	N35.3097	E139.5313		
	Josen-ji Temple	7	N35.3073	E139.4936	\bigcirc	
	Manpuku-ji Temple	19	N35.3078	E139.4951	\bigcirc	\bigcirc
	Reiko-ji Temple	34	N35.3105	E139.5092		
	Hongaku-ji Temple	5	N35.3172	E139.5521		
	Ko-machi	20	N35.3210	E139.5579		
	Tsurugaoka-hachimangu Shrine	23	N35.3254	E139.5569		
	Kotoku-in Temple	17	N35.3170	E139.5354		
Zushi-city	Sotai-ji Temple	16	N35.2911	E139.5819		
Miura-city	Konen-ji Temple	17	N35.1420	E139.6201		
Kawasaki-city	Honnon-ji Temple	45	N35.6018	E139.5655	\bigcirc	\bigcirc
	Jodo-ji Temple	56	N35.6057	E139.5650	\bigcirc	\bigcirc
	Higashi-ikuta	48	N35.6052	E139.5659	\bigcirc	
	Kofuku-ji Temple	37	N35.6144	E139.5595	\bigcirc	\bigcirc
	Ikuta-ryokuchi Park	44	N35.6083	E139.5610		
	Tenjin-sha Shrine	35	N35.6150	E139.5579	\bigcirc	\bigcirc
	Todoroki-ryokuchi Park	9	N35.5846	E139.6479	\bigcirc	
	Hosoyama-nakajima Dai 2 Park	74	N35.6175	E139.5185	\bigcirc	
	Korin-ji Temple	97	N35.6161	E139.5130		
	Shuko-ji Temple	65	N35.5942	E139.4944		

Table 1. Continued

(https://tenbou.nies.go.jp/gis/). The data for these air pollutants were measured at Ambient Air Pollution Monitoring Stations. Data from Roadside Air Pollution Monitoring Stations were not included due to their significant localized impacts.

Results and Discussion

Distribution of Parmotrema tinctorum

The growth of *Parmotrema tinctorum* in Kanagawa Prefecture was observed at 60 out of 140 sites in 2005–2007 (Fig. 2A), and at 70 out of 128 sites in 2022 (Fig. 2B). Within the large gap area of 2005–2007 in the eastern part of the prefecture (the pink area showing in Fig. 2A), *P. tinctorum* recolonized six sites by 2022 and a new growth site was observed (Fig. 2B). Across the entire prefecture, recolonization occurred at 18 of the same sites. For two sites, although *P. tinctorum* was present in 2005–2007, it could not be found in 2022 but this was due to the disap-

pearance of the substrate on which it was growing.

Air pollutants and the gap area of Parmotrema tinctorum

There was a significant distribution gap of *P. tinctorum* in 2005–2007 within the eastern part of Kanagawa Prefecture. To investigate the relationship between this distribution gap of *P. tinctorum* and air pollution, five-year average values of NO, NO₂, SPM, SO₂, OX, and NMHC from 2000 to 2004 were visualized in Fig. 3.

The distribution gap of *P. tinctorum* largely coincides with the area where higher concentrations of NO, NO₂ and SPM were observed (Fig. 3A–C). These air pollutants are primarily originated from automobile exhaust emissions and industrial factories (Kanagawa Environmental Research Center, 2005). The concentration of SO₂ had already dropped to less than 0.01 ppm in all areas (Fig. 3D), suggesting that it has likely reached a level with minimal on *P. tinctorum*



Fig. 2. Distribution of *Parmotrema tinctorum*. A. In 2005–2007. B. In 2022. ● = present. ○ = absent. The pink area indicates the gap area of *P. tinctorum* in 2005–2007 both for A and B. The satellite images of Kanagawa Prefecture and its surrounding areas in 2005 (A) and 2022 (B) were acquired via Google Earth

because this species is known to decline when the annual average concentration of SO_2 exceeds 0.02 ppm (Sugiyama *et al.*, 1976). Regarding OX, which is produced by photochemical reactions of nitrogen oxides and volatile organic compounds (VOC), no correlation was observed



Fig. 3. Five-year average values of air pollutants from 2000 to 2004 in Kanagawa Prefecture. A. NO. B. NO₂. C. SPM. D. SO₂. E. OX (annual average of the daytime highest one-hour value). F. NMHC. The pink area represents the distribution gap of *Parmotrema tinctorum* in 2005–2007.

between the high concentration area and the distribution of *P. tinctorum* (Fig. 3E). NMHC, which is also related to automobile exhaust emissions, might be associated with the distribution gaps of *P. tinctorum* (Fig. 3F). However, due to limited data, the relationship remains unclear.

As a result of the regulations for diesel vehicle exhaust gas emissions implemented in October 2003, the values of atmospheric pollutants except OX decreased significantly at all air pollution monitoring stations in Kanagawa Prefecture. According to the latest available data on air pollutants for 2018, the concentration of NO was ≤ 0.005 ppm, NO₂ was ≤ 0.017 ppm, SPM was ≤ 0.019 mg/m³, SO₂ was ≤ 0.003 ppm, OX was ≤ 0.052 ppm, and NMHC was ≤ 0.20 ppmC (data were obtained from https://www.pref. kanagawa.jp/docs/b4f/taikiosen/2021taiki.html).

Compared with the distribution data in 2005-2007, there was a noticeable shift in the distribution of P. tinctorum in 2022, with recolonizations into the gap areas observed in 2005-2007 (Fig. 2). This suggests that the reduction in air pollutants, particularly NO, NO2 and SPM associated with automobile exhaust emissions, might have promoted a more favorable environment for P. tinctorum growth. The size of recolonized thalli ranged from 3.2 to 8.1 cm in diameter in 2022, indicating steady growth in the area. Similarly, it has been reported that the significant improvements in air quality after the strict regulations of automobile exhaust emissions have contributed to the recovery of lichen diversity, including the recolonization of P. tinctorum in Tokyo Metropolis (Ohmura et al., 2012, 2014, 2022; Ohmura and Sugimoto, 2019). These facts indicate that P. tinctorum, in addition to its bioindicator properties for SO₂ (Sugiyama 1973; Sugiyama et al., 1976), serves as an excellent bioindicator for air pollution caused by automobile exhaust emissions. However, given that there are still many sites where *P. tinctorum* has not yet recovered in Kanagawa Prefecture, it is possible that factors other than air pollution are hindering the settlement of *P. tinctorum*.

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