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Pressures from long term environmental change at the shrines and temples of Nikkō

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Abstract

Background: Important historic buildings at Nikkō are designated National Treasures of Japan or important cultural properties and illustrate notable architectural styles. We examine the records of damaging events and environmental change to estimate that changing balance of threats to guiding strategic planning and protection of the buildings and associated intangible heritage.

Methods: Historic records from Nikkō allow past damage to be assessed along with projections of likely future threats. Simple non parametric statistics, Lorenz curves and its associated Gini coefficient aids interpretation of observations.

Results: Earthquakes have long represented a threat, but mostly to fixed stone structures. Flooding may be as growing problem, but historically river management has improved. Increasing warmth may mean an increase in the threat of fungal attack. However, insect attack on wood has been a particular problem as recent years have seen damage by wood boring insects, particularly at Sanbutsudō in the temple complex of Rinnō-ji. Although warmer climates may enhance the abundance of insects such as *P. cylindricum* the life cycle of this rare anobiid is not well understood. The risk of forest fires tends to be higher in drought period, but summer rainfall may well increase at Nikkō. Additionally good forestry practice can reduce this risk. Future changes to climate are likely to alter the flowering dates and the arrival of autumn colours.

Conclusion: The results show that environmental changes are likely to affect the material structure and also the nature of celebrations and visitor frequency at Nikkō. Conservation architects and skilled engineers will be challenged by these changes, so need to be well briefed on strategic environmental threats.

Keywords: Climate change, Flooding, Fire, Fungi, Earthquakes, Insects, Landscape change, Wooden buildings

Introduction

There are more than a hundred important historic buildings at Nikkō. These are designated National Treasures of Japan or important cultural properties. This site is important because it illustrates the architectural style of the Edo period as applied to Shinto shrines and Buddhist temples. These are arranged on forested mountain slopes so as to create striking visual effects making the setting significant in addition to the importance the historic buildings. Although many of the buildings were constructed in the 17th century, the earliest date from the 8th century. They are distributed among the various temple complexes discussed in the text, along with a satellite set of buildings associated with Rinnō-ji situated fifteen kilometres away at Tyuzen-ji. The key sites, Rinnō-ji, Tōshō-gū and Futarasan Shrine form the *Shrines and Temples of Nikkō* that represent important elements of UNESCO World Heritage. The temple complex and its surroundings have long been a destination for travelers. The poets Sōgi [1] and Matsuo Basho made visits in 1468 and 1689 respectively and Nikkō features in Basho's most famous work, *The Narrow Road to the Deep North*. Western tourism started early also with a notable visit from the crew of the *Challenger* in 1875 [2] and early travel writers [e.g. 3]. Many important Japanese painters have found inspiration in Nikkō and its surroundings, notably

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the 20th-century painter and printmaker Hiroshi Yoshida [4]. In the 21st century annual reports reveal that there are typically some six million visitors to Nikkō each year, but they go there as much to enjoy the natural environment as the temples, with autumn popular to observe the leaves.

Heritage always faces a range of threats and Nikkō has been vulnerable to earthquake, floods, lightning strikes, fire and most recently insect attack. In future these threats may be exacerbated by environmental and climate change. The aim here is to examine the records of damaging events and environmental change to estimate that shifting balance of threat in the future as a way of guiding long term strategic planning and risk assessment at Nikkō.

Method

This work uses historic records from Nikkō to assess past damage along with the magnitude of various climate and environmental threats. The layout of the site is shown by the map in Fig. 1b, which marks the key religious complexes of the site along with individual monuments and buildings discussed in the text. Where possible we have used climate projections available from the Japanese

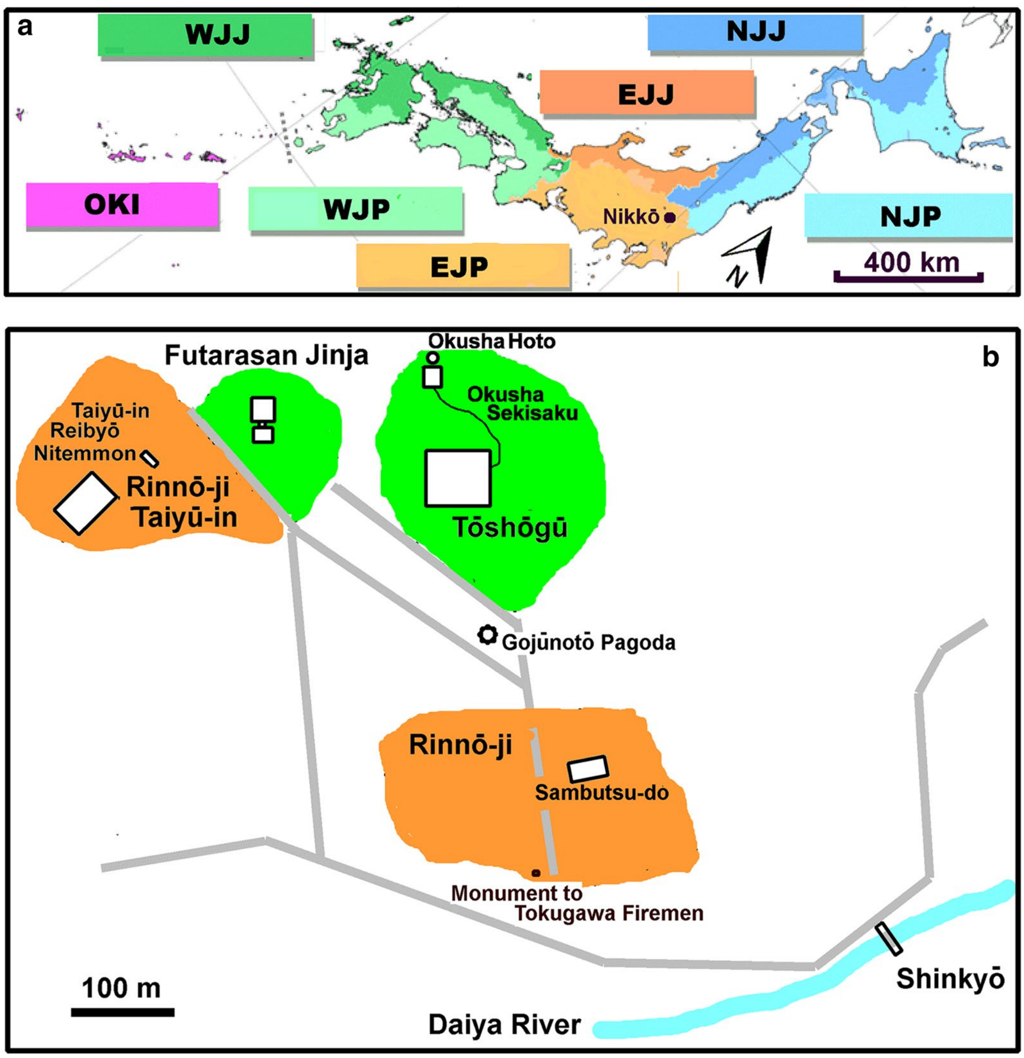

Fig. 1 Maps: **a** the climate types of Japan as adopted by the Japanese Meteorological Agency, which defines seven regions (i) the Sea of Japan side of northern Japan (NJJ), (ii) the Pacific side of northern Japan (NJP), (iii) the Sea of Japan side of eastern Japan (EJJ), (iv) the Pacific side of eastern Japan (EJP), (v) the Sea of Japan side of western Japan (WJJ), (vi) the Pacific side of western Japan (WJP), and (vii) Okinawa/Amami (OKI) and **b** the site of the Shrines and Temples of Nikkō marking locations discussed in the text. The larger lettering defines the major religious sites, while smaller lettering denotes individual buildings and monuments that are discussed in the text, with green areas denoting sites with shrines and orange with buildings belonging to Rinnō-ji

Meteorological Agency to estimate likely future threat from changed weather. The Japanese climate is generally temperate, though it ranges from the subarctic zone of the most northerly island of Japan, Hokkaido, where the average annual temperature is 6–10 °C to the subtropical zone of the southern island, Okinawa and is divided into regions as shown in Fig. 1a. We have used simple statistical tests to explore the data gathered. The Kendall tau test used Wessa-net (https://wessa.net/) for non parametric correlation analysis, while the Sen slope (median slope) was determined using the Theil-Sen calculator at Single Case Research (http://www.singlecaseresearch.org/calculators/theil-sen). Additionally Lorenz curves and the associated Gini coefficient were used to describe the insect catch as the distribution is highly dispersed [5]. The Gini coefficient and its standard error were calculated from the number of trapped insects using the method suggested by Owang [6].

Results and discussion have been split into a number of sections for clarity: past impacts on the site, earthquakes, climate and climate change at Nikkō, floods and storms, fungal damage at Nikkō, insect damage at Nikkō, fires at Nikkō and landscape change and seasons at Nikkō. The recent discovery of insect damage at Nikkō, makes the section on insects rather long, so it is been split to include introductory material and other subsections.

Past impacts on the site

The historic site of Nikkō has often experienced serious damage in the past from extreme events. The occurrence of such events can give us a sense of past threats, although we have to remember there are more subtle long-term threats, which lead to cumulative, rather than catastrophic damage, have probably gone unrecorded in the past. It is clear from Table 1 that flood and earthquake disasters are the most notable, with landslides and debris flows less frequently recorded. The floods have had a particular influence of the bridges and most importantly the *Sacred Bridge* (Fig. 1b). Typically earthquakes appear to have caused damage to walls, but on some occasions important structures collapsed. The events as recorded in the Japanese earthquake history of Usami [7] reveal no major earthquakes at Nikkō prior to the 17th century.

A comparison of the earlier records from 1532 to 1899, with those of the 20th century reveals a changing frequency with which floods were recorded, such that they have been seen more important than earthquakes to those assembling the record of damage. Over the earlier period there were 14 records of disastrous floods compared to 19 earthquakes, while in the 20th century the numbers were 12 and 3 records respectively. Thus there is a significant change ($p = 0.015$; $\chi^2 = 5.86$) in the recording of the major threats to Nikkō.

Earthquakes

Earthquakes have long represented a threat to buildings in Japan and their design even in historic times attempted to resist the shocks. The record of significant earthquakes starts with accounts of events as early as the 5th century [7] and at Nikkō damage was noted from the Edo or Tokugawa period (1603–1868), but the accounts seem to list only minor damage (Table 1).

There was a large earthquake in 1683 and possibly some smaller shocks. The damage caused was costly and led to disagreements between Lord Date Tsunamura (1659–1719), who wanted a minimalist restoration and the Tokugawa Shogunate who wished for a fuller restoration. The dispute occurred as the famous poet Matsuo Basho and his travelling companion Kawai Sora, were to depart on a journey through Nikkō early in 1689 [8]. The government hoped that Matsuo Basho could provide information about the restoration. However, Basho wrote relatively little of Nikkō in *The Narrow Road to the Deep North,* although this prose-poem offers clues and suggests that his thoughts would not be public ones: "To say more of the shrine would be to violate its holiness [9]". A minimalist restoration seems to have prevailed and reminds that in the past, as with today, there were tensions over funding and extent of restoration.

The traditional wooden buildings of Japan are resistant to earthquakes as they respond to earth movements. The five-story pagoda characteristic of Japanese architecture consists of floors with beams only weakly linked, but held in vertical alignment by a central pole. Each floor is effectively an independent structure of decreasing dimension with height. Wide heavy eaves stabilize the building as the inertia reduces the degree to which the building sways. Wooden Japanese buildings have the ability to recover from the rocking. Further, the buildings were often constructed on large trays that allowed movement between the ground and the building [10]. The historical record of earthquake destruction at Nikkō in Table 1 illustrates the effectiveness of resistance wooden buildings to earthquakes as damage to fixed structures is most frequent. In the earthquake of 1683, *kasa-ishi* (coping stones) on fence tops were affected and more significantly a hoto; a stupa (typically miniature) with a cylindrical body on stone foundations with a four-sided roof. This was probably the *Okusha Hōtō*, which enshrines the remains Tokugawa Ieyasu and was rebuilt in stone in 1641. Later the 1725 and 1746 earthquakes damaged some stone yarai (fence), and another caused damage to the Sekisaku and stone stairs at Tōshō-gū in 1827. These structures are understandably less resistant than those of wood.

An earthquake, followed by a tsunami caused devastation across Japan in 2011. The effects of this earthquake on structures at Nikkō has been studied [11, 12], but

Table 1 Floods and earthquakes which caused damage at Nikkō

Floods	Earthquakes
16th Century 1532 Flood	
17th Century 1662 Flood of Inari River after heavy rain until one day before the flood; *1684* Flood of Daiya River and Inari Rivers; *1685* Flood of Inari River; *1687* Flood, with ponds at lower sides of each deck of the Sacred Bridge so unusable for half a day; *1688* Flood, with ponds at lower sides of each deck of the Sacred Bridge; *1699* Flood of Daiya River and Inari River	*17th Century 1644* Earthquake, a little damage to stone wall at Tōshōgu; *1649* Earthquake, damage to stone wall and stone Igaki at Tōshōgu; *1650* Earthquake, Damage to Sōrintō and stone wall at Tōshōgu; *1658* Earthquake, minor damage in Nikko; *1683 June 17/18* Earthquakes, Landslide at Mount Akanagi and Nothern Akanagi; Earthquake, Damage of Hōtō and Kasaishi etc. at Tōshōgu and Taiyu-in; Flood of the Daiya River and Inari Rivers, *October 20* Earthquake and landslide and no more water flow in Kinugawa River and Inari Rivers and possibly damage to buildings under restoration
18th Century 1704 Flood of Daiya River, Inari River and Tamozawa; *1721* Flood of Daiya and Inari Rivers; *1723* Heavy rains and wind, flood of Inari River; *1786* Flood of Daiya River	*18th Century 1703* Genroku Earthquake; *1707* Hōei Earthquake; *1710* Nikkō shrines safe after main earthquake shock; *1725* Earthquake damages some 7-9 m length of a stone yarai and three or four stone lanterns fell down; *1735* Earthquake, minor damage to stone wall at Tōshōgu; *1746* Earthquake, damage to Stone Yarai and wall at Tōshōgu; *1755* Damage to stone yarai, wall and stairs at Tōshōgu; *1767* Earthquake, fall of sculpture about 1.8 m
19th Century 1858 Flood of Daiya, Akahori and Namegawa Rivers; *1859* Flood of Daiya and Morokawa Rivers	*19th Century1827* Earthquake, minor damage to Okusha Sekisaku at Tōshōgu; *1835* Earthquake, collapse of stone wall; *1888* Earthquake, Tochigi Prefecture
20th Century (first half) 1902 Heavy rain and wind, flood of Daiya and Inari Rivers; *1906* Washout of the Sacred Bridge and Inari Bridge; *1909* Flood, the Sacred Bridge under water; *1919* Flood, outburst of the Daiya River levee; *1938* Flood and typhoon, damages the whole Tochigi Prefecture with deaths (8), injuries (8), houses destroyed (204), half destroyed (125), parts washed away (248); *1946* flood and Typhoon No. 9; *1947* Flood Kathleen Typhoon, damage whole Tochigi Prefecture; Inundation of about 170 houses, partly washed away (4) by flood and levee collapse in Tochigi, dead (361), missing (76), injured (549), houses destroyed (1432), parts washed away (817); *1949* Flood Typhoon Kitty, damage to whole of Tochigi Prefecture; dead (12), injured (37), houses destroyed (248), half destroyed (2318), parts washed away (28);'	*20th Century (first half) 1923* Great Kanto Earthquake; *1931* Nishisaitama Earthquake, damage to stone wall; *1949* Imaichi Earthquake
20th Century (second half) 1959 Flood from Isewan Typhoon; *1966* Flood and torrential rain from Typhoon No. 26, damage whole Tochigi Prefecture; dead 12, injury 51; *1972* Flood and torrential rain from Typhoon No. 20, damage whole Tochigi Prefecture; dead 1, injury 3, houses destroyed 1, half destroyed 1, partial destroyed 6, landslide in Hosoo in Nikkō; *1981* Flood from Typhoon No. 15, damage whole Tochigi Prefecture; partial destroyed 15, victim 20; *1982* Debris flow Takumi and Hoso in Nikko city, isolation of Kawamata Onsen from Typhoon No. 10; isolation of Kawamata Onsen by Typhoon No. 18; *1991* Torrential rain from Typhoon No. 12; Debris flow in Tamozawa; *1998* River blockage	

Timeline of Nikko's disaster, http://www.ktr.mlit.go.jp/nikko/nikko00044.html; Nikko Sabo Office, Ministry of Land, Infrastructure, Transport and Tourism. Kanto Regional Development Bureau and Report of disaster assessment survey findings in 2006—Chapter 2 Disaster history https://www.city.kanuma.tochigi.jp/manage/contents/upload/5816b5371f02d.pdf, Kanuma city, Tochigi, Japan

there is no clear change due to building deformation, although slight damage to lacquer finishes. However, there was a decline in visitors (Fig. 2a) after the accompanying tsunami struck the Fukushima nuclear power station (~150 km from Nikkō) and initiated fears of a spread of radioactive material. There is also a potential interaction between other factors such as insect damage weakening wooden elements and then the earthquake causing the failure. No particular change in the frequency of earthquakes would be expected for the future, but it could well be that other environmental factors change (humidity, insect infestation etc.) in a way that renders structures more sensitive to earthquake vibrations.

Climate and climate change at Nikkō

The mean surface temperature in Japan for 2015 is estimated to have been some 0.7 °C above the 1981–2010 average. It is also the 4th warmest year on record since 1898. Rainfall records suggest a decrease in the annual number of wet days, but an increase in extremely wet days over the period 1901–2015 [13]. The projected temperature in Japan as likely to increase by 4.2 °C for the period 2071–2100 (under the A1B scenario, which

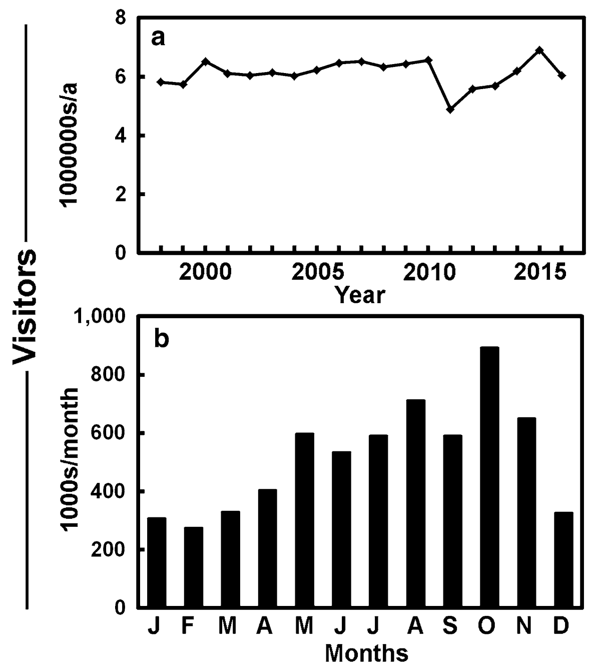

Fig. 2 **a** Visitors at Nikko by (year) and **b** season (years 2009–10 and 2012–2016)

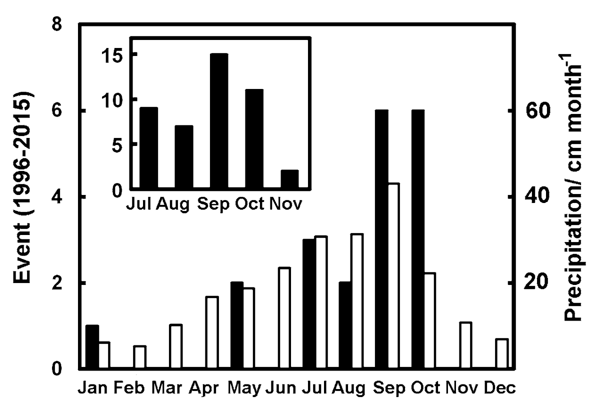

Fig. 3 The month of occurrence of the yearly maximum flood height at the gauging station on the Hitachitone River for the 20 year period 1996–2015 (black bars) and the monthly precipitation at Nikko (white bars). The inset shows the month of maximum daily water height for the years 1930–1974, after which the prior to extensive water management and the water-gate remained closed. Data provided by the Ministry of Land, Infrastructure, Transport and Tourism. Kanto Regional Development Bureau, Kasumigaura office

imagines a future world of very rapid economic and population growth) compared to that for 1971–2000. Summer precipitation will change steadily due to global warming with the annual average precipitation increasing 19% by the last 30 years of the 21st century. Looking at regional climate between 1980–1999 and 2076–2095 the annual mean temperature is projected to increase by more than 3 °C in region EJP (see Fig. 1a). Summer mean relative humidity is projected to decrease in most regions, especially region EJP where Nikkō lies, by about 4%, although winter mean relative humidity is projected to increase across most of Japan. The annual number of dry days (< 1 mm) is likely to increase by 5–10 days across Japan (JMA, V8). These changes in climate set a background against which we can explore the climate pressures on the Shrines and Temples.

Floods and storms

There is a general observation that typhoons over the northwest Pacific that cross land have increased over the past 37 years, with the proportion of storms of categories 4 and 5 doubling or even tripling. Additionally they have intensified by 12–15% [14]. However, the future is not clear, but typhoons at Nikkō might show only a very slight increase [15] perhaps 0.2 per season (September–December). Nevertheless it is likely that there will be more heavy falls of rain, with the frequency of days where precipitation exceeds 200 mm perhaps some 50% higher [16] (Fig. 3).

There have been a number of studies on the effects of future climate change on the upper Tone River basin, which includes the Nikko catchment [17, 18]. Kim et al. [18] argue that changes in river discharges may slightly decrease or peak river flows could change a little, but overall this will not affect the water supply from the river. The river is carefully managed and the river height is controlled at the gauging station Ga (Observatory No. 303031283303130) on the Hitachitone River of the Tone Catchment. However Nikkō, which is in the mountains, may remain at risk of seasonal flooding.

Fungal damage at Nikkō

There are a number of approaches to estimating potential fungal damage to wood, but here we adopt the Scheffer index (*Sch*). The values are determined from the formula [19]

$$Sch = (1/16.7)\sum_{Jan}^{Dec}(D-3)(T-2)$$

where D is the number of wet days (defined at precipitation > 0.25 mm) each month and T is the average monthly temperature, where T is greater than 2, otherwise the value is zero. It is not always easy to get precipitation days > 0.25 mm as these are most frequently available for > 1.0 mm. However, at Nikkō a limited number of observations at other daily precipitation amounts suggest that multiplying $D_{>1.0}$ by 1.5 is a reasonable approximation for $D_{>0.25}$. The number of dry days for various seasons in the region EJP and rise in temperature have been estimated for the end of the 21st century, so it is possible to approximate a future Scheffer index for Nikkō (Fig. 4). The Scheffer index increases from a recent values for 1961–1990 of 82 and 1981–2010 of 84.5 to just on 100 in the last years of the 21st century (2076–2095). There is an increase in the Scheffer index despite the declining number of wet days, but this is more than compensated for by the increasing temperature. The conclusion of increasing fungal risk made here is similar to results from work in Korea, which suggests that "that Korean weather tends to turn into the weather of [a] subtropical region, the decay hazard of Korea seems to have high possibility to be gradually increased" [20].

Insect damage at Nikkō

Historical background

Historically insect damage to wooden buildings has been common in Japan, with termite damage most apparent. However, over the last 100 years a wider range of attack has become apparent and recently at Nikkō problems have been especially pronounced. From the late 19th century advice was available to limit insect attack, but the extensive use of bamboo made protection of this material a focus of studies [21] in the Meiji era (1868–1912). There were investigations (1900–1907) of the larval attack (possibly by *Omphisa fuscidentalis*) and damage by the powderpost beetle (*Lyctus* spp.), which caused damage to bamboo furniture [22].

The work of the Forest Research Institution [23] examined a range of pesticides, but noted only camphor oil penetrated bamboo and effective over long periods [23]. Although protection with the oil had been known for some time it was not used as it was difficult to obtain in early Edo times (17th century), so only became popular

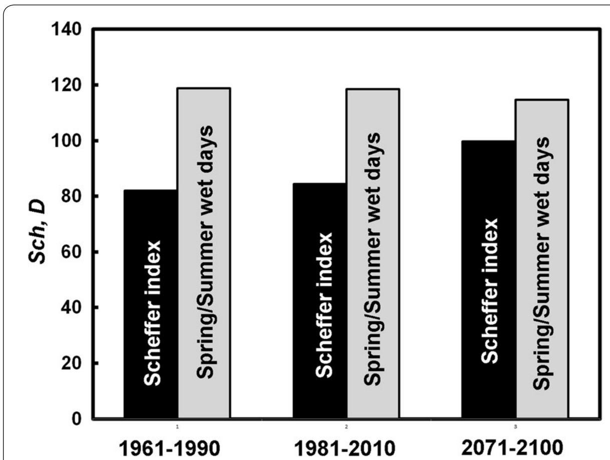

Fig. 4 The Scheffer index at Nikkō and the number of wet days in spring and summer over various periods

by the mid 19th century [24]. From latter half of 1940′s the use of plywood from Lauan trees had increased, but insect damage was so great that the Housing Authority prohibited its use in the 1950′s. However, more recent decreases in the supply Japanese hardwoods had led to re-adoption of Lauan wood protected using repellents such BHC, DDT, PCP and chloronaphthalene. Death watch beetles (i.e. *Anobiidae* in Japan) have been a cause of damage, but a lack systematic surveys means they may have occurred earlier, but their presence passed unnoticed [25].

Wood types and damage surveys at Nikkō

The Shrines and Temples of Nikkō are set within forested area, so the presence of wood boring insects is to be expected. The buildings are principally constructed from pine, hinoki, tsuga, chestnut, red cedar [26] and in general domestic wood has been promoted in recent years [27], with hinoki and cedar have maintained as aged stands [28]. However, heritage conservation studies have not established the relative vulnerability of the different types of wood. Most of the wooden structural elements are coated with *urushi* varnishes, increasingly taken from Japanese sources, and sometimes paint. These layers tend to hide the damage until it becomes severe [26]. In 2008 restoration work at Sambutsu-do in Nikkō led to the discovery of extensive structural damage to wooden pieces. Severe damage to wood is common after termite infestation, but in this case larvae of *Priobium cylindricum* (a death-watch beetle, in earlier literature called *Trypopitys*), collected from infested wooden parts were thought to have caused the damage [24]. The beetle is about 5 mm, but its ecology and sensitivity to temperature and relative humidity is not known [29]. The survey at Nikkō considered *P. cylindricum* to enter the adult phase between May and July, for a period likely to be less than 1 month. *Priobium* spp. (probably *Priobium carpini*) have been found in ancient Egyptian coffins [30], but were rare in Japan and prior to the observations at Nikko in 2008; there had been no reports of damage to wooden buildings in literature. Although damage by *P. cylindricum* came to be noticed only recently, a survey of older records and photos hinted at a longer history to the activity of this wood-boring beetle [31]. There are similar the suggestions for *P. carpini* (alternatively *T. carpini*) infestations in houses in Poland, which although not noticed until 1955 revealed hints of a longer history [32].

Growing concern over insect damage at Nikkō promoted pilot survey of Sanbutsudō and Taiyū-in Nitenmon in 2009. This was followed by an extensive investigation using almost 30,000 sticky traps, placed in the buildings at the shrine complex in 2010 [33–36]. Additionally a more limited, but well-structured survey took place in

2016 [37]. The large survey reaffirmed that infestations in Sanbutsudō were dominated by *P. cylindricum,* but at Taiyū-in Reibyō Nitemmon (belonging to Rinnō-ji) most of the anobiids were *Trichodesma japonicum.* Traps from this large gate in the Taiyū-in complex showed the presence of anobiids, *T. japonicum* and *Sculptotheca hilleri*, but failed to reveal any *P. cylindricum* [34]. The distribution of beetles in the Sambutsu-do and the Taiyū-in Nitenmon were investigated using the large-scale survey data by Hayashi and colleagues [33–35]. Comb-clawed beetles (Family: *Tenebrionidae*) and reticulated beetles (*Cupedidae*) might also cause damage to infested wood at Nikkō, although they are not generally seen as pests for wooden heritage.

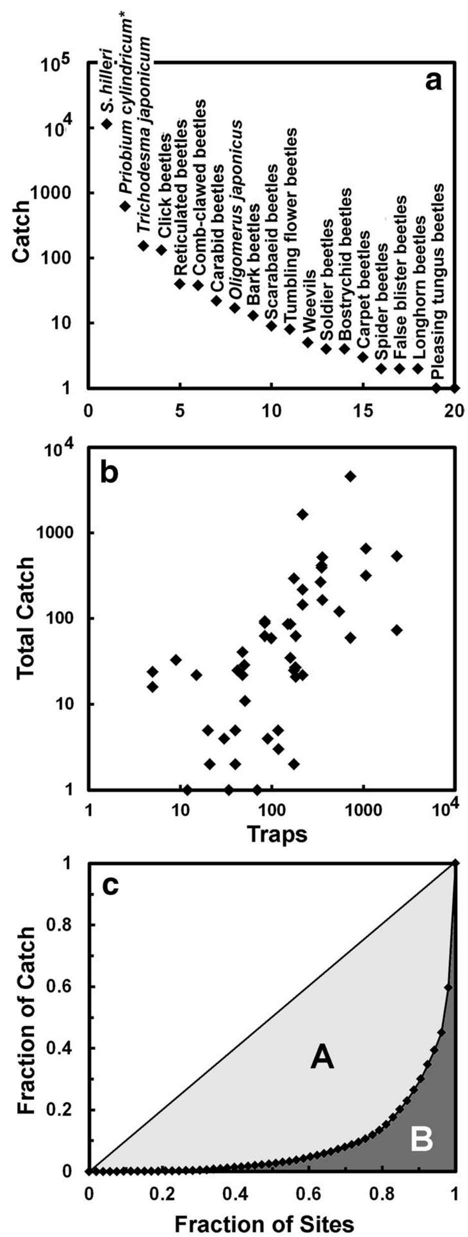

Fig. 5 **a** Insects at Rinnō-ji plotted as rank abundance. **b** Total catch at Rinnō-ji as a function of the traps set. **c** A Lorenz plot of the fraction the *S. hilleri* catch at Rinnō-ji as a function of the fraction of the number of sites to determine the Gini coefficient, which expresses the dispersion a the ratio the areas A/(A + B). Note: More formal names are Click beetles *Elateridae*; Reticulated beetles—Cupedidae; Comb—clawed beetles—Family: *Tenebrionidae*; Bark beetles—*Scolytinae*; Tumbling Flower Beetles—*Mordellidae*; Carpet beetles- *Dermestidae*; Spider beetle possibly *Ptinus japonicas*; Longhorn beetles—*Cerambycidae*

Analysis of insect catch

Using data from Hayashi et al. [35] we investigated the dependence of catch on trap density, building size, construction materials and local environment. Additionally we show the wide range of insect species caught at the buildings of Rinnō-ji in Fig. 5a, although many are not harmful to historic buildings. The most abundant of the species was *S. hilleri* and although it is recognized that damage probably arises from larger anobiids, rather than these numerous smaller insects. It can be sometimes difficult to distinguish the more damaging *P. cylindricum* from *Hadrobregmus pertinax*, but the later represents only 10% of the catch yet it is likely to be misclassified, so this combination is denoted as *P. cylindricum**. The *P. cylindricum** was rather abundant, but this is somewhat of an illusion of its presence as all but 40 of these insects caught were in a single building, Sambutsu-do. Nevertheless this implies that although an infestation only appeared in one building the insect is quite widely spread, so were conditions favorable outbreaks could occur at other locations. In a similar way the catch of *T. japonicum* were all from the loft of Taiyū-in Reibyō Nitemmon, so shows an uneven distribution.

Table 2 shows the distribution of the total catch from pooled data from the entire Nikkō site and at Rinnō-ji, is distributed between the lofts and basements, with the largest number of insects caught in basements. A somewhat similar picture emerges for the catch of different insect species *S. hilleri* and also *P. cylindricum**, but there are discrepancies particularly *P. cylindricum**, where a high catch in the attic largely arises from the infestation at Sanbutsudō.

Figure 5b shows that there is a rough relationship between the effort in trapping, expressed as the number of traps set out in a given building or rooms and the number of insects caught (mostly as *S. hilleri*). There is no evidence that so many insects are being caught that the population is being depleted, which might typically appear as a flattening of the curve when the number of traps is extremely large.

Following earlier work [5] the dispersion in the catch is represented as a Lorenz curve and its associated Gini

Table 2 The total catch, the catch of individual insect types loft-basement pairs the entire Nikkō site and at Rinnō-ji, along with Gini coefficients

	Total catch		***S. hilleri***		***P. cylindricum* H. pertinax**		**Click beetles**	
	Lofts	Basements	Lofts	Basements	Lofts	Basements	Lofts	Basements
Nikkō	5918	14,682	4886	11,533	419	315	23	190
Rinnō-ji	2907	9481	2247	8467	400	189	15	99

	S. hilleri		**Large Beetles**		**Click Beetles**		***P. cylindricum* H. pertinax**	
	Gini coefficient	**Standard error**	**Gini coefficient**	**Standard error**	**Gini coefficient**	**Standard error**	**Gini Coefficient**	**Standard error**
Nikkō	0.774	0.060	0.842	0.058	0.768	0.029	0.935	0.041
Rinnō-ji	0.780	0.098	0.840	0.049	0.726	0.049	0.934	0.030

coefficients, so frequently used in economics for describing income distribution of a population. The curve is plotted by arranging the catches from buildings in order of size, small to large and expressing the running cumulative total of these as a proportion of the complete catch. The x-axis is the proportion of the number of buildings that account for the cumulative proportion of the catch. The Gini coefficient expresses the dispersion as the ratio the areas A/(A + B) shown in Fig. 5c of the total catch in the sites at Rinnō-ji, which means that the coefficient is zero for situations where the same number of insects would be found in each building, which might rise to almost 1 in the case of extremely uneven distributions. The even distribution (coefficient is zero) is shown by the diagonal line.

The larger beetles are taken as the sum of the catch of *T. japonicum, P. cylindricum H. pertinax, O. japonicus* and the click beetles, but omitting the smaller *S. hilleri*. The calculated values are given in Table 2. Figure 5c shows the Lorenz plot of *S. hilleri* at Nikkō. This species along with the click beetles have the most even distributions and thus the smallest Gini coefficients, 0.78 and 0.73 (Table 2). By contrast *P. cylindricum/H. pertinax* reveal a high Gini coefficient of 0.93. This is because most of these beetles are found in just a few lofts and basements. Some 85% of the entire catch from the 42 sites at Rinnō-ji is found to come from the loft and basement of Sambutsu-do. The standard error is listed which allows us to gain a sense where the differences between the Gini coefficients are likely to be significant. The large beetles show a similar Gini coefficients to the *P. cylindricum/H. pertinax* because most of the large beetles come from these two species at Rinnō-ji.

Future of insects at Nikkō

While there is a potential for insects to increase as a result of climate change [38], future trends can be hard to detect and additionally influenced by food and habitat availability [39]. Although there is a potential for invasive species, there are also worries about the impact of climate change and urbanization reducing bees and butterflies [40] and in Japan dragonflies also [41]. There is little information about the temperature and relative humidity relevant to the development of anobiids found at Nikkō, typically causing a faster rate of growth and higher rates of reproduction. However, it is possible to approximate these through comparison with the tolerances observed by Fisher [42] in his studies of the deathwatch beetle some 80 years ago. He made laboratory studies of the egg development time, number of eggs and their viability as a function of relative humidity and temperature. Once the relative humidity is greater than 40%, it has little effect on the rate of development of the eggs. Temperatures between about 15 and 25 °C seem suitable for development of the eggs are typically required for the egg stage [43].

The degree days at Nikkō are best calculated using daily temperature data, but in the absence of an extensive set of daily data we established a best fit relationship between the number of degree days in a given month DD_{m} and the monthly average temperature T_{m}

$$DD_m = -0.0016 * T_m^4 + 0.0673 * T_m^3 + 0.1271 * T_m^{2-} 1.0255 * T_m$$

although when T_{m} fell below −4 °C it was neglected to avoid negative values of DD_{m}. The number of degree days

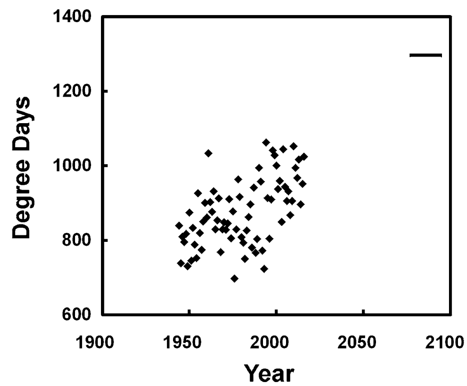

Fig. 6 The degree days at Nikkō established from monthly temperature observations

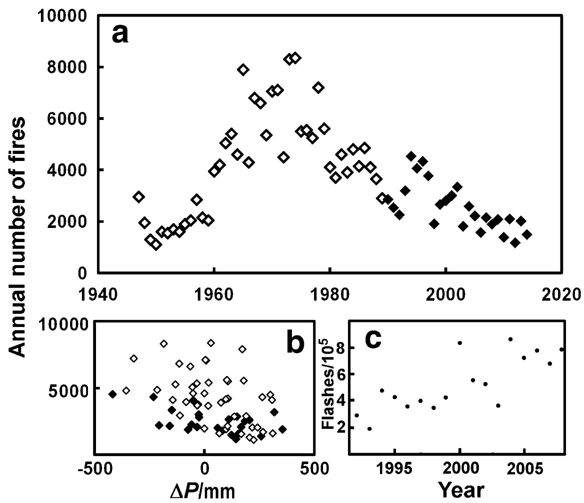

Fig. 7 **a** Annual frequency of forest fires in Japan distinguishing the earlier set of data (white diamonds) and those from 1990 (black diamonds). **b** The relationship between the deviation in annual precipitation from the 30-year mean (1981–2010) and the frequency of forest fires in Japan for both earlier and later periods. **c** The change in annual lightning flashes in Japan over recent decades

at Nikkō are shown in Fig. 6 along with estimates based on the increase that results from the warming at the end of the century under the A1 scenario for the EJP region that includes Nikkō. An increase in warmth is clear since the 1940s and this is set to continue through the current century. This increased number of degree days will likely decrease the amount of time required for beetle eggs to hatch or adults emerge. Such life cycle stages likely to occur earlier in the year as the century progresses because of the increasing temperatures predicted for Nikkō; similar changes are to be expected throughout much of Japan. Environmental controls on the life cycle of *Priobium* spp. are poorly known, but trial calculations would suggest that dates could easily occur a week or two earlier by the end of the century. There are some species of beetle which are dependent on the presence of fungi so may well be affected on the conditions that promote fungal growth.

Fires at Nikkō

Traditional Japanese buildings being of wood were frequently destroyed by fire and led to much concern in cities with the early development of official fire-watches and towers [3]. Pagodas were frequently struck by lightning which resulted in their destruction. As an example Toji, in Kyoto has caught fire three times after being struck since its construction some 1200 years ago. The Gojunoto Pagoda at Nikkō was destroyed in a fire started by lightning in 1815 and was rebuilt in 1818 by Sakai Tadayuki, a feudal lord of Wakasa Province (present day Fukui Prefecture). The dangers were well recognized so the Tokugawa government provided fireman (*Hachioji Sen-nin Doshin*) to protect the shrines and temples from 1652 with the construction of Taiyū-in. Their contribution continued until 1868 as celebrated on a memorial stone in the grounds of Rinnō-ji (Fig. 1). At the beginning of Meiji era, there was a large scale of fire at Rinnō-ji and Futarasan shrine had also suffered from fire. In 1961 there was a fire at Tōshō-gū Honji-do [44]. Official documents from the Agency of Cultural Affairs of the Government of Japan (2015) about Nikkō world heritage site under subheadings: climate change and natural disaster and fires comment on the concern over damage to surrounding forests due to lightning strikes and the appropriateness of lightning protection.

In the past fire suppression has been assisted by using nonflammable exterior materials such as clay-plaster. Additionally roofs have sometimes been designed so that they can rapidly be dismantled in case of fire. Further protection comes through digging networks of water channels to draw water from nearby rivers with weirs to control the flow such that it can be used in firefighting [10]. At Nikkō the issue is covered by UNESCO *World Heritage List* (http://whc.unesco.org/en/list/913) inscription: "As fire is the greatest risk to the property, the monuments are equipped with automatic fire alarms, fire hydrants, and lightning arresters. In addition, the property owners organize fire brigades which work in cooperation with public fire offices."

Forest fires are also a problem for the environment at Nikkō and lightning can initiate forest fires [45]. Figure 7a shows the frequency of forest fires in Japan since the 1940s [46]. The record is divided into earlier data and data after 1990 and the decline since 1990 represents a decrease of some 80 each year, using the Sen slope (-80.4 ± 21.5). The number of fires peaked in the

1960–80s and probably represents changes in forestry practice, so we need to be cautious in using the data to establish the role of climate change. This was a reason for dividing the data into two periods. The relationship between annual precipitation and the number of fires is shown in Fig. 7b, with both earlier and later data suggests a negative relationship between forest fires and rainfall (Kendall $\tau = -0.32$; $p_2 = 0.003$ and Kendall $\tau = -0.31$; $p_2 = 0.03$ respectively). i.e. drought years seem to encourage forest fires. Figure 7c taken from Shindo et al. [47] shows the number of lightning flashes per year over Japan and potentially hints at an increased threat from this source. Any increase in the threat of directs strikes on the Gojūnotō Pagoda could enhance the risk of fire so well maintained protection remains important Thus despite the potential for climate change to lead to more convective activity, fire suppression and forestry practice may serve to lessen the likelihood of serious fires from lightning strikes both on the building and within forests.

Landscape change and seasons at Nikkō

The temples and shrines are embedded in a forested landscape, which forms a magnificent backdrop to the site so that visitors can be as much attracted to the landscape as to the buildings. There is a distinct seasonal pattern with about twice as many visitors over the period April–November as in the rest of the year, with the peak month October when viewing the fall leaves is very popular (Fig. 2b). The seasons bring a range of new colours, and no doubt encourage many to return to Nikkō and autumn is an especially popular time as the colours are so vivid. However, the autumn colours arrive earlier by as much as 10 days compared to last century (Fig. 8a). Additionally in Japan the flowering of the cherry (*Prunus* spp.) is an important event and closely followed by the public as it moves northwards. The blossoms are seen as a metaphor for the transience of life and celebrated in the ancient practice of *Hanami*, which may involve picnicking under a tree in bloom or simply viewing the landscape covered with blossoms. At Nikkō springtime is heralded with the Yayoi Festival, which occurs between April 13th and 17th; floats decorated with cherry blossom are prepared and the leaders of local towns visit other towns to exchange ritual greetings. The alternate name for the festival, *Gota Matsuri* means festival of disputes, so any deviation from the ancient customs is seen as likely to cause trouble for the coming year; thus the date is necessarily fixed. Such celebrations are altered by climate change as the blooming dates of cherry blossoms in rural cities are occurring earlier (Fig. 8b), so the floats decorated in present-day Nikkō often use artificial blossoms because the natural ones have already fallen from the trees. Allen et al. [48] suggest shifts in flowering under the A1B emissions scenario, that over the coming century the cherry blossom may arrive some 30 days earlier than at present (see Fig. 8c), which means that the Yayoi Festival will seem increasingly late in terms of floral display.

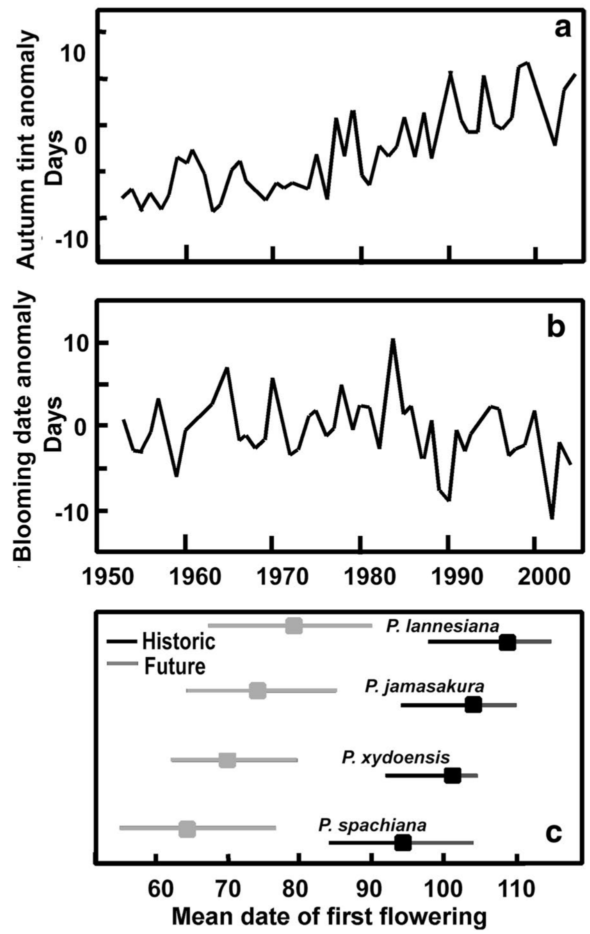

Fig. 8 **a** Long-term trend in the date of the autumnal tint of the Japanese maple [49] **b** Long-term trend in the anomaly of blooming dates of cherry blossoms in rural cities (JMA 2007). **c** The daily probability of first flowering of four species cherry blossoms and their 95% intervals (lines) for the historic (1981–2000) and future (2081–2100) periods [48]

Conclusions

There is already subtle evidence that environmental change is underway at Nikkō. This is likely to affect the risks imposed on the buildings, where warmer conditions could see enhanced biological attack. Protection from floods and heavy rain may need attention under future climates. As Nikkō is embedded in a forested landscape there are risks from forest fires or wood boring insects, so forest management need to account for likely changes in these threats. Future changes to climate are likely to affect visitor appreciation because of earlier flowering dates and a later arrival of autumn colours.

The UNESCO *World Heritage List* inscription reads "The inscribed property is owned by the Religious Organizations of Futarasan-jinja, Tōshō-gū, and Rinnō-ji, which are responsible for the management. Necessary repair works are conducted by the Foundation for Preserving Nikkō Shrines and Temples, which includes qualified conservation architects and skilled engineers". There is an impressive history to the management of the site and the transfer of craft skills over the centuries, this is especially derived through *Shikinen sengu* of the Shinto tradition that expresses an ideal that buildings meticulously disassembled and rebuilt at regular intervals. This has ensured continuity in the techniques. While the desire for professional qualifications expressed within the UNESCO inscription is admirable, as yet it is unclear whether architects and skilled engineers are always well versed in the environmental changes that are likely to confront Japan's heritage in the coming century, so a broadening education seems important.

Authors' contributions

Both authors contributed to the entire paper and although only MH read papers in Japanese, PB was involved in identifying important historical Japanese writings. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Data is available on the websites noted in the MS.

Consent for publication

Not required, although scientists at Nikkō have been made aware of the MS content.

Ethics approval and consent to participate

No ethical issues.

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