Japanese knotweed (*Fallopia japonica*): An analysis of capacity to cause structural damage (compared to other plants) and typical rhizome extension

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Fallopia japonica (Japanese knotweed) is a well-known invasive alien species in the United Kingdom and elsewhere in Europe and North America. The plant is known to have a negative impact on local biodiversity, flood risk, and ecosystem services; but in the UK it is also considered to pose a significant risk to the structural integrity of buildings that are within 7 m of the above ground portions of the plant. This has led to the presence of the plant regularly being used to refuse mortgage applications. Despite the significant socioeconomic impacts of such automatic mortgage option restriction, little research has been conducted to investigate this issue. The '7 m rule' is derived from widely adopted government guidance in the UK. This study considered if there is evidence to support this phenomenon in the literature, reports the findings of a survey of invasive species control contractors and property surveyors to determine if field observations support these assertions, and reports a case study of 68 properties, located on three streets in northern England where *F. japonica* was recorded. Additionally, given the importance of proximity, the 7 m rule is also tested based on data collected during the excavation based removal of *F. japonica* from 81 sites. No support was found to suggest that *F. japonica* causes significant damage to built structures, even when it is growing in close proximity to them and certainly no more damage than other plant species that are not subject to such stringent lending policies. It was found that the 7 m rule is not a statistically robust tool for estimating likely rhizome extension. *F. japonica* rhizome rarely extends more than 4 m from above ground plants and is typically found within 2 m for small stands and 2.5 m for large stands. Based on these findings, the practice of automatically restricting mortgage options for home buyers when *F. japonica* is present, is not commensurate with the risk.

1   Japanese knotweed (*Fallopia japonica*): An analysis of capacity to cause structural damage

2   (versus other plants) and typical rhizome extension

3

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13

14 **Abstract**

15

16 *Fallopia japonica* (Japanese knotweed) is a well-known invasive alien species in the United

17 Kingdom and elsewhere in Europe and North America. The plant is known to have a negative

18 impact on local biodiversity, flood risk, and ecosystem services; but in the UK it is also

19 considered to pose a significant risk to the structural integrity of buildings that are within 7 m of

20 the above ground portions of the plant. This has led to the presence of the plant regularly being

21 used to refuse mortgage applications. Despite the significant socioeconomic impacts of such

22 automatic mortgage option restriction, little research has been conducted to investigate this issue.

23 The '7 m rule' is derived from widely adopted government guidance in the UK. This study

24 considered if there is evidence to support this phenomenon in the literature, reports the findings

25 of a survey of invasive species control contractors and property surveyors to determine if field

26 observations support these assertions, and reports a case study of 68 properties, located on three

27 streets in northern England where *F. japonica* was recorded. Additionally, given the importance

28 of proximity, the 7 m rule is also tested based on data collected during the excavation based

29 removal of *F. japonica* from 81 sites. No support was found to suggest that *F. japonica* causes

30 significant damage to built structures, even when it is growing in close proximity to them and

31 certainly no more damage than other plant species that are not subject to such stringent lending

32 policies. It was found that the 7 m rule is not a statistically robust tool for estimating likely

33 rhizome extension. *F. japonica* rhizome rarely extends more than 4 m from above ground plants

34 and is typically found within 2 m for small stands and 2.5 m for large stands. Based on these

35 findings, the practice of automatically restricting mortgage options for home buyers when *F.*

36 *japonica* is present, is not commensurate with the risk.

37

1. Introduction

Japanese knotweed (*Fallopia japonica*) is a tall, herbaceous, perennial plant with woody rhizomes when mature. *F. japonica* is now recognised as one of the most problematic weeds in the UK and Ireland (Environment Agency, 2013; Property Care Association, 2018). It is also recognised as one of the worst invasive alien species (IAS) at a European scale (Nentwig *et al.*, 2017) and globally (Lowe *et al.,* 2000), being particularly invasive in parts of North America, Europe, Australia and New Zealand (CABI, 2018a). On a global scale its reputation as a problematic invasive alien species (IAS) primarily stems from its vigorous growth and impacts on riparian habitats (Child & Wade, 2000) coupled with difficulty of eradication (Bailey, 2013; Jones *et al.*, 2018). Verified impacts include the creation of dense monodominant stands (Gillies, Clements & Grenz, 2016; MDNR, 2012); reductions in ecosystem services in riparian zones, e.g. by impeding access (Environment Agency, 2013; Gerber *et al.*, 2008; Kidd, 2000; Urgenson, 2006); negative effects on native plant and invertebrate assemblages in riparian habitats (Gerber 2008); reductions in species richness (Aguilera *et al.*, 2010; Hejda *et al.*, 2009; Urgenson, 2006) and abundance of native understory herbs, shrubs, and juvenile trees in riparian woodlands (Urgenson, 2006); modifications to nutrient cycles (Urgenson, 2006); and impacts on flood defence through impeding water flow and facilitation of riverbank erosion (Booy, Wade & Roy, 2015; Environment Agency, 2013; Kidd, 2000).

The plant is associated with significant economic impacts in the UK, particularly in the development sector, due in large part to soil containing the species being classified as controlled waste, which can result in significant waste management costs (Williams *et al.*, 2010; Pearce, 2015). Economic impacts have been estimated at £166,000,000 per year (Williams *et al.*, 2010) in the UK; however, the validity of this, frequently misquoted, figure is strongly debated (Pearce, 2015).

Fallopia japonica was introduced to Europe from Japan in the mid-19th Century by the Bavarian Phillip von Siebold, a renowned importer of exotic plants at this time (Bailey, 2013). In 1850, von Siebold sent a package to Kew Gardens in London, which included a female (male sterile) *F. japonica* plant (Bailey, 2013). Once established in Kew Gardens it was distributed throughout the UK, being planted in Victorian parks and gardens (Bailey, 2013). Despite rumblings from

69 Victorian gardeners as far back as 1898, e.g. William Robinson (Bailey & Conolly, 2000), about

70 the plant's invasiveness, it was available for sale in UK nurseries up until at least 1990 (Philip,

71 1990). It was first recorded outside cultivation in South Wales in 1886 (Storrie, 1886) and is

72 currently recorded in most hectads within the UK and Ireland (BSBI, 2018; Figure 1A).

73

74 By the late 1970s, the invasive nature of *F. japonica* was becoming widely recognised (Bailey,

75 2013) in the UK (also see Section 2.1 below). Within the popular press and through various

76 online sources, *F. japonica* is increasingly sensationalised and is credited on a regular basis with

77 an ability to 'grow through concrete' and 'destroy building foundations' (e.g. Ellery, 2016;

78 Sweeny, 2017; Willey, 2018). Accordingly, in the 21st Century, property surveyors and lenders

79 started taking an increasingly risk-averse approach to the species (RICS, 2012). Ultimately, this

80 has led to the presence of *F. japonica* on or near a residential property preventing its sale (RICS,

81 2012; Pearce, 2015). Frequently, financial institutions will automatically restrict mortgage

82 options where *F. japonica* is within the boundary of the property or within 7 m of a habitable

83 space, conservatory, or garage. This '7m rule' is derived from widely adopted government

84 guidance, which states that *F. japonica* rhizome may extend 7 m laterally from a parent plant

85 (Environment Agency, 2013).

86

87 Where *F. japonica* is preventing a property sale, this issue can typically be eliminated if

88 evidence can be provided to a lender that an appropriate treatment programme, effective against

89 *F. japonica*, is in place (RICS, 2012). Such control programmes can be expensive; between

90 £2,000 and £5,000 in total for a typical three-bedroom semi-detached house (at December 2011;

91 RICS, 2012). Additionally, the stigma associated with the species can result in diminution of

92 property value (Santo, 2017) even following control action. The cumulative impact of the above

93 is that home owners can lose all, or a significant portion, of their property's value. This

94 automatic restriction of mortgage options where *F. japonica* is present on or near a property has

95 led to significant hardship and associated, often reported, emotional stress (Dunn, 2015; The

96 Telegraph, 2015). The claimed ability of *F. japonica* to cause significant structural damage is

97 widely acknowledged within the professional weed control sector in the UK as not being

98 representative of the vast majority of casual field observations and that, due to current public

99 perception, impacts on the market value of a property are out of proportion to the cost of

100 remediation (Santo, 2017).

101

102 In order to understand if the lender response to *F. japonica* presence, described above, is

103 proportionate, the impacts typically associated with *F. japonica* must be compared to those of

104 other plants. The potential for plants, in general, to cause issues in the built environment is well

105 understood. Accordingly, in the UK, developers follow guidance (NHBC, 2017) when building

106 near trees. The automatic restriction, however, of mortgage options due to the mere presence of a

107 plant species is a new phenomenon. Although this is currently a UK phenomenon, recent reports

108 have emerged of *F. japonica* presence impacting property sales in the Republic of Ireland

109 (personal correspondence: Collette O'Flynn, National Biodiversity Data Centre, Ireland, 2018),

110 suggesting that this issue has the potential to spread, and sensationalist articles have begun to

111 appear in North American tabloids (The Calgary Eyeopener, 2015).

112

113 Plants are known to cause damage to built structures primarily by three mechanisms: (i) indirect

114 damage, via subsidence or heave, caused by plant mediated modifications to soil water content

115 (Biddle, 2001; O'Callaghan & Kelly, 2005), (ii) direct damage due to physical impact, typically

116 associated with falling trees (O'Callaghan & Kelly, 2005), and (iii) direct damage caused by

117 physical pressure exerted through growth (Biddle, 1998, 2001).

118

119 There are many causes of subsidence, with plants only contributing to a proportion of the total

120 and only then on shrinkable clay soils. Plant mediated subsidence in such soils occurs when

121 plants remove water from the soil through a process called transpiration and, as a result of this

122 removal of water, the soil shrinks. This is particularly common during the summer months and/or

123 periods of drought. The soil swells again once water is returned via rainfall. If foundations are

124 not sufficiently deep or strong to withstand such stress, this process can lead to structural damage

125 over time, typically characterised by vertical cracks up through the brickwork. Swelling of soil

126 can also occur when mature trees, that were helping regulate soil moisture content, are removed

127 (NHBC, 2017).

128

129   While the mechanisms behind impact-based direct damage are relatively straight forward, a

130   range of factors — biological, chemical and physical — become relevant with respect to direct

131   damage caused by physical pressure. Plants acquire the energy they need to grow through

132   photosynthesis, which converts light energy, carbon dioxide and water into chemical energy that

133   can later be released to fuel the plant's activities. Driven by the energy produced by

134   photosynthesis, plant roots and rhizomes grow through the soil seeking water and nutrients.

135   Ultimately, using the products of both photosynthesis and the materials collected by

136   roots/rhizomes, plants grow (increase in biomass) and reproduce. These growing underground

137   plant structures follow the path of least resistance through the soil along water and/or chemical

138   gradients, typically from areas of low water or nutrient concentration to areas of higher water or

139   nutrient concentration (Rellán-Álvarez, Lobet & Dinneny, 2016). When solid structures (natural

140   or anthropogenic) are encountered by extending plant tissue, highly sensitive receptors on the

141   outer surface on the plant detect the change in pressure, resulting in the release of plant growth

142   regulators and chemical signals that stimulate differential growth rates within plant tissues,

143   ultimately causing the plant to grow away from the solid structure and find the path of least

144   resistance (Takeda *et al*., 2008) where possible. However, where a plant becomes trapped

145   between two structures and growth away from or around the structure is no longer possible, the

146   risk of damage increases. The greatest risk of direct damage occurs close to the main trunk, stem

147   or crown; this is due to incremental growth of such structures over time and secondary

148   thickening of the roots/rhizomes, which are thickest in close proximity to such structures.

149

150   The impacts of *F. japonica* on residential property sale and value are ultimately predicated on the

151   species' ability to cause significant structural damage, but this proposition has never been

152   scientifically tested. This paper, therefore, proposes a methodology for conducting such

153   assessments and implements the proposed methodology using a case study of 68 residential

154   properties in the north of England, with the aim of determining the capacity of *F. japonica* to

155   cause structural damage relative to other common plants in the UK. The paper also includes an

156   assessment of published records of *F. japonica's* ability to cause structural damage; an

157   assessment of how plants cause structural damage in the context of *F. japonica*'s biology; and an

158   assessment of the findings of two surveys conducted on members of the Royal Institution of

159   Chartered Surveyors (RICS) and the Property Care Association's (PCA) Invasive Weed Control

160   Group (IWCG). Additionally, given the importance of proximity, the 7 m rule is also tested,

161   based on an assessment of a survey carried out on members of the PCA IWCG, with the aim of

162   determining typical rhizome extension distance relative to above ground *F. japonica* plants.

163

164 **2. Materials & Methods**

165

166 **2.1. Study Species: *Fallopia japonica***

167

168 *F. japonica* is a tall, vigorous, clump-forming, herbaceous perennial, which grows up to 2–3 m in

169 height (Figure 2A) and often forms dense thickets. The stems are robust, bamboo-like, slightly

170 fleshy and hollow, with a diameter of up to 4 cm. Tall-brown to bronze canes remain over winter

171 and persist for approximately 3 years. Leaves are 10–15 cm long, lush, light green, and shield-

172 shaped with a flattened base (Figure 2B). Growth over successive years builds up a sturdy dense

173 crown at the base of canes (Figure 2C). New growth primarily emerges from crowns at the start

174 of the growth season, but also directly from rhizomes. Rhizomes are initially white, extremely

175 fleshy and fragile while extending (Figure 2D), but mature into yellow/orange sturdier woody

176 structures (Figure 2D). The majority of rhizome is found in the upper 50 cm of soil, but it can

177 penetrate down to 3 m and, depending on soil type and site features, spread up to 10 m from

178 parent plants is possible under very rare circumstances (Booy, Wade & Roy, 2015). Only female

179 (male sterile) plants are known to be present in the UK, which form drooping grape-like clusters

180 of flowers with distinct stigmas. Seeds are shiny, triangular, dark brown, 3–4 mm long, 2 mm

181 wide and sterile in the UK. See Booy, Wade & Roy (2015) for additional information on the

182 biology of the species. *F. japonica* can regenerate from rhizome fragments weighing as little as

183 0.7 g (Brock & Wade, 1992), providing a node is present, and stem sections, where suitable

184 conditions are present (very moist, well-lit soils with high nutrient availability). The species is

185 dispersed effectively in transported soil and by water (Environment Agency, 2013; Booy, Wade

186 & Roy, 2015). *F. japonica* is tolerant of a wide range of habitat and soil types, but is most

187 frequently found in disturbed urban habitats, particularly brownfield sites, railway verges and the

188 banks of waterways, where it thrives in damp soils.

189

190 *F. japonica* is closely related to two other members of the Fallopia genus, *F. sachalinensis* and

191 *Fallopia x bohemica*, which have similar invasive ranges and have similar impacts. Of note, in

192 some parts of its invasive range, *Fallopia x bohemica* spreads via the production of large

193 numbers of wind-dispersed viable seeds that germinate at rates approaching 100% in some

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194 populations (Gillies, Clements & Grenz, 2016). However, in the UK, spread by this means does
195 not currently occur in the UK.

196

197 **2.2. Literature Assessment**

198 In order to contextualise impacts associated with *F. japonica* within the larger subject of the
199 capacity of plants that cause structural damage, this study assessed various guidance documents
200 and papers published on the topic of plants causing damage and the relationship between various
201 plant traits and capacity to cause damage. The primary points of interest from these documents
202 are highlighted in Section 3.1.1. Additionally, a focused literature search on Web of Science was
203 conducted on 27th June 2017 to identify academic papers that provide reference to or evidence of
204 *F. japonica*-mediated damage to structures. The search terms used for the Web of Science search
205 were "Fallopia japonica" and "Polygonum cuspidatum", an old name for the same species, and
206 within the returned publications "damage". The abstracts were reviewed to determine what type
207 of damage was referred to within the paper.

208

209 **2.3. *F. japonica* Impact Survey**

210 A survey of *F. japonica* management contractors (PCA) and property surveyors (RICS) was
211 conducted to collect evidence either for or against the assertion that *F. japonica* is a major cause
212 of structural damage to properties. Survey forms were sent out to contractors and surveyors to
213 determine, based on their last field observation of *F. japonica*, the presence, if any, of damage
214 linked to the presence of the plant across a range of built structure types (see Table 1 for included
215 questions; see Supplemental Information 1 for individual responses). In total, 51 PCA members
216 and 71 RICS surveyors provided records relating to 122 properties (Table 1). Each respondent
217 was also asked how near the closest evident aboveground *F. japonica* plant was from the
218 residential building on the site that they had visited. This was cross-referenced against reports of
219 damage (Table 2). Yes/No responses are presented as raw numbers and converted to percentage
220 values and differences between PCA and RICS respondents were considered. Statistical analyses
221 were undertaken in PAST version 3.15 (Hammer et al., 2001).

222

223 **2.4. *F. japonica* Rhizome Extent Survey**

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224   The survey of PCA contractors also asked respondents to provide details, based on the last five

225   *F. japonica* excavation-based remediation works that they had conducted, on the above ground

226   area of *F. japonica* and to provide the horizontal (i.e. distance from visible above ground plants)

227   and vertical (i.e. distance from soil surface) extent of rhizomes encountered. In total, 26

228   contractors provided records of 81 excavations with sufficient detail (e.g. clear rhizome extent

229   linked to an identified individual stand) to be included in the assessment. Eight records were

230   removed due to reporting multiple stands, partial excavation or disturbed sites where it was not

231   possible to accurately determine the rhizome extent from an individual stand (see Supplemental

232   Information 1). Subsequently, stands were sub-classified into either "small" or "large"

233   categories. The small category included any plants that covered a soil area of 4 m^2 or less, aimed

234   at encompassing the typical size of stands found in small residential gardens. Stands covering an

235   area greater than this were placed into the large category. This allowed for an examination of the

236   relationship between above-ground area and rhizome extension, as well as an analysis of typical

237   rhizome extension. Data were tested for normality (Anderson Darling test) and difference

238   between stand categories (large or small) were tested using the Mann Whitney U test for non-

239   normally distributed data. Data analyses were conducted using PAST version 3.15 (Hammer et

240   al., 2001).

241

242

243   **2.5. Case Study**

244   A survey was conducted on 68 residential properties located on three streets in northern England.

245   The houses on all three streets were built prior to 1900 (CDRC, 2018). All properties have been

246   abandoned for at least ten years and were in a state of disrepair, with most having cracked patios

247   and crumbling brickwork (particularly on boundary walls). *F. japonica* was previously known to

248   be present on properties located on all three streets. An assessment was carried out in September

249   2017 to determine any constraints that the species might pose to restoration and re-development

250   (see Supplementary Information 2 for details). These sites represented a close to "worst case"

251   scenario in terms of susceptibility to damage from unchecked plant growth. With this in mind, a

252   survey was conducted to determine presence and associated damage for *F. japonica*, trees,

253   woody shrubs and woody climbers. All damage was compared against a baseline of existing

254   damage that was present due to neglect, weathering and wear and tear over the lifetime of the

255   properties, regardless of plant presence. Where plants were associated with damage to a
256   structure, the damage was quantified based on the scale presented in Table 3 (see also
257   Supplemental Information 2). Figure 3 presents examples of the rating scale that was applied.
258

259   By chance, a large number of *Buddleja davidii* (buddleia) plants were present at the case study
260   sites. As such, this species was included in the assessment separately from other woody plants.
261   *B. davidii* in a non-native woody shrub that is known to be invasive in the UK and elsewhere
262   (CABI, 2018b). Damage associated with the following species or plant groups are discussed in
263   this case study: *F. japonica*, *B. davidii*, 'trees' (other woody, independently standing mature
264   plants) and 'woody climbers' (woody plants that are not independently standing, e.g. attached to
265   walls). In addition to presence, for *F. japonica*, mature (with crowns) and immature (without
266   crowns) plants were assessed. Similarly, for *B. davidii*, mature (woody) and immature (not
267   woody) plants were considered.

268 **3. Results**

269

270 **3.1. Literature Assessment**

271

272 **3.1.1. Plants and Structural Damage**

273

274 The literature assessment revealed that indirect damage, typically characterised by subsidence

275 caused by modifications to soil moisture content, was by far the most relevant mechanism

276 identified by which plants caused major damage to built structures (Biddle, 2001; O'Callaghan &

277 Kelly, 2005) and high water-use tree species were the most likely plant type to cause this type of

278 damage (NHBC, 2017).

279

280 Such impacts are only a potential problem on shrinkable clay soils (Biddle, 2001; O'Callaghan &

281 Kelly, 2005). Clay soils are found in less than 50% of the United Kingdom and not all clay soils

282 will be extremely shrinkable. The degree to which a clay soil is shrinkable depends on its

283 mineral composition. All clay minerals are built from combinations of two types of molecular

284 sheet, (i) a sheet with repeating units of silicon surrounded by four oxygen atoms in a tetrahedron

285 and (ii) a sheet with an aluminium or magnesium atom surrounded by six oxygen or six hydroxyl

286 molecules in an octahedron. How these sheets are arranged determines how ridged the clay soil

287 is. For example, soils composed of alternating sheets, one tetrahedron followed by one

288 octahedron, and so on, and held together by a pair of hydrogen ions are quite ridged. However,

289 when an aluminium octahedral sheet is between two silicon tetrahedral sheets and held together

290 by weak oxygen bonds a clay called montmorillonite is formed, which is a relatively weak clay

291 susceptible to shrinkage (Chapman, 2012). Surveys by the Botanical Society of Britain and

292 Ireland (Figure 1A) show that *F. japonica* has been found in most areas of Britain but only a

293 small fraction of this area is identified by the British Geological Society as having moderate to

294 high risk of swell-shrinkage (Figure 1B), with most shrinkable clays being found in the south

295 east of England. Additionally, it is likely that the area at actual risk of plant-mediated shrinkage

296 is lower again because not all of this area necessarily has the correct mineral combination

297 required to be at high risk for facilitation of subsidence.

298

299   The second most relevant mechanism by which plants cause damage, was identified as direct

300   damage due to physical impact, typically characterised by trees falling and striking buildings and

301   power lines (O'Callaghan & Kelly, 2005) and is only relevant to large plants such as trees.

302

303   Finally, plants can also cause direct damage to buildings and structures by pressure exerted

304   through growth; however, this is comparatively rare in terms of meaningful damage; it is also

305   well understood (Biddle, 1998, 2001). While growth at the base of plants, or of roots near the

306   surface, exerts relatively small forces, paving slabs or low boundary walls can be lifted or pushed

307   aside. Heavy loaded or stronger structures are more likely to withstand these forces without

308   damage, as plants preferentially distort around such obstruction before damage occurs (British

309   Standard, 5837:2012). Certain combinations of variables can increase the potential for damage,

310   e.g. water leaking from damaged drains, sewers or water mains can encourage localised root

311   growth, as plants typically grow towards areas of higher water availability, which can lead to

312   roots/rhizomes entering a drain or sewer through the defect and proliferating, causing blockage

313   and an enlarging of the initial defect. The risks associated with direct pressure based damage are

314   (i) primarily associated with trees, (ii) vary for different types of structures, and (iii) diminish

315   rapidly with distance. Minimum recommended planting distances for young trees or new

316   planting, to avoid direct damage to a structure from future tree growth, are described in British

317   Standard (5837:2012) and range from (i) no minimum distance required for planting trees near

318   buildings, heavily loaded structures, services > 1 m deep, and masonry boundary walls, where

319   the tree will have a stem diameter below 0.3 m (at 1.5 m above ground level) at maturity to (ii) 3

320   m distance required for planting trees near paths and drives with flexible surfaces, paving slabs,

321   and services < 1 m deep, where the tree will have a stem diameter above 0.6 m (at 1.5 m above

322   ground level) at maturity (British Standard, 5837:2012).

323

324   These three mechanisms described above are evaluated against the biology and growth

325   characteristics of *F. japonica* in Sections 4.1 and 4.2.

326

327   Based on the literature assessment, there is essentially no evidence to support the claim that *F.*

328   *japonica* causes damage in excess of the norm for many plants. While evidence was found to

329   support the claim that trees can cause major damage, no such evidence could be found for *F.*

330   *japonica*. Of particular interest were records of insurance claims related to trees being involved

331   in subsidence issues: 12,800 such records, between 2002 and 2005, were identified by Mercer,

332   Reeves & O'Callaghan (2011), 1,030 of which met their criteria for records having sufficient

333   detail to assess and as being important from a subsidence risk perspective. The top five genera

334   implicated in subsidence-related insurance claims were Oak (*Quercus*), Ash (*Fraxinus*), Cyprus

335   (*Cupressus*), Maple (*Acer*), and Willow (*Salix*). At maturity, these trees frequently reach 24 m,

336   23 m, 20 m, 18 m, and 24 m respectively. No evidence of any insurance claims was identified

337   for *F. japonica* with respect to structural damage. While many recent papers include in their

338   description of *F. japonica* that the species can cause notable damage to built structures (e.g.

339   Mclean, S. 2010, Djeddour & Shaw, 2010), this claim is never supported by evidence.

340

341   Based on the search terms "Fallopia japonica" and "Polygonum cuspidatum", the Web of

342   Science search returned 778 journal papers published between 1937 and 2016. When the term

343   "damage" is included the number of papers dropped to 46. Five were removed for being

344   irrelevant. Of the remaining 41 papers, 15 focused on biocontrol, 20 on general biology/genetics,

345   two on ecological damage and two on other interactions. None of the abstracts suggested that the

346   papers would focus on structural damage but some did refer to it as a "known problem". This

347   highlights the limited academic engagement with the problem – it appears to be accepted without

348   supporting evidence that *F. japonica* causes clear and problematic structural damage.

349

350   **3.2. Survey Results**

351

352   **3.2.1. Survey results (reported damage)**

353   In total, 51 contractors and 71 surveyors responded to the survey. Details of the responses are

354   provided in Table 1 and Table 2. The results of the two property damage surveys (PCA and

355   RICS) showed clearly that reports for defects or structural damage to residential properties,

356   where *F. japonica* is present, were extremely rare (between 2% and 6%). As the survey data are

357   interpreted as a worse case situation, it is likely that more detailed surveys would reduce this

358   number, if better designed to discriminate between causation, exacerbation and correlation. This

359   statement is relevant to all types of damage reported. Reports of defects to lighter structures such

360   as sheds or paths were more apparent, with 35% (PCA) and 23% (RICS) of respondents noticing

361   such damage. Reports of damage to drains or subterranean services were low, 16% (PCA) and

362   3% (RICS). The only question to obtain a "yes" above 50% was for Question 4 from the PCA

363   contractor surveys where 51% noticed evidence for loss of amenity. However, only 18% of

364   surveyors considered that the *F. japonica* observed was likely to impact garden amenity (Table

365   1). There was also a clear difference between the responses of surveyors and contractors for

366   Question 3 (Table 1), with contractors reporting more damage than surveyors. It should be noted

367   that PCA contractor members are more likely to be called out where problematic stands of *F.*

368   *japonica* are present, which could account for the differences observed between groups. It could

369   also be explained by differences between the two groups with respect to training, perception or

370   bias. Investigating this was beyond the scope of the current study.

371

372   Each respondent was also asked how near the closest evident aboveground *F. japonica* plant was

373   from the residential building on the site that they had visited (Table 2). This was cross-referenced

374   (Table 2) against reports of damage, as per Question 1 (Table 1). One contractor (PCA) reported

375   damage caused by *F. japonica* (Table 1); in this case the closest reported plant to the property

376   was 1 m (Table 2). Four surveyors (RICS) reported damage caused by *F. japonica* (Table 1).

377   Two stated that the nearest plants were 0 m from the property, one stated 1 m from the property

378   and one stated 4 m from the property (Table 2). It is worth noting that the report at 4 m was for a

379   property built prior to 1900.   No other responses suggested that *F. japonica* had caused damage

380   to the residential property. Among contractors reporting no damage to the residential property,

381   25 reported *F. japonica* growing within 4 m of the residential property and a further nine

382   reported *F. japonica* growing within 7 m of the residential property. Among surveyors, 21

383   reported *F. japonica* within 4 m of the residential property and a further ten reported *F. japonica*

384   within 7 m of the residential property and none of these reports were linked to damage to the

385   property. See Table 2 for more detail.

386

387   **3.2.2. Survey results (reported rhizome extension)**

388   There was a statistically significant difference (Mann Whitney U; $p < 0.05$) in the horizontal

389   extent of *F. japonica* rhizomes between small and large stands, with larger stands found to have

390   further reaching rhizomes (Figure 4). None of the small stands included in the assessment had

391   rhizomes extending further than 4 m, and the majority (75%) had rhizomes extending 2 m or
392   less. The average rhizome extension reported for small stands was 1.4 m. Only one plant in the
393   large category had rhizome extension greater than 5 m (identified as a statistical outlier); all
394   other records were below 4 m and the majority (75%) had rhizome extensions of 2.5 m or less.

395

396   There was also a statistically significant difference (Mann Whitney U; p < 0.001) between the
397   large and small stands for vertical rhizome extent, with larger stands found to have deeper
398   reaching rhizomes (Figure 5). No records with vertical rhizome extent in excess of 3.5 m were
399   recorded. The small stands had rhizomes with a mean 1.02 m depth and a maximum of 2 m,
400   whereas the maximum vertical extent recorded for the large stands was 3.2 m and the mean was
401   1.64.

402

403   **3.3. Case study**

404   In all but the most severe examples, the level of damage caused by plants did not exceed damage
405   that was observed elsewhere within the study area in locations where plants were not growing. It
406   would appear, in the context of dilapidation, that plants are generally not the cause but rather an
407   accelerator to natural weathering and dilapidation.

408

409   *F. japonica* was identified within the boundary of six properties (five mature stands and one
410   immature stand) and the plant was identified within 7 m of the main building of a further 12
411   properties, leading to a total of 18 properties where *F. japonica* was within the area identified by
412   the "7 m rule" as being at risk. *B. davidii* was identified on 62 properties (31 mature and 31
413   immature). Trees were observed on six properties and woody climbers were observed on four.

414

415   In general, *F. japonica* was linked to less damage than the other species/species groups assessed
416   (Table 4). Where *F. japonica* was linked to damage, mature plants were more likely to
417   exacerbate the damage than to have been the original cause. There were no reported incidences
418   of immature *F. japonica* causing or exacerbating damage.

419

420   *F. japonica* was not linked to any damage to the main buildings. The three other groups were
421   linked to damage, at varying degrees, typically in the form of simple co-occurrence (e.g. as in

422 appearing together without a clear causal link) or interference with brickwork through
423 exacerbation of existing weakness. Mature woody *B. davidii* was more likely to exacerbate
424 damage than immature *B. davidii*, with immature *B. davidii* rarely exceeding co-occurrence or
425 minor exacerbation. There was only one example of a plant being linked to causing direct
426 damage to a building, rather that exacerbating it. This was a tree falling against a house.

427

428 With respect to damage to walls, *F. japonica* was correlated with two occurrences of damage; in
429 both cases it was emerging from a crack and causing no detectable variation away from baseline
430 damage elsewhere in the wall. The three other plant groups were linked to more damage than *F.*
431 *japonica*, to varying degrees, typically in the form of simple co-occurrence or interference with
432 brickwork through exacerbation of existing weakness. In all groups, the average damage score
433 was higher than that of *F. japonica* (Table 4). Mature woody *B. davidii* was more likely to
434 exacerbate damage than immature *B. davidii*, with immature *B. davidii* rarely exceeding co-
435 occurrence or minor exacerbation. There were only two examples of a plant being linked to
436 causing damage to walls, rather than exacerbating it, a tree pushing over a boundary wall and *B.*
437 *davidii* pushing over a small retaining wall.

438

439 With respect to damage to paving, *F. japonica* was correlated with six occurrences of damage. In
440 three cases it was emerging from a crack and causing no detectable variation away from baseline
441 damage elsewhere in the paving, and in three other cases it was exacerbating existing damage
442 (one minor, two moderate examples). *B. davidii* was linked to more damage to paving than *F.*
443 *japonica*, typically in the form of simple co-occurrence or interference with paving through
444 exacerbation of existing weakness. The average damage score was considerably higher for *B.*
445 *davidii* than *F. japonica*. Mature woody *B. davidii* was more likely to exacerbate damage than
446 immature *B. davidii*, with immature *B. davidii* rarely exceeding correlation or minor
447 exacerbation. There was only one example of a plant being linked to causing damage to paving,
448 rather that exacerbating it, which was a tree where the roots had lifted a large area of concrete
449 paving with significant associated cracking.

450

451   **4.   Discussion**

452

453   **4.1. Indirect damage: in the context of *F. japonica***

454   Plants are considered to cause structural damage to buildings primarily through indirect damage,

455   e.g. through subsidence caused by modification to soil water content. High water-use tall trees

456   are the main plant type implicated. Subsidence, with respect to plants, is only an issue on

457   shrinkable clay soils, which are reasonably restricted in extent (Figure 1). Importantly, to

458   properly assess risk, individual site investigation is required to determine the exact type of clay

459   present in a clay-soil area. The rate that water is removed from soil by plants varies depending on

460   the characteristics of the plant and also by the total biomass of the plants. There is a strong linear

461   relationship between water use and plant biomass (i.e. larger plants remove more water from the

462   soil), as noted by Nielsen *et al*., (2015). Plants with higher water use and larger biomass are

463   therefore the most likely to cause subsidence through the action of their roots removing water

464   from soil. Some unpublished work suggests that *F. japonica* may be a high water use plant

465   (Guzner, Galster & Vanderklein, 2013); however, even if this is the case, it is not a high biomass

466   plant by comparison to mature woody trees such as oak. The plants that are most likely to

467   influence subsidence in the UK are listed in the NHBC (2017) guidance for building near trees.

468   These species range in height between 10 m and 28 m. In comparison, *F. japonica* typically only

469   grows to between 2 m and 3 m. The potential for plants to influence subsidence is calculated

470   based on a zone of influence of between 0.5, 0.75, and 1.25 times the height of the plant (NHBC,

471   2017), depending on the water demand at maturity of the species in question (low, moderate, or

472   high, respectively). For *F. japonica*, this would suggest a maximum zone of influence of 3.75 m

473   (the typical maximum height of the plant is 3 m, hence 3 x 1.25). However, when compared to

474   mature trees, given the comparatively diminutive size of *F. japonica*, both in terms of above

475   ground and below ground biomass, it is more likely to be at the lower end of the scale. As such, a

476   calculation of 0.5 x 3 = 1.5 m or 0.75 x 3 = 2.25 m is more likely to reflect the potential zone of

477   influence of *F. japonica* at maturity. Furthermore, the mean rhizome length of small *F. japonica*

478   stands, such as those more likely to be found in residential properties, is 1.4 m (Section 4.2 and

479   Figure 4), which falls comfortably within the lower zone. Such areas of influence are unlikely to

480   be able to create a large enough area of soil shrinkage to impact all but the flimsiest of structure

481   and, even then, only on properties shown to have shrinkable clay soil. As such, the risk

482   associated with *F. japonica* causing subsidence based damage falls well below many other

483   species commonly found in properties in the UK.

484

485   **4.2. Direct damage: in the context of *F. japonica***

486   In some situations, trees and vegetation can adversely affect structures by direct action, e.g.

487   structural failure of trees (collapse and impact), impact of branches with superstructures,

488   displacement/lift/distortion, and disruption of underground services and pipelines (British

489   Standard, 5837:2012).

490

491   The leading causes of damage due to direct physical contact by plants, i.e. collapsing vegetation

492   striking buildings and power lines and branch impact, are not relevant in any meaningful way to

493   *F. japonica* as the species is not tall enough and does not possess heavy enough aboveground

494   structures. This is due to the fact that *F. japonica* aboveground material dies back at the end of

495   each growth season; as such, the plant cannot accumulate sufficient above ground size and weigh

496   from successive years of growth.

497

498   Plants can also cause damage by exerting accumulating physical pressure on structures as they

499   grow over time; however, as stated above, this is comparatively rare in terms of meaningful

500   damage. Damage of this type is typically characterised by superficial or cosmetic damage to

501   paving. However more significant damage can occur where plants become trapped between two

502   structures, e.g. two walls in close proximity to each other, and are allowed to exert pressure for

503   an extended period of time without intervention (i.e. woody plants are allowed to mature in areas

504   where management would be advisable) or where roots find their way into drains and pipes, as

505   described above. The mechanisms by which plants grow and cause such damage are well

506   understood (Biddle, 1998, 2001), as are the planting distances required to limit or avoid such

507   damage (British Standard, 5837:2012). While *F. japonica* can cause such damage due to direct

508   action over time, it does not exceed that caused by woody species. The case study described in

509   this paper demonstrates that *F. japonica* is less capable of causing this type of damage than trees

510   and woody shrubs. Where *F. japonica* is implicated in such damage, this is likely to typically be

511   a result of the plant exploiting a weakness or defect that was already present, rather than the plant

512   initiating the damage, or it is simply a case of *F. japonica* emerging from an existing crack

513 without influence. Regardless, even if it is assumed that *F. japonica* can equal trees in causing

514 such damage (which is not the case), based on well understood principles (British Standard,

515 5837:2012), a safe distance for mature *F. japonica* (crowns between 30 and 60 cm) would be 0.5

516 m for buildings and heavily loaded structures, and 1.5 m for paths and drives with flexible

517 surfaces or paving slabs.

518

519 Additionally, the frequently stated ability of *F. japonica* to 'grow through concrete' is simply not

520 supported by any evidence, as it is not possible due to the laws and principles of physics and

521 biology. The extending tip of the *F. japonica* rhizome is remarkably soft and fleshy (Figure 1)

522 and it would be impossible for it to grow through intact concrete; however, these same

523 characteristics make the extending rhizome adept at finding cracks and *F. japonica* has been

524 shown to have significant ability to alter the direction of rhizome growth (Smith *et al*., 2007),

525 highlighting the plant's biological preference to go around obstructions, rather than through

526 them. Where *F. japonica* is implicated in such damage, existing cracks or weaknesses are

527 always present.

528

529 **4.3. Typical Rhizome Extension**

530 When the above is considered, the typical maximum rhizome extension of *F. japonica* is not all

531 that relevant with respect to structural damage. Regardless, the results of the survey detailed

532 above demonstrate that even large stands of *F. japonica* do not usually produce rhizomes that

533 extend further than 4 m, showing that the "7 m rule" is not a statistically robust tool for

534 estimating likely rhizome extension from above ground plants. The mean rhizome extent for

535 small stands was 1.4 m and for large stands (above 4 m^2) was 2.02 m. Similarly, the mean

536 vertical extent recorded averaged between 1.02 m for the small stands and 1.64 for the large

537 stands, with a maximum of 3.2 m.

538 **5. Conclusions**

539 The biology of *F. japonica* makes it less capable of causing significant structural damage than
540 many woody plant species. This conclusion has been reached for all three of the main
541 mechanisms by which plants are known to cause structural damage: subsidence (indirect);
542 collapse and impact (direct); and accumulating pressure due to growth (direct).   There is
543 essentially no support for *F. japonica* as a major cause of damage to property in the literature,
544 and this study found that *F. japonica* is less likely to cause damage than other common species.
545 Based on the results obtained though surveys completed by PCA members, it is clear that the '7
546 m rule' is not a statistically robust tool for estimating likely rhizome extension. *F. japonica*
547 rhizome rarely extends more than 4 m from above ground plants and is typically found within 2
548 m for small stands and 2.5 m for large stands. When this is considered in conjunction with the
549 water-use requirements of an herbaceous perennial, and the limited presence of shrinkable clay
550 soils in the UK, the likelihood of *F. japonica* as a major cause of structural damage depletes even
551 further. While *F. japonica* is clearly a problematic invasive non-native species with respect to
552 environmental impacts and land management, this study provides evidence that *F. japonica*
553 should not be considered any more of a risk, with respect to capacity to cause structural damage
554 in urban environments, than a range of other species of plant, and less so than many. In this
555 context, although the impacts of *F. japonica* on biodiversity and other ecosystem services remain
556 a cause for concern, there is no evidence to support automatic mortgage restriction based on the
557 species' presence within 7 m of a building.

558

559 **Acknowledgements**

570

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744

Table 1(on next page)

Results from yes/no questions to contractors and surveyors.

Results are presented as percentages for easier comparison between contractor and surveyor respondents and rounded to the nearest whole number. The actual number of responses are included in brackets. n = sample size. Three surveyors did not answer the third and fourth questions making n = 68 for those responses. (See supplemental information 1 for more details.)

Question	Contractor responses (n = 51)		Surveyor responses (n = 71)	
	Yes	No	Yes	No
Q1: Was there evidence of defects or structural damage to the residential building caused by the Japanese knotweed?	2% (1)	98% (50)	6% (4)	94% (67)
Q2: Was there evidence of defects or structural damage to retaining garden walls, sheds, garages, greenhouses or lightly built garden structures caused by the Japanese knotweed?	35% (18)	65% (33)	23% (16)	77% (55)
Q3: Was there evidence of defects or structural damage to drains, sewers and other subterranean services caused by the Japanese knotweed?	16% (8)	64% (43)	3% (2)	97% (66)
Q4: Was there evidence of loss of amenity to the garden or grounds resulting from the presence of Japanese knotweed?	51% (26)	49% (21)	18% (13)	82% (55)

1

2

Table 2(on next page)

F. japonica proximity to residential properties as reported by survey respondents and number of reports of damage (see supplemental information 1 for more details).

1

Distance from residential property in 1 m bins until 11 m	Number reported by contractors; n = 46. Reports of damage in brackets.	Number reported by surveyors (n = 65). Reports of damage in brackets.
0 – 1.0	10 (**1**)	9 (**3**)
1.1 – 2	8 (0)	3 (0)
2.1 – 3	4 (0)	7 (0)
3.1 – 4	2 (0)	6 (**1**)
4.1 – 5	3 (0)	5 (0)
5.1 – 6	3 (0)	1 (0)
6.1 – 7	3 (0)	4 (0)
7.1 – 8	2 (0)	3 (0)
8.1 – 9	2 (0)	1 (0)
9.1 – 10	2 (0)	8 (0)
10.1 – 11	No record	1 (0)
11.1 – 20	4 (0)	9 (0)
20.1 – 30	2 (0)	4 (0)
30.1 – 40	No record	No record
40.1 – 50	No record	3 (0)
50.1 or greater	1 (0)	1 (0)

2

3

4

Table 3(on next page)

Scale used to quantify damage where plants were present.

1

Rating	Rating description
0	Not associated with damage (e.g. just growing in soil or present beneath the soil)
1	Correlation with existing damage (e.g. emerging from a crack in paving or a gap in brickwork, but with no detectable variation away from baseline damage)
2	Minor exacerbation of existing damage (e.g. a detectable increase in crack width away from baseline damage)
3	Moderate exacerbation of existing damage (e.g. a detectable addition to damage away from baseline damage, i.e. new cracks forming around an initial crack)
4	Major exacerbation (damage beyond cracking, e.g. a damaged wall becoming undermined)
5	Causing minor damage (e.g. creating a crack)
6	Causing medium damage (e.g. creating a crack which has spread to form additional cracks)
7	Causing major damage (damage beyond cracking, e.g. a previous undamaged wall becoming undermined, or concrete hard standing being significantly lifted and cracked, or a roof being smashed in due to collapse)

2

3

Table 4(on next page)

Summary data of damage linked to each of the different plant classes included in the survey.

Av. damage score = the average damage value assigned to each species for each particular type of damage. For *F. japonica* % of properties with the species present includes those with a Knotweed plant within 7 m of the main residential building (see supplemental information 2).

1

	Plant damage to house			Plant damage to walls			Plant damage to paving		
	Plants linked to damage, % of occurrences	Plants linked to damage, % of total properties	Av damage score	Plants linked to damage, % of occurrences	Plants linked to damage, % of total properties	Av damage score	Plants linked to damage, % of occurrences	Plants linked to damage, % of total properties	Av damage score
F. japonica	**0%** 0/18	**0%** 0/68	0	**11%** 2/18	**3%** 2/68	0.029	**33%** 6/18	**9%** 6/68	0.176
B. davidii	**68%** 42/62	**62%** 42/68	0.75	**79%** 49/62	**72%** 49.68	1.529	**73%** 45/62	**66%** 45/68	0.824
Trees	**33%** 2/6	**3%** 2/68	0.132	**67%** 4/6	**6%** 4/68	0.235	**50%** 3/6	**4%** 3/68	0.176
Woody Climbers	**75%** 3/4	**4%** 3/68	0.103	**75%** 3/4	**4%** 3/68	0.044	**0%** 0/4	**0%** 0/68	0

2

Figure 1

Distributions maps showing *F. japonica* records and soil shrink-swell potential.

(A) Records from the Botanical Society of Britain and Ireland live database based on presence/absence data in each hectad. Almost all hectads report fewer than 100 records. Map was produced using records collected mainly by members of the Botanical Society of Britain and Ireland (BSBI, 2018). (B) British Geological Society map showing areas at risk of shrink-swell action. Reproduced with the permission of the British Geological Survey ©UKRI. All rights Reserved (BGS, 2018).
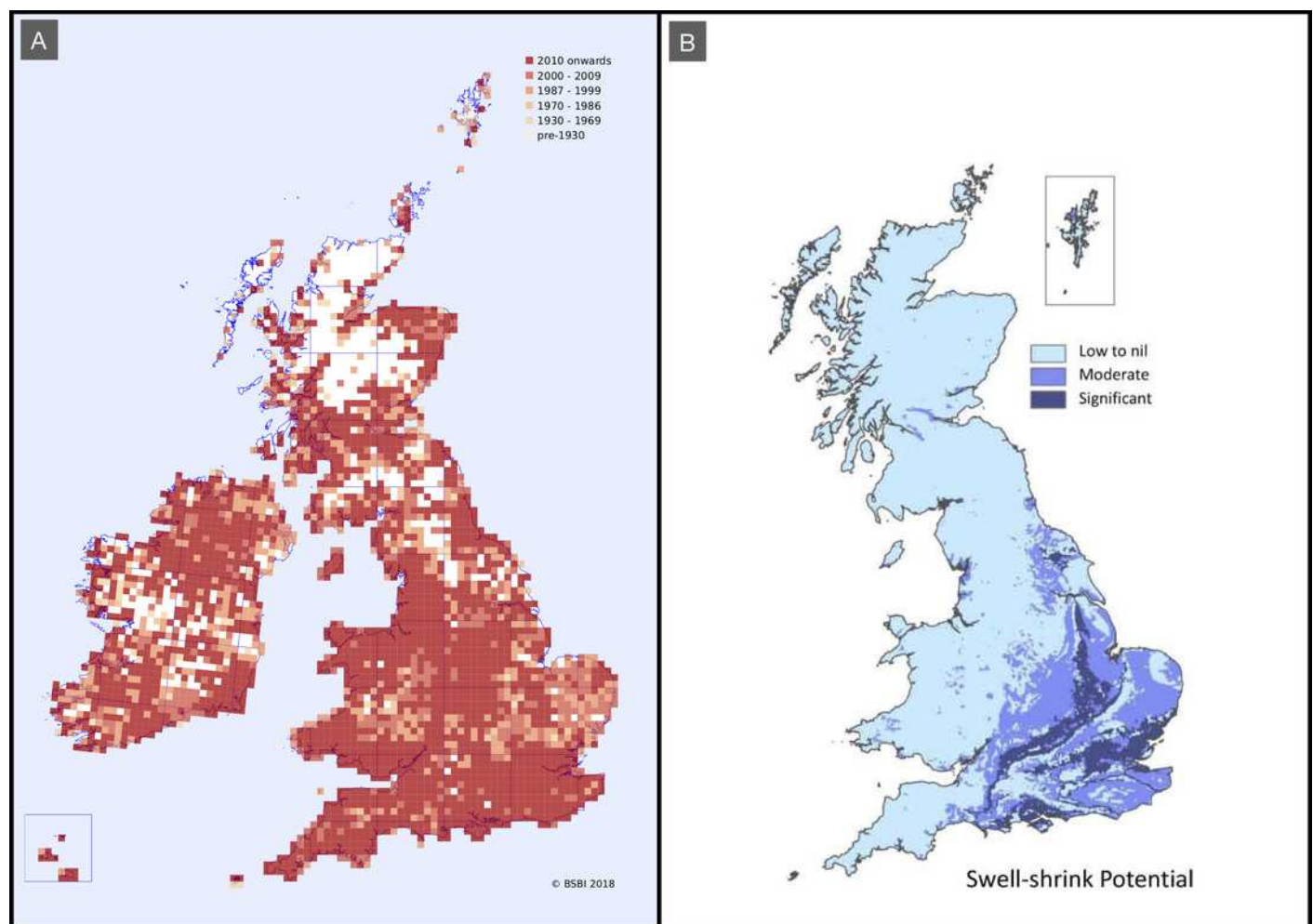
Figure 2

Photographs illustrating *F. japonica* appearance and structure.

(A) *F. Japonica* growing within the case study area. (B) Specimen of *F. japonica* leaves, stem and inflorescence. (C) *F. Japonica* crown, associated with the plant from panel A. (D) Specimen of *F. japonica* mature rhizome with immature rhizomes emerging. Photos by M. Fennell.

Figure 3

Photographs illustrating examples of the rating scheme that was applied.

(A) Example of non-plant-based wear and tear to hard standing. (B) Rating '0' - *B. davidii* growing in a raised landscaping area, having no discernible impact on undamaged adjacent built structures. (C) Rating '1' - *F. japonica* emerging from existing cracks in paving at the base of a wall, causing no discernible impact away from baseline damage. (D) Rating '2' - *F. japonica* emerging from existing gaps in worn paving, while the gab has not been widened some mortar has been punched aside. (E) Rating '3' - *B. davidii* growing out of a crack in worn concrete hardstanding, with additional cracks forming in the area. *F. japonica* visible in the background emerging from similar cracks in the hardstanding, also exacerbating existing damage but to a lesser extent. (F) Rating '3' - *B. davidii* growing out of cracks in worn brickwork, with additional cracks forming in the area. (G) Rating '4' - *B. davidii* growing out of cracks in worn brickwork. It has found its way between two structures and is facilitating the dilapidation of the wall and pushing out brickwork. (H) Rating '6' *B. davidii* growing behind a small retaining wall and pushing some brickwork over. (I) The remains of a tree stump, which have destabilised the base of what remains of a dilapidated wall. Photos by M. Fennell.

Figure 4(on next page)

Comparison of horizontal rhizome extent between small (4 m^2 or less) and large (greater than 4 m^2) stands of *F. japonica*.

The box represents the lower 25 percentile, the median value and the upper 25% percentile and the whiskers represent the range of the data. The circle represents an outlier value (greater than two standard deviations away from the median value). Mann Whitney U: U = 412; p < 0.05 (p = 0.01802). N = 21 (small) and 60 (large).
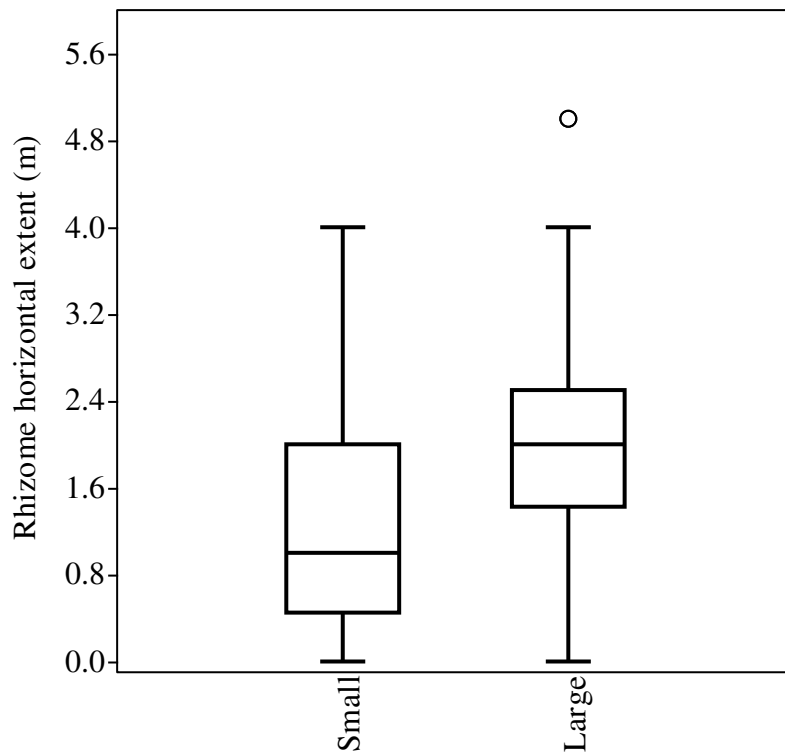
Figure 5(on next page)

Comparison of vertical rhizome extent between small (4 m^2 or less) and large (greater than 4 m^2) stands of *F. japonica*.

The box represents the lower 25 percentile, the median value and the upper 25% percentile and the whiskers represent the range of the data. The circle represents an outlier value (greater than two standard deviations away from the median value). Mann Whitney U: U = 260; p < 0.0001 (p = 6.105^{e-5}). N = 21 (small) and 60 (large).