Legibility of Prints on Paper Made from Japanese Knotweed

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The spread of invasive alien plant species (IAPS) is a leading reason for worldwide environmental change due to their effects on biodiversity and humans. Some valued goods from IAPS have been produced, *e.g.* paper that consists of cellulose fibres from Japanese knotweed. Therefore, the aim of this study was to establish the usability of this paper grade as a printing substrate, since it does not have ideal optical properties as it is expected from commercial office paper. Because it is widely used, inkjet printing technology was employed. Print permanence is essential, especially when printing documents. However, typographic characteristics must be considered to make a text more legible. Two widely used typefaces (Arial and Times) were tested in three commonly used type sizes (8 pt, 10 pt, and 12 pt). The results showed that the paper made from Japanese knotweed could have valuable properties and suitable legibility, especially when using typefaces with a moderate counter size, high x-height, and minimal differences in the letter stroke width to obtain an appropriate typographic tonal density with an adequate type size. Even after exposure to light, the texts printed in a proper type size and stroke width remained visible.

Keywords: Colorimetric properties; Inkjet printing; Invasive alien plant species; Japanese knotweed paper; Legibility; Typography

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INTRODUCTION

Invasive alien plant species (IAPS) cause problems worldwide (Simberloff 2014; Foxcroft *et al.* 2017). They have widespread impacts on ecosystems from the local level to the landscape level (Coutts *et al.* 2010; Mattos and Orrock 2010; César de Sá *et al.* 2019). Their influence comes from their ability to replace a diverse ecosystem with a single plant species or impoverished ecosystem, directly threatening native flora and fauna, and altering the chemistry of soil and geomorphological processes (Kimber 2017a; Lavoie 2017). Invasive alien plant species also have socio-economic impacts on human well-being (Simberloff *et al.* 2013). The economic costs of controlling and containing already established IAPS are very high (Hulme 2006; Jones *et al.* 2018). Therefore, prevention, early detection, raising awareness, and rapid response are crucial to avoid further spreading of these species (European Union 2014). Engaging citizens to help with the early detection of IAPS could be very valuable (European Union 2014; César de Sá *et al.* 2019). Both ecologists and the community benefit from such engagement, as they are both informed of the location of IAPS (César de Sá *et al.* 2019; Pagès *et al.* 2019). In addition, citizens can improve their ecological knowledge and increase ecological awareness and community affiliation (Vaz *et al.* 2017; McGinlay *et al.* 2018; Shackleton *et al.* 2019).

Japanese knotweed (*Fallopia japonica*) is a widely spread IAPS in Europe and the USA (Lavoie 2017). The plant has lush green leaves, dense annual stems, and a rhizome crown at the plant base (Kimber 2017b; Jones *et al.* 2018). It is a fast-growing competitor that effectively adapts its growth to environmental conditions (Jones *et al.* 2018). Therefore, it is among the most invasive non-native plant species worldwide. However, it can have a positive impact and aid certain ecosystems (Kimber 2017b; Lavoie 2017), as its presence in a riparian habitat provides cover for otters and nesting birds, and its flowers can provide nectar. The plant can also be used as a source of food, dyes (Kimber 2017b; Lavoie 2017; Jaroszewska *et al.* 2019), or cellulose fibres (Vijayan and Joy 2018) that can be used in paper production (Lavrič *et al.* 2018).

Several studies (Ali *et al.* 1993; Saikia *et al.* 1997; Zhang *et al.* 2013; Jaroszewska *et al.* 2019; Wang *et al.* 2019) reported that papers made from different fast-growing annual plant species had adequate strength properties. An additional study (Lavrič *et al.* 2018) established that the fibre processing and papermaking processes should improve printability by increasing whiteness (elemental chlorine-free (ECF) delignification) (Anderson and Amini 1996; Johnson *et al.* 1996) and decreasing roughness (intensive calendering) (Ullrich 2003; Černič 2008; Li *et al.* 2015; Rizduan *et al.* 2016). The aim of this study was to examine the usability of paper with included cellulose fibres extracted from Japanese knotweed (Japanese knotweed paper) as a printing substrate.

One of the leading digital printing technologies that has recently gained importance is inkjet printing technology. Its main advantages are low cost and reliability (Hudd 2010). Therefore, this printing technology is widely used in the home environment and for printing documents intended for storage. For the latter, the permanence of prints is essential, especially when they are influenced by interconnected external factors, such as light, heat, and humidity (Možina *et al.* 2010; Rat *et al.* 2011; Blaznik *et al.* 2013). Though the ageing of prints cannot be prevented, document permanence can be improved by choosing the correct substrate and printing ink. Using pigment-based inks instead of dye-based inks results in better colour fastness (Wnek *et al.* 2002; Medley 2009; Hudd 2010). Additionally, paper coating can influence the colour resistance of inkjet prints (Feller 1994; Vikman 2004; Kandi 2013).

The visual presentation of information affects legibility. Many studies on legibility highlight its importance (Reynolds 1988; Bix *et al.* 2003; Tai *et al.* 2010; Sharmin *et al.* 2012; Možina *et al.* 2019). Some typeface characteristics must be considered to increase legibility, such as counter shape, x-height, ascender, descender, serifs, stroke weight, set width, type size, and leading (space between lines) (Reynolds 1988; Gaultney 2001; Tracy 2003; Legge and Bigelow 2011; Možina *et al.* 2019). The height of un-extended lowercase letters (*e.g.*, a, c, m, r, u, and x) is called x-height. Furthermore, x-height refers to the visual angle, which affects reading speed (Legge and Bigelow 2011). The ascender is the part of a lowercase character (*e.g.*, b, d, h, and k) that extends above the height of the lowercase x. The descender is the part of a character (*e.g.*, p, q, and y) that descends below the baseline. The small projections extending off the main strokes of characters are called serifs. Set width defines the width of a letter (Bringhurst 2002; Možina 2003; Možina *et al.* 2019). The optimum type size for a continuous text is either between 9 pt and 11 pt (1 pt = 4.233 mm) (Reynolds 1988) or between 8 pt and 12 pt (Možina 2003). However, a precise type size depends on the x-height of a typeface, and typefaces with larger x-heights are generally more legible at small sizes (Gaultney 2001; Bix 2003; Možina 2003; Wilkins *et al.* 2009; Legge and Bigelow 2011; Možina *et al.* 2019). In typography design, typographic tonal density (TTD) or typographic tonality should also be considered. Typographic tonality refers to the relative blackness of type on a page, which can be expressed as the relative amount of ink per square centimetre, pica, or inch (Keyes 1993). The changes in various type characteristics can influence typographic tonal density, which affects text legibility (Reynolds 1988; Možina 2003; Možina *et al.* 2013, 2019).

The aim of this study was to establish the usability of paper with included cellulose fibres extracted from Japanese knotweed (Japanese knotweed paper), *i.e.*, air-dried biomass plant steams (without leaves, flowers and roots) (UIA 2018). The paper properties, colorimetric properties, and typographic properties of inkjet prints on Japanese knotweed paper were measured and compared to prints on commercial office paper. Furthermore, the influence of light on colorimetric and typographic properties was examined. To evaluate legibility, a group of observers read texts in two different typefaces and in three different type sizes printed on both paper types.

EXPERIMENTAL

Materials and Methods

Paper Properties

To assess the printability of Japanese knotweed paper, its properties were compared with those of widely used commercial office paper used in the home environment and for printing documents intended for storage. Both papers were machine produced, *i.e.*, Japanese knotweed paper was produced on an Andritz paper machine (Andritz AG, Graz, Austria, located in Pulp and Paper Institute, Ljubljana, Slovenia), and the commercial office paper was produced on a Paper Machine 4 (PM4) (Voith Paper Krieger, Mönchengladbach, Germany, located in the paper mill Radeče papir Nova, Radeče, Slovenia).

Table 1. Properties of Paper Made from Japanese Knotweed and Commercial Office Paper

Properties	ISO standard	Japanese Knotweed Paper	Commercial Office Paper
Grammage (g/m^2)	ISO 536 (2012)	96.9 ± 4.6	78.0 ± 0.7
Thickness (mm)	ISO 534 (2011)	0.157 ±0.004	0.100 ±0.002
Density (kg/m^3)	ISO 534 (2011)	619 ± 21	782 ± 22
Specific volume (cm^3/g)	ISO 534 (2011)	1.62 ±0.05	1.28 ± 0.04
Roughness (mL/min)	ISO 8791-2 (2013)	950 ± 41	315 ± 21
Roughness (Ra) - TR200 (µm)	ISO 4287 (1997)	6.32 ± 0.51	3.75 ± 0.30
Porosity (mL/min)	ISO 5636-3 (2013)	335 ± 46	1320 ±136
Water Absorption - Cobb (g/m^2)	ISO 535 (2014)	20.4 ± 0.7	19.1 ± 0.9
ISO Brightness with UV (%)	ISO 2470 (2016)	35.17 ± NA	103.06 ± NA
ISO Brightness without UV (%)	ISO 2470 (2016)	35.09 ± NA	86.40 ± NA
Opacity (%)	ISO 2471 (2008)	99.31 ± NA	95.02 ± NA

NA – Not Available

The microscopic analysis of both studied papers showed that the Japanese knotweed paper was produced from 40% Japanese knotweed fibres, 35% eucalyptus and 25% TMP (thermomechanical pulp) spruce fibres, and additives (on paper surface), *i.e.* 0.03% retention agents, 2.5% AKD (alkyl ketene dimer), 0.75% cationic 0.03% starch, and 6.5% $CaCO_3$. The studied commercial office paper contained spruce, pine, and beech fibres with the conventional filler $CaCO_3$ and additives.

Before the printing, the 10 samples of each papers were conditioned according to the ISO 187 (1990) standard, and their physical and colorimetric properties were measured on the felt (*i.e.*, upper) side according ISO standards (Table 1).

Colorimetric and typographic properties of prints

Before the printing, the samples of both papers were conditioned according to the ISO 187 (1990) standard, and printed in a room at the temperature of 22 °C and 55% of relative humidity. Black prints were made with an HP Officejet Pro X576dw MFP inkjet printer, in 1200 dpi resolution and maximum speed 42 ppm (Hewlett-Packard Development Company Dallas, TX, USA). The prints were made using the original pigment-based black ink. On each of the two papers, five screened field intensities were printed (100%, 80%, 60%, 40%, and 20%). Two different, widely used typefaces were tested, namely one sans-serif typeface (Arial) (McLean 1996; Bringhurst 2002; Možina 2003) and one transitional typeface (Times New Roman) (McLean 1996; Bringhurst 2002; Možina 2003). Each typeface was printed in three different sizes (8 pt, 10 pt, and 12 pt).

Permanence of prints

The lightfastness of five samples of each print and paper was determined according to the ISO 12040 (1997) standard using a Xenotest Alpha (Atlas, Mount Prospect, IL, USA) with a xenon arc lamp. The lamp simulates intensive daylight with a Xenochrome 320 filter, which transmits only wavelengths above 320 nm and simulates light behind the window glass. In a Xenotest chamber, the samples of prints and papers were exposed to xenon light for 72 h with a constant temperature of 35 °C and a constant relative humidity of 35%.

Because the covered surface of the type characters was much smaller than the measuring aperture, they could not be directly measured spectrophotometrically. Therefore, the influence of light on the fastness of the prints and papers was studied spectrophotometrically. The measurements were performed in line with the ISO 13655 (2017) standard using an iOne (X-Rite, Grand Rapids, MI, USA) spectrophotometer with (45°a:0°) measurement geometry and white backing, D65 illuminant, and a 10° standard observer. The colour differences between non-exposed and exposed samples were calculated with the CIEDE2000 equation as per ISO 11664-6 (2014) (Eq. 1),

$$\Delta E^*_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)} \quad (1)$$

where $\Delta L'$ is lightness difference, $\Delta C'$ is chroma difference, and $\Delta H'$ is hue difference. Parametric factors (k_L, k_C, and k_H) were set to 1 under reference conditions.

The differences in the typographic tonal density of the non-exposed and exposed typefaces (each in five samples) were measured *via* image analysis (ImageJ, National Institutes of Health, Bethesda, MD, USA). This software can measure, analyse, and provide output values, such as area, number of particles, circularity, and coverage percentage

(National Institutes of Health 2019). All measured samples were the same size (800 × 300 pixels).

Legibility

Different texts from the *National Geographic* (Slovenian edition) journal were printed in two different typefaces (Arial and Times New Roman) and three type sizes (8 pt, 10 pt and 12 pt) onto both paper types. The length of the texts varied between 640 characters and 707 characters. All letters of the alphabet were printed in each text, while the number of characters differed in the used texts. The leading for the 8 pt type size was 9 pt, the leading for the 10 pt type size was 11 pt, and the leading for the 12 pt type size was 13 pt. At the 8 pt type size, the calculated values of the vertical view angle (Legge and Bigelow 2011) were 0.229° for the Arial typeface and 0.196° for the Times typeface. At the 10 pt type size, the vertical view angle was 0.278° for Arial and 0.246° for Times. At the 12 pt type size, the vertical view angle was 0.327° for Arial and 0.295° for Times. The time required to read 700 characters was defined in seconds as the time taken by participants to read the whole text. To check reading comprehension, the proportion of correct responses to multiple-choice questions with two possible answers was analysed.

The observers (N = 50) were between 19 years old and 22 years old (mean (M) = 20.30, standard deviation (SD) = 4.8) with normal or corrected-to-normal vision. To avoid fatigue, the study was divided into two parts. In the first part, the participants read the texts printed on Japanese knotweed paper. In the second part, which occurred 1 week later, they read different texts printed on commercial office paper. The participants were divided into four groups. There were two groups of 12 participants and two groups of 13 participants. Each observer read all 12 combinations of the different levels of the three independent-measure factors (2 typefaces × 3 type sizes × 2 papers). The combinations of factors were presented in a random order to each participant to eliminate possible order effects.

The influence of typeface, type size, and paper grades on legibility was statistically analysed with IBM SPSS 23 (IBM Corp., Armonk, NY, USA). A three-way analysis of variance with the time needed to read 700 characters was performed. Statistical hypotheses were tested with an alpha level of 0.05 or less. McNemar's tests were performed to investigate the influence of samples on observers' responses. The statistical hypotheses about the change in reading comprehension were tested with a 0.005 alpha level.

RESULTS AND DISCUSSION

Colorimetric Properties of Prints

Figure 1 shows all five field intensities printed on both papers.

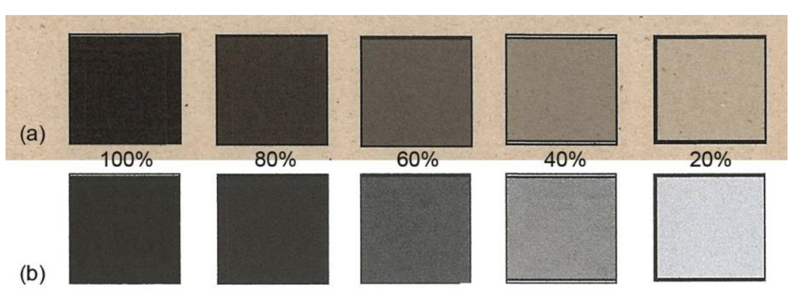

Fig. 1. Field intensities printed on Japanese knotweed paper (a) and commercial office paper (b)

Table 2 shows the CIELAB values for the prints and paper types before illumination. Table 3 shows colour differences for the prints and papers after the illumination.

According to the L^* value in Table 2, the commercial office paper was brighter than the Japanese knotweed paper. The Japanese knotweed paper was more yellowish ($b^* > 0$), and the commercial office paper was bluish ($b^* < 0$). The ISO brightness values (Table 1) indicate that the commercial office paper contained a large amount of fluorescent whitening agents (FWAs), which are also called optical brightening agents.

For the prints at 100% printing intensity, similar CIELAB values were expected on both papers. However, significant differences were observed in the lightness (L^*) of the prints, which indicates the impact of paper type on the prints. The difference in lightness (L^*) between paper types was greater than eight units.

Table 2. CIELAB Parameters of Black Prints with 100%, 80%, 60%, 40%, and 20% Intensity Printed on Japanese Knotweed Paper and Commercial Office Paper

Intensity		100%	80%	60%	40%	20%	0% (Paper)
Japanese Knotweed Paper	L^*	24.85 ± 0.46	31.08 ± 0.50	45.09 ± 0.38	58.80 ± 0.19	68.89 ± 0.55	75.38 ± 0.41
	a^*	1.29 ± 0.04	1.75 ± 0.02	2.19 ± 0.04	2.84 ± 0.02	3.56 ± 0.08	4.22 ± 0.06
	b^*	3.76 ± 0.13	5.69 ± 0.11	8.92 ± 0.15	12.63 ± 0.20	15.92 ± 0.10	18.66 ± 0.48
Commercial Office Paper	L^*	33.28 ± 0.12	37.20 ± 0.28	49.54 ± 0.40	66.43 ± 0.16	82.05 ± 0.09	93.17 ± 0.09
	a^*	1.01 ± 0.01	1.11 ± 0.01	1.14 ± 0.02	1.18 ± 0.02	1.22 ± 0.02	1.22 ± 0.02
	b^*	2.66 ± 0.05	2.29 ± 0.12	–0.02 ± 0.13	–3.05 ± 0.11	–6.09 ± 0.07	–8.39 ± 0.09

Table 3. Colour Differences (ΔL^*, Δa^*, Δb^*, and ΔE^*_{00}) on Prints after Exposure to Xenon Light

Intensity		100%	80%	60%	40%	20%	0% (Paper)
Japanese Knotweed Paper	ΔL^*	0.91	0.71	1.51	2.46	3.33	4.61
	Δa^*	–0.04	–0.11	–0.31	–0.59	–0.79	–1.10
	Δb^*	–0.04	–0.12	–0.41	–0.49	–0.18	–0.84
	ΔE^*_{00}	0.67	0.58	1.52	2.29	2.72	4.81
Commercial Office Paper	ΔL^*	0.65	–0.06	–0.25	–0.61	–0.65	–0.07
	Δa^*	–0.24	–0.30	–0.62	–1.13	–1.60	–1.93
	Δb^*	0.53	1.05	2.83	5.89	9.31	11.70
	ΔE^*_{00}	0.80	1.06	2.83	5.88	8.90	11.85

According to the colour differences in Table 3, substantial changes occurred on commercial office paper after 72 h of illumination (ΔE^*_{00} = 11.85). The most evident changes occurred at the b^* coordinate, indicating that the commercial office paper became yellowish under the influence of light. Such substantial changes in the b^* coordinate indicated that the influence of FWAs decreased as a result of decomposition of organic components (Norberg and Andersson 2002). However, the most considerable difference in lightness was observed ($\Delta L^* > 4$) after illumination of the Japanese knotweed paper, indicating that the paper faded, and its characteristic brownish colour became less intense.

The colour changes of the prints were inversely proportional to the amount of ink on the paper, which was mainly due to changes in the paper. Therefore, the smallest colour changes, which were not visible to the naked eye, were observed ($\Delta E^*_{00} < 1$) on the prints with 100% ink coverage.

Typographic Properties of Prints

The TTD of each typeface that were each in different sizes was measured before and after exposure. Magnified letter "a" characters in the two different typefaces and their binary pictures, which served as the base for image analysis, are presented in Fig. 2.

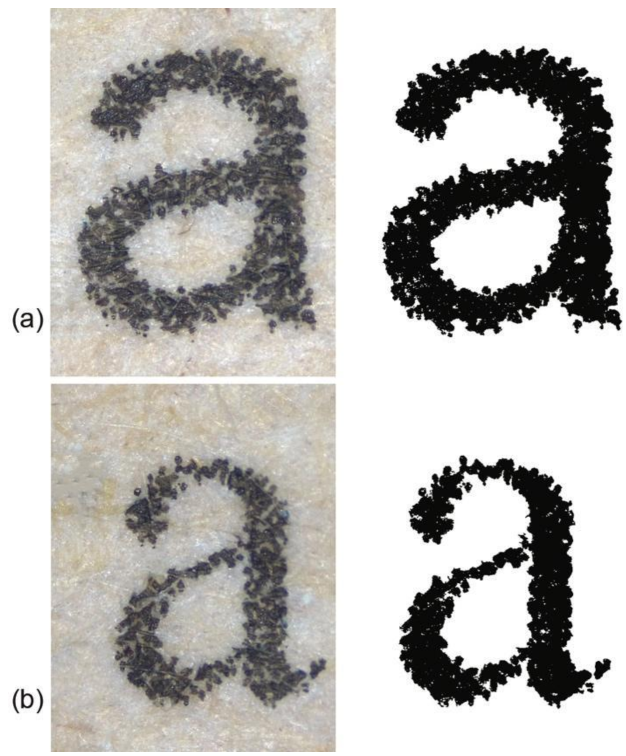

Fig. 2. The 50× magnified letter "a" characters (8 pt) in two different typefaces: (a) Arial and (b) Times with their evident differences (counter shape, serif presence, stroke width, and size) and their binary picture

Several basic design differences between the letters were observed. The samples of the studied typefaces (Arial and Times) in 8 pt size, which were printed on Japanese knotweed paper and commercial office paper are presented in Fig. 3. The prints and their TTD values are shown in Table 4. The TTD values before and after exposure are presented in Tables 5 and 6.

The results showed higher TTD for the sans-serif Arial typeface (Tables 4, and 5), which was expected due to its smaller differences in letter stroke width. The lowest TTD was observed for Times, which is a transitional typeface. Its letters had an evident difference between the thick and thin strokes and a small counter size and x-height. A comparison of both typefaces found that the highest TTD was observed for the typefaces in 8 pt size (Table 4). The TTD for smaller typeface sizes is usually higher due to the smaller counter size of the letters and leading (Reynolds 1988; Možina *et al*. 2010; Rat *et al.* 2011; Možina *et al.* 2019).

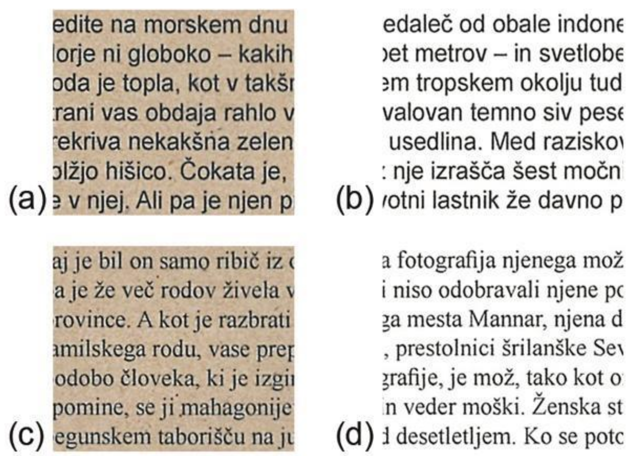

Fig. 3. Samples of 8 pt Arial typeface printed on Japanese knotweed paper (a) and commercial office paper (b) and samples of 8 pt Times typeface printed on Japanese knotweed paper (c) and commercial office paper (d)

After exposure to light, all printed texts exhibited lower TTD (Tables 5, and 6), which was also evident from the colour difference after exposure (Table 3). A slightly higher average difference in TTD after exposure occurred for the Times typeface (0.63) than for the Arial typeface (0.62) (Table 5). This occurred because thinner thick strokes (Fig. 2) lead to lower resistance to light (Možina *et al.* 2010, 2019).

The results (Tables 5, and 6) indicate that paper selection influences print properties. The Japanese knotweed paper had higher TTD regardless of typeface and type size. The Japanese knotweed paper (Table 1) had much smaller porosity (335 mL/min) than the commercial office paper (1320 mL/min) due to the compact paper structure obstructing the penetration of ink. The TTD difference between the non-exposed and exposed printed texts (Tables 5, and 6) was greater due to the presence of 27% lignin (T 222 (2006) standard), 35.0% cellulose (Kürchner-Hoffer method; Browning (1967)) and 36.6% hemicellulose (T 249 (2000) standard) obtained from Japanese knotweed and spruce. A comparison of the printing quality of the studied papers showed smaller changes in TTD for commercial office paper than for the Japanese knotweed paper (Tables 5, and 6).

Table 4. Average TTD of Tested Typefaces on Both Papers According to Type Size (8 pt, 10 pt, and 12 pt)

Typeface	TTD (%)		
	8 pt	10 pt	12 pt
Arial	20.66 ± 0.49	19.76 ± 0.42	19.65 ± 0.37
Times	17.33 ± 0.45	16.69 ± 0.42	16.00 ± 0.35

Table 5. TTD of Tested Typefaces before and after Exposure for Prints on Japanese Knotweed Paper and Commercial Office Paper

Typeface	TTD (%)	
	Japanese Knotweed Paper	Commercial Office Paper
Arial – Non-exposed	20.49 ± 0.44	19.55 ± 0.39
Arial – Exposed	19.74 ± 0.55	19.05 ± 0.42
Times – Non-exposed	16.90 ± 0.41	16.45 ± 0.36
Times – Exposed	16.34 ± 0.51	15.79 ± 0.44

Table 6. TTD of Tested Typefaces in 8 pt, 10 pt, and 12 pt Sizes before and after Exposure for Japanese Knotweed Paper and Commercial Office Paper

Typeface Sizes	TTD (%)					
	8 pt		10 pt		12 pt	
	Japanese Knotweed Paper	Commercial Office Paper	Japanese Knotweed Paper	Commercial Office Paper	Japanese Knotweed Paper	Commercial Office Paper
Non-Exposed	19.50 ± 0.52	18.49 ± 0.44	18.49 ± 0.46	17.97 ± 0.40	18.11 ± 0.42	17.55 ± 0.31
Exposed	18.95 ± 0.59	18.16 ± 0.50	17.17 ± 0.44	16.96 ± 0.47	17.19 ± 0.47	16.95 ± 0.43

Legibility of Prints

Figures 4, 5, and 6 show the influence of typeface, type size, and paper type on reading speed, respectively. There was a significant effect of typeface on reading time ($F(1, 49) = 38.04$, $p < 0.001$), indicating that the participants spent more time reading the texts in Times ($M = 32.01$ s, SD = 6.12) than the texts in Arial ($M = 31.11$ s, SD = 5.89). This may have been due to the typographic characteristics of the typefaces. The Times typeface had much lower TTD than the Arial typeface. The Times typeface had a difference in stroke width and a much smaller x-height and counter size than the Arial typeface. There was also a significant type size × typeface interaction effect ($F(1, 98) = 4.01$, $p < 0.05$) indicating that the texts in 12 pt size were more affected by the Times typeface than the texts in other type sizes (Fig. 4). Further, there was a significant effect of paper type ($F(1, 49) = 15.85$, $p < 0.001$), suggesting that commercial office paper enabled shorter reading times ($M = 29.61$ s, SD = 5.59) than the Japanese knotweed paper ($M = 33.51$ s, SD = 5.80). The Japanese knotweed paper was not white (Table 1) but had a brownish color (Table 2). Therefore, the contrast between the substrate and typography was poor (Fig. 3). A significant paper × typeface interaction effect ($F(1, 49) = 31.83$, $p < 0.001$) indicated that the Times typeface affected reading speed more if the texts were printed on Japanese knotweed paper than if printed on commercial office paper (Fig. 5). This result was expected because the TTD of this typeface was the lowest, leading to the poorest contrast between the paper and typography among the used typefaces. In addition, a statistically significant difference was found in the reading times for the texts in different type sizes ($F(2, 98) = 129.33$, $p < 0.001$.) The *post hoc* analyses with the Bonferroni correction indicated that the texts in 12 pt were read faster ($M = 29.04$ s, SD = 4.99) than the texts in 10 pt ($M = 31.59$ s, SD = 5.89, $t(199) = 7.93$, $p < 0.001$). Furthermore, the texts in 10 pt were read significantly faster than the texts in 8 pt ($M = 34.04$ s, SD = 6.06, $t(199) = 8.79$, $p < 0.001$). There was also a significant type size × paper interaction effect (Fig. 6). Type size had a different effect on reading time depending on the paper type ($F(1, 98) = 27.25$, $p < 0.001$). Small sizes (8 pt and 10 pt) affected the reading time more if the texts were printed on Japanese knotweed paper than if printed on commercial office paper. The latter was expected, because smaller typefaces need to have a higher contrast with their background to achieve optimal legibility. This is especially important in cases where the typeface has a moderate x-height (Možina 2003; Legge and Bigelow 2011; Možina *et al.* 2019).

Figure 7 shows the analyses of participants' answer accuracy across the conditions. Despite the higher answer accuracy for the Arial typeface (95.7%) than the Times typeface (92.3%), the difference between these two typefaces was not statistically significant ($p = 0.08$). In contrast, McNemar's test revealed a significant effect of paper type on the participants' responses, ($\chi^2 = 15.56$, $p < 0.0001$), indicating that answer accuracy was higher for the texts printed on Japanese knotweed paper (98%) than on commercial office paper (90%). This suggests that when inappropriate typographic design, such as poor contrast, obstructed the reading, the texts were remembered better than the texts that were easily legible (Diemand-Yauman *et al.* 2011; Price *et al.* 2015). Additionally, Cochran's Q test showed a significant difference in participants' answer accuracy after reading the texts in different type sizes ($\chi^2(2) = 12.67$, $p < 0.005$). However, the *post hoc* comparisons conducted *via* McNemar's tests showed that the only significant difference was between 8 pt and 12 pt size ($\chi^2 = 10.71$, $p < 0.005$), revealing that more correct answers were given when texts were written in 8 pt (98%) than when written in 12 pt (90.5%). This result also indicates that inappropriate typographic design might improve participants' memory in some cases (Diemand-Yauman *et al.* 2011; Price *et al.* 2015).

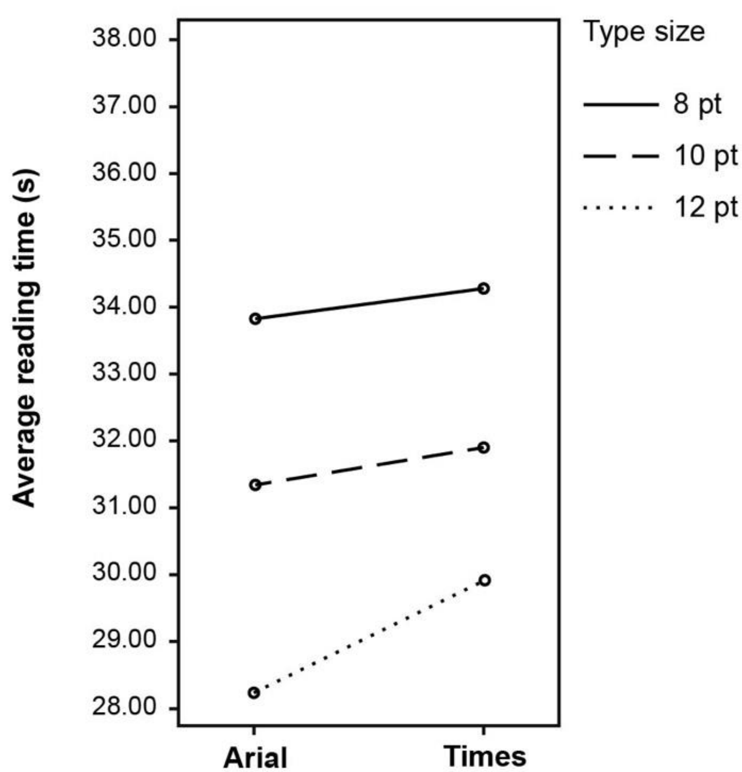

Fig. 4. Average reading time for different typefaces and type sizes

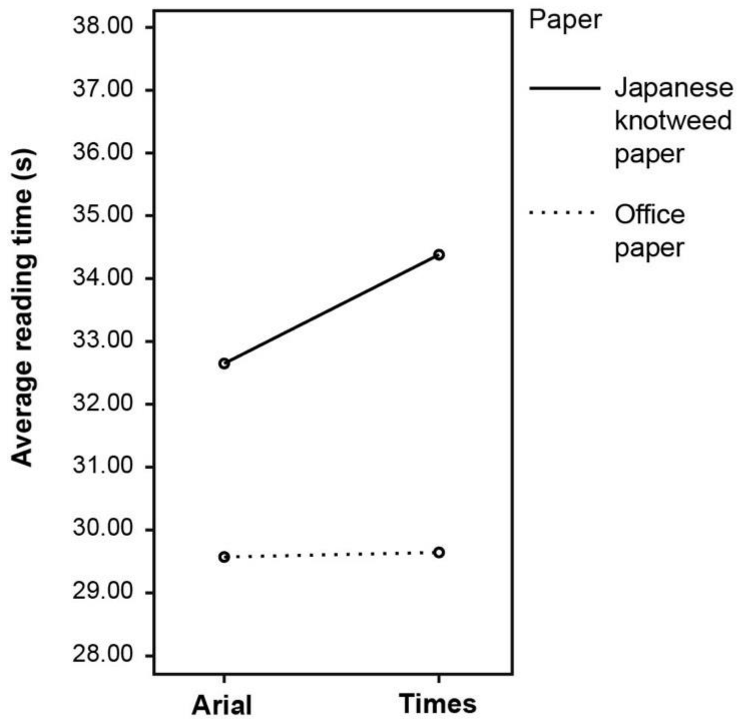

Fig. 5. Average reading time for different typefaces on Japanese knotweed paper and commercial office paper

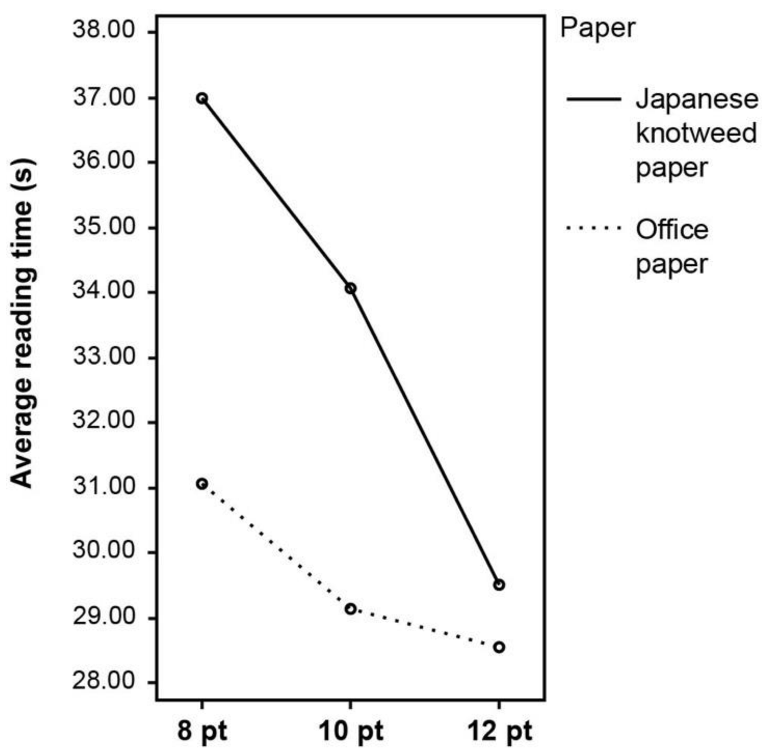

Fig. 6. Average reading time for different type sizes on Japanese knotweed paper and commercial office paper

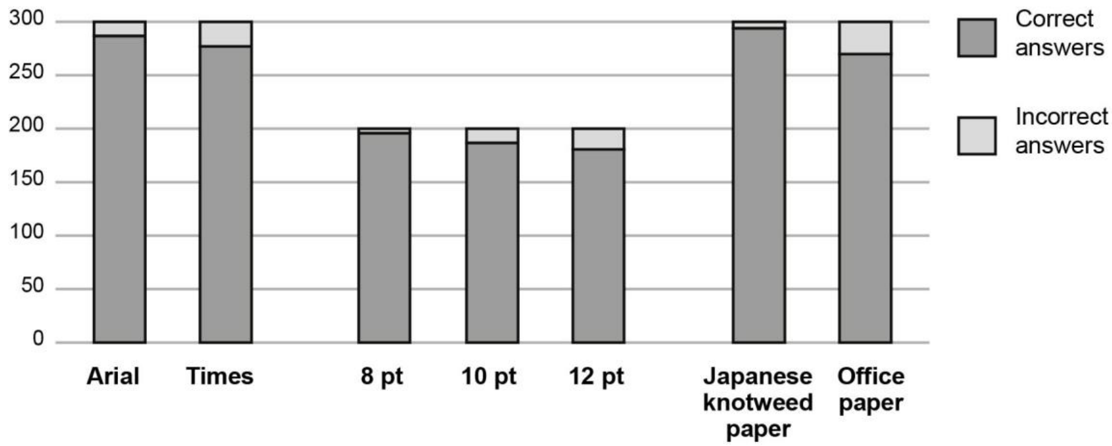

Fig. 7. Number of correct and incorrect answers across conditions

Studying prints on different paper types with selected typefaces and type sizes revealed that substrate had a crucial impact on legibility. If there was enough contrast between the paper and typography, the legibility could be improved with a typeface that had a higher TTD and larger x-height.

CONCLUSIONS

Invasive alien plant species have a widespread impact on ecosystems. Researchers and ecologists are trying to find ways to avoid further spreading. Additionally, they are trying to find some benefits from these plants. Due to their ability to form cellulose fibre nets in a paper structure, these plant species can be used in paper production. Therefore, the aim of this study was to examine the performance of Japanese knotweed paper when it is used as a printing substrate. Based on the results obtained on prints made on Japanese knotweed paper in comparison to commercial office paper, it could be concluded:

1. Regardless of the fact that the Japanese knotweed paper was not produced from bleached cellulose fibres and it did not undergo any surface treatment, the quality of text printed with the inkjet technology was insignificantly inferior in comparison to the print quality achieved on commercial office paper.
2. The reading speed results showed a notable influence of paper characteristics. The brownish colour of the Japanese knotweed paper reduced the contrast between the substrate and typefaces and impaired reading speed.
3. Smaller-sized typefaces, such as footnotes in documents, patient information leaflets, and user manuals, are not suitable for printing on this paper. This is especially important if the typeface has a difference in letter stroke width like the Times typeface. A 10 pt type size could be used in combination with a sans-serif typeface such as Arial. The results suggest that typefaces with distinctive character features and a minor difference in stroke width even at larger type sizes should be used with this paper.
4. This study yielded useful information about the usability of Japanese knotweed paper. The paper made from this invasive plant offers some valuable properties and appropriate legibility, particularly with typefaces with a moderate counter size, large

x-height, and minimal differences in the stroke width. It is recommended that a sufficiently large type size be used.

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