Effects of flooding on the seed bank and soil properties in a conservaiton area on the Han River floodplain, South Korea

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ABSTRACT

Flooding can have a major impact on riverside plant communities, which is likely to be especially important in monsoonal climates, where large floods occur after heavy rain. In urban areas where riparian vegetation remnants are the only remaining vegetation of conservation interest, understanding the impacts that floods have on such ecosystems is needed to inform their future conservation. Accordingly we assessed the impact of a flood caused by Typhoon "Ewiniar" on the soil seed bank of five plant communities in the only remaining fragment of high-quality riverine habitat within the Seoul city stretch of the Han River, South Korea. We surveyed the seed bank composition of the five dominant plant communities before and after the flood. We also measured selected soil physico-chemical properties in each community. We used uni- and multivariate methods to examine the effect of the flood on both seed bank and soil properties. Flooding resulted in variable deposition of sediment within and across plant communities; in four of them it ranged between 14.6 and 18.8 cm but the fifth (dominated by *M. sacchariflorus*) had much less (4.8 cm). The physico-chemical properties of the surface soil also changed after the flood, with the sediment particle size being most affected. The species richness and composition of the seed bank suffered significant changes after the flood. In both cases there was a homogenization process, with was also impinged on species with different life forms (annuals and perennials). Our results suggest that an extreme flood can affect the riparian vegetation seed bank by removing wetland plant species and allowing common and ruderal species to establish. There may also be different interactions between the different plant communities in terms of sediment capture and this translates into altered soil conditions and seed banks. These results are of use to conservation policy-makers aiming to conserve a native flora within severely modified urban rivers, and these remnant areas can also provide an important seed source of wetland plants to aid restoration of riparian ecosystems.

1. Introduction

Natural river landscapes of the temperate regions can harbour a high biodiversity due to their high habitat heterogeneity and both lateral and longitudinal river connectivity (Naiman et al. 1993, Van Looy et al. 2009). The longitudinal exchange via water flow, creates areas of geo-diversity within river landscapes through the erosion, transportation and deposition of sediment (Stromberg et al. 2011). Flooding is also a major factor in controlling biological community structure (Alves Pagotto et al. 2011), often moderating the relationships between the hydrological regime, soil structure (sediment), flora and fauna.

Riverine systems usually include the land within a water catchment, a network of streams which drain it, and its component flora and fauna (FISRWG 1998). Riverine systems are, therefore, important landscape components from an holistic conservation perspective and many are under great threat, especially those parts of the river flowing through urban areas (Karr and Chu 2000, Gergel et al. 2002, Paul and Meyer 2008). The remnant vegetation within urban river systems is usually highly-fragmented, degraded and susceptible to human disturbance. Many parts of the riverine system are subject to environmental pressures which affect both the chemical and physical environment, being some parts disturbed on a regular basis by flooding which varies in extent and duration (Abernethy and Willby 1999, Hölzel and Otte 2001, Jutila 2001, Amiaud and Touzard 2004, Cho and Cho 2005, Capon and Brock 2006). When flooding occurs there is a large flow of water, usually resulting from heavy rain within the upstream catchment, and the effects can be severe, changing the river topography (Yarie et al. 1998, Schmidt et al. 2001, Alves Pagotto et al. 2011, Stromberg et al. 2011). However, in less severe cases, there is often sediment transport within the water flow which is deposited downstream (Hayashi et al. 2012). In these cases, the flood-deposited sediment provides an incoming source of both mineral and organic material, each containing nutrients, and of course plant propagules, e.g. seeds and vegetative fragments (Riis and Baattrup-Pedersen 2011, Cockel and Gurnell 2012). The role of seed banks in riverine restoration has recently been emphasized by Cui et al. (2013) who showed species densities varied between river position, depth in the sediment and pollutant load. Flooding can have direct negative effects through both the erosion of plants and soils

(Capon and Brock, 2006; Eldridge and Lunt, 2010), and through the physical deposition of flood-borne sediments (van der Valk et al. 1983); the latter killing newly-emergent seedlings and preventing seedling emergence as the surface soil is buried. Recovery after flooding can also be affected by the sediment deposition as it impinges on both soil physico-chemical characteristics and the seed bank, both of which could alter successional recovery. Here, therefore, we examine the impact of deposited sediment on the vegetation and soil seed bank in the floodplain of a refuge of semi-natural vegetation of conservation interest within a highly-modified river.

In this paper we studied the flooding impacts within a refuge of semi-natural vegetation on the banks of the Han River within Seoul City, South Korea. The Han River is subject to annual flooding during the heavy monsoonal rainfall with exceptional peaks every 3-5 years. To minimize this flooding water flows are managed in two ways; first, there are three large dams upstream from Seoul (Soyang, Chungju and Paldang dams; Kim 2008), and second in Seoul, the river was channelized and embanked in the mid-1960s, providing public parks, roads, and car parks along the river banks (Woo 2010). As a result, the previous ecological functions derived from the natural riparian vegetation have been lost within the urban reaches of the Han River. However, there are four refuge areas within the confines of the Seoul city where natural vegetation remains. Lee at al. (2011) described the plant communities and seed banks of these four refuges; though, three of these had suffered recent disturbance, and one, the Amsa wetland was shown to be the only remaining fragment of relatively-undisturbed, semi-natural riverine vegetation within the city reaches. Therefore, the Amsa refuge area is extremely important from a conservation viewpoint as it retains some vegetation along with a bank of propagules in the soil which could assist in future river restoration strategies (Kim and Ju 2005, Jeon et al. 2008, Lee et al. 2011).

More precisely, we studied the impact of the severe 2006 flood on the seed banks and soils of five plant communities types along a transect from the river through to the landward end within the Amsa wetland. This flood was generated as a result of exceptionally heavy, seasonal rainfall (typhoon 'Ewiniar') which produced one of the highest floods in the last 25 years. The effect of this flood on the riverine communities within the Amsa wetland was analyzed by measuring change before and after the flood in (1) a range of soil physico-chemical variables, and (2) the soil seed banks of the five dominant plant communities (Lee 2010, Lee et al. 2011). It was hoped that this information would provide a preliminary assessment to help inform conservation planning of riverbank vegetation in protected areas.

2. Methods

2.1. Study site and flood event

The Han River is a major river in South Korea; it is 470 km long with a watershed area of 26,200 km^2 and flows through the capital Seoul through to the Yellow Sea (Fig. 1). Within the catchment, the average annual precipitation is 1,294 mm, with 65% occurring between July and September. The Han River is subject to annual flooding during the heavy monsoonal rainfall with exceptional peaks every 3-5 years. The studied flood was generated as a result of exceptionally heavy, seasonal rainfall (typhoon 'Ewiniar') which produced one of the highest floods in the last 25 years (Fig.2). Since 1984, the South Korean flood forecasting system has issued 13 flood alerts under two categories ('Flood advisory' and 'Flood warning'). The 2006 event was classified as "Flood advisory", and produced the 9th highest recorded water level at the Hang River Bridge monitoring station since 1920; indeed the monitoring station was itself flooded for 24 hours.

Lee et al. (2011) described the plant communities and seed banks of the four refuges on the Han River; three of these had suffered recent disturbance, and one, the Amsa wetland (0.1 km^2, Fig. 1), was shown to be the only remaining fragment of relatively-undisturbed, semi-natural riverine vegetation within the city reaches. This site was designated an "Ecological Landscape Protected Area" to conserve this habitat in 2002, and has been fenced to prevent human access. Five plant communities were described at this site (Lee 2010, Lee et al. 2011) forming a zonation from the river bank side to the land-side as follows (Fig. 1; Nomenclature follows Lee 1999), i.e. Waterfront (WF), Bankside (Bn), and communities dominated by *Salix* spp. (Ss), *Phragmites australis* (Pa), and *Miscanthus sacchariflorus* (Ms). The Amsa wetland, therefore, contains a mosaic of habitats which would otherwise be absent from the urban reaches of the Han River, providing aesthetic and educational services as well as a semi-natural habitat much valued for migratory birds (Yoo and Choi 2007).

2.2. Soil/sediment sampling for seed bank assessment and chemical analysis

The pre-flood soil physico-chemical conditions and seed bank characteristics were assessed in Spring (March) of 2005 and 2006 respectively; there was a small flood in 2005. On both sampling occasions, five replicate 1m^2 quadrats were located randomly within each of the 5 plant communities. At each of these quadrats, five soil cores were taken using a soil corer (Eijkelkamp BV, Netherlands; corer dimensions = 5 cm diameter, 5 cm depth, 500 ml volume in total per sample). Seed bank assessment was performed in March because at this time all seeds available for germination over the summer would be present.

The post-flood conditions were measured on the site after the deposition of flood-derived sediments. In order to measure sedimentation rates, five replicate soil traps (plastic square plates, 25×25 cm) were placed in the each of the five communities 14 d before the flood. Immediately after the flood these were re-visited, depth and the total mass of sediment were measured in each trap, thereafter the sample were collected and moved to lab. Using the same corer of pre-flood samples, four cores were sampled from each soil trap for the seed bank analysis (400 ml volume in total per sample), and rest of the sample used for soil physico-chemical analysis.

2.3. Assessment of soil physico-chemical properties

Soil/sediment pH and electrical conductivity were measured in a 1:2 mixture of fresh soil in distilled water. Moisture content was then measured by weighing before, and after, drying a sub-sample at 105ºC for 48 hours. The organic matter content was estimated by loss-on-ignition (Heiri et al. 2001). Soil/sediment texture analysis was carried out by shaking 40 g in 300 ml of 5% sodium hexa-metaphosphate solution overnight. Following dilution to 1,000 ml with the distilled water and shaking for 1 minute at 60 rpm density measurements were made using a Bouyoucos soil hydrometer (USA/ASTM 151H) after 40 seconds and 7 hours. Drops of Iso-amyl alcohol were added to remove bubbles if necessary (Sheldrick and Wang 1993). Total nitrogen was analyzed using a Kjeldahl Protein/Nitrogen Analyzer (Automatic; Kjeltec Auto 1035/1038 System). Extractable phosphorus (EP) and exchangeable cations (Na, Mg, K, Ca) were extracted using Mehlich III solution(Sims et al.

2002); EP was analyzed using the ascorbic acid method (APHA 1992) and exchangeable cations using an induced coupled plasma (ICP) Emission Spectrometer (Shimadzu /ICPS-7510).

2.4. Assessment of species in the seed bank

All soil/sediment samples for seed bank assessment were stored in at 4ºC until the start of the seedling emergence experiment following Looney and Gibson (1995). All samples were then inspected and any roots or plant stems present were removed by hand; the samples were then placed in individual seed trays (44×30×7 cm) and transferred to a glasshouse where the trays were watered daily. Seedling emergence was observed for 16 weeks, during which time the minimum and maximum temperatures recorded in the glasshouse were 10.4ºC and 35.8 ºC respectively. Emergent seedlings were identified using Asano (2005) and counted every two weeks for 4 months; most seedlings emerged in the first ten weeks (Lee 2010). Where identification was not possible the seedling was transferred to a separate pot and grown on until identification was possible. The seed numbers emerging were converted to seed densities on an area basis (m^{-2}).

Species detected in the seed bank were classified into three life-form groups (annuals, perennials and biannual) using the database of "Korea Biodiversity Information System (NATURE)"(Korea National Arboretum 2012).

2.5. Statistical analysis

All analyses were performed using the packages 'nlme' (LMMs) and 'vegan (Oksanen et al. 2011)' within the R statistical environment (version 2.15.2.,R Core Team, 2013).

Principal component analysis (PCA) was used to provide an integrated analysis of the patterns of variation for soil physico-chemical variables. PCA was carried out over the correlation matrix of soil data considering 13 variables (see Table 2 for detailed list). All variables were standardized before analysis to correct for different scales of measuring units. Differences between pre- and post-flood values were testing using a t-test.

Linear Mixed Models (LMMs) were used to evaluate the changes (size, diversity) in soil seed bank between flood events and five vegetation communities. In this analysis, flood (pre- and post-flood) and vegetation communities (5 levels) were treated as categorical fixed factors, and plot nested within sites were included as random factors to account for spatial autocorrelation (Pinheiro and Bates 2000). All variables were log-transformed ($log_e(x+1)$) before analysis.

The effect of flood events and vegetation communities on seed bank composition were also tested using Permutational Multivariate Analysis of Variance (PMAV, ‘adonis’ function; Oksanen et al., 2011). These analyses were performed first for all seeds found and then discerning between the three life-forms considered (i.e. annuals, biennials and perennials). The species-abundance matrix was log-transformed (log(x+1)) to reduce the influence of the most abundant species. In these analyses, the 5 sub-samples from the same vegetation community were pooled to reduce the spatial heterogeneity of the seed banks. Bray–Curtis distance was used with 999 permutations. Finally, Detrended Correspondence Analysis (DCA, ‘decorana’ function; Oksanen et al., 2011) was used to identify in ordination space the seed bank compositional differences between flood events and vegetation communities. To help the interpretation standard deviational ellipses of each flood event and vegetation community were used (‘ordiellipse’ function; Oksanen et al., 2011).

3. Results

3.1. Sediment deposition by the flood

The depth of sediment deposited in four of the plant communities varied between 14.6 and 18.8 cm; the exception was the *M. sacchariflorus* community (Ms) where sediment depth was less (4.8 cm, Table 1). The mass of sediment deposited showed the same rank order as the sediment depth but with greater variation; greatest mass was found in the Bank (Bn) and *Phragmites australis* communities (Pa), intermediate values in the Waterfront (WfF) and *Salix* spp. communities (Ss) and the least in the *M. sacchariflorus* community (Ms) (Table 1).

3.2. Change in soil physico-chemical properties before and after the flood

Most of the soil physico-chemical properties showed a significant difference between the pre- and post-flood conditions (Table 2). Four variables showed a consistent pattern after the flood event on all communities; soil moisture content, pH and extractable P concentration either stayed the same or increased after the flood, and extractable Na concentration decreased after the flood. The other variables showed an inconsistent pattern between communities; for example, the organic matter increased in three communities (Waterfront, *P .australis* and *M. sacchariflorus*) and decreased in two others (Bank and *Salix* spp.).

The PCA ordination of the soil physico-chemical variables provided a clearer interpretation of the changes caused by the flood; the first two PCA axes produced eigenvectors of 7.123 and 3.982 which explained 51% and 28% of the variance (Fig. 3). A clear gradient was found on Axis 1 based on particle size, with increased clay and silt at the positive end of axis 1 and increased sand at the negative end (Fig. 3). The clay and silt end of this gradient was correlated with exchangeable Ca and Mg and the sand end was correlated with increasing pH. The gradient on Axis 2 showed a high moisture content and extractable P at the negative end and electrical conductivity, exchangeable K and Na and total N at the positive end. The pre-flood communities were ordered along axis 1 in order (clay/silt to sand) *M. sacchariflorus*, *Salix* spp., the Bank and *P. australis* which were very close together and then the Waterfront. However, all of these communities had positive values on axis 2. After the flood all of the communities moved down axis 2 indicating an increase in moisture content and available P (Fig. 3). The rank order of communities along axis 1 also changed to: *M. sacchariflorus*, the Water front and *P. australis* which were very close together and then *Salix* spp. and Bank. *M. sacchariflorus* and *P. australis* moved more or less vertically downwards showing little shift on the clay-silt gradient but water front soils increased in silt/clay and both Bank and *Salix* spp. increased in sand content.

3.3. Change in soil seed banksbefore and after the flood

3.3.1. Size and diversity

Overall, the pre-flood seed bank size contained seeds of 86 species corresponding to an overall seed density of 37,308±9,508 seeds m^{-2}. In contrast, after the post-flood seed bank was reduced significantly to 4,702±538 seeds m^{-2} (t-value=3.92, P=0.001) of 57 species. Seed densities varied considerably between the five communities (Table 3). The reduction in overall seed number after the flood was only consistent for biennial life-form seeds (reduction=7,190±1,946, t-value=3.70, P=0.011, Table 3), although in the case of annual and perennial seeds there was a significant flood×plant community interaction (Annuals F-value=9.90, P<0.001; Perennials F-value=3.20, P=0.034).
For the most part density of seed bank was siginificantly or slightly reduced in annuals, biennials and perennials in all communities (Table 3, Fig. 4a and 4b)).

Species number in seed bank was reduced from 86 to 57 species after the flood (Appendix 1). Thirty-nine species present in the pre-flood soil seed banks were absent post-flood, 10 new species were detected, and 47 species were present before and after the flood. Seed bank richness was influenced by the flood×plant community interaction (F-value=4.70, P=0.008, Fig 4c), showing a significant reduction in richness within the Wf, Bn, Pa and Ms communities after the flood (average reduction of 10 species per community), but there was no effecton the SS community seed bank richness.The same patterns were observed analyzing for the richness of the three life-forms considered. On the other hand, the flood produced a significant increase in seed bank evenness in four communities (flood×plant community interaction, F-value=47.74, P<0.001, Fig 4d); only the Pa community maintained identical evenness values before and after the flood.

3.3.2. Compositional changes.

The DCA of seed bank composition produced eigenvalues (λ) of 0.32, 0.25, 0.19 and 0.12, and gradient lengths (GL) of 2.61, 2.75, 3.15 and 1.90 for the first four axes, respectively. The sites biplot showed significant differences in the seed bank composition before and after the flood (r^2=0.43, P=0.008; Fig. 5a,b); the pre-flood samples were located in the central right side of the ordination and were correlated with species such as *Persicaria perfoliata*, *Eleocharis acicularis* var. *longiseta*, *Cyperus flaccidus*, *Eclipta prostrata*, *Mazus japonicus*. In contrast, the post-flood samples were located at the negative end of axis 1 and were correlated with species such as *Arenaria serpyllifolia*, *Portulaca oleracea*, *Panicum dichotomiflorum*, *Bromus japonicus,* and *Carex dimorpholepis*. At the same time, there was an interaction between pre/post-flood and vegetation communities on seed bank communities (r^2=0.93, P<0.010, Fig 5c). In the pre-flood samples, there were significant differences in seed bank composition between the five communities (r^2=0.70, P<0.001). However, after the flood the seed bank compositional differences were exclusively between Ms and the other communities (r^2=0.40, P=0.010, Fig 5c). These significant changes in seed bank composition produced by the flood were maintained if the life-form of the seeds was considered (Annuals r^2=0.21, P=0.013; Biennials r^2=0.26, P=0.026; Perennials r^2=0.27, P=0.010).

The relationship between individual species in the seed bank were investigated further by calculating a ratio from the difference in seed densities in the pre-and post-flood samples and then dividing by the pre-flood densities (Fig. 6). This showed a clear separation into species that increased after flooding, and those that declined. The species were classified on the basis of this analysis into three groups; those that showed (a) a large increase, (b) a small increase, and (c) a small decrease (Table 4). Of the common species, all except six were either classified as alien or ruderal species. Only six perennial species were classified as native wetland species (Table 4), two (*Scirpus radicans*, *Typha angustifolia*) showed an increase after flooding and four decreased (*Juncus alatus*, *J. effusus* var. *decipiens*, *Penthorum chinense*, *Phragmites australis*) in the seed bank after the flood.

4. Discussion

The riverine ecosystem, in many developed countries have been highly modified and the Han River in South Korea is no exception (Kim et al. 2004). Upstream of Seoul the water flow is heavily controlled and within the city it is channelized and embanked (Woo 2010) with very little river bank left with a high conservation value (Lee et al. 2011). In spite of this, the river is still subject to periodic floods, especially during the Typhoon season and here we investigated the impacts of a flood induced by Typhoon "Ewiniar" at the Amsa conservation wetland on the Han River; this site is the last remaining refuge of semi-natural, riverine vegetation of conservation interest within Seoul (Lee et al. 2011). As such it provides a range of cultural ecosystem services (MEA, 2005) within the Seoul city landscape; as well as an aesthetic value there are potential educational opportunities as well as its intrinsic conservation value (Jeon et al. 2008). Accordingly information on how it responds to environmental pressures, such as flooding, is sorely needed.

An important result was the differences in the depth of sediment deposited in the communities during the flood; the four communities nearest the river had sediment deposited to between 14 and 19 cm depth, but even the landward community had a 4.8cm deposition. Thus, flood events during the Typhoon season can produce very large, albeit variable, sediment inputs to these riverine communities as has been demonstrated elsewhere (Yamamoto and Chiba 1994, Yang 1999). Given that seed richness in the sediment bank has been shown to reduce from the river edge to mid-channel, and down the soil profile (Cui et al. 2013), the addition of sediment in such large quantities during flood, will inevitably change both the physico-chemical conditions of the surface and the surface seed bank profile. The latter can be brought about in two ways, through the importation of new species (Barrat-Segretain et al. 1998, Barrat-Segretain and Bornette 2000) and through the burial of existing seeds present in the surface soil layers. Moreover, the action of the sediment deposition may also cause physical damage to existing vegetation thus creating disturbance and bare ground suitable for new species colonization (Kalamees and Zobel 2002, Amiaud and Touzard 2004). Taken together, there are, therefore a range of processes through which extreme flooding can affect riverine communities and their seed banks, and hence their restoration potential and subsequent successional trajectories.

4.1. Effects of the flood on soil physico-chemical properties

Whilst there were significant differences in most of the soil physico-chemical properties between the pre- and post-flood conditions; soil moisture content, pH and extractable P concentration either remaining the same or increasing after the flood, or extractable Na concentration decreases. There were other variables showeing inconsistent patterns between communities with some variables increasing in some communities and not others. Multivariate analysis helped interpret the effects producing a clear gradient between sites that was based on particle size (soils with greater clay and silt fractions at one end through to a greater sand component at the other). The second axis reflected a gradient of soils with a high moisture content and extractable P at the negative end and electrical conductivity, exchangeable K and Na and total N at the positive end. The pre-flood communities were ordered along axis 1 in order (clay/silt to sand) *M. sacchariflorus*, *Salix* spp., the Bank and *Phragmites australis* which were very close together and then the Waterfront. After the flood the rank order of communities on this gradient changed indicating differential capture of different-sized sediments by the differing structures found in these plant communities. Specifically, the Waterfront increased in clay/silt and both the *Salix* spp. and bank communities moved to sandier condition. All the pre-flood soils had positive values on axis 2 and they moved down the axis indicating an increase in moisture content and available P. There is no doubt that the effects of the flood changed the soil properties and this may reflect merely physical forces with respect of sediment deposition, which is known to occur in floodplains at a range of spatial scales (Walling and He 1998). However, it may also reflect an interaction with the vegetation structure (Gurnell et al. 2006, Corenblit et al. 2009), as sediment deposition differed between the communities. We suggest that some of this variation would result from differential interception induced by the different vegetation types; i.e. from sparse plant cover at the Waterfront, through dense grass stands (*Miscanthus sacchariflorus* and *Phragmites australis*) to the shrub-dominated *Salix* spp. communities (Lee et al. 2011).

4.2. Impacts of the flood on seed banks

The immediate impact of flooding was to reduce the differences in species diversity between the plant communities (Asaeda et al. 2011, Uchida et al. 2012), as weel as to produce a compositional homogenization in post-flood seed bank in comparison with pre-flood seed bank. In particular, the seed banks of the pre-flood soils showed an heterogeneous distribution pattern, probably because at least some seed inputs to the soil resulted from local dispersal from nearby parent plants (Willems and Bik 1998). Before the flood the most diverse communities were the ones nearest the river,whereas after the flood they appeared more similar, essentially they suffer a biotic homogenization (Smart et al. 2006). Thus, immediately after the flood the differences between the communities in diversity and composition were reduced. The flood also impinged on species with different life-history strategies. All life-history categories were reduced on the river bank; both annuals and perennials were affected in the intermediate *Salix* woodland and the *P. australis* communities, but annuals were most affected in the *M. sacchariflorus* community.

The effect of the flood would be expected to increase seed inputs on the sites nearest the river (Gurnell et al. 2008), which are exposed to a greater degree of flooding than sites farthest from the river channel (Capon and Brock 2006). This was not apparent here, as there was a reduction in the total number of species detected in the soil seed bank, and all life-history categories were reduced in most communities. There were small increases in biennials in the *P. australis* community and perennials in the Waterfront; the number of perennials remained the same in the *Salix* woodland. Here, we also classified species according to change in seed bank numbers after flooding. Overall, the results were complex, with some species increasing markedly after flooding and some decreasing. However, as a remarkable results highlights that most of the species that increased in the seed bank after flooding were either aliens or ruderal species, and only two species of conservation interest (*Scirpus radicans, Typha angustifolia*). Thus these results suggest that after extreme flood events the compositional homogenization of seed bank is mainly produced by common and ruderal species, with litte input of conservation interest species. As a consequence, seed bank homogenization might have a negative effect on future successional trajectories of these communities, if the interest species seed bank is not properly restored.

The seed bank of the Amsa wetland can be considered as the only potential source of seeds for restoration of this and similar wetland communities on Han River floodpain. However, after extreme floods events the sediments deep can compromise the seed bank regeneration potential (i.e. deep prevented seedling emergence), being the extant vegetation of interest the main source of the seeds for the seed bank regeneration (González-Alday et al. 2009). Thus, conservation actions after extremen floodings must focus on (1) the recovery of vegetation structure and (2) on the reduction of sediments deep facilitating previous seed bank seedling emergence, being both of them vital for the maintainance of these areas. In any case, the lack of good amounts of interest species in flood sediments limits the use of the sediments found in this area for future restoration projects of vegetation refugies in Han River.

4.3. Conclusions

Flooding is the major disturbance of these riparian ecosystems, inducing change to the topography of river channel. In urban areas where riparian vegetation remnants are the only vegetation of conservation interest remaining, understanding the impacts that floods have on these ecosystems is needed to inform their future conservation. Our results showed that immediately after the flood, the species richness were reduced in both the above-ground vegetation (1-10 species) and seed banks (1~21 species). In addition, the flood transported a large amount of sediment containing some seeds over the floodplain, with an overall homogenizing effect (species composition and diversity); indeed after the flood there was a 9~50% similarity. Furthermore, the flood sediment (4.8~18.8 cm depth) had a low seed density and this prevented germination from the underlying pre-flood soil later and hence encouraging those species with vegetative propagation. Our results suggest that extreme floods can impinge on the riparian vegetation by removing wetland plant species and allowing common, ruderal or perennial wetland species to persist, mainly because the reproductive patterns of these perennials occur by vegetative propagation rather than seeds. These results, therefore, inform conservation management policies for maintaining of semi-natural areas inreaches of urban rivers such as the Han River in South Korea that are subject to substantive flooding.

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Fig. 6. Change of seedlings densities of common species of pre and post-flood soil within five communities at the Amsa wetland on the Han River, Seoul, South Korea. The ratio was the change in mean seed number after the flood (post-pre) over the number in the pre-flood soil expressed as a percentage. Key to species: Afi: *Androsace filiformis*, Apr: *Artemisia princeps* var. *orientalis*, Ase: *Arenaria serpyllifolia*, Bfr: *Bidens frondosa*, Cbu: *Capsella bursa-pastoris*, Cdf: *Cyperus difformis*, Cfe: *Cardamine flexuosa*, Cfi: *Chenopodium ficifolium*, Cmi: *Centipeda minima*, Cor: *Cyperus orthostachyus*, Csa: *Cyperus sanguinolentus*, Dsa: *Digitaria sanguinalis*, Ean: *Erigeron annuus*, Ecr: *Echinochloa crus-galli*, Emu: *Eragrostis multicaulis*, Gci: *Galinsoga ciliata*, Gsp: *Galium spurium*, Ich: *Ixeris chinensis* var. *strigosa*, Jal: *Juncus alatus*, Jef: *Juncus effusus* var. *decipiens*, Lap: *Lepidium apetalum*, Lat: *Lindernia attenuata*, Lmi: *Lindernia micrantha*, Lpr: *Lindernia procumbens*, Lup: *Ludwigia prostrata*, Mja: *Mazus japonicus*, Ood: *Oenothera odorata*, Pau: *Phragmites australis*, Pch: *Penthorum chinense*, Pdi: *Panicum dichotomiflorum*, Pno: *Persicaria nodosa*, Pol: *Portulaca oleracea*, Ppa: *Potentilla paradoxa*, Ppr: *Poa pratensis*, Psp: *Poa sphondylodes*, Rcr: *Rumex crispus*, Rgl: *Rorippa globosa*, Ris: *Rorippa islandica*, Rsc: *Ranunculus sceleratus*, Sal: *Stellaria alsine* var. *undulata*, Saq: *Stellaria aquatica*, Spl: *Salvia plebeia*, Sra: *Scirpus radicans*, Tan: *Typha angustifolia*, Tpe: *Trigonotis peduncularis*, Vam: *Veronica americana*, Vun: *Veronica undulata*.