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SEASONAL VARIATION OF THE ALIEN PLANTS INVATION INTO RIVER ECOSYSTEM

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ABSTRACT: Many alien species have invaded into fluvial environment. The invasion of alien species affect seriously damages to the biological diversity. Authors pointed out that invasion of alien plants is mainly occurred in spring, and recommended that the improvement of river environment should be done from summer to autumn in order for prevent invasion of alien species. However, there is little report about the phenomenon when the improvement of river was occurred from summer to autumn. So we investigated how the vegetation recovered at the improvement river area with no burial seeds in summer. During the investigation we removed all emerging seedlings in the half of the investigation area and always kept as the bare ground. As a result four of the following became clear, 1) seedlings of alien species could not easily invade bared area in summer, 2) only some seedlings of a few native species can be established in summer, 3) the vegetation by native species that recovered in summer prevented the invasion of alien species, 4) seedling removal hasten the invasion of alien species. The character that the seeds are able to emerge anytime and anywhere like the alien plants species are advantageous at the fluvial environment where rising of the river sometimes occurs. But the condition of river bed in summer is too severe to invade open area. Only a few native species can established their seedlings.

Keywords: Seedling emergence, Phenology, River bed, Regeneration, Reproduction.

1. INTRODUCTION

The weed risk assessment (WRA) has been paid attention as a risk evaluation system of the species before alien species intentionally introduces into Japan. In Australia the operation results of the WRA system have exceeded twenty years [1]. Because the damage of the exoticism to biodiversity has become the largest problem worldwide, the WRA begins to be used also in Japan [2]. In the WRA, there is a check item concerning the item concerning a character of ruderal strategy. Actually, the invasion of alien species with ruderal strategy has become a big problem in Japan.

Now, the vegetation of the fluvial environments has been seriously affected by alien plants. In the river ecosystem the bare land is formed frequently by flood. The alien ruderal species easily invade the bare land faster than native species do [3]. The invasion of an alien plants have been diminishing the biodiversity at the river condition. Especially, the alien plant that invades the fluvial environment brought in to Japan by the seed medium. Therefore, genetic diversity is very high which adjusts easily to the each invading environment [4].

The authors reported that the strategy of alien plants has longtime seedlings emergence in spring in previous paper [5]. There we also suggested that the construction of river ecosystem should be finished during summer. But there is few seasonal research in river ecosystem about alien plants seedlings invasion in bared land in summer.

The Ministry of Land, Infrastructure and Transport experimentally restored the old fluvial environment consist of round pebbles using 'Nature oriented river works' Toki river at central Japan. There were seeds of *Sicyos angulatus,* the species notorious alien species, in this area. So to recover the rich biodiversity of the river, all the surface soil and pebbles were washed in order to remove the burial seeds and installed there in 2010. The construction was finished in early summer fortunately. Then, we investigated how the invasion of alien plants in summer to autumn was done in the "Nature oriented river work". 1) Is there few alien plant species invasion compared native species in summer construction? 2) What kind of plant species invasion trespasses upon bared ground from summer to autumn? 3) Is the alien plants affect the native plant succession? It was paid attention to these three points, and analyzed.

2. MATERIALS AND METHODS

2.1 The Study site

The study was carried out on a left bank of the Toki River at Miyamae, Tajimi City (35° 33' 56''N, 137° 12' 92''E, altitude 96.6 m). Toki river is a upper river in the Shonai River water system of the extension 23km and 115 km^2 in the valley area. Because this river region had frequently received the flood damage, bank repair and a river dredge are continuing.

At the study area, the restoration of old fluvial environment was finished in 2010. The environment condition is a place of the old natural environmental condition without dam controls. This place is consists of round pebbles without burial seeds. And in order to everyone can easily access the river flow and enjoy nature condition, the loose inclination at lower riverbed is designed.

2.2 Seedling emergence census

The restoration was done in the investigation place at June in 2010, where all the buried seeds were removed from the soil within 1m in depth. For seedling emergence census, 20 quadrats (1 x 1m) were set at 20m in higher bed part, medium part and waterside part on the hydrophilicity shore protection slope, each interval is 1m. The total area was 60m^2 (Fig 1, 2). Two treatments were done in each quadrat, one is seedling remained and the other is seedling removal. Two treatments were arranged like a checkerboard.

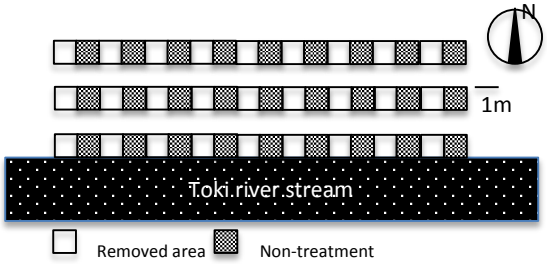

Fig. 1 The investigation areas map.

The species of emerging seedlings was identified by comparison with the seedling specimen that had been prepared by germinating the collected seeds under laboratory conditions. The recorded seedlings were checked by pigment ink. Census was carried out from June 30'2010 to Apr 24'2011 at every week intervals. Unidentifiable seedlings constituted only less than 0.1% of the total seedlings recorded during the study period except grass family. Using this data, it was compared the duration of seedling emergence between alien and native plants by Mann-Whiteney test.

Fig. 2 The condition of investigation areas in June 23'2010.

3. RESULTS

In the census, we observed a total of 41 native plant species and 26 alien species. The number of species observed that emerging in each season at each treatment area showed in Table 1. In spring there are sometimes hard rain fall in the census area and we cannot count the seedling number exactly because hard rainfalls had flowed out seedlings. The number of native species is larger than that of alien species in each condition, treatment and seasons except for spring. The observed number of species is lower in summer in all area. But the number of native species is larger than that of alien species and the number of summer emergence species is smaller than that of autumn.

Table I. The number of species observed that emerging in each season at each treatment area. Native species normal exhibit and (alien species).

	Sum.	Autumn.	Win.	Spr.
Higher				
Removed	12 (8)	23 (16)	10 (7)	3 (2)
No treat	13 (7)	23 (17)	1 (2)	0 (0)
Medium				
Removed	10 (2)	21 (17)	4 (6)	0 (0)
No treat	6 (1)	16 (15)	1 (1)	1 (0)
Water side				
Removed	13 (7)	29 (16)	5 (5)	0 (0)
No treat	11 (8)	37 (22)	0 (1)	0 (1)

The duration of emergence in summer and autumn at each plot showed in Fig. 3 and 4 (more precisely data showed in Appendix 1-3).

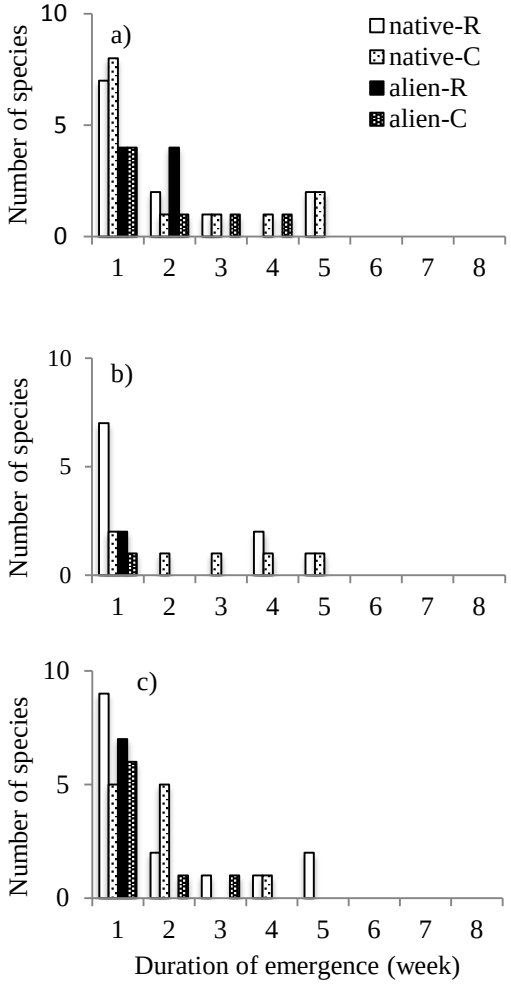

Fig. 3 The histogram of observed summer seedling emergence the durations. a) is the higher bed part, b) is the medium part, c) is the water side part. native-R is native species observed in removed area, native-C is native species observed in control area, alien-R is alien species in removed area, and alien-C is alien species in controlled area.

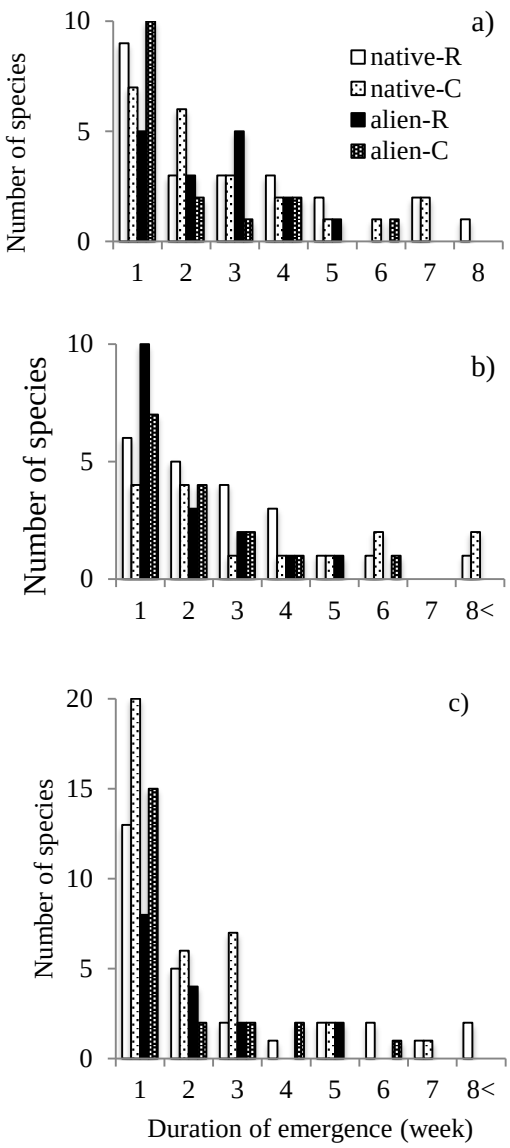

Fig. 4 The histogram of observed autumn seedling emergence the durations. a) is the higher bed part, b) is the medium part, c) is the water side part. native-R is native species observed in removed area, native-C is native species observed in control area, alien-R is alien species in removed area, and alien-C is alien species in controlled area.

There were large differences observed the duration of emergence between native species and alien species in summer (Fig. 3). The duration of alien species seedling emergence was shorter than that of native species. Especially in medium plots alien species emergence were observed at one week, though native species emerged from one week to 5 weeks. In all area seedlings of *Digitaria ciliaris*, *Setaria viridis* and *Cyperus sp* were observed from 3 to 5 weeks, and a large number seedling emergence observed. In autumn, there was few differences about seedling emergence duration between alien species and native species, but the longest seedling emergence were native species, *Eleusine indica*, *Cardamine scutata* and *Digitaria ciliaris*, in some area (Fig. 4). In removed area in autumn, durations of seedling emergence were longer than those of no treatment area. In alien species, *Cerastium glomeratum*, *Oenothera erythrosepala*, *Eragrostis curvula and Mollugo pentapylla*, long durations of autumn seedling emergence were observed. Mann-Whitney statistical tests were performed to examine the presence of differences in the duration of seedling emergence among native species and alien species at each season (Table II). In summer, the duration of seedling emergence of native

species in highest riverbed and waterside are longer those of alien species. In medium water condition plots there were only two alien species seedling emergence observed, so we cannot use this test, but alien seedling emergences were observed once time only. In autumn at control area of highest riverbed and medium water level there were differences between native species and alien species. But other condition there was no differences observed.

Table II. The result of the Mann-Whitney U test for duration of seedling emergence of co-occurring native species vs alien species in different moist level plots.

season	Moist level	Removed	Control
Summer	highest	*	*
	medium	-	-
	water side	***	*
Autumn	highest	N. S.	*
	medium	N. S.	*
	water side	N. S.	N. S.

*; $p<0.05$, ***; $p<0.001$; N. S. means non-significant.

4. DISCUSSION

Invasion of alien species into some areas has had a devastating impact on the native biodiversity [6]-[8]. Native species most vulnerable to the impact of alien species invasions are those which have evolved in isolation from high levels of competition. Especially the invasion of alien species in the river system, where continuous disturbance of each rainfall occurred, is the serious problem [9]. In order to manage the alien species Ministry of Land, Infrastructure and Transport has constructed many biotopes in river ecosystem. They removed burial seeds and vegetation of alien plants from the construction area, but the open areas are immediately occupied by alien species [10]. From the investigation of another biotope area [5], the alien plants invasion mainly occurred in spring, and there is rarely invasion in summer season. Then if the construction is finished in summer, alien invasion prevented by severe hot condition?

In our research the method to prevent alien species invasion is cleared. In summer more 10 native species can emerge in open area at severe condition, but there are few alien species occurred. And the number of alien seedling was very few, moreover the survival rate of seedling in very low. But some native species survived in severe conditions, the number of native species seedling is large, and establishment of vegetation cover can successful. Bared land in summer can easily prevent the alien species invasion. Only *Mollugo verticillata* is exception, they can emerge and survive in summer although there are few numbers (totally 10 seedlings in higher river bed area).

In autumn there is few differences in seedling emergence duration between native and alien species, both species emerged longer than that in summer. But some occupied vegetation effect observed. The prevention of alien invasion was observed in non-removed area. It seems there is no bared space where seedlings can emerge. The effect of vegetation cover is more serious in alien species than native species.

It is continuing being said that removal of the alien species in fluvial environment is very difficult [11][12]. However, it was shown by our research findings in the summer that invasion of alien species was prevented. Moreover, if occupied by native species in a summer, alien species will become difficult to invade even if autumn condition. In order to press down invasion of alien species, construction plan in which an open space should be made to form in a summer is required. However although only *Mollugo verticillata* was a small number, it was able to invade into the fluvial environment of the summer. For this reason, in order to press down invasion of *M. verticillata*, it is thought that another technique is important.

5. CONCLUSION

The following conclusions are drawn based on the study:
1) Seedlings of alien species could not easily invade bared area in summer, 2) Only some seedlings of a few native species can be established at the investigated area in summer, 3) The vegetation by native species that recovered in summer prevented the invasion of alien species, 4) Seedling removal hasten the invasion of alien species.

6. ACKNOWLEDGEMENTS

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Appendix 1. the list of observed seedling emergence and duration of the emergence in each season at high river bed area. The number showed the times of emergence observation in each season.

		Summer	Autumn	Winter	Spring			Summe	Autum	Winter	Spring
removed	native species					Non-removed					
	Acalypha australis	1	2			*Acalypha australis*	2				
	Digitaria ciliaris	3	7		2	*Digitaria ciliaris*	4	6			
	Setaria viridis	5	7			*Setaria viridis*	5	5			
	Zoysia japonica	1	4	1		*Zoysia japonica*	1	2			
	Cyperus sp.	5	5	1		*Cyperus sp.*	5	3		1	
	Rumex acetosa	1	1			*Phragmites japonica*	3				
	Cayratia japonica	1				*Cardamine scutata*	1	4			
	Bothriospermum tenellum	1				*Rumex acetosa*	1				
	Sonchus oleraceus	1				*Artemisia indica* var. *maximowiczii*	1	1			
	Cardamine scutata		3	1		*Sonchus oleraceus*	1				
	Phragmites japonica	2	2			*Setaria viridis form. misera*	1	1			
	Portulaca oleracea	1	1	1		*Portulaca oleracea*	1	2			
	Setaria viridis form. misera	2	3			*Eleusine indica*	1	7			
	Eleusine indica		5			*Chenopodium album*		1			
	Lespedeza juncea var. *subsessilis*		1			*Poaceae*		7			
	Poaceae		8	2		*Torilis japonica*		3			
	Cyperus iria		1			*Sonchus oleraceus*		2			
	Scirpus wichurae		1			*Galium spurium* var. *echinospermon*		3			
	Galium spurium var. *echinospermon*		4			*Sedum bulbiferum*		1			
	Solanum nigrum		2			*Stellaria media*		4			
	Oxalis corniculata f. erecta		4			*Solanum nigrum*		2			
	Torilis japonica		1			*Paederia scandens*		1			
	Stellaria media		3	2		*Panicum bisulcatum*		1			
	Echinochloa crus-galli var. *caudata*		1			*Trigonotis peduncularis*		2			
	Trigonotis peduncularis		1	1		*Capsella bursa-pastoris*		1			
	Sagina japonica		1	1	1	*Oxalis corniculata f. erecta*		2			
	Poa annua			1		*Rorippa indica*		1			
	Persicaria hydropiper			1							
	Rorippa palustris				1						
	Alien plants										
	Trifolium repens	2	4	1		*Trifolium repens*	4	3			
	Bidens frondosa	1				*Bidens frondosa*	1				
	Ipomoea triloba	1				*Ipomoea triloba*	2				
	Chamaesyce mitans	2	3			*Chamaesyce mitans*	1				
	Mollugo pentaphylla	2	5			*Mollugo verticillata*	3	4			
	Chenopodium ambrosioides	2				*Chenopodium ambrosioides*	1	1			
	Paederia scandens	1	2			*Amaranthus hybridus*	1				
	Phytolacca americana	1				*Solanum carolinense*		1			
	Lamium purpureum		3			*Cerastium glomeratum*		4			
	Cerastium glomeratum		3	2		*Veronica persica*		1			
	Erigeron sp		2		1	*Rumex sp*		6			
	Eragrostis curvula		4			*Lamium purpureum*		2			
	Gnaphalium pensylvanicum		1			*Paederia scandens*		1			
	Verbena brasiliensis		3	1	1	*Eragrostis curvula*		2			
	Lamium amplexicaule		1			*Veronica arvensis*		1			
	Rumex sp		1	1		*Veronica persica*		1			
	Vicia sativa subsp. nigra		2	1		*Phytolacca americana*		1			
	Coreopsis lanceolata		1			*Vicia sativa subsp. nigra*		1			
	Nuttallanthus canadensis		1	1		*Verbena brasiliensis*		1			
	Veronica persica		3	1		*Nuttallanthus canadensis*		1		1	
						Veronica persica		1		1	

Appendix2. the list of observed seedling emergence and duration of the emergence in each season at mid river bed area. The number showed the times of emergence observation in each season.

		Summe	Autum	Winte	Spring			Summ	Autum	Winte	Spring
removed	*Acalypha australis*	1	1			Non-removed	*Acalypha australis*	1			
	Digitaria ciliaris	4	3				*Digitaria ciliaris*	4	3		2
	Setaria viridis	5	3				*Setaria viridis*	5	6		5
	Zoysia japoinica	1	4	1			*Zoysia japoinica*				
	Cyperus sp	4	2				*Cyperus sp*	3	6		
	Paederia scandens	1					*Setaria viridis form. misera*	2	2		
	Rumex acetosa	1					*Eleusine indica*	1	9		1
	Phragmites japonica	1					*Poaceae*		10		
	Persicaria longiseta	1					*Echinochloa crus-galli var. caudate*		2		
	Glycine soja	1					*Torilis japonica*		4		
	Cyperus iria		1				*Lactuca indica*		1		
	Poaceae		8				*Stellaria media*		5		
	Echinochloa crus-galli var. caudata		1				*Oxalis corniculata f. erecta*		2		
	Sonchus oleraceus		2				*Wahlenbergia marginata*		1		
	Eleusine indica		6				*Cardamine scutata*		2		
	Galium spurium var. *echinospermor*		4	2			*Digitaria timorensis*		1		
	Cardamine scutata		4				*Galium spurium* var. *echinospermo*		2		
	Setaria viridis form. misera		2				*Portulaca oleracea*		1		
	Torilis japonica		3				*Paspalum thunbergii*				
	Oxalis corniculata f. erecta		5	1			*Persicaria lapathifolia*			1	
	Wahlenbergia marginata		1				*Sonchus oleraceus*				
	Solanum nigrum		1								
	Bothriospermum tenellum		2								
	Stellaria media		3	1							
	Trigonotis peduncularis		2								
	Lapsana apogonoides		1								
	Trifolium repens	1					*Trifolium repens*		2		
	Bidens frondosa	1					*Bidens frondosa*		2		1
	Chamaesyce nutans		3				*Ipomoea triloba*				
	Mollugo pentapylla		2				*Chamaesyce nutans*	1	1		
	Chenopodium ambrosioides		1				*Mollugo pentapylla*		1		
	Amaranthus hybridus		1				*Chenopodium ambrosioides*		1		
	Lamium purpureum		3				*Amaranthus hybridus*		1		1
	Trifolium repens		2				*Verbena brasiliensis*		3		
	Eragrostis curvula		4				*Cerastium glomeratum*		6		
	Cerastium glomeratum		5	1			*Eragrostis curvula*		4		
	Rumex sp		2	1			*Rumex sp*		2		
	Chenopodium ficifolium		1				*Bidens pilosa var. pilosa*		1		
	Lamium amplexicaule		1				*Sorghum halepense*		1		
	Specularia perfoliata		1				*Vicia sativa subsp. nigra*		2		
	Amaranthus hybridus		1				*Lamium purpureum*		3		
	Verbena brasiliensis		1	1			*Chenopodium ficifolium*		1		
	Nuttallanthus canadensis		1	1			*Veronica persica*			1	
	Erigeron sp		1	2							
	Trifolium campestre			1							
	Veronica persica		1								

Appendix 3. the list of observed seedling emergence and duration of the emergence in each season at low river bed area. The number showed the times of emergence observation in each season.

		Summe	Autum	Winte	Spring			Summ	Autun	Winte	Spring
removed	*Acalypha australis*	1				Non-remov	*Acalypha australis*		1		
	Digitaria ciliaris	4	6				*Digitaria ciliaris*	1	2		
	Setaria viridis	5	5				*Setaria viridis*	4	2		
	Zoysia japoinica	3	1	2			*Zoysia japoinica*	2			
	Cyperus sp	5	9				*Cyperus sp*	2	5		
	Paederia scandens	1					*Torilis japonica*		3		
	Torilis japonica	1	3				*Eleusine indica*	1			
	Eleusine indica	1	6				*Portulaca oleracea*	2	3		
	Portulaca oleracea	1	2				*Persicaria lapathifolia*	1	5		
	Persicaria lapathifolia	2	1				*Portulaca oleracea*	2	2		
	Chenopodium album	1	1				*Digitaria timorensis*	1	1		
	Phragmites japonica	1					*Mimulus nepalensis*	1			
	Phyllanthus urinaria	1	1				*Albizia julibrissin*	2			
	Solanum nigrum	2	3				*Setaria faberi*		1		
	Setaria faberi		1				*Persicaria longiseta*		2		
	Setaria viridis var. minor	1	2				*Eragrostis ferruginea*		1		
	Poaceae		8	1			*Rumex sp*		3		
	Cardamine scutata		7				*Phragmites japonica*		1		
	Lindernia crustacea		1				*Panicum bisulcatum*		1		
	Sedum bulbiferum		1				*Solanum nigrum*		3		
	Oxalis corniculata f. erecta		2	2			*Lophatherum gracile*		1		
	Sonchus oleraceus		4				*Cyperus exaltatus var. iwasakii*		3		
	Stellaria media		5				*Oxalis corniculata f. erecta*		5		
	Erigeron sp		2				*Chenopodium album*		1		
	Sagina japonica		2				*Cyperus iria*		1		
	Poa annua		1				*Centipeda minima*		3		
	Bothriospermum tenellum		1				*Poaceae*		7		
	Trigonotis peduncularis		1	1			*Digitaria timorensis*		1		
	Galium spurium var. echinospermor		1				*Cardamine scutata*		3		
	Rorippa indica		1				*Bothriospermum tenellum*		1		
	Potentilla anemonifolia		1				*Wahlenbergia marginata*		1		
	Artemisia indica var. *maximowiczii*						*Trigonotis peduncularis*		1		
	Sagina japonica			1			*Erigeron sp*		1		
							Sagina japonica		1		
							Stellaria media		2		
							Potentilla anemonifolia		1		
							Artemisia indica var. *maximowiczii*		1		
							Lespedeza juncea var. subsessilis		1		
							Galium spurium var. echinospermo		2		
							Sonchus oleraceus		1		
							Sagina japonica		1		
	Trifolium repens	1	2	1			*Trifolium repens*				1
	Bidens frondosa		1				*Bidens frondosa*		1		
	Ipomoea triloba	1					*Chamaesyce nutans*		4		
	Chamaesyce nutans		2				*Mollugo pentaphylla*		1		
	Mollugo pentaphylla	1	3				*Chenopodium ambrosioides*	1	1		
	Chenopodium ambrosioides		1				*Oenothera erythrosepala*	1	7		
	Oenothera erythrosepala	1					*Cerastium glomeratum*	3	1		
	Cerastium glomeratum	1	3	1			*Lamium purpureum*	1			
	Lamium amplexicaule	1					*Paederia scandens*	2	1		
	Eragrostis curvula		5	1			*Amaranthus hybridus*	1			
	Lamium purpureum		1				*Galinsoga quadriradiata*	1	1		
	Rumex sp	1	5				*Oenothera erythrosepala*		3		
	Specularia perfoliata		1				*Verbena brasiliensis*		2		
	Plantago lanceolata		1				*Sorghum halepense*		1		
	Verbena brasiliensis		2				*Sisyrinchium rosulatum*		2		
	Medicago polymorpha		1				*Cerastium glomeratum*		4		
	Paederia scandens		1				*Eragrostis curvula*		3		
	Gnaphalium pensylvanicum		1				*Vicia sativa subsp. nigra*		1		
	Nuttallanthus canadensis			2			*Trifolium repens*		1		
	Veronica persica		2	1			*Chenopodium ficifolium*	1	1		
							Lamium purpureum		1		
							Senecio vulgaris		1		
							Gnaphalium pensylvanicum		1		
							Nuttallanthus canadensis		1		
							Veronica persica		1		
							Nasturtium officinale				1