Altered ecosystem carbon and nitrogen cycles by plant invasion: A meta-analysis

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Appendix A

A list of papers from which data were extracted for this metadata analysis

1. **Allison SD, Nielsen C, Hughes RF. 2006.** Elevated enzyme activities in soils under the invasive nitrogen-fixing tree *Falcataria moluccana*. *Soil Biology and Biochemistry* **38:** 1537-1544.
2. **Allison SD, Vitousek PM. 2004a.** Extracellular enzyme activities and carbon chemistry as drivers of tropical plant litter decomposition. *Biotropica* **36:** 285-296.
3. **Allison SD, Vitousek PM. 2004b.** Rapid nutrient cycling in leaf litter from invasive plants in Hawai'i. *Oecologia* **141:** 612-619.
4. **Angeloni NL, Jankowski KJ, Tuchman NC, Kelly JJ. 2006.** Effects of an invasive cattail species (Typha x glauca) on sediment

nitrogen and microbial community composition in a freshwater wetland. *Fems Microbiology Letters* **263:** 86-92.

5. **Ashton IW, Hyatt LA, Howe KM, Gurevitch J, Lerdau MT. 2005.** Invasive species accelerate decomposition and litter nitrogen loss in a mixed deciduous forest. *Ecological Applications* **15:** 1263-1272.
6. **Asner GP, Beatty SW. 1996.** Effects of an African grass invasion on Hawaiian shrubland nitrogen biogeochemistry. *Plant and Soil* **186:** 205-211.
7. **Baer SG, Church JM, Williard KWJ, Groninger JW. 2006.** Changes in intrasystem N cycling from N_2-fixing shrub encroachment in grassland: multiple positive feedbacks. *Agriculture Ecosystems and Environment* **115:** 174-182.
8. **Baruch Z, Goldstein G. 1999.** Leaf construction cost, nutrient concentration, and net CO_2 assimilation of native and invasive species in Hawaii. *Oecologia* **121:** 183-192.
9. **Batten KM, Six J, Scow KM, Rillig MC. 2005.** Plant invasion of native grassland on serpentine soils has no major effects upon selected physical and biological properties. *Soil Biology and Biochemistry* **37:** 2277-2282.
10. **Bellingham PJ, Peltzer DA, Walker LR. 2005.** Contrasting impacts of a native and an invasive exotic shrub on flood-plain succession. *Journal of Vegetation Science* **16:** 135-142.
11. **Belnap J, Phillips SL. 2001.** Soil biota in an ungrazed grassland: Response to annual grass (*Bromus tectorum*) invasion. *Ecological Applications* **11:** 1261-1275.
12. **Belnap J, Phillips SL, Sherrod SK, Moldenke A. 2005.** Soil biota can change after exotic plant invasion: does this affect

ecosystem processes? *Ecology* **86:** 3007-3017.

13. **Belote RT, Weltzin JF, Norby RJ. 2004.** Response of an understory plant community to elevated CO_2 depends on differential responses of dominant invasive species and is mediated by soil water availability. *New Phytologist* **161:** 827-835.
14. **Blank RR, Youn JA. 2002.** Influence of the exotic invasive crucifer, *Lepidium latifolium*. on soil properties and elemental cycling. *Soil Science* **167:** 821-829.
15. **Booth MS, Stark JM, Caldwell MM. 2003**. Inorganic N turnover and availability in annual- and perennial-dominated soils in a northern Utah shrub-steppe ecosystem. *Biogeochemistry* **66:** 311-330.
16. **Boswell CC, Espie PR. 1998.** Uptake of moisture and nutrients by *Hieracium pilosella* and effects on soil in a dry sub-humid grassland. *New Zealand Journal of Agricultural Research* **41:** 251-261.
17. **Bradley BA, Houghtonw RA, Mustard JF, Hamburg SP. 2006.** Invasive grass reduces aboveground carbon stocks in shrublands of the Western US. *Global Change Biology* **12:** 1815-1822.
18. **Caldwell BA. 2006.** Effects of invasive scotch broom on soil properties in a Pacific coastal prairie soil. *Applied Soil Ecology* **32:** 149-152.
19. **Chapuis-Lardy L, Vanderhoeven S, Dassonville N, Koutika LS, Meerts P. 2006.** Effect of the exotic invasive plant *Solidago gigantea* on soil phosphorus status. *Biology and Fertility of Soils* **42:** 481-489.
20. **Chen ZY, Li B, Chen JK. 2005.** Some growth characteristics and relative competitive ability of invasive *Spartina alterniflora*

and native *Scirpus mariqueter*. *Biodiversity Science (In Chinese)* **13:** 130-136.

21. **Christian JM, Wilson SD. 1999.** Long-term ecosystem impacts of an introduced grass in the northern Great Plains. *Ecology* **80:** 2397-2407.
22. **Corbin JD, D'Antonio CM. 2004.** Competition between native perennial and exotic annual grasses: Implications for an historical invasion. *Ecology* **85:** 1273-1283.
23. **Cushman JH, Tierney TA, Hinds JM. 2004.** Variable effects of feral pig disturbances on native and exotic plants in a California grassland. *Ecological Applications* **14:** 1746-1756.
24. **Durand LZ, Goldstein G. 2001.** Photosynthesis, photoinhibition, and nitrogen use efficiency in native and invasive tree ferns in Hawaii. *Oecologia* **126:** 345-354.
25. **Ehrenfeld JG, Kourtev P, Huang WZ. 2001.** Changes in soil functions following invasions of exotic understory plants in deciduous forests. *Ecological Applications* **11:** 1287-1300.
26. **Englund SR. 2004.** *Bromus tectorum impacts soil carbon storage in semiarid grasslands of Canyonlands National Park. Thesis.* The University of Utah, USA.
27. **Evans RD, Rimer R, Sperry L, Belnap J. 2001.** Exotic plant invasion alters nitrogen dynamics in an arid grassland. *Ecological Applications* **11:** 1301-1310.
28. **Farnsworth EJ, Meyerson LA. 2003.** Comparative ecophysiology of four wetland plant species along a continuum of

invasiveness. *Wetlands* **23:** 750-762.

29. **Fickbohm SS, Zhu WX. 2006.** Exotic purple loosestrife invasion of native cattail freshwater wetlands: Effects on organic matter distribution and soil nitrogen cycling. *Applied Soil Ecology* **32:** 123-131.
30. **Funk JL. 2005.** *Hedychium gardnerianum* invasion into Hawaiian montane rainforest: interactions among litter quality, decomposition rate, and soil nitrogen availability. *Biogeochemistry* **76:** 441-451.
31. **Grout JA, Levings CD, Richardson JS. 1997.** Decomposition rates of purple loosestrife (*Lythrum salicaria*) and Lyngbyei's sedge (*Carex lyngbyei*) in the Fraser River estuary. *Estuaries* **20:** 96-102.
32. **Guesewell S, Jakobs G, Weber E. 2006.** Native and introduced populations of *Solidago gigantea* differ in shoot production but not in leaf traits or litter decomposition. *Functional Ecology* **20:** 575-584.
33. **Hager HA. 2004.** Competitive effect versus competitive response of invasive and native wetland plant species. *Oecologia* **139:** 140-149.
34. **Harcombe PA, Cameron GN, Glumac EG. 1993.** Above-ground net primary productivity in adjacent grassland and woodland on the coastal prairie of Texas, USA. *Journal of Vegetation Science* **4:** 521-530.
35. **Hartemink AE, O'Sullivan JN. 2001.** Leaf litter decomposition of *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica* in the humid lowlands of Papua New Guinea. *Plant and Soil* **230:** 115-124.
36. **Hawkes CV, Wren IF, Herman DJ, Firestone MK. 2005.** Plant invasion alters nitrogen cycling by modifying the soil nitrifying

community. *Ecology Letters* **8:** 976-985.

37. **Henderson DC, Naeth MA. 2005.** Multi-scale impacts of crested wheatgrass invasion in mixed-grass prairie. *Biological Invasions* **7:** 639-650.

38. **Heneghan L, Fatemi F, Umek L, Grady K, Fagen K, Workman M. 2006.** The invasive shrub European buckthorn (*Rhamnus cathartica, L.*) alters soil properties in Midwestern US woodlands. *Applied Soil Ecology* **32:** 142-148.

39. **Hibbard KA, Archer S, Schimel DS, Valentine DW. 2001.** Biogeochemical changes accompanying woody plant encroachment in a subtropical savanna. *Ecology* **82:** 1999-2011.

40. **Hook PB, Olson BE, Wraith JM. 2004.** Effects of the invasive Forb *Centaurea maculosa* on grassland carbon and nitrogen pools in Montana, USA. *Ecosystems* **7:** 686-694.

41. **Hoopes MF, Hall LM. 2002.** Edaphic factors and competition affect pattern formation and invasion in a California grassland. *Ecological Applications* **12:** 24-39.

42. **Hughes RF, Archer SR, Asner GP, Wessman CA, McMurtry C, Nelson J, Ansley RJ. 2006.** Changes in aboveground primary production and carbon and nitrogen pools accompanying woody plant encroachment in a temperate savanna. *Global Change Biology* **12:** 1733-1747.

43. **Hughes RF, Denslow JS. 2005.** Invasion by a N_2 fixing tree alters function and structure in wet lowland forests of Hawaii. *Ecological Applications* **15:** 1615-1628.

44. **Hughes RF, Uowolo A. 2006.** Impacts of *Falcataria moluccana* invasion on decomposition in Hawaiian lowland wet forests: The importance of stand-level controls. *Ecosystems* **9:** 977-991.

45. **Kelly DJ, Hawes I. 2005.** Effects of invasive macrophytes on littoral-zone productivity and foodweb dynamics in a New Zealand high-country lake. *Journal of the North American Benthological Society* **24:** 300-320.

46. **Kourtev PS, Ehrenfeld JG, Haggblom M. 2003.** Experimental analysis of the effect of exotic and native plant species on the structure and function of soil microbial communities. *Soil Biology and Biochemistry* **35:** 895-905.

47. **Lett MS, Knapp AK, Briggs JM, Blair JM. 2004.** Influence of shrub encroachment on aboveground net primary productivity and carbon and nitrogen pools in a mesic grassland. *Canadian Journal of Botany-Revue Canadienne De Botanique* **82:** 1363-1370.

48. **Li WH, Zhang CB, Jiang HB, Xin GR, Yang ZY. 2006.** Changes in soil microbial community associated with invasion of the exotic weed, Mikania micrantha HBK. *Plant and Soil* **281:** 309-324.

49. **Liao CZ. 2007.** *The effects of invasive alien plants on ecosystem carbon and nitrogen cycles*: *a case study of Spartina alterniflora invasion in the Yangtze Estuary and a Meta-analysis*. PhD thesis, Fudan University, China.

50. **Liao JD-Y. 2004.** *Woodland development and soil carbon and nitrogen dynamics and storage in a subtropical savanna ecosystem.* PhD thesis, Texas A & M University, USA.

51. **Liao JD, Boutton TW, Jastrow JD. 2006.** Organic matter turnover in soil physical fractions following woody plant invasion of

grassland: Evidence from natural ^{13}C and ^{15}N. *Soil Biology and Biochemistry* **38:** 3197-3210.

52. **Lindsay EA, French K. 2004.** *Chrysanthemoides monilifera* ssp rotundata invasion alters decomposition rates in coastal areas of south-eastern Australia. *Forest Ecology and Management* **198:** 387-399.
53. **Lindsay EA, French K. 2005.** Litterfall and nitrogen cycling following invasion by *Chrysanthemoides monilifera* ssp rotundata in coastal Australia. *Journal of Applied Ecology* **42:** 556-566.
54. **Litton CM, Sandquist DR, Cordell S. 2006.** Effects of non-native grass invasion on aboveground carbon pools and tree population structure in a tropical dry forest of Hawaii. *Forest Ecology and Management* **231:** 105-113.
55. **Mack MC, D'Antonio CM. 2003a.** The effects of exotic grasses on litter decomposition in a Hawaiian woodland: The importance of indirect effects. *Ecosystems* **6:** 723-738.
56. **Mack MC, D'Antonio CM. 2003b.** Exotic grasses alter controls over soil nitrogen dynamics in a Hawaiian woodland. *Ecological Applications* **13:** 154-166.
57. **Mahaney WM, Smemo KA, Yavitt JB. 2006.** Impacts of *Lythrum salicaria* invasion on plant community and soil properties in two wetlands in central New York, USA. *Canadian Journal of Botany-Revue Canadienne De Botanique* **84:** 477-484.
58. **McCarron JK, Knapp A, Blair JM. 2003.** Soil C and N responses to woody plant expansion in a mesic grassland. *Plant and Soil* **257:** 183-192.
59. **McCulley RL, Archer SR, Boutton TW, Hons FM, Zuberer DA. 2004.** Soil respiration and nutrient cycling in wooded

communities developing in grassland. *Ecology* **85:** 2804-2817.

60. **McIntosh PD, Loeseke M, Bechler K. 1995.** Soil changes under mouse-ear hawkweed (*Hieracium pilosella*). *New Zealand Journal of Ecology* **19:** 29-34.
61. **Meyerson LA, Chambers RM, Vogt KA. 1999.** The effects of *Phragmites* removal on nutrient pools in a freshwater tidal marsh ecosystem. *Biological Invasions* **1:** 129-136.
62. **Mitchell RJ, Marrs RH, Le Duc MG, Auld MHD. 1997.** A study of succession on lowland heaths in Dorset, southern England: Changes in vegetation and soil chemical properties. *Journal of Applied Ecology* **34:** 1426-1444.
63. **Morghan KJR, Seastedt TR. 1999.** Effects of soil nitrogen reduction on nonnative plants in restored grasslands. *Restoration Ecology* **7:** 51-55.
64. **Musil CF. 1993.** Effect of invasive Australian acacias on the regeneration, growth and nutrient chemistry of South African lowland fynbos. *Journal of Applied Ecology* **30:** 361-372.
65. **Nagel JM, Griffin KL. 2004.** Can gas-exchange characteristics help explain the invasive success of *Lythrum salicaria*? *Biological Invasions* **6:** 101-111.
66. **Norris MD, Blair JM, Johnson LC. 2001.** Land cover change in eastern Kansas: litter dynamics of closed-canopy eastern redcedar forests in tallgrass prairie. *Canadian Journal of Botany-Revue Canadienne De Botanique* **79:** 214-222.
67. **O'Dell RE, Claassen VP. 2006.** Relative performance of native and exotic grass species in response to amendment of drastically

disturbed serpentine substrates. *Journal of Applied Ecology* **43:** 898-908.

68. **Ogle SM, Reiners WA, Gerow KG. 2003.** Impacts of exotic annual brome grasses (*Bromus* spp.) on ecosystem properties of northern mixed grass prairie. *American Midland Naturalist* **149:** 46-58.

69. **Otto S, Groffman PM, Findlay SEG, Arreola AE. 1999.** Invasive plant species and microbial processes in a tidal freshwater marsh. *Journal of Environmental Quality* **28:** 1252-1257.

70. **Perry LG, Galatowitsch SM, Rosen CJ. 2004.** Competitive control of invasive vegetation: a native wetland sedge suppresses *Phalaris arundinacea* in carbon-enriched soil. *Journal of Applied Ecology* **41:** 151-162.

71. **Reed HE, Seastedt TR, Blair JM. 2005.** Ecological consequences of C_4 grass invasion of a C_4 grassland: A dilemma for management. *Ecological Applications* **15:** 1560-1569.

72. **Rimer RL, Evans RD. 2006.** Invasion of downy brome (*Bromus tectorum L.*) causes rapid changes in the nitrogen cycle. *American Midland Naturalist* **156:** 252-258.

73. **Rothstein DE, Vitousek PM, Simmons BL. 2004.** An exotic tree alters decomposition and nutrient cycling in a Hawaiian montane forest. *Ecosystems* **7:** 805-814.

74. **Saggar S, McIntosh PD, Hedley CB, Knicker H. 1999.** Changes in soil microbial biomass, metabolic quotient, and organic matter turnover under *Hieracium* (*H. pilosella L.*). *Biology and Fertility of Soils* **30:** 232-238.

75. **Scott NA, Saggar S, McIntosh PD. 2001.** Biogeochemical impact of *Hieracium* invasion in New Zealand's grazed tussock

grasslands: Sustainability implications. *Ecological Applications* **11:** 1311-1322.

76. **Sher AA, Marshall DL, Gilbert SA. 2000.** Competition between native *Populus deltoids* and invasive *Tamarix ramosissima* and the implications for reestablishing flooding disturbance. *Conservation Biology* **14:** 1744-1754.

77. **Sperry LJ, Belnap J, Evans RD. 2006.** *Bromus tectorum* invasion alters nitrogen dynamics in an undisturbed arid grassland ecosystem. *Ecology* **87:** 603-615.

78. **Standish RJ, Williams PA, Robertson AW, Scott NA, Hedderley DI. 2004.** Invasion by a perennial herb increases decomposition rate and alters nutrient availability in warm temperate lowland forest remnants. *Biological Invasions* **6:** 71-81.

79. **Steinaker DF, Wilson SD. 2005.** Belowground litter contributions to nitrogen cycling at a northern grassland-forest boundary. *Ecology* **86:** 2825-2833.

80. **Stock WD, Wienand KT, Baker AC. 1995.** Impacts of invading N_2-fixing *Acacia* species on patterns of nutrient cycling in two Cape ecosystems: evidence from soil incubation studies and ^{15}N natural abundance values. *Oecologia* **101:** 375-382.

81. **Stratton LC, Goldstein G. 2001.** Carbon uptake, growth and resource-use efficiency in one invasive and six native Hawaiian dry forest tree species. *Tree Physiology* **21:** 1327-1334.

82. **Svejcar T, Sheley R. 2001.** Nitrogen dynamics in perennial- and annual-dominated arid rangeland. *Journal of Arid Environments* **47:** 33-46.

83. **Thomsen MA, Corbin JD, D'Antonio CM. 2006.** The effect of soil nitrogen on competition between native and exotic perennial

grasses from northern coastal California. *Plant Ecology* **186:** 23-35.

84. **Valéry L, Bouchard V, Lefeuvre JC. 2004.** Impact of the invasive native species *Elymus athericus* on carbon pools in a salt marsh. *Wetlands* **24:** 268-276.

85. **van Derhoeven S, Dassonville N, Meerts P. 2005.** Increased topsoil mineral nutrient concentrations under exotic invasive plants in Belgium. *Plant and Soil* **275:** 169-179.

86. **Vinton MA, Goergen EM. 2006.** Plant-soil feedbacks contribute to the persistence of *Bromus inermis* in tallgrass prairie. *Ecosystems* **9:** 967-976.

87. **Vitousek PM, Walker LR. 1989.** Biological invasion by *Myrica faya* in Hawai'i: Plant demography, nitrogen fixation, ecosystem effects. *Ecological Monographs* **59:** 247-265.

88. **Wedin DA, Pastor J. 1993.** Nitrogen mineralization dynamics in grass monocultures. *Oecologia* **96:** 186-192.

89. **Wilsey BJ, Polley HW. 2006.** Aboveground productivity and root-shoot allocation differ between native and introduced grass species. *Oecologia* **150:** 300-309.

90. **Windham L. 2001.** Comparison of biomass production and decomposition between *Phragmites australis* (common reed) and *Spartina patens* (salt hay grass) in brackish tidal marshes of New Jersey, USA. *Wetlands* **21:** 179-188.

91. **Windham L, Ehrenfeld JG. 2003.** Net impact of a plant invasion on nitrogen-cycling processes within a brackish tidal marsh. *Ecological Applications* **13:** 883-896.

92. **Windham L, Lathrop RG. 1999.** Effects of *Phragmites australis* (common reed) invasion on aboveground biomass and soil properties in brackish tidal marsh of the Mullica River, New Jersey. *Estuaries* **22:** 927-935.

93. **Witkowski ETF. 1991a.** Effects of invasive alien *Acacias* on nutrient cycling in the coastal lowlands of the cape fynbos. *Journal of Applied Ecology* **28:** 1-15.

94. **Witkowski ETF. 1991b.** Growth and competition between seedlings of *Protea repens* (*L.*) L. and the alien invasive, *Acacia saligna* (Labill.) Wendl. in relation to nutrient availability. *Functional Ecology* **5:** 101-110.

Note: The invasive plant species are N-fixing invaders in papers of 1, 2, 3, 6, 7, 18, 20, 39, 42, 43, 44, 49, 50, 51, 59, 64, 80, 87, 93, and 94.

Appendix B

Table of weighted response ratio (RR_{++}) and number of data sets (in parentheses) for 20 variables extracted from each of the papers

Paper	Citation	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
1	Allison *et al*., 2006					-0.12 (3)			0.66 (3)												
2	Allison & Vitousek, 2004a																0.06 (30)				
3	Allison & Vitousek, 2004b											1.07 (30)			0.38 (30)	-0.01 (30)					
4	Angeloni *et al*., 2006	0.79 (1)		2.63 (1)	1.41 (1)															3.62 (1)	2.79 (1)
5	Ashton *et al*., 2005				-0.24 (1)							0.15 (16)				0.30 (16)		-0.40 (16)		0.29 (1)	-0.05 (1)
6	Asner & Beatty, 1996														0.25 (2)	0.03 (2)		-0.42 (2)			
7	Baer *et al*., 2006				-0.06 (1)	-0.47 (1)			0.01 (1)	-0.94 (1)											
8	Baruch & Goldstein, 1999														0.40 (3)						
9	Batten *et al*., 2005		0.31 (2)																		
10	Bellingham *et al*., 2005														-0.05 (1)						
11	Belnap & Phillips, 2001								0.11 (2)											0.04 (2)	-0.05 (2)
12	Belnap *et al*., 2005				0.37 (1)				0.14 (1)											0.25 (1)	0.02 (1)
13	Belote *et al*., 2003										1.92 (6)										
14	Blank & Youn, 2002				0.50		0.93									0.30					

					(1)		(1)									(1)					
15	Booth *et al*., 2003								0.27 (2)				0.73 (1)	0.45 (2)						0.31 (1)	-0.59 (1)
16	Boswell & Espie, 1998	2.27 (1)	1.38 (1)																		
17	Bradley *et al*., 2006	-1.85 (3)			0.13 (3)																
18	Caldwell, 2006				0.20 (1)				0.23 (1)												
19	Chapuis-Lardy *et al*., 2006	0.91 (3)			0.04 (3)				0.07 (3)												
20	Chen *et al*., 2005	1.83 (1)	1.81 (1)																		
21	Christian & Wilson, 1999	0.86 (2)	-0.63 (2)		-0.32 (2)				-0.29 (2)						-0.39 (2)						
22	Corbin & D'Antonio, 2004										-1.81 (1)										
23	Cushman *et al*., 2004	0.85 (4)																			
24	Durand & Goldstein, 2001														0.38 (4)						
25	Ehrenfeld *et al*., 2001	0.33 (3)	-1.35 (5)				0.66 (3)						-0.13 (10)	0.55 (10)						-0.18 (10)	2.00 (10)
26	Englund, 2004		-1.89 (1)		-0.48 (1)																
27	Evans *et al*., 2001			0.75 (2)														1.04 (2)	0.86 (2)		
28	Farnsworth & Meyerson, 2003	2.85 (4)													0.30 (4)						
29	Fickbohm & Zhu, 2006	0.55 (2)	0.26 (2)										0.36 (1)	0.27 (1)						0.33 (1)	-1.09 (1)
30	Funk, 2005											0.77 (2)	0.41 (1)	-1.44 (1)	0.77 (2)	0.07 (2)	-0.88 (2)	-0.08 (2)	-0.86 (2)		

31	Grout *et al*., 1997											1.39 (1)									
32	Güesewell *et al*., 2006														0.03 (1)	0.06 (1)					
33	Hager, 2004	0.48 (3)																			
34	Harcombe *et al*., 1993										1.00 (1)										
35	Hartemink & O'Sullivan, 2001															-0.48 (1)	-0.89 (1)	0.37 (1)			
36	Hawkes *et al*., 2005		1.14 (2)							0.42 (2)										0.17 (2)	-2.11 (2)
37	Henderson & Naeth, 2005	-0.41 (1)		-0.57 (1)																	
38	Heneghan *et al*., 2006				0.61 (3)				0.70 (3)				-0.42 (2)	-0.01 (2)							
39	Hibbard *et al*., 2001				0.56 (3)				0.63 (3)				1.08 (3)								
40	Hook *et al*., 2004				-0.03 (9)				-0.03 (9)				-0.55 (8)								
41	Hoopes & Hall, 2002																			0.47 (2)	0.21 (2)
42	Hughes *et al*., 2006				0.09 (7)				0.04 (7)						0.04 (1)	0.38 (1)					
43	Hughes & Denslow, 2005										0.53 (3)				0.43 (3)	1.42 (8)		-1.41 (3)			
44	Hughes & Uowolo, 2006											1.45 (3)				1.47 (1)	0.28 (1)	-1.56 (1)	-1.22 (1)		
45	Kelly & Hawes, 2005	1.17 (1)									2.39 (1)										
46	Kourtev *et al*., 2003				0.08 (2)								0.37 (2)							0.24 (2)	-0.57 (2)
47	Lett *et al*., 2004	3.04			0.00		2.24		0.09		1.30										

		(1)			(1)		(1)		(1)		(1)										
48	Li *et al*., 2006				-0.55 (1)				0.16 (1)											-0.26 (1)	-0.31 (1)
49	Liao, 2007	1.17 (2)	0.80 (2)	0.33 (2)	0.03 (2)		0.62 (2)	0.31 (2)	0.17 (2)		1.41 (2)	-0.33 (2)			-0.14 (2)	-0.28 (2)	-0.70 (2)	0.66 (2)	0.08 (2)		
50	Liao, 2004				0.82 (3)				0.79 (3)												
51	Liao *et al*., 2006		1.32 (3)	1.32 (3)	0.49 (3)	0.67 (3)		1.95 (3)	0.47 (3)												
52	Lindsay & French, 2004															0.24 (4)					
53	Lindsay & French, 2005								1.37 (4)						0.28 (3)	-0.11 (3)				0.42 (3)	0.23 (3)
54	Litton *et al*., 2006	0.03 (1)																			
55	Mack & D'Antonio, 2003a															-0.34 (8)	0.24 (8)	0.30 (8)			
56	Mack & D'Antonio, 2003b				-0.02 (1)				-0.08 (1)				1.00 (2)	0.85 (2)							
57	Mahaney *et al*., 2006														-0.11 (3)						
58	McCarron *et al*., 2003												-0.30 (1)							0.01 (1)	
59	McCulley *et al*., 2004				0.64 (3)	0.41 (3)			0.58 (3)	0.53 (3)			0.69 (3)	0.85 (3)						0.54 (3)	0.88 (3)
60	McIntosh *et al*., 1995	0.71 (1)	0.56 (1)				0.50 (1)	0.36 (1)													
61	Meyerson *et al*., 1999	1.82 (1)					1.41 (1)		-0.04 (1)											0.13 (1)	
62	Mitchell *et al*., 1997																			1.14 (37)	0.15 (37)
63	Morghan & Seastedt, 1999	-1.56 (1)									-1.56 (1)										

64	Musil, 1993								0.38 (1)						0.54 (6)						
65	Nagel & Griffin, 2004														-0.09 (2)						
66	Norris *et al*., 2001															0.43 (1)	1.19 (1)	-0.30 (1)	0.77 (1)		
67	O'Dell & Claassen, 2006	0.01 (6)																			
68	Ogle *et al*., 2003	-0.17 (2)	-0.59 (2)	0.06 (2)												0.06 (6)	0.20 (6)		-0.04 (6)		
69	Otto *et al*., 1999					-0.12 (2)			-0.11 (2)	0.16 (2)			-0.84 (2)		0.64 (2)					-0.01 (2)	
70	Perry *et al*., 2004																			-0.70 (1)	
71	Reed *et al*., 2005	0.19 (1)	1.77 (1)		0.09 (2)		0.22 (1)		0.05 (2)	0.12 (2)		0.60 (1)	-0.28 (2)	-0.65 (2)							
72	Rimer & Evans, 2006											0.41 (1)	-2.23 (1)								
73	Rothstein *et al*., 2004															0.35 (1)	-0.22 (1)		-0.57 (1)		
74	Saggar *et al*., 1999				0.27 (2)	0.26 (2)			0.16 (2)	0.11 (2)											
75	Scott *et al*., 2001				0.27 (2)				0.18 (2)												
76	Sher *et al*., 2000	-2.36 (1)													-0.61 (1)						
77	Sperry *et al*., 2006								0.20 (2)											0.12 (2)	0.04 (2)
78	Standish, *et al*., 2004											0.44 (2)									
79	Steinaker & Wilson, 2005		1.15 (1)								0.89 (1)										
80	Stock *et al*., 1995				0.82				1.15				0.51							0.18	0.41

					(2)				(2)				(2)							(2)	(2)
81	Stratton & Goldstein, 2001														-0.11 (6)						
82	Svejcar & Sheley, 2001												0.06 (3)	-0.14 (3)						0.01 (3)	0.41 (3)
83	Thomsen *et al*., 2006	0.11 (9)	0.56 (9)																		
84	Valéry *et al*., 2004			1.47 (1)	-0.02 (5)						0.41 (1)						0.57 (5)	-0.17 (5)			
85	van Derhoeven *et al*., 2005	1.38 (3)			0.01 (8)		0.98 (3)		0.02 (8)						-0.42 (3)						
86	Vinton & Goergen, 2006																	-0.70 (1)	-0.64 (1)		
87	Vitousek & Walker, 1989												2.46 (1)	2.35 (1)	0.83 (1)	0.86 (1)				0.94 (3)	2.64 (1)
88	Wedin & Pastor, 1993				0.07 (6)				0.01 (6)				0.32 (12)								
89	Wilsey & Polley, 2006	0.59 (24)	-0.16 (24)				0.53 (24)				0.59 (24)										
90	Windham, 2001	0.94 (1)	0.51 (1)																		
91	Windham & Ehrenfeld, 2003				-0.05 (3)		0.45 (1)	0.25 (1)	-0.12 (3)				1.34 (1)		-0.47 (1)	-0.39 (1)				0.25 (3)	
92	Windham & Lathrop, 1999	2.24 (1)																			
93	Witkowski, 1991a			0.65 (4)					0.21 (2)						0.78 (2)	0.86 (2)				0.77 (2)	0.25 (2)
94	Witkowski, 1991b														0.33 (1)						

Note: Carbon pools in shoots (1), roots (2), litter (3), soils (4), and microbe (5); nitrogen pools in shoots (6), roots (7), soils (8) and microbe (9); fluxes of ANPP (10), litter decomposition (11), soil net N mineralization (12), soil net N nitrification (13); other

parameters including plant N concentration (14), litter N (15) and lignin concentrations (16), litter C:N (17) and lignin:N ratios (18), soil NH_4^+ (19) and soil NO_3^- concentrations (20).

Appendix C

Two figures of frequency distribution of logarithm response ratios of 14 variables ($n > 30$) related to C and N cycles under plant invasion

Figure legends

Fig. 1 Frequency distribution of logarithm response ratio (*RR*) of C pools including shoots (a), roots (b) and soils (c); N pools including shoots (d) and soils (e); fluxes including ANPP (f), litter decomposition (g), and soil net N mineralization (h). The solid curves were the fitted Gaussian distribution to frequency data. The vertical lines were drawn at $RR = 0$

Fig. 2 Frequency distribution of logarithm response ratio (*RR*) of the parameters related to C and N pools and fluxes including plant N concentration (a), litter N (b) and lignin concentrations (c), litter C:N ratio (d), soil NH_4^+ (e) and NO_3^- concentrations (f). The solid curves were the fitted Gaussian distribution to frequency data. The vertical lines were drawn at $RR = 0$

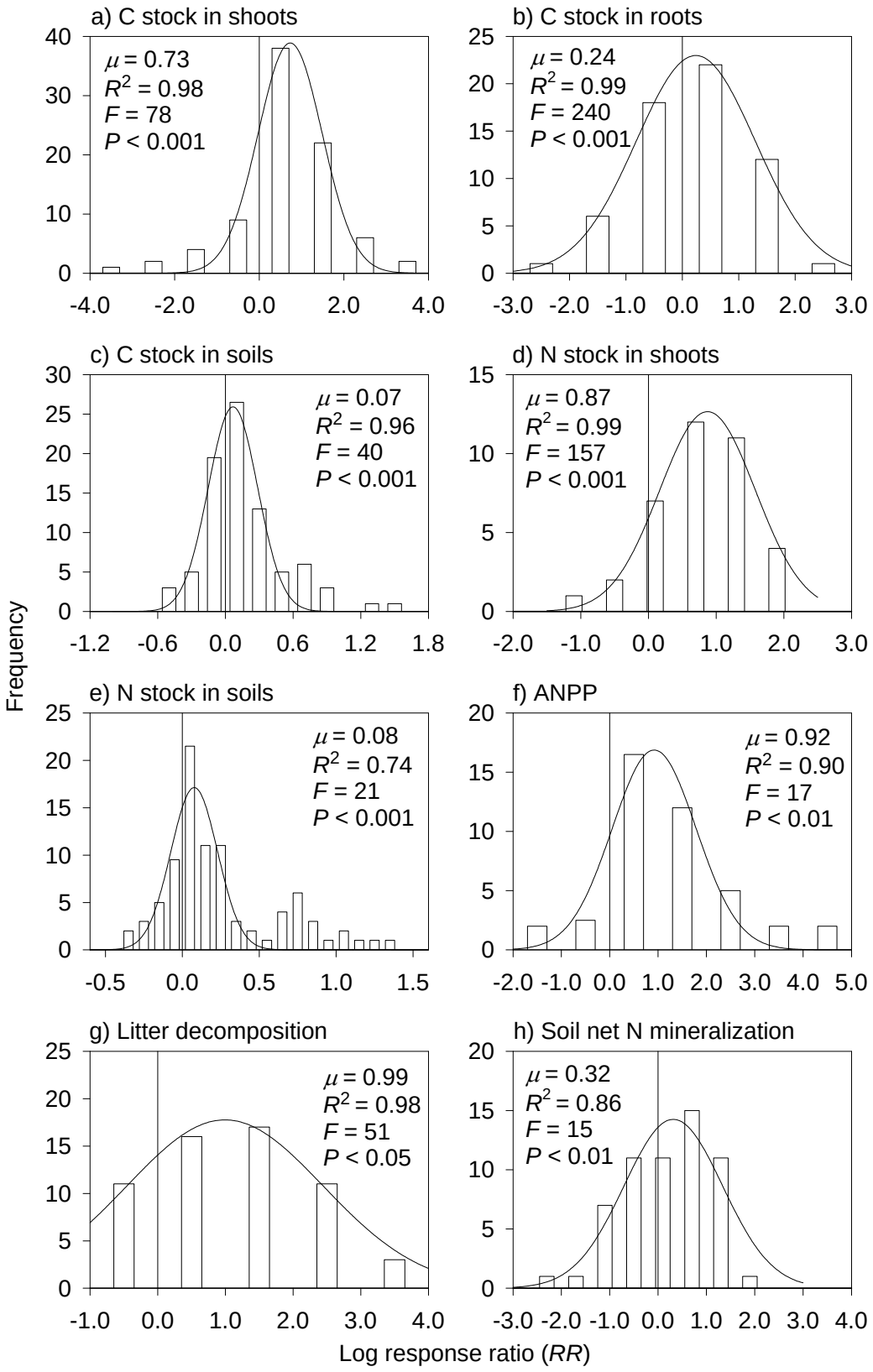

Fig. 1 (Appendix C)

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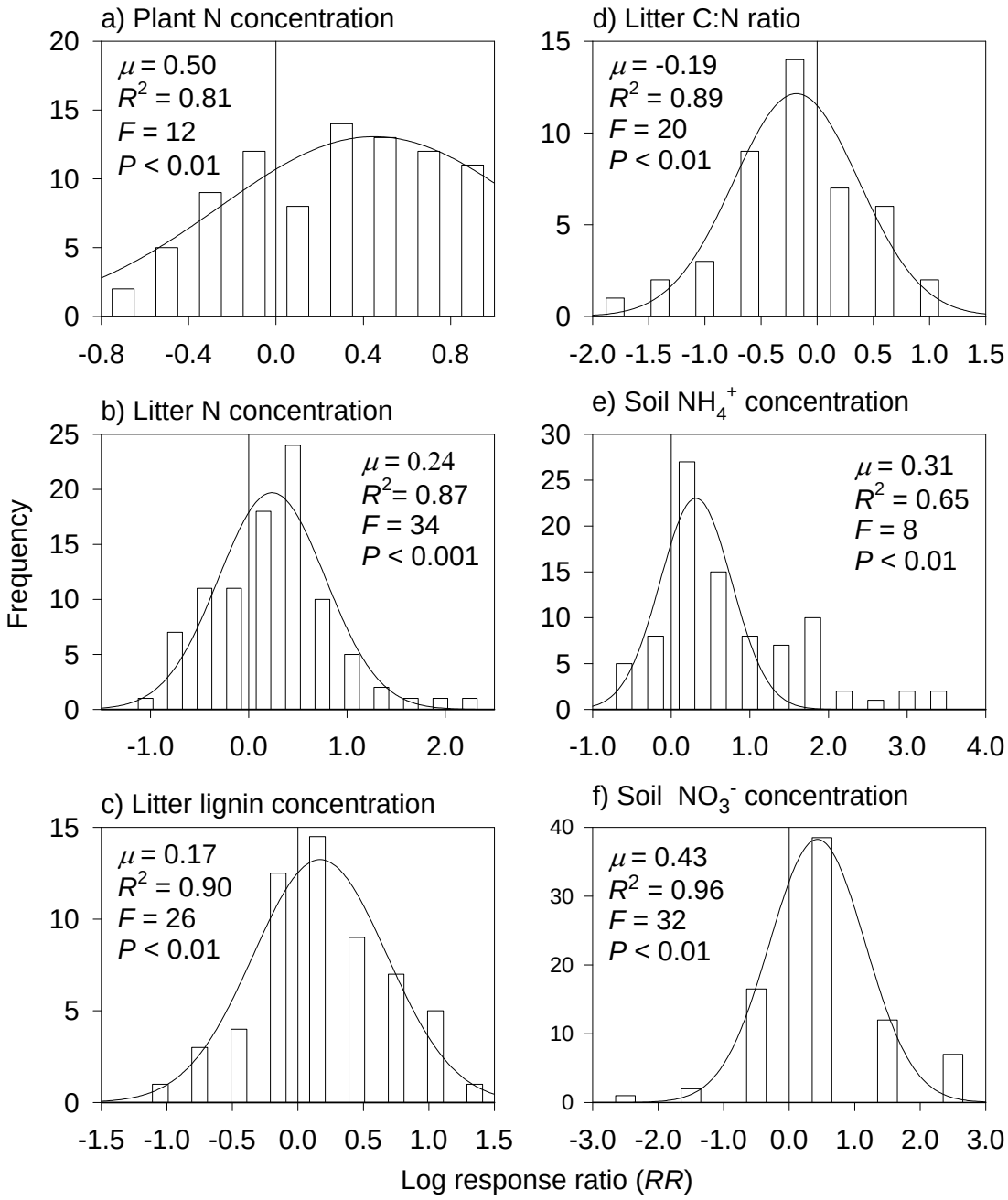

224 Fig. 2 (Appendix C)

Appendix D

Table of 95% *CI*s of weighted response ratio (RR_{++}) and sample size (*n*) of 20 variables related to C and N cycles under the invasion of woody and herbaceous species, N-fixing and non-N-fixing plants, and in forests, grasslands and wetlands

Variables	Life forms				Functional groups of N fixation				Ecosystem types					
	Woody		Herbaceous		N- fixing		Non-N-fixing		Forests		Grasslands		Wetlands	
	95% *CI*	*n*	95% *CI*	*n*	95% *CI*	*n*	95% *CI*	*n*	95% *CI*	*n*	95%*CI*	*n*	95% *CI*	*n*
Carbon pools														
Shoots	0.50 ± 0.21^{b}	4	0.85 ± 0.02^{a}	80	1.47 ± 0.13^{a}	3	0.82 ± 0.02^{b}	81	-0.79 ± 0.17^{c}	8	0.53 ± 0.03^{b}	59	1.13 ± 0.05^{a}	24
Roots	0.66 ± 0.13^{a}	7	0.02 ± 0.03^{b}	53	1.25 ± 0.12^{a}	6	-0.04 ± 0.03^{b}	54	-1.35 ± 0.19^{c}	5	-0.04 ± 0.04^{b}	49	0.45 ± 0.06^{a}	7
Litter	0.70 ± 0.17^{a}	7	0.25 ± 0.10^{b}	9	0.51 ± 0.12^{a}	9	0.28 ± 0.13^{b}	7	0.65 ± 0.22^{a}	4	0.27 ± 0.12^{b}	8	0.54 ± 0.12^{a}	8
Soil	0.19 ± 0.01^{a}	31	-0.07 ± 0.01^{b}	52	0.19 ± 0.02^{a}	25	0.02 ± 0.02^{b}	58	0.09 ± 0.03^{a}	14	0.04 ± 0.02^{b}	57	0.07 ± 0.01^{ab}	14
Microbe	0.38 ± 0.07^{a}	10	0.05 ± 0.12^{b}	4	0.37 ± 0.07^{a}	10	0.05 ± 0.12^{b}	4	-0.12 ± 0.11^{b}	3	0.57 ± 0.07^{a}	9	-0.12 ± 0.16^{b}	2
Nitrogen pools														
Shoots	2.06 ± 0.26^{a}	3	0.55 ± 0.06^{b}	34	0.62 ± 0.15	2	0.62 ± 0.06	35	0.66 ± 0.29	3	0.60 ± 0.06	30	0.72 ± 0.13	5
Roots	1.95 ± 0.23^{a}	3	0.31 ± 0.14^{b}	4	0.81 ± 0.12^{a}	5	0.31 ± 0.34^{b}	2			1.66 ± 0.21^{c}	4	0.30 ± 0.14^{b}	3
Soil	0.42 ± 0.03^{a}	39	0.06 ± 0.02^{b}	49	0.44 ± 0.03^{a}	31	0.06 ± 0.02^{b}	57	0.33 ± 0.03^{a}	17	0.09 ± 0.02^{b}	66	0.08 ± 0.04^{b}	11
Microbe	0.40 ± 0.26	4	0.28 ± 0.12	8	0.06 ± 0.23^{b}	4	0.28 ± 0.12^{a}	8			0.32 ± 0.12	10	0.16 ± 0.29	2
Fluxes														
ANPP	0.76 ± 0.08^{a}	9	0.58 ± 0.03^{b}	33	0.76 ± 0.09^{a}	5	0.59 ± 0.03^{b}	37	0.58 ± 0.11^{b}	9	0.58 ± 0.03^{b}	29	1.13 ± 0.13^{a}	5

LIDE	0.72±0.05^{b}	20	0.82±0.05^{a}	38	1.06±0.04^{a}	35	0.24±0.06^{b}	23	0.85±0.03^{a}	54	-0.60±0.47^{b}	1	-0.28±0.13^{b}	3
SNNM	0.50±0.11^{a}	19	0.37±0.09^{b}	39	0.67±0.12^{a}	9	0.31±0.08^{b}	49	0.32±0.11^{b}	21	0.32±0.09^{b}	33	1.13±0.19^{a}	4
SNNN	0.73±0.33^{a}	12	0.35±0.16^{b}	15	1.29±0.50^{a}	4	0.35±0.15^{b}	23	0.53±0.23	17	0.42±0.25	9	0.27±0.28	1
Parameters														
PNCO	0.45±0.02^{a}	31	0.22±0.01^{b}	55	0.43±0.01^{a}	48	0.06±0.02^{b}	38	0.43±0.01^{a}	65	-0.15±0.04^{c}	12	-0.01±0.03^{b}	18
LNCO	0.65±0.01^{a}	35	-0.06±0.02^{b}	57	0.44±0.02^{a}	47	0.20±0.02^{b}	45	0.36±0.01^{a}	79	0.27±0.04^{b}	9	-0.27±0.05^{c}	4
LLCO	0.18±0.04	4	0.16±0.02	53	0.07±0.03^{b}	33	0.36±0.02^{a}	24	0.13±0.02^{b}	43	0.45±0.09^{a}	7	0.16±0.02^{b}	7
LCNR	-0.53±0.01^{b}	22	-0.14±0.02^{a}	22	-0.43±0.02^{b}	8	-0.31±0.01^{a}	36	-0.46±0.01^{c}	33	-0.24±0.04^{b}	4	0.50±0.03^{a}	7
LLNR	-0.90±0.06^{b}	3	-0.17±0.06^{a}	13	0.08±0.11^{a}	2	-0.65±0.05^{b}	14	-1.02±0.06^{b}	4	0.01±0.08^{a}	10	0.08±0.11^{a}	2
SNHC	0.21±0.11	22	0.27±0.03	65	0.37±0.16^{a}	10	0.26±0.03^{b}	77	0.12±0.09^{b}	25	0.29±0.04^{a}	53	0.25±0.06^{ab}	10
SNOC	0.22±0.07^{a}	20	0.14±0.04^{b}	57	0.34±0.10^{a}	8	0.13±0.04^{b}	69	0.22±0.06^{a}	23	0.12±0.04^{b}	52	0.25±0.11^{a}	4

Note: Abbreviations: ANPP-aboveground net primary production, LIDE-litter decomposition, SNNM-soil net N mineralization, SNNN-soil net N nitrification, PNCO-plant N concentration, LNCO-litter N concentration, LLCO-litter lignin concentration, LCNR-litter C:N ratio, LLNR-litter lignin:N ratio, SNHC-soil NH_4^+ concentration, SNOC-soil NO_3^- concentration.

"-" means the lack of data. Different letters indicate significant differences between invasive woody and herbaceous species, between invasive N-fixing and non-N-fixing plants, and among forests, grasslands and wetlands within the row for each variable.