A threat to biodiversity through international trading of grains and horticultural plant materials

Akihiro Konuma, Yoshiko Shimono
National Institute for Agro-Environmental Sciences
3-1-3 Kannondai, Tsukuba, Ibaraki 305-8604, Japan
akihirok@niaes.affrc.go.jp

Abstract: International trade is a major route by which non-indigenous organisms are introduced into new habitats. Invasive species has been introduced as weed unintentionally through mass-trading of agricultural products and/or as garden or useful plant intentionally. The objectives of the paper were to show the factors that affect the initial assemblage of plant species introduced by the international grain trade and to extract their general attributes and importance of residence time of alien plant from the introduction for recognition of invasiveness. An analysis of weed seed contamination of spring wheat imported from Canada to Japan showed the field abundance of each weed was positively correlated with the weed seed quantity, seeds of short weeds and seeds with a pappus were eliminated from the wheat by the harvesting or cleaning process, and many other crop plants contaminated the wheat. A comparison of number of invasive plant species between New Zealand and Japan suggested that Japan has more invasive species then has been recognized.
Keywords: Invasive alien plant, grain trade, contamination, introduction history

1. Introduction

Invasion by exotic plants is a growing issue, since the invasive species frequently cause economic and ecological impacts (Mack et al., 2000; Lockwood *et al*., 2005). For example, the economic losses associated with invasive alien plants (crop weeds, weeds in pasture and weeds in lawns, gardens and golf courses) in the United States alone, was estimated at US$34.5 billion per year (Pimentel *et al*., 2005), not including damage to ecosystem function or loss of biodiversity, which also contribute to agricultural production. Contamination of weed seeds in agricultural products (Mack, 1991; Shimono & Konuma, 2008) and escapes of imported landscaping and horticultural plant materials (Mack & Lonsdale, 2001; Reichard & White, 2001; Dehnen-Schmutz *et al*., 2007) are the major causes of alien plant invasion, with the naturalization of deliberately introduced plants being the most common source of invasive plants. In the United States, most herbaceous invasive species were introduced unintentionally through crop seed contaminated with weed seed (e.g., Mack, 1991) and 82% of woody invasive plants were introduced intentionally to the USA for horticultural purposes (Reichard & Hamilton, 1997). Similarly, 57 to 65% of the naturalized plants of Australia were introduced intentionally for horticulture (Kloot, 1987; Groves, 1998 as cited in Reichard and White, 2001).

Many hypotheses have been proposed for explaining successful plant invasion (reviewed in Catford *et al*., 2009). These hypotheses can be classified into introduction part of the invasive plant (typically propagule pressure), abiotic environmental conditions and biotic interactions with other plants or organisms (Catford *et al*., 2009). Among those factors, in this paper, we focused on introduction process and the role of introduction history of alien plant. Identifying general attributes of introduced species can help prevent their establishment and spread.

2. Unintentional introduction through grain trade

Many worldwide invasive plants were introduced unintentionally or intentionally through global commerce (Mack *et al*., 2000). Exotic weeds in agricultural fields are typical cases of unintentional introduction. Grain trade is a major (and may be largest) route of unintentional introduction of those weeds. Some studies reported that various kinds of weed seeds were contained in imported grain seeds (Fay, 1990; Huelma *et al*., 1996; Shimizu, 1998, Shimono & Konuma, 2008). Because the volume of global trade of cereals is more than 100 million tonnes every year (USDA, 2004), a very large amount of weed seeds is introduced into grain - importing countries, even if the commodity contamination levels are very low. Human-driven movements of organisms now have more impact on species distribution than the movements of organisms by natural forces (Carlton & Geller, 1993).

Successful invasion comprises three stages: introduction of a species to a new habitat outside its native range, establishment of self-sustaining populations within the habitat and spread of the organism to nearby habitats (Williamson, 1996). The establishment and spread stages have received the greatest attention. On the other hand, very limited study has focused on understanding how species are introduced (Puth & Post, 2005, but see Green, 1997; Tilman, 1997; Lonsdale, 1999), although several authors have pointed out that variations in the level of invasions among recipient communities could be simply the consequence of differences in the numbers of exotics introduced (Williamson,1996; Mack *et al*., 2000). Identifying general attributes of introduced species can

help prevent their establishment and spread. Weed seed introduction through grain trade is a human-mediated dispersal process of plant propagule.

The objectives of this study were to understand the factors that affect the assemblage of plant species introduced as contaminants through the international grain trade and to extract their general attributes. We surveyed weed seed contamination of spring wheat imported from Canada to Japan for the following reasons: (i) Canada is one of the worlds principal exporters and Japan is a major importer of cereal grains (FAO, 2004); (ii) the grain cleaning process in Canada is well documented (CGC, 2006b); and (iii) the species composition and density of the weed flora have been well surveyed periodically in agricultural ecosystems in Canada (Thomas, 1985; Leeson *et al*., 2005).

We hypothesized following factors could be responsible for the contamination of wheat by weed seed (i.e., unintentional human-mediated weed seed dispersal), which were (1) field abundance, (2) plant height, (3) seed size, (4) annual or perennial, (5) with or without pappus, and (6) crop or weed. We took these factors into account for several reasons:

(1) Generally, a positive correlation is expected between the field abundance of a weed and its total seed production. Therefore, seeds of abundant weeds are more likely to contaminate wheat.
(2) Wheat grows ca. 100–120 cm tall. Seeds of shorter weeds than this are likely to be eliminated during harvesting. Therefore, seeds of taller weeds are more likely to contaminate wheat.
(3) Seeds larger or smaller than wheat can be eliminated by the cleaning processes. Therefore, similar size seeds to wheat are more likely to contaminate wheat.
(4) Most annuals reproduce only by seeds, but perennials often regenerate from vegetative organs. Because perennials sometimes allocate resources for reproduction into vegetative propagation instead of into seeds, field abundance and seed production of perennials do not necessarily correlate positively. Therefore, fewer seeds of perennials than of annuals were expected.
(5) Seeds with a pappus are likely to disperse and be eliminated by the harvesting or cleaning processes. Therefore, seeds without a pappus are more likely to contaminate wheat.
(6) Various transportation vehicles, temporary storage sites and port elevators are used between the farm fields and the commodity sampling in Japan, all of which usually handle various crops and are subject to incomplete cleaning, resulting in carry-over of non-commodity crops into wheat. Therefore, seeds of other crops are more likely to contaminate wheat.

We used a general linear mixed-effects model fitted by maximising the restricted log-likelihood to analyse the effects of field abundance, plant height, life cycle, seed size, pappus presence and status as crop or weed on the number of weed seeds in the wheat. The wheat samples were included as a random variable. We added 0.5 to the seed number and field abundance and then log-transformed the seed number, field abundance, seed size and plant height.

As would be expected, field abundance was the most significant factor affecting the number of seeds contaminating the wheat samples. Plant height, presence or absence of a pappus and status as weed or crop also had significant effects. Seeds of short weeds and seeds with a pappus were likely eliminated from the wheat by the harvesting and cleaning processes. Common use of various transportation vehicles, temporary storage sites and port elevators would explain carry-over of other crops into wheat. The adjusted R^2 of this model was 0.387. So, 38.7% of the variability in the number of contaminant seeds was explained by fitting the model.

These relationships can also apply to other grains, which are handled similar to wheat. Identifying the predominant attributes of introduced weed species can help identify critical species, evaluate their invasiveness and prevent their spread. Therefore, predictions of potential alien weeds based on the flora and weed control systems of trading partner countries will become increasingly important.

3. Intentional introduction of horticultural plant

Horticulture has been recognized as major pathways for the introduction of invasive plants (Mack & Lonsdale, 2001; Reichard & White, 2001; Dehnen-Schmutz *et al*., 2007). Many of invasive plants are recognized as garden escape. In New Zealand, about three-quarters (74%) of terrestrial weeds were deliberately introduced as ornamental garden plants, with a further 14% deliberately introduced for agriculture, commercial horticulture or forestry (Owen 1998). Only 10% were introduced accidentally as contaminants with soil, animals or other plants. Similarly over half (54%) of aquatic plants were introduced as ornamental plants (Owen 1998).

Both Japan and New Zealand have similar soil properties because of volcanic activities, location in similar climatic zone and share many introduced exotic plants. Despite the similar environmental conditions, number of invasive plant is different between the two countries. It is pointed out that there is a time lag for recognition of invasive plant from the introduction (e.g., Crooks, 2005). The difference of introduction history may be the reason of the different number of invasive plants because New Zealand has longer history of introduction of alien plant. Approximately, 25,000 plant species have been introduced to New Zealand (Duncan & Williams, 2002) and 2,500 of

these have naturalized (Lynley Hayes, personal communication) since European colonization, it had started late 1700s. 120 (MAF Biosecurity New Zealand, 2008) to 328 (Howell, 2008) species are recognized as "Invasive" and most of them were introduced as garden plants. Compared to New Zealand, the history of alien garden plant introduction is shorter in Japan and, until mid of 1800s, the introduction of exotic plants increased only gradually. The rate of such introductions jumped twice in the history, which were 1860's and 1950's accompanies opening the country to the world and after World War II (Muranaka 2008). However, in terms of commercial distribution of horticultural plant, it was accelerated rapidly only from 1960-70s along with major economic growth. In general, it takes long time (more than 100 years in some cases), for introduced plants to become naturalized and then become recognized as invasive. It is estimated that 1200-2200 alien plant species has been naturalized in Japan (Shimizu, 2003; Muranaka, 2008) now. Extrapolating from the New Zealand experience, one might expect that 100 to 200 of these are now naturalizing and have the potential to become invasive weeds in Japan. Nevertheless, the official banned alien plant list comprises only 12 species and even the plant under observation is still 84 species (Ministry of Environment, 2008). Therefore, it may be urgently required to Japan to develop strict rule of introducing alien plant and monitoring system of rapidly spreading weed that is potential invasive.

Acknowledgement

This study was supported by the Research and Development Program for Resolving Critical Issues of the Ministry of Education, Culture, Sports, Science and Technology. We thank A. Gordon Thomas for providing us with publications on weed surveys in Canada and improvement of the manuscript, M. Asai and T. Enomoto for help with seed identification, S. Yonezawa for sample arrangement, Y. Fujii and Y.Yoshimura for helpful advice, H. Ikeda and K. Kawada for help with plant identification, and members of the Experimental Farm Management Division, NIAES for assistance with wheat sorting.

References

[1] Carlton J. T. & Geller J. B. (1993) Ecological roulette – the global transport of nonindigenous marine organisms. *Science* 261, 78–82.
[2] Castro, S. A., J. A. Figueroa, Munoz-Schick, M. & Munoz-Schick, M. (2005). Minimum residence time, biogeographical origin, and life cycle as determinants of the geographical extent of naturalized plants in continental Chile. *Diversity and Distributions* 11(3): 183-191.
[3] Catford, J. A., Jansson, R. & Nilsson, C. (2009) Reducing redundancy in invasion ecology by integrating hypotheses into a single theoretical framework. *Diversity and Distributions*, 15, 22-40
[4] CGC (2006) *Official Grain Grading Guide* [WWW document]. Canadian Grain Commission. Available at: URL http://www.grainscanada.gc.ca/Pubs/GGG/ggg-e.htm [accessed on 20 December 2006].
[5] Crooks, J. A. (2005). Lag times and exotic species: The ecology and management of biological invasions in slow-motion. *Ecoscience* 12(3): 316-329.
[6] Dehnen-Schmutz, K., Touza, J., Perrings, C. & Williamson, M. (2007). The horticultural trade and ornamental plant invasions in Britain. *Conservation Biology*, 21, 224-231.
[7] Duncan, R. P. & Williams, P. A. (2002). Darwin's naturalization hypothesis challenged. *Nature*, 417, 608-609.
[8] FAO (2004) *FAO statistical yearbook, 2004. C.16. Imports and exports of selected agricultural commodities, Group I* [WWW document]. Available at: URL http://www.fao.org/docrep/009/a0490m/a0490m00.htm [accessed on 20 December 2006].
[9] Fay P. K. (1990) A brief overview of the biology and distribution of weeds of wheat. In: *Systems of Weed Control in Wheat in North America* (ed. WW DONALD), 35–50. Weed Science Society of America, Champaign, IL, USA.
[10] Green, R. E. (1997). The influence of numbers released on the outcome of attempts to introduce exotic bird species to New Zealand. *Journal of Animal Ecology* 66, 25–35.
[11] Groves R. H. (1998) Recent Incursions of Weeds to Australia 1971–1995.Australia: Cooperative Research Centre for Weed Management Systems. Technical Series no. 3.
[12] Howell, C. (2008). Consolidate list of environmental weed in New Zealand: *DOC Research & Development series* 292, Science & Technical Publishing, Department of Conservation, PO Box 10420, The Terrace, Wellington6143, New Zealand.
[13] Huelma C. C, Moody K. & Mew T. W. (1996) Weed seeds in rice seed shipments: a case study. International Journal of Pest Management 42, 147–150.
[14] Kloot, P. M. (1987) The invasion of Kangaroo Island by alien plant. Australian Journal of Ecology, 3, 263-266.
[15] Leeson, J. Y., Thomas, A. G., Hall, L. M., Brenzil, C. A., Andrews, T., Brown K. R. & Van Acker, R. C. (2005) *Prairie Weed Surveys of Cereal, Oilseed and Pulse Crops from the 1970s to the 2000s*. Agriculture and Agri-Food Canada, Saskatoon Research Centre, Saskatchewan, Canada
[16] Lockwood, J. L., Cassey, P. & Blackburn, T. (2005). The role of propagule pressure in explaining species invasions. *Trends in Ecology & Evolution*, 20, 223-228.
[17] Lonsdale, W. M. (1999) Global patterns of plant invasions and the concept of invasibility. *Ecology* 80, 1522–1536.
[18] Mack, R. N. (1991) The commercial seed trade - An early disperser of weeds in the United States. *Economic Botany*, 45, 257-273.

[19] Mack, R. N. & Lonsdale, W. M. (2001). Humans as global plant dispersers: Getting more than we bargained for. *Bioscience*, 51, 95-102.
[20] Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M. & Bazzaz F. A. (2000). Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications*, 10, 689-710.
[21] MAF Biosecurity New Zealand. (2008). *National Pest Plant Accord*. [WWW document]. MAF Biosecurity New Zealand. Available at: URL. http://www.biosecurity.govt.nz/files/pests/plants/nppa/nppa-accord-manual.pdf
[22] Ministry of Environment (2008). *List of regulated living organisms under the Invasive Alien Species Act*. Ministry of Environment. [WWW document]. Available at: URL http://www.env.go.jp/nature/intro/1outline/files/siteisyu_list_e.pdf
[23] Muranaka T. (2008). Naturalization and invasion of alien plants in Japan: Relationships among their origin, use, and time of introduction. *Japanese Journal of Conservation Ecology*, 13, 89-101.
[24] Owen, S. J. (1998) Department of Conservation Strategic Plan for Managing Invasive Weeds. Department of Conservation, Wellington, New Zealand.
[25] Pimentel, D., Zuniga, R. & Monison, D. (2005) Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, 52, 273-288.
[26] Puth, L. M. & Post, D. M. (2005) Studying invasion: have we missed the boat? *Ecology Letters* 8, 715–721.
[27] Reichard, S. H. & Hamilton, C. W. (1997) Predicting invasions of woody plants introduced into North America. *Conservation Biology*, 11, 193-203.
[28] Reichard, S. H. & White, P. (2001). Horticulture as a pathway of invasive plant introductions in the United States. *Bioscience*, 51, 103-113.
[29] Shimizu N. (1998) Recent situation of invasion and diffusion of alien weeds and its control. *Japanese Journal of Ecology* 48, 79–85.
[30] Shimizu T. (2003) *Naturalized plants of Japan*. Heibonsha, Tokyo, Japan
[31] Shimono, Y. & Konuma, A. (2008). Effects of human-mediated processes on weed species composition in internationally traded grain commodities. *Weed Research*, 58, 10-18.
[32] Thomas, A. G. (1985) Weed survey system used in Saskatchewan for cereal and oilseed crops. *Weed Science* 33, 34–43.
[33] Tilman, D. (1997) Community invasibility, recruitment limitation, and grassland biodiversity. *Ecology* 78, 81–92.
[34] USDA (2006) PLANTS database [WWW document]. United States Department of Agriculture, Natural Resources Conservation Service. Available at: URL http://plants.usda.gov/index.html
[35] Williamson, M. (1996). *Biological invasions*. Chapman & Hall, London, UK