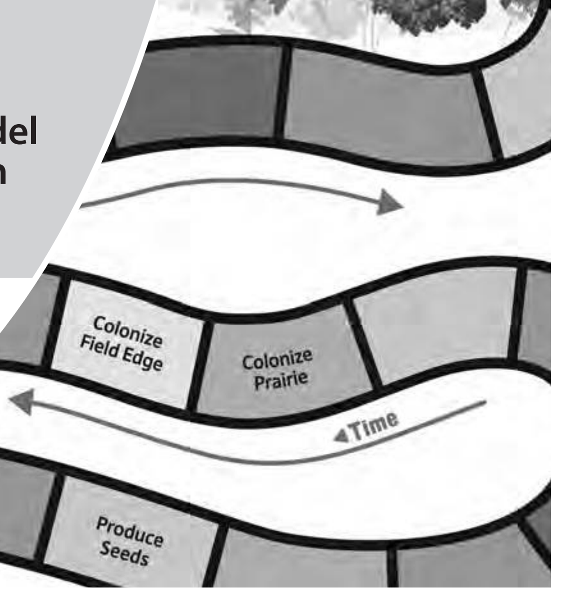
INQUIRY & INVESTIGATION

Race to Displace: A Game to Model the Effects of Invasive Species on Plant Communities



NABT BioClub RECOMMENDATION

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Abstract

Invasive species are a substantial threat to biodiversity. Educating students about invasive species introduces fundamental concepts in biology, ecology, and environmental science. In the Race to Displace game, students assume the characteristics of select native or introduced plants and experience first hand the influences of species interactions and changing environmental conditions on community composition as they advance across a game board. Through game play, students learn about ways in which species can interact, as well as attributes of successful invaders and the impacts of invasion on communities.

Key Words: *Invasive species; plants; competition; adaptations; biodiversity; community ecology.*

We have developed a game to help students in grades 6–12 learn about the ecological effects of invasive species on native plant communities. "Race to Displace" models the competitive interactions among plant species that are common in a variety of habitats across the eastern and midwestern United States. In our game, students adopt characteristics of six plant species and interact with each other as environmental conditions change. Game play provides a framework for learning about species interactions, community and ecosystem organization, regulation of populations, species diversity, and adaptations of organisms. We originally developed this game as an educational outreach activity for students visiting Washington University's Tyson Research Center near St. Louis, Missouri, to help illustrate ecological concepts behind ongoing field research at Tyson. We have used the activity with middle school and high school students, but we think that the difficulty level can be adjusted to meet a wide range of abilities from elementary school to the undergraduate level.

Invasive species spread aggressively outside their native ranges and are currently one of the largest threats to global biodiversity. Some non-native species that have become invasive were intentionally introduced into new ecosystems for horticulture and other uses (Reichard & White, 2001), whereas others have been accidently introduced through increased human movement around the world. Many introduced species do not become invasive (Mitchell & Power, 2003), but when some species are introduced into new environs, they are able to increase their populations quickly without the predators, parasites, and other factors that limit their populations in their native range. Species that become invasive displace native organisms, dominate communities, spread widely, and are capable of greatly reducing the diversity of natural communities and, potentially, ecosystem function in a relatively short period. Of the species listed as threatened or endangered under the Endangered Species Act, 42% are considered to be at risk due to invasive species (Wilcove et al., 1998). There are also economic costs associated with invasive species. The control of, and damage by, invasive species is estimated to cost about $120 billion per year in the United States (Pimentel et al., 2005).

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We chose to focus Race to Displace on plants because many invasive exotic species are plants; plants are at the base of the food web and, thus, influence animal community composition in ecosystems; and species interactions between many plants are relatively well understood (Gurevitch et al., 2002). Plants introduced to the United States from other parts of the world have come to dominate millions of acres of forest, desert, grasslands, and wetlands (Anderson et al., 1996; Pimentel et al., 2005). In addition to environmental impacts, invasive plants also economically affect agriculture, forestry, and other U.S. industries (Office of Technology Assessment, U.S. Congress, 1993).

Successful invaders often have certain life-history characteristics that aid in their dispersal and potential dominance (Rejmanek & Richardson, 1996). Garlic mustard (*Alliaria petiolata*), a plant with a natural range in Europe, was introduced to the northeastern United States by settlers who used it as a culinary herb and as a medicinal treatment for gangrene (Meekins et al., 2001). With traits that allow rapid reproduction, such as the production of thousands of seeds by an individual plant and the ability of flowers to self fertilize, garlic mustard has spread throughout much of the eastern and midwestern

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United States, posing a serious threat to plants and animals in the forest communities it invades (Anderson et al., 1996). It is important for students to understand the attributes of invasive species in order to understand their subsequent disruption of native plant communities. In Race to Displace, plant characters respond to events encountered on the game board according to their biology. Garlic mustard, which produces thousands of seeds per plant, moves forward three spaces when landing on the "Produce seeds" square, whereas wild geranium, which produces much less seed per plant, moves forward only one.

One of our goals for development of the game as an educational tool was to increase students' self-direction in understanding how species interactions can change the composition of real plant communities. When we limited the amount of background information provided to students before game play, we observed students constructing an understanding of the species they represented. Acting as a particular plant species, they personally experienced interactions with other species and environmental factors, and perceived some species characteristics as competitive strengths or weaknesses. We observed that the game framework naturally lends itself to students reasoning about why some species gain advantages over others. In the discussions that followed game play, students explored how outcomes might have been different for their plant species if different interactions or environmental conditions had transpired, and looked for trends across several rounds when comparing results with other groups. Students became comfortable using key terms to discuss the results of the game and made connections to real ecosystems. Race to Displace is well matched to the national framework for K–12 life science education with its focus on "patterns, processes, and relationships of living organisms" (Table 1). It could be used to reinforce any of the seven interdisciplinary crosscutting concepts: patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter; structure and function; and stability and change (National Research Council, 2011).

Table 1. Connections to science education standards.

Life Science Content Standard C (NRC, 1996)
• Grades 5–8: Students should develop understanding of structure and function in living systems, reproduction and heredity, regulation and behavior, populations and ecosystems, and diversity and adaptations of organisms. • Grades 9–12: Students should develop understanding of the cell; molecular basis of heredity; biological evolution; interdependence of organisms; matter, energy, and organization in living systems; and behavior of organisms.
Core Ideas in the Life Sciences (NRC, 2011)
• LS2: Ecosystems: Interactions, Energy, and Dynamics ◦ LS2.A: Interdependent relationships in ecosystems ◦ LS2.C: Ecosystem dynamics, functioning, and resilience • LS4: Biological Evolution: Unity and Diversity ◦ LS4.B: Natural selection ◦ LS4.C: Adaptation ◦ LS4.D: Biodiversity and humans
Practices for K–12 Science Classrooms (NRC, 2011)
1: Asking questions 2: Using models 4: Analyzing and interpreting data 6: Constructing explanations 7: Engaging in argument from evidence 8: Obtaining, evaluating, and communicating information

○ Materials for Activity

The complete game components (board, plant tokens, plant information cards, and action cards) are available in color as pdfs for download from the instructional materials section of the Washington University Institute for School Partnership website (http://schoolpartnership.wustl.edu/instructional-materials/race-to-displace/).

Per group of 6 students:

Game board (Figure 1)
6 plant tokens
6 plant information cards (Figure 2)
99 action cards (examples in Figure 3)
3 optional management cards for game play with ecological restoration included

Options:
The game can be played in a classroom setting in small groups using regular-sized game boards, as a class with projection via education technology (such as a SMART or Promethean board), or, if space is available, carpet squares can be used to construct a life-sized game board for a class to play divided into six teams. We observed a high level of excitement and engagement using a life-sized game board with middle school students.

○ Background

Teachers could use the game at the beginning of a unit to introduce ecological interactions and invasive species, or teachers could instead provide a thorough introduction to invasive species and then use the game to help students internalize the material. Instructors can incorporate the profiles of species included in the game (Table 2) in their introduction or during discussions after game play. We provided our students with the background information about plant ecology included in this section, but we did not provide specific biological information about the six plant species in the game, allowing students to extrapolate the biology of their species from experiences and interactions during game play.

Resources that plants need to survive, such as light, water, certain soils and nutrients, and a way to disperse their pollen and their seeds, are limited within an ecosystem. Plants must compete with each other through a variety of methods to obtain the resources they need. Tall plant species may outcompete other species for sunlight by shading out those beneath. Species with deep or extensive root systems may outcompete other plants by finding and absorbing

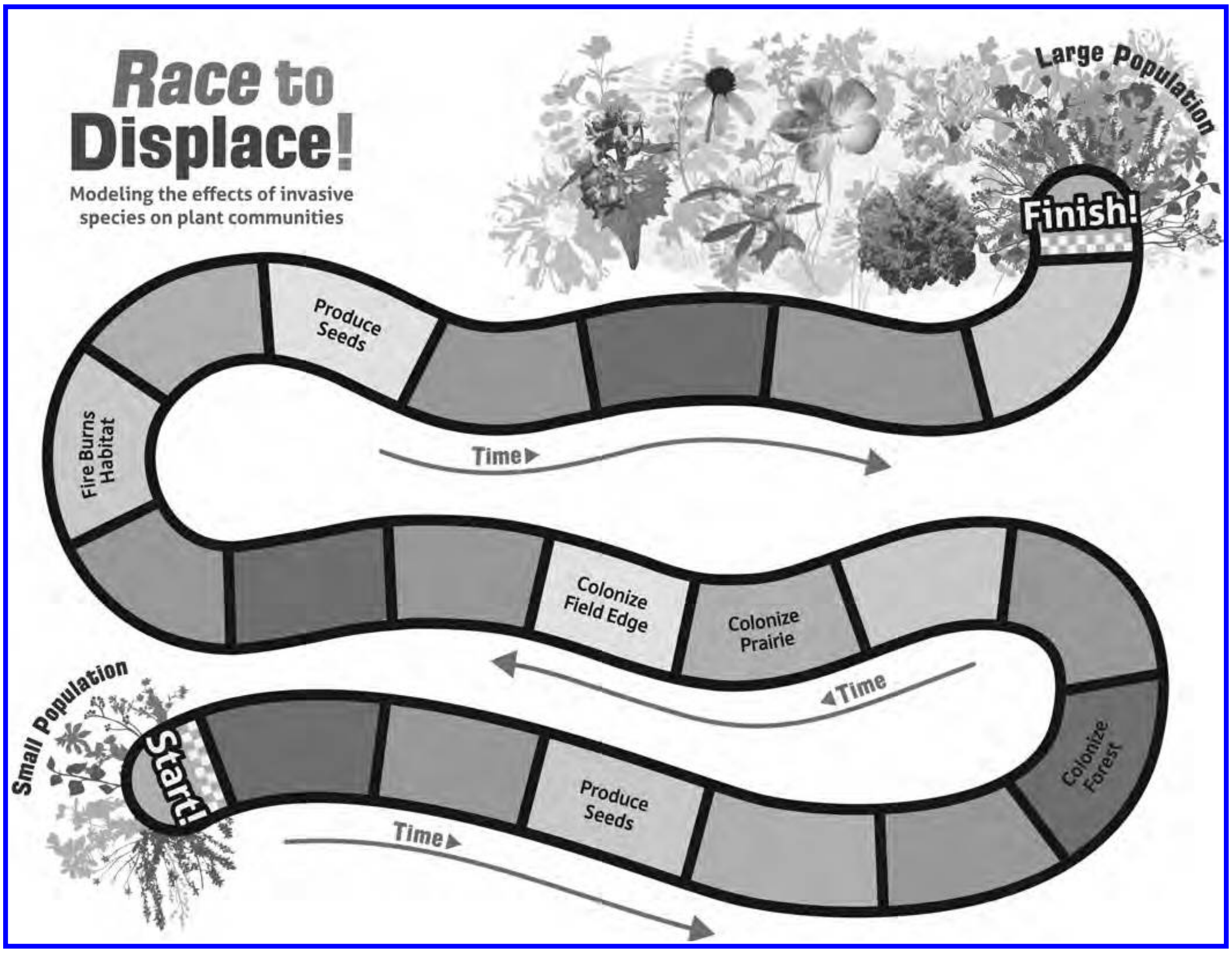

Figure 1. Game board. Players move from the Start area, representing a small population size, to the Finish area, representing a large population size, with the passage of time.

limited nutrients or water before or at the exclusion of others. Plant species that produce compounds to deter herbivores may outcompete more edible plants. Some species secrete chemicals that make the soil nearby uninhabitable for other plants (termed *allelopathy*), thus inhibiting the competitors' growth and spread.

Plants may also compete with each other for places in which to live. Colonization is the spread of a species into a new habitat, and a plant might colonize a new location through seed dispersal or through clonal root extensions. Disturbances, which change the physical environment or the resources available in an ecosystem, can offer opportunities for some species to colonize the altered habitat and become established, making it more accessible to organisms that were not able to live there previously. For example, a wildfire disturbs a plant community by clearing out much of the aboveground biomass of plants. Grasses and wildflowers, which store many nutrients in their deep roots, can recover faster than trees, which have most of their biomass above ground. After a fire, herbaceous plants can colonize previously shaded forest habitats because fire opens up the canopy and increases the amount of sunlight that reaches wildflowers and other understory plants. Some types of disturbances can limit the expansion of invasive species (e.g., fire can inhibit the spread of bush honeysuckle), but disturbances can also favor the expansion of invasive species, allowing them to colonize new areas and to take over new niches (unique species roles within the community).

Species invade new environments through competitive interactions with other species and by taking advantage of disturbances that disrupt niches. In addition to ecological factors that allow introduced species to become abundant, such as the lack of natural enemies, it has been suggested that invasive species possess certain traits that allow them to be highly adaptable, successful invaders (Rejmanek & Richardson, 1996; Dickson et al., 2012). These traits may include the ability to germinate and grow more quickly, rapid reproduction, the ability to reproduce asexually, variability of physical traits (phenotypic plasticity), tolerance of a wide range of environmental conditions, the ability to disperse widely, an association with humans that allows for multiple opportunities for establishment, or novel methods of species interactions (e.g., chemical allelopathy).

○ Playing the Game

(1) Divide students into groups of no more than six. Each student will represent a single plant species.

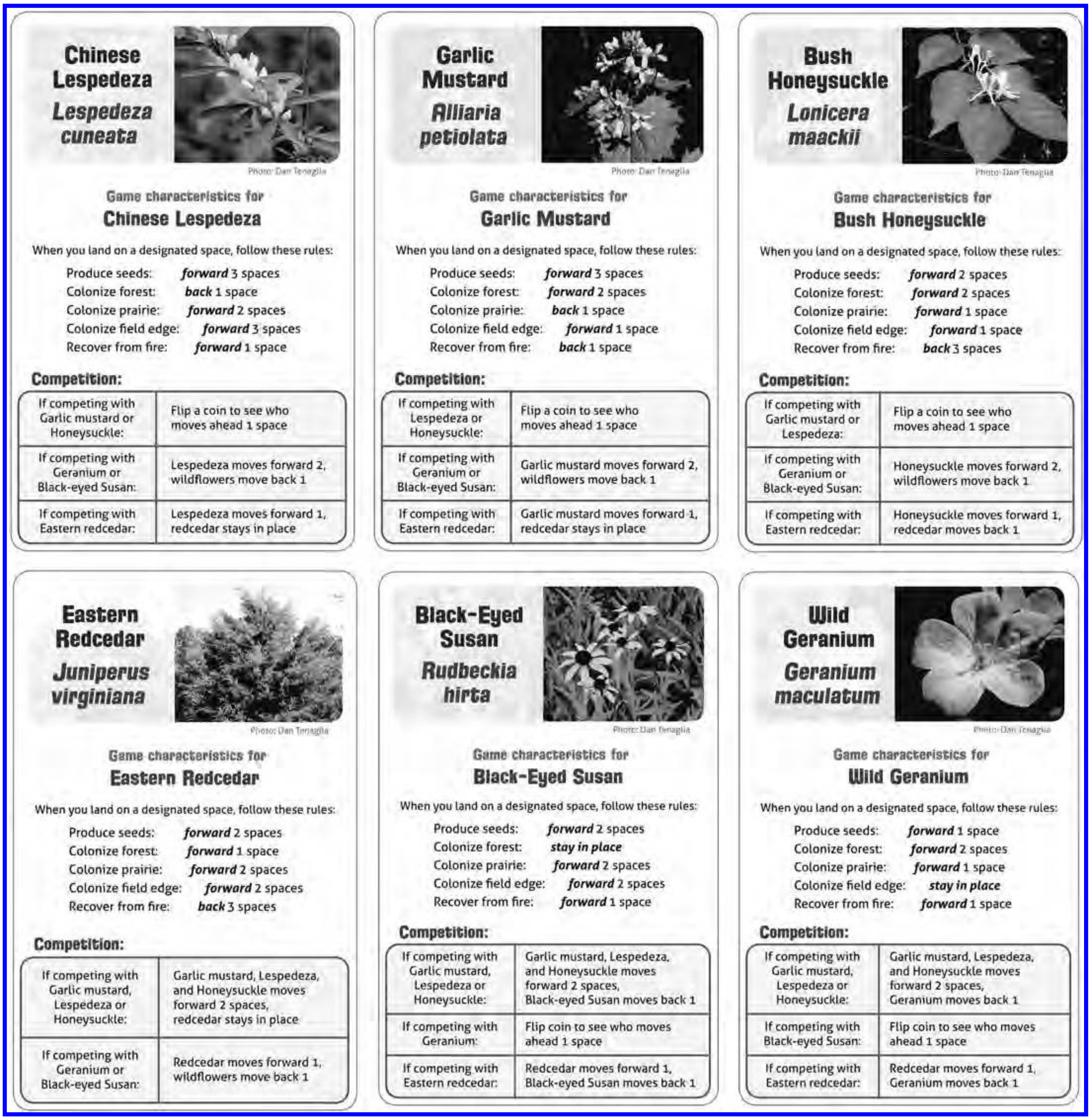

Figure 2. Plant information cards. Each student is given one plant information card that provides instructions for how that plant responds to environmental conditions and interactions with other plant species.

(2) Distribute the game boards and materials (Figures 1–3) and a data table to record the results of game play through several rounds (see Table 3 for an example).

(3) Explain the rules of play to students.

Rules of play:
The object of the game is to be the plant species with the largest population in the community. The species that reaches the finish first has the largest population size and wins. Students should play the game at least three times and track the ranking of each plant in each round (see Table 3). Optional "management" cards can be introduced after the first three rounds so that students can make comparisons to the results of previous "unmanaged" rounds.

(1) Each player chooses a Plant Token that represents their species identity for the duration of the game and then finds the corresponding Plant Information Card and looks it over to briefly become acquainted with their species' unique characteristics. Place all Plant Tokens in the "Start" area.

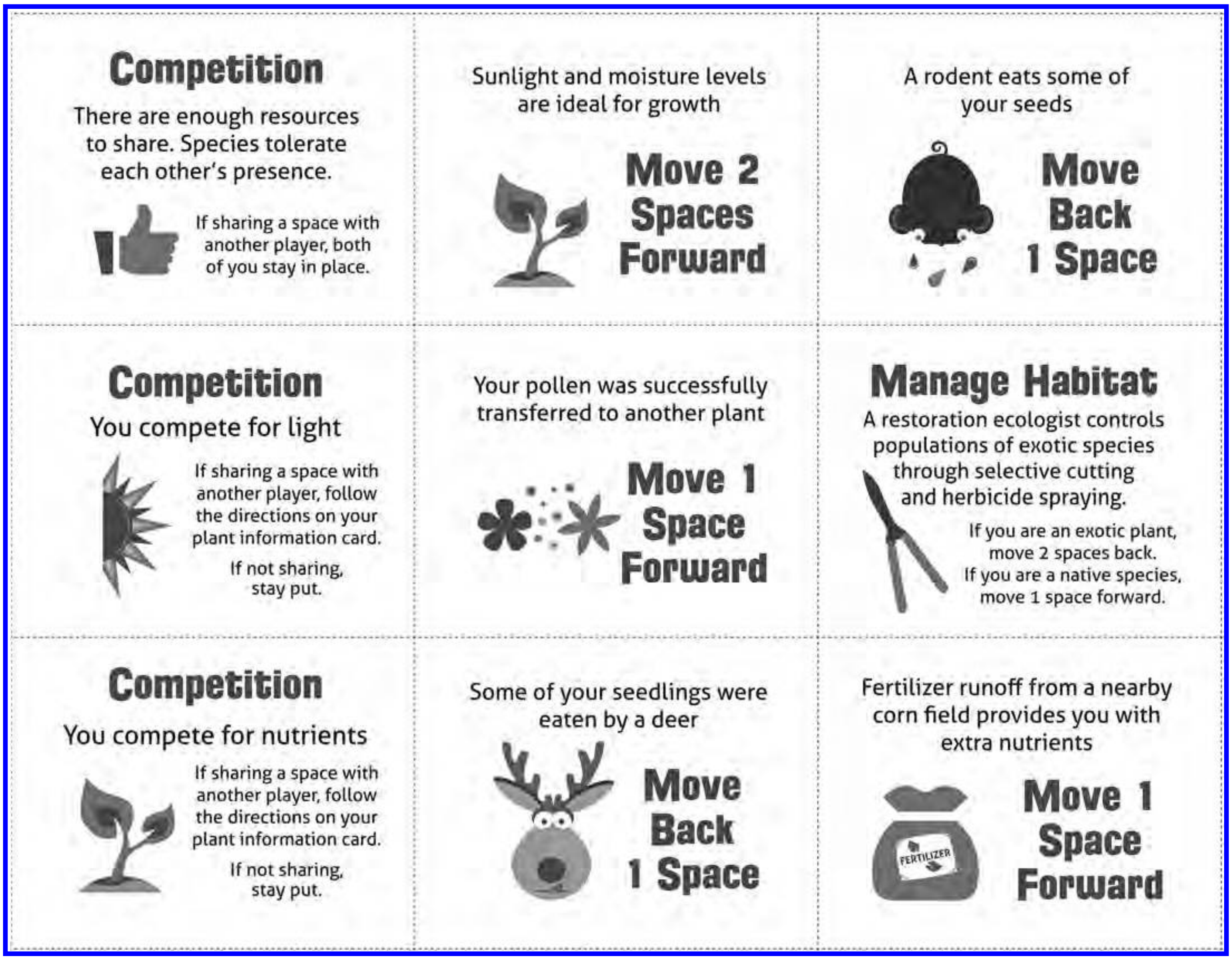

Figure 3. Examples of action cards. Each player draws one action card during her or his turn. The full set of action cards can be downloaded from http://schoolpartnership.wustl.edu/instructional-materials/race-to-displace/.

(2) Shuffle the Action Cards and place them near the game board.

(3) Players draw an Action Card at the beginning of each turn and follow the instructions on it to move around the board. Turns will occur in the following order: wild geranium, black-eyed Susan, eastern redcedar, garlic mustard, Chinese lespedeza, and bush honeysuckle.

(4) When a player lands on a space that contains an event, they should refer to their Plant Information Card, which will tell them how to respond. For example, when the player representing Chinese lespedeza lands on a "produce seeds" space, they should move an additional three spaces ahead.

(5) Some Action Cards are competition cards, which are relevant if two or more players are on the same space. These players should refer to their Plant Information Cards for direction on how to proceed. For example, if the player representing Chinese lespedeza and the player representing black-eyed Susan are on the same space, they compete, the result being that lespedeza moves forward two spaces and black-eyed Susan moves back one. If a player draws a competition card but is not sharing the space, the player stays in place. If a player is sharing the space with more than one other player, they must compete with each.

(6) If the Action Cards run out, shuffle and reuse the discarded cards.

(7) The first player to reach the Finish area wins! After a student reaches the Finish area, have students rank the plants from the largest populations (those closest to the finish) to the smallest (those closer to the starting point). Use Table 3 to collect data.

(8) Students should play at least three rounds of the game and continue to record plant population rankings from each round. Optional "management" cards can be introduced after the first three rounds.

○ Discussion

Following game play, students should discuss the results of the experience within their small group using the first set of questions in Table 4. Students can answer the second set of questions in Table 4 as

Table 2. Plant character species profiles.

Native Plants	Exotic Plants
Black-eyed Susan (*Rudbeckia hirta*) Black-eyed Susan is a native wildflower that blooms from June to August. It occurs in both dry and moist soils, prefers full sun, and can grow up to 3 feet tall. It can be found in prairies, forest openings, and disturbed areas. It can recover moderately well from fire and can reseed new areas effectively, but it may eventually lose ground to longer-lived or taller plants.	**Garlic mustard (*Alliaria petiolata*)** Garlic mustard was introduced from Europe, perhaps for culinary use. It can grow to 2 feet in height and prefers shade to partial sun. It blooms in May, and each plant can produce hundreds of seeds. Initially, fire may increase new growth, but over time it can decrease garlic mustard populations. This species aggressively invades forests and forest edges and can exclude other species from the forest understory.
Wild geranium (*Geranium maculatum*) Wild geranium is a wildflower that can grow up to 2 feet tall in moist to moderately dry soil. This species prefers light shade to partial sun and is more common in woodlands than open habitat, but it will tolerate full sun. It is not usually found on disturbed sites. It can recover well following a fire. It blooms from April to June.	**Chinese lespedeza (*Lespedeza cuneata*)** Introduced from Asia for use in erosion control, Chinese lespedeza tolerates a variety of soil conditions but does not tolerate shade. Stems may reach 5 feet tall, and flowers bloom from July to October. Lespedeza produces toxins that harm nearby plants. This species can recover from fire quickly; fire increases seed germination. Lespedeza displaces native species in prairies, pastures, roadsides, and field edges.
Eastern redcedar (*Juniperus virginiana*) Eastern redcedar, a native evergreen tree, can tolerate a wide range of soil types and soil moisture levels. It is found in forests but can also quickly colonize prairies, old pastures, field edges and along highways, where it can shade out wildflowers. Historically, frequent forest fires reduced redcedars in pastures and prairies, but human suppression of fire has indirectly served to increase populations of this tree.	**Bush honeysuckle (*Lonicera maackii*)** Bush honeysuckle was introduced from Asia as an ornamental plant. It can grow to heights of 6–20 feet and tolerates shade to partial sun, as well as a broad range of soils and moisture levels. It thrives in disturbed habitats and woodland openings, where it often replaces native shrubs and eliminates woodland wildflowers from the forest floor. This shrub does not recover from fire quickly.

Table 3. Rank of species success over the course of game play. Assign a rank of 1 to the species with the largest population (the species that finishes first), and assign a rank of 6 to the species with the smallest population (the species that finishes last).

Species	Round 1	Round 2	Round 3	Round 4 (managed)	Round 5 (managed)
Wild geranium					
Black-eyed Susan					
Eastern redcedar					
Garlic mustard					
Chinese lespedeza					
Bush honeysuckle					

a small group or as individual homework. Pool game-play data from all groups and lead the entire class through analysis of their results using the final set of questions in Table 4.

○ Extensions

We recommend that students be evaluated on the basis of their participation in the activity and discussion, or by performance of optional extensions below. The results of the game will vary each time because of the randomness introduced by drawing cards, and there is no correct outcome of game play, so results themselves should not serve as a basis for assessment.

Report/presentation. As individuals or small groups, students may research local invasive species, including information about distribution, habitat requirements, successful invasion traits/strategies, reproduction, dispersal, means of introduction, effects on the plant community, and current methods of monitoring and controlling invasive species. The students could present what they learn either as a written report, poster, or oral presentation.

Adapt the game to other regions. The version of the game included here is generally relevant to the midwestern and eastern United States. We are willing to provide a template and guidance to educators adapting the game to other locations, and we can further explain the criteria for why plant characters were scored a certain way. Students can research native and invasive plant species in the region of their choice, and identify and score life-history traits for their own Plant Identification Cards.

Collect field data. Students can collect data on invasive species abundance on school grounds and/or at nearby natural areas. Hula hoops can be used to standardize sample areas. Students will gain

Table 4. Possible discussion questions.

Initial Postgame Questions (Small Group Discussion)
(1) What does it mean to be the winner of one round of the game? What about the winner of multiple rounds (if that occurred)?
(2) How do the population sizes of the different species compare across the rounds of play?
(3) Do you notice any overall trends as the game progressed?
(4) Why might some plant species end up with larger populations than others?
(5) Give an example of a species that moves backward on the game board when trying to colonize certain habitats. Why do you think this species moves backward instead of forward?
(6) Do you think your plant is an exotic species or a native species? Why?
(7) On the basis of your experiences playing the game and the information on your Plant Information Card, describe the features of your plant species to the other players in your group. Is your species susceptible to fire? Does it produce lots of seeds? Which habitats can it successfully colonize? Is your species a strong competitor with other plants?
(8) If you introduced management cards to the game, did you notice any difference in that round of play?
Science Content Questions (Completed as a Small Group or as Individuals)
(1) What did you learn from the game about the adaptations of each plant species? (e.g., Does it tolerate disturbance? Does it produce lots of seeds?)
(2) Based on the game results, in what habitat is each plant species likely to grow most successfully?
(3) Based on the game results, which species were the most successful? (e.g., Which ones had the largest populations? Which ones were able to colonize the most habitats?)
(4) What characteristics/adaptations do you think enabled these species to be successful?
(5) Give examples of any pivotal interactions or events that gave a particular species an advantage.
(6) What are the potential problems of introducing a species into a new habitat?
(7) Name two ways in which an invasive species such as the ones included in this game might affect the environment.
(8) Describe two ways in which you think a non-native species might be introduced into a new environment.
(9) If the results from the game were in your backyard, how do you think that would influence the biodiversity in your yard? If you were to scale up game results, how might invasion influence global biodiversity?
Analysis Questions (Large Group Discussion)
(1) How did results differ between groups in the class?
(2) If any groups had different results, why might this be the case? What are the implications for predicting future invasions?
(3) Were there any class-wide trends? Were certain types of plants consistently able to outcompete others?
(4) Are only exotic species invasive?
(5) Based on game play, which species might be more successful in disturbed habitats?
(6) If all groups used the management cards in later rounds, what effects did the cards have on the outcome of the game?
(7) Give two examples of disturbances that benefit some species while limiting others.
(8) Suggest ways in which we could limit the spread of invasive species.
(9) Are there any benefits of invasive species; if so, can you think of a specific example?
(10) In your opinion, in what ways is the game, as a model, incomplete or inaccurate? Give examples.

experience identifying plants and observing trends in plant communities and have the opportunity to pose and investigate their own questions about plant distributions in different habitats and long-term effects of invasive species on ecosystems.

Citizen science/restoration ecology. Ask students to get involved with local projects to remove invasive plants. Land trusts, community organizations, native plant organizations, and other groups often seek assistance with invasive plant control, a hands-on opportunity for students to view the effects of invasive species on native plant communities as well as the positive effects of invasive plant removal. Find examples of citizen involvement in invasive control at http://www.texasinvasives.org/invaders.

Additional media materials. Use mobile applications, such as those available through the University of Georgia's Center for Invasive Species and Ecosystem Health, to track invasive species locally at http://apps.bugwood.org/apps.html. View and discuss relevant videos, such as *Cane Toads: An Unnatural History*, the 1988 documentary by Mark Lewis about the consequences of the introduction of cane toads into Australia, or episode 3 of season 10 of *The Simpsons* ("Bart, the Mother"), in which Bart Simpson releases a pair of bird-eating lizards into Springfield, with cascading ecological effects.

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References

Anderson, R.C., Dhillion, S.S. & Kelley, T.M. (1996). Aspects of the ecology of an invasive plant, garlic mustard (*Alliaria petiolata*), in central Illinois. *Restoration Ecology*, *4*, 181–191.

Dickson, T.L., Hopwood, J.L. & Wilsey, B.J. (2012). Do priority effects benefit invasive plants more than native plants? An experiment with six grassland species. *Biological Invasions*, *14*, 2617–2624.

Gurevitch, J., Scheiner, S.M. & Fox, G.A. (2002). *The Ecology of Plants*. Sunderland, MA: Sinauer Associates.

Meekins, J.F., Ballard, H.E., Jr. & McCarthy, B.C. (2001). Genetic variation and molecular biogeography of a North American invasive plant species (*Alliaria petiolata*, Brassicaceae). *International Journal of Plant Sciences*, *162*, 161–169.

Mitchell, C.E. & Power, A.G. (2003). Release of invasive plants from fungal and viral pathogens. *Nature*, *421*, 625–627.

National Research Council. (1996). *National Science Education Standards*. Washington, D.C.: National Academy Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. Washington, D.C.: National Academy Press.

National Research Council. (2011). *A Framework for K–12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: National Academies Press.

Office of Technology Assessment, U.S. Congress. (1993). Harmful non-indigenous species in the United States. OTA-F-565. Washington, D.C.: U.S. Government Printing Office. Available online at http://govinfo.library.unt.edu/ota/Ota_1/DATA/1993/9325.PDF.

Pimentel, D., Zuniga, R. & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, *52*, 273–288.

Reichard, S.H. & White, P. (2001). Horticulture as a pathway of invasive plant introductions in the United States. *BioScience*, *51*, 103–113.

Rejmanek, M. & Richardson, D.M. (1996). What attributes made some plant species more invasive? *Ecology*, *77*, 1655–1661.

Wilcove, D.S., Rothstein, D., Bubow, J., Phillips, A. & Losos, E. (1998). Quantifying threats to imperiled species in the United States. *BioScience*, *48*, 607–615.

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