**Impacts of Introduced Species:**

**Interspecific Competition, Predation, and Other Species Interactions**

**AUTHOR**

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**ABSTRACT**Due to increasing global connectivity, global biotic interchange has been escalating, leading to species introductions in regions in which they are not indigenous. Most of these species do not establish and/or do not cause significant impacts, but a small proportion do and can have positive or, more often, negative ecological, economic, and cultural impacts. These species often interact with species native to the novel range that are not coevolved or adapted to living with the introduced species. Given the ecological importance of introduced species, this module is intended to introduce students to species interactions (e.g., predation, parasitism, mutualism) and incorporate information on invasive species and how they interact with native species within a novel environment. Suggested activities for the species interactions component of the curriculum are provided and include a lecture crossword puzzle and jigsaw and small writing activities that introduce students to introduced versus invasive species, western and Indigenous perspectives on invasive species, and explore species interactions between introduced and native species, as well as invasive species environmental impacts. An additional lab activity is outlined, which actively engages students in the scientific process by allowing them to develop their own hypotheses and predictions, process and analyze quantitative and qualitative data, interpret and communicate results, develop and interpret a food web, and gather information about an invasive species of interest to them. Questions from this module can be included on a quiz and exam to test students on their knowledge of species interactions and introduced and invasive species.

**LEARNING OBJECTIVES**

* **Objective 1.** Explain the nature of interactions between organisms (i.e., mutualism, commensalism, parasitism, predation, competition).
* **Objective 2.** Contrast the biological and life history traits that help introduced species succeed in a novel environment and distinguish how that success impacts native organisms in the same environment.
* **Objective 3.** Investigate species interactions through analysis of biological data.

**TIMEFRAME
*Instructor*:** The materials are provided, so preparation time should largely only include the time necessary to download the materials, make minor formatting changes for the particular class, and print or post to a learning management system to share with students (likely less than one hour). Additional time might be necessary to adapt the jigsaw materials to a particular region or modify the dataset used for the lab activity (approximately 5-6 hours). If the materials are used in a course that does not provide separate labs on hypothesis testing and data analysis or lectures on species interactions, additional content may have to be added to the materials for students to carry out the activities (approximately 2-4 hours). This module can be carried out over multiple class periods over multiple weeks but is highly scalable, with the option to pick and choose activities to use. Time required to grade will depend on the number of students in the course, but is expected to take between 2-10 hours to grade the crossword puzzle, lab, and jigsaw reflection.

***Student*:** The module is expected to take a few hours total for students to complete. Specifically, the crossword puzzle will take approximately 15-20 minutes, lab will take approximately 2-4 hours (depending on student skill in Microsoft Excel), and lecture, jigsaw activity, and jigsaw reflection will take approximately 45-75 minutes. Instructors can have students read the jigsaw fact sheets before class (approximately 20 minutes) to reduce time in class if time is limited.

**LIST OF MATERIALS**computer, internet access, Microsoft Excel, Word, and PowerPoint, activity handouts, pens

**PROCEDURE AND GENERAL INSTRUCTIONS FOR INSTRUCTORS**
**Module Sequence**

1. Students start learning about species interactions with a lecture that on species interactions, including amensalism, commensalism, competition, mutualism, parasitism, and predation (starter slides available in the “Species Interactions Lecture” PowerPoint file). This lecture is *required* to prime the students for the forthcoming lab and jigsaw activities. They receive slides from the lecture via their learning management system (e.g., Canvas, Blackboard). After this lecture, students complete an in-class crossword puzzle (“Species Interactions Crossword Puzzle” file) to learn and practice using the species interactions terminology. Students can use their notes and/or work with a peer to complete the assignment. The activity is short (~15 minutes) and easy to grade.
2. Students are introduced to the lab topic (species interactions and invasive species) and work on the activity in pairs/groups over two lab periods, approximately 2-4 hours (“Introduced Species and Species Interactions Lab Handout” and “… Lab FAQ Sheet” files).
	1. The first part of the lab activity provides students the opportunity to learn about the impacts of an invasive amphibian on native amphibian species and assess differences in elevation as it pertains to habitat overlap between the species. The dataset used for this component of the lab (Roth et al. 2015; <https://doi.org/10.5061/dryad.7gt4m>) can be downloaded by the instructor or students in Dryad. The dataset includes several variables and can be given to the students as is or reduced to the most basic variables necessary to complete the lab (i.e., yellow-bellied toad, common midwife toad, natterjack toad, and water frog counts, elevation). Students get to practice basic analysis, data classification, and figure creation for quantitative and qualitative data in Microsoft Excel. The instructor can demonstrate these analyses and figure creation during lab time. A supplementary Frequently Asked Questions (FAQ) sheet is provided to walk students through the process of making the figures for the lab report and can be provided in addition to or in lieu of instructor demonstration.
	2. The second part of the lab activity focuses on creating a food web for the spongy moth (*Lymantria dispar dispar*), linking it to Lyme disease. Students are provided with the different organisms involved in the ecosystem and are expected to label each species as a primary producer or primary, secondary, etc. consumer, link the species with positive or negative interactions, and, ultimately, explain how spongy moth impacts other organisms and Lyme disease prevalence in the environment.
	3. The last component of the lab activity, the “choose your own adventure,” tasks students with identifying an invasive species of interest through EDDMapS (<https://www.eddmaps.org/>) and write some responses about it. This component allows them to explore other impacts of invasive species and make a choice about which species they are most interested in learning more about.
3. Via a short lecture, students learn about the basics of invasion ecology and invasive species, difference between introduced and invasive species, and western and Indigenous perspectives on introduced and invasive species (“Introduced Species Lecture” and “Introduced Species and Species Interactions Jigsaw Activity” PowerPoint file). If an introduction to species interactions was not completed prior to this point, provide the students with a primer on species interactions so they are prepared for the activity. Following the lecture, students participate in a jigsaw activity. For this activity, students learn about five introduced species in the southeastern United States - European honey bee (*Apis melifera*), European starling (*Sturnus vulgaris*), feral pigs (*Sus scrofa*), hydrilla (*Hydrilla verticillata*), and silver carp (*Hypophthalmichthys molitrix*). The instructor can assign students to particular species or students can choose the species on which they want to be the “expert.” Fact sheet and activity reflection handouts for each species are distributed to each respective student “expert” (“Introduced Species and Species Interactions Jigsaw Fact Sheets” and “Introduced Species and Species Interactions Jigsaw Reflection Handout” files). For round one, students have 10 minutes to read through their fact sheet and think about three key points they would like to share about their species with their peers. For round two, students move into 15-20 minute focus groups with other students who had the same species. Here, they discuss the three key points they want to share and collectively formulate three key points that they all agree on. Instruct the students to write the three key points from their focus group under their species on the reflection sheet. For round three, one individual from each of the five focus groups joins a new “sharing group” in which each student “expert” takes 3-4 minutes to share the three key points from their focus group with the others in the sharing group (15-20 minutes total). Non-experts in the group listen, learn, ask questions, and note the key points for each of the species on their reflection sheet. After all students share their species, bring the class back together to wrap-up and solicit feedback about organisms that students found interesting. Students take the remaining class time to reflect on content they learned, what they found interesting about the species from the activity, and how their perceptions of introduced and invasive species may have changed (or not changed) as a result of the activity and why that might be. In total, this lecture and activity takes ~45-75 minutes.
4. Students are assigned a quiz to complete online after the jigsaw activity.
5. Students submit their lab reports and quiz by the end of the second week.
6. Students complete their exam, which includes questions about species interactions and introduced species.

**Description of Module Activities, Resources, and Assessments**

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| Objective(s) | Activity Description | Assessment Description | Formative or Summative? |
| LO1 | Lecture activity: Species interactions crossword puzzle | Students are introduced to species interactions and complete an in-class activity where they work independently or in pairs to complete a crossword puzzle using common species interactions terms. | Formative |
| LO1, LO3 | Lab activity: Invasive species and species interactions | Students are provided with a dataset and lab handout with background information on invasive species and prompts to help them through the lab analysis process. They will develop a question and hypothesis based on the dataset, then perform some hypothesis testing and analysis of the dataset. They will use their results to draw conclusions about invasive species and species interactions, while learning how to create basic quantitative and qualitative figures in Microsoft Excel. Additionally, students build a food web with an invasive species to see how the species affects other trophic levels, and they conduct research on a species of interest to learn more about impacts of invasive species. | Formative |
| LO1, LO2 | Lecture activity: Introduced species impacts and interactions jigsaw  | Students are provided a short lecture on species interactions and introduced species before they participate in a jigsaw activity with five introduced species. Students split into five groups, receive a handout with info on one of the five introduced species, and review and summarize the species assigned to their group. Once they have completed their first group discussion, they rotate to new groups composed of one person from each of the five original groups. Each student in the new group has a few minutes to instruct their peers about their species who take notes and ask questions about the species as their peers instruct. After all groups finish, the class reassembles and discusses thoughts on introduced species and species interactions.  | Formative |
| LO1, LO2 | Lecture activity: Introduced species impacts and interactions reflection  | Just before the jigsaw activity, students receive a worksheet to complete during and after the jigsaw activity. During the activity, students make notes about the five species from their peer instructors. At the end, students take a few minutes to reflect on the introduced species they learned about and the impacts and interactions those species had with other species.  | Formative |
| LO1, LO2 | Quiz | Students take a 10-question quiz that tests their knowledge about the species interactions module. | Summative |
| LO1, LO2 | Exam  | Students take an exam that includes questions about the species interactions module. | Summative |

**Integration of Life Discovery Themes**

This module was created to incorporate two of the three Life Discovery themes. First, the module helps ***connect current events to the curriculum*** by having students discuss and investigate impacts of invasive species and species interactions between introduced and native species. This module was created to include introduced species that are currently very publicized and prevalent in the southeastern United States, so students could relate to the content. This aspect of the module could be adapted for other regions within or outside of North America.

This module was also designed to ***integrate inclusive pedagogy***. All content was created so students could view the documents and/or download the documents and read them with a screen reader. Recorded videos had closed captioning, and most content was provided so students could interact with it physically and digitally, during class and on their own or at their own pace. Students had the choice to work independently or in pairs or groups for all assignments except the jigsaw activity (mandatory group activity), and, during the lab, they had the opportunity to select species that interested them and were able to be creative with the figures they made for the lab report. Activities were scaffolded within the lecture and lab class time to walk students through the tasks and ensure everyone was on the same page. Students were provided rubrics, frequently asked questions guides, and/or immediate, positive feedback for all activities, with frequent reminders during class and through the learning management system about due dates for activities. Students were encouraged to reflect on their learning and provided time to brainstorm ideas alone and in pairs before acting. During the introduced and invasive species lecture, students were introduced to western and Indigenous perspectives on introduced and invasive species to present differing viewpoints. This element also serves to connect students to current events due to the recent increase in interest in and integration of traditional ecological knowledge into western science and education systems. Overall, UDL guidelines and other actions to improve inclusivity were used to optimize teaching and learning for all students.

Though this module was not designed to directly ***engage non-science majors*** (the course it was created for is exclusively for science majors), the content could easily be adapted to engage non-science majors due to its topical focus on introduced and invasive species, which can have ecological, cultural, and economic impacts. The jigsaw activity could be used as is or adapted to include introduced species from other regions of the world or emphasize certain impacts of invasive species (e.g., economic impacts for business majors, cultural and spiritual impacts for sociology or anthropology majors). Further, the “choose your own adventure” component of the lab, in which students identify an invasive species of interest and write some responses about it, could be adapted so students create a one-page fact sheet or video to share with their peers and teach them about the impacts and interactions invasive species have in their novel environments.

**Module Development, Implementation, and Substitutions**

This module was created from raw materials, not adapted from another previously published module, so all modifications that occurred before implementation were a result of feedback received from members of the Life Discovery Faculty Mentoring Network “Pushing Past Barriers: Ecological Science for All” group. In particular, the content focused on introducing students to Indigenous perspectives of introduced and invasive species was suggested by the group and added to the module to connect to current events and improve classroom inclusivity.

Implementation of the primary activities included in this module can be carried out over a period of two weeks. If this course is offered in the spring, this module can align with National Invasive Species Awareness Week (<https://www.nisaw.org/>), which is typically at the end of February or early March. To start this module, students should be introduced to species interactions terminology via at least one lecture on species interactions. Some starter slides have been provided in the materials that correspond with this module. Additional detail to each slide, additional slides, and/or additional lectures may be added to provide more information about each type of species interaction, as well as differences between intraspecific and interspecific competition, Lotka-Volterra models, competitive exclusion principle, resource partitioning, species interactions and natural selection, fundamental vs. realized niche, and/or predator-prey cycles. After this lecture, students can complete a crossword puzzle activity using notes and/or working with a peer to practice using the species interactions terminology. The activity is short, effective, and easy to grade, but other activities can be used in place of this to assess learning.

The lab activity starts after the first lecture in the module and it is recommended that students have approximately two, two-hour lab periods to complete it. The first part of the lab activity focuses on impacts of an invasive amphibian on native amphibian species, and provides students with practice conducting basic analysis, data classification, and figure creation for quantitative and qualitative data in Microsoft Excel. The analysis component focused on the amphibian species counts and elevation variables, but the activity can be adapted to exchange these variables for other variables, including fish occurrence, vegetation cover around the bodies of water, or size of the bodies of water at the site, for example. The course this activity was developed for is a sophomore level course, so we did not use advanced statistics, though the dataset that was used (Roth et al. 2015) could be adapted for more advanced courses and/or could include review and discussion of corresponding literature (e.g., Schmidt 2005, Tanadini and Schmidt 2011, Roth et al. 2016). In more advanced and smaller courses, students could also be introduced to Dryad more generally and required to identify a dataset to analyze focused on species interactions and/or invasive species.

The second part of the lab activity focused on creating a food web for the spongy moth (*Lymantria dispar dispar*), linking it to Lyme disease. This activity challenges students to think about bottom-up and top-down species interactions, trophic levels, and positive and negative impacts of invasive species, while allowing students to get creative in how they display these complex interactions. Most students turn in basic diagrams with names of the organisms in boxes, but some draw out the species by hand or develop a digital diagram with clip art. This component could also be split out to an in-class discussion where students team up and draw their interactions on individual team poster boards or collectively on the classroom chalkboard.

The last component of the lab activity, the “choose your own adventure,” had students identify an invasive species of interest through EDDMapS and write some responses about it. This component allowed them to explore other impacts of invasive species and make a choice about which species they were most interested in learning more about. If the second part of the lab activity is removed, this third part may be changed to include a more creative element where students can choose to present the ecology, distribution, impact, and management of their chosen species in a format other than a question-answer format. For example, students might be encouraged to create a one-page fact sheet, infographic, or video about their species instead.

The second lecture activity can be implemented at the end of the two week module. After a short lecture on the definitions of introduced and invasive species, western and Indigenous perspectives of introduced and invasive species, and positive and negative impacts of introduced species, the students participate in a jigsaw activity where they learn about five introduced species in the southeastern United States - European honey bee, European starling, feral pigs, hydrilla, and silver carp – and then teach their peers about these species in small groups. This jigsaw activity can be modified to include species that are significant within your area or another area of interest. If it would take too much time to create new fact sheets, the instructor can assign students to research a particular species before the jigsaw activity class period. After the lecture, students with the same species would then get together to discuss what they found from their individual research on the species and develop three key takeaways on the species to share with their peers who had other species. In general, it is suggested to have a diverse array of organisms (e.g., plants, insects, mammals, fish, birds) that have positive and/or negative impacts on the organisms and environment around them. This activity helps break up the monotony of a standard lecture and promotes peer instruction, which improves learning in the classroom.

The final two assessments for this module include a quiz and exam. The quiz includes 10 questions, is open note, and is delivered via the class learning management system. Students have a few days after the jigsaw activity to complete the quiz. In addition to a provided study guide, the quiz helps students study for the exam, which includes approximately 15 questions multiple choice and short answer questions relating to the content covered during this module. The quiz and exam components of this module are optional. Questions can be developed from the materials provided in the handouts associated with this module.

**PROCEDURE AND GENERAL INSTRUCTIONS FOR STUDENTS**
**Background**

Species interactions describe the relationships among different species living in the same location. Species can have many types of interactions, ranging from mutualisms and commensalism to competition and parasitism. Interactions can occur between species that are native to an area, as well as between native species and species that are introduced into an area. The relocation of these “introduced” organisms across geographical boundaries mostly occurs directly or indirectly by humans and has increased over time as humans have improved transportation systems and increased global connectivity. In some cases, humans have intentionally dispersed species, such as reptiles (e.g., Burmese pythons (*Python bivittatus*) were imported through the pet trade and subsequently released into the Florida Everglades) or plants (e.g., Chinese tallow tree (*Triadica sebifera*) was transported from Asia to North America for ornamental purposes). Other species are accidentally transported by planes, trains, and automobiles, cargo and cargo ships, horticultural and ornamental plants, and wood products. Many of these introduced species are not able to survive in the new ecosystem, but others may find their new environment optimal for establishing, growing, reproducing, adapting, and dispersing to create new populations. Some of these species that adapt well increase their populations rapidly, and have negative impacts on native species, disturbance and biogeochemical cycles, and/or the economy. These “invasive species” can alter the ecology and evolution of native species, ecology of ecosystems, and can be important drivers of species extinction. The purpose of this module is to introduce you to species interactions terminology and concepts of invasion biology so that you might: (1) explain the nature of interactions between organisms, (2) contrast the biological and life history traits that help introduced species succeed in a novel environment and distinguish how that success impacts native organisms in the same environment, and (3) investigate species interactions through analysis of biological data.

**Timeline and Directions**

The module is comprised of lectures and four key activities, as described in chronological order below. More specific instructions are also included on each respective handout.

* ***Introduction to species interactions lecture:*** Attend lecture, take notes, and learn about the different types of interactions that occur between and within species.
* ***Species interactions crossword puzzle:*** Use the clues provided at the bottom of the page to fill in the “Species Interactions Crossword Puzzle.” To be completed and turned in before the end of the species interactions lecture class period.
* ***Invasive species and species interactions lab activity:*** Follow the exercise instructions in the “Introduced Species and Species Interactions Lab Handout” file. Follow along with your instructor’s demonstration and/or use the “Introduced Species and Species Interactions Lab FAQ Sheet” to help you develop the figures for the first part of the lab.
* ***Introduced species impacts and interactions jigsaw:*** Attend the lecture and take notes on invasion biology concepts and perspectives on introduced species. Follow the directions provided by your instructor (also on the “Introduced Species and Species Interactions Reflection Handout”) to complete the jigsaw activity.
* ***Introduced species impacts and interactions reflection:*** Record your answers from the jigsaw activity on the “Introduced Species and Species Interactions Reflection Handout” sheet and turn it in at the end of class.

**Prerequisite Skills and Knowledge**

For the lecture activities, students should be able to work with their peer group to read and synthesize a short description of an introduced species, communicate the synthesized information to peers outside of their group, and write a reflective summary of what they learned. For the lab activity, students should be able to ask questions, formulate a hypothesis, develop a prediction, design and conduct an experiment (using a supplied dataset), analyze, display, and interpret data, and communicate results (covered during first part of semester in lab). Additionally, students should have some knowledge about species interactions and food webs.

**REFERENCES**

Roth, T., Bühler, C., Amhein, V. 2015. Data from: Estimating effects of species interactions on populations of endangered species, Dryad, Dataset, <https://doi.org/10.5061/dryad.7gt4m>

Roth, T., Bühler, C., and Amrhein, V. 2016. Estimating effects of species interactions on populations of endangered species. The American Naturalist, 187(4), pp.457-467. <https://doi.org/10.1086/685095>

Schmidt, B.R. 2005. Monitoring the distribution of pond-breeding amphibians, when species are detected imperfectly. Aquatic Conservation: Marine and Freshwater Ecosystems 15:681-692.

Tanadini, L.G. and Schmidt, B.R. 2011. Population size influences amphibian detection probability: implications for biodiversity monitoring programs. PLOS ONE 6:e28244.

**APPENDIX**

Supplemental materials include the following files used in the module (in chronological order):

* Lecture slides: Species interactions lecture (PPT)
* Lecture activity: Species interactions crossword puzzle (Word)
* Lab activity: Introduced species and species interactions lab handout (Word)
* Lab activity: Introduced species and species interactions lab FAQ sheet (Word)
* Lecture slides: Introduced species lecture (PPT)
* Lecture slides: Introduced species and species interactions jigsaw activity (PPT)
* Lecture activity: Introduced species and species interactions jigsaw fact sheets (PPT)
* Lecture activity: Introduced species and species interactions reflection handout (Word)