*The following text is a transcript to help increase the accessibility of our presentation. Text for all narration is in the order it appears in the presentation, and is grouped by slide.*

**TITLE SLIDE**

***Slide 1.*** Hello everyone. My name is Trevor Drees and today, I will be presenting to you some of my recent research on how increased temperatures shift flower height distributions and seed dispersal patterns in two invasive thistles.

**BACKGROUND AND INFORMATION**

***Slide 1.*** First, I will start by offering some background on dispersal and climate change, as well as what the goal of our study is.

***Slide 2.*** What is dispersal? Simply put, it is any movement of organisms that can possibly generate gene flow.

***Slide 3.*** Why should we quantify dispersal? There are several good reasons, most of which are related to explaining the movement of genes, individuals, populations, species, and communities.

If we seek to quantify the spread of a given species, particularly an invasive, we’re often interested in estimating a spread rate, understanding the life stages that contribute the most to said spread, and understanding the agents that most strongly drive dispersal.

All in all, we care about quantifying dispersal because a better understanding of dispersal in invasive species can help us make more informed management decisions that save time and money.

***Slide 4.*** However, quantifying dispersal is already challenging, and is further complicated by the fact that climate change can alter patterns of dispersal by affecting dispersal-related factors such as temperature, precipitation, wind speeds, and frequency of extreme events.

For example, consider a wind-dispersed plant like the one shown in the picture here.

Increases in temperature and precipitation can enhance plant growth, leading to taller flower heights. This increase in seed release height means that seeds will be suspended in the air for longer and can be blown further by wind.

Increases in wind speed also means that seeds can be blown further by wind.

Increases in the frequency of extreme events can also affect seed dispersal; storms with strong winds can cause seeds to travel extremely long distances, which may become more common if extreme storms become more frequent.

***Slide 5.*** Thus, the goal of the research described here is to use empirical data and mechanistic models to predict how climate change will alter dispersal patterns in invasive plant species. Our research examines this in the form of increases in temperature, ultimately setting the stage for examining how other climatic shifts affect dispersal.

However, because not all species will exhibit the same responses to temperature increases, we need to be specific about which species we’re working with, and use them as a case study to inform possible dispersal changes in similar species.

**STUDY SYSTEM AND METHODS**

***Slide 1.*** So now, let’s take a look at the study system we are using, as well as the methods used to quantify dispersal and how temperature increases affect it.

***Slide 2.*** The two species we will use for our study system are *Carduus nutans* and *Carduus acanthoides*. Both of these are invasive thistles often found in highly disturbed areas such as roadsides and pastures.

***Slide 3.*** While these two invasive species are of Eurasian origin, they can be found in many places outside their native range, and have been reported in a large number of U.S. states and Canadian provinces.

***Slide 4.*** Both thistle species are dispersed by seed, with seeds displaying a smooth elongated achene and a small elaiosome at the end. The elaiosome is particularly attractive to ants and plays a role in ant-mediated seed dispersal.

***Slide 5.*** Wind is the primary dispersal vector for these thistle seeds. They are often blown out of the flower head after a gust of wind, as can be seen in the photo here. The seeds are small and are carried in the wind due to their lightweight pappus, the small feathery structure on top of the seed. This pappus allows seeds to stay suspended in the air for significantly longer, increasing the time that they are exposed to wind and thus the distance they travel.

So, we know that wind is the primary dispersal mode, but how can we model it?

***Slide 6.*** We can actually simulate wind dispersal using an inverse Gaussian distribution based on a fluid dynamics model, and obtain the probability of a seed travelling a given distance.

This is a dispersal kernel, or probability distribution, for a seed travelling some distance from release.

The dispersal kernel here is dependent upon a variety of parameters including wind speed, seed terminal velocity, and seed release height.

***Slide 7.*** This model of wind dispersal has actually been tested in several systems for various wind-dispersed plant species, including *Carduus* *nutans* and *acanthoides*.

Previous work with these two thistle species compares the WALD model against empirical data from seed traps and demonstrates that this model can accurately model dispersal in this system.

***Slide 8.*** So, we have our dispersal model now. But what about the climate change aspect?

To model increases in temperature, we used an experiment to assess how warming affects seed release height, which strongly affects dispersal distances. For each species, we randomly assigned half of the plants translucent open-top fibreglass chambers, which increase the ambient temperature by approximately 0.6 degrees Celsius.

***Slide 9.*** Previous studies have actually shown, at least in *Carduus* *nutans*, that warming increases plant height and shifts dispersal kernels to the right, leading to longer dispersal distances being more common. However…

We don’t know if the same thing happens for *Carduus* *acanthoides*, as previous studies have not examined that. Also, previous studies have only considered seed release as a single point source at the maximum flower height; what about all of the other release heights?

***Slide 10.*** If we use the maximum height like previous studies did, we’re only considering a single point of seed release on a given plant.

But in reality, seeds are released from other flowers on the same plant too. So the question here is how does the dispersal kernel change when we account for those other seed release heights?

To address this, we integrate across the distribution of flower heights, , to account for dispersal from flower heads across the entire plant.

***Slide 11.*** So, thinking about how warming affects seed release height (which in turn affects dispersal distances) as well as how our estimates of dispersal distances can change if we use the distribution flower heights rather than just the tallest one, we seek to address three questions with this research. First, how does increased temperature affect the distribution of flower heights (and thus seed release heights)? Second, how does increased temperature affect dispersal distances over the distribution of flower heights? And third, are there differences in dispersal when using the distribution of seed release heights rather than the maximum height?

**RESULTS**

Let’s take a look at the results.

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First, how does increased temperature affect the distribution of flower heights (and thus seed release heights)?

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Our results indicate that, on average, flowers from warmed thistles are taller compared to flowers from unwarmed thistles. As can be seen in the left pair of bars in the chart, warmed *nutans* flowers are approximately 14 centimetres taller than their unwarmed counterparts; *acanthoides*, represented by the right pair of bars, are approximately 20.5 centimetres taller when warmed. Each of these differences are statistically significant.

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We can see that the entire distributions of flower heights are different after warming. It seems that warming shifts the distributions to the right, resulting in taller flowers all across the plant. This can be seen in both *nutans* (the top graph) and *acanthoides* (the bottom graph).

The dotted lines here represent the mean flower height for warmed and unwarmed thistles, corresponding to the bars shown on the last slide.

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So, we see that warming shifts the distribution of flower heights across the entire plant to the right, leading to taller flowers. How does this change in the distribution of flower heights affect dispersal, though?

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Well, it turns out that warming-induced increases in flower height also change the shape of the dispersal kernels. For both *nutans* (the top graph) and *acanthoides* (the bottom graph), differences between the warmed and unwarmed dispersal kernels are statistically significant; they are indeed two different distributions. For the warmed flower height distribution in each species, peaks of the distributions decrease and the rest of the distribution shifts to the right; that is, shorter dispersal distances become less common, while longer dispersal distances become more common.

Here, we’ve just taken the same plots on the previous slides and zoomed in on the tails of the dispersal kernels. The tails of the warmed distributions are slightly higher than those of the unwarmed distributions, indicating that longer dispersal distances are more common in warmed thistles. While the tails of the distributions don’t seem too different, minor differences here can actually have significant impacts on dispersal at longer distances.

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And we can see that here. This graph displays the minimum dispersal distance for a given percentile of dispersal distances; that is, if we took the outcome of all dispersal events and put them in order by distance, what would the minimum distance be for the top 10% (or 5%, or 1%, or 0.1%) of events. It appears that as we look at increasingly rare dispersal events, the distances we observe are greater for warmed than unwarmed *nutans*. This makes sense; the graphs in the last slide show that the tails of the warmed distributions are slightly higher than those of the unwarmed distributions, so we would expect to see more long distance dispersal events and increases in the distances involved in said events.

We also see the same trend for *acanthoides* as well.

Note that the bootstrap intervals in our figures grow larger for increasingly rare dispersal events. Part of this is because we’re incorporating variability in wind speed and seed terminal velocity into our analyses, so we’re bound to see more variability in long-distance dispersal in the first place. If we used only the mean wind speed and mean seed terminal velocity, the error bars would not be as large.

Here, I’ve just taken the previous two graphs and put them side-by-side for easier comparison. This is mostly just to show that long-distance dispersal events tend to cover a greater distance in *nutans* than in *acanthoides* since *nutans* flowers tend to be taller, and thus seeds are released higher and spend more time in the air.

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So, we see that warmed thistles yield taller flowers when considering the entire height distributions, and that dispersal distances over the distribution of flower heights tend to be greater for warmed thistles. But when looking at dispersal distances, does it really make a difference if we use the distribution of flower heights instead of just using the maximum height like the previous studies did?

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Here, you can see what happens when we compare kernels using maximum height to those using the distribution of flower heights, for each species warmed or unwarmed. The top two graphs are for *nutans*, and the bottom two are for *acanthoides*. Keeping the same colour scheme we’ve used for all of the previous graphs, red represents warmed plants, while grey represents unwarmed plants. This time, dotted lines represent kernels using only the maximum height, while solid lines represent using the entire distribution of flower heights. Mind that up until now, our dispersal kernels have used the entire distribution of flower heights. The kernel pairs may not look too different, but statistically speaking, most of them are. For *nutans*, we see that in both the warmed and unwarmed treatments, dispersal kernels using maximum flower height have lower peaks and shift to the right, meaning that longer dispersal distances become more common. Note that we saw the same trend earlier when comparing warmed thistles to unwarmed ones. And this makes sense too: if we’re using the maximum possible height, of course dispersal distances will be greater that if we’re using the distribution of flowers on a plant, since all but one of the flowers are below the maximum and will thus release seeds from a lower height.

We see the same pattern for *acanthoides*: dispersal kernels using maximum flower height again have lower peaks and shift to the right, meaning that longer dispersal distances become more common. Note that the maximum height and height distribution dispersal kernels for the unwarmed treatment (in the third graph) are not different at the level.

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Again, we have our graph that displays the dispersal distance for a given percentile of dispersal distances; so, if we took the outcome of all dispersal events and put them in order by distance, what would the minimum distance be for the top 10% (or 5%, or 1%, or 0.1%) of events. Only this time, we’re examining differences between using maximum height or the entire height distribution rather than examining differences between warmed and unwarmed. It appears that as we look at increasingly rare dispersal events, the distances we observe are greater when using maximum height instead of the entire height distribution for unwarmed *nutans*. This makes sense, given what was discussed in the previous few slides: seeds are released higher when using the max height and will thus travel further.

We see the same pattern with warmed *nutans*…

And with unwarmed *acanthoides*…

And with warmed *acanthoides*…

Again, the bootstrap intervals in our figures increase in size for increasingly rare dispersal events. Note that in all of the graphs, the differences when using the max height compared to the entire distribution of heights are there, but they’re not very large.

Here, I’ve just taken the last four graphs and put them all on the same slide so it’s a little easier to compare them. We see when comparing *nutans* to *acanthoides*, seeds in those long-distance dispersal events tend to travel a little bit further, with the difference a bit more pronounced in the unwarmed plants. Within each species, warming increases distances in those long-distance dispersal events. And in general, using the maximum flower height yields higher distances for long-distance dispersal events when compared to using the entire height distribution.

So, what did we learn from our experiment and analyses?

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Our study is the first to examine the distributions of seed release heights over the entire plant for *Carduus nutans* and *Carduus acanthoides*, and how warming affects those distributions.

We learned that warming increases the mean flower heights for both *nutans* and *acanthoides*, and shifts the distribution mean rightward. Previous studies have demonstrated this shift with maximum flower height; we demonstrate this shift with the entire flower height distribution.

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We also leaned that warming changes the shape of the dispersal kernel.

Our results show that even when using the entire height distribution instead of the max height, warming shifts the dispersal kernel to the right and makes the tail “fatter”; dispersal at shorter distances becomes less common, while dispersal at longer distances becomes more common.

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And we learned that even though the tails of the dispersal kernels may not look that different, even minor differences in these tails can affect dispersal distances. Warming increases the magnitude of long-distance dispersal events, and this increase becomes more pronounced when looking at more rare dispersal events, like that 1 in 1000 seed that gets carried by a strong gust of wind and is blown 60 metres away.

The variation in the magnitude of those more rare events also increases.

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It’s these long-distance dispersal events at the tails of the distribution that are highly influential in how a population moves across the landscape; models of population spread are often sensitive to these rare events. Sometimes, all it takes is one seed to start a new colony several hundred metres away from the main population.

Thus, warming-induced increases in the magnitude of long-distance dispersal events could very well increase spread rates. While we have not yet done this with using the entire flower height distribution, increased spread rates have been observed when using the maximum height.

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And these results have implications for weed management. As warming leads to greater dispersal distances, the spread of weeds will be more challenging to contain. Knowing how invasive plants respond to warming can help us continue effective management in future climates, and be better equipped to handle effects of warming-induced phenological changes in invasives we manage.

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For now, we’ve created a model examining effects of temperature increase on dispersal. But make no mistake, this achievement is not as small as it might seem because in creating this dispersal model, we have actually set up all of the framework necessary to move forward and incorporate other elements of climate change to examine how they affect dispersal too. These other elements can be incorporated with ease.

For example, we can incorporate projected shifts in wind speed. This wouldn’t be difficult at all since our model already uses wind speeds to estimate dispersal; all we would have to do is use projected wind speeds instead of the ones measured at our field site. I’ve actually already been working on modelling how changes in wind speeds affect dispersal.

We could even incorporate shifts in other climatic variables as well.

We will continue to consider additional variables one at a time. Rather than a small step in the right direction, we’ve really made more of a leap, but there are still more steps before we cross the finish line.

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That concludes my presentation. If you have any questions, please ask them in-call, post them in the chat, or email me. Finally, I would like give a big thanks to all the members of the Shea lab for their assistance in this research and the valuable feedback they have provided.

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