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INVASION NOTE

The Jorō spider (*Trichonephila clavata*) in the southeastern U.S.: an opportunity for research and a call for reasonable journalism

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Abstract *Trichonephila clavata*, also known as the Jorō spider, was first discovered in Georgia, USA in 2014. Its arrival from Asia and subsequent range expansion across the southeastern U.S. has received much media coverage, spanning from factual to sensational. Here, we describe *T. clavata*'s invasion potential and known invasive range, and review its biology, dispersal abilities, potential impacts, and management strategies. As of October 2022, *T. clavata*'s range spans at least 120,000 km^2, occurring across Georgia, South Carolina, North Carolina, and Tennessee, with additional reports in Alabama, Maryland, Oklahoma, and West Virginia. Its pattern of spread suggests it is primarily driven by natural dispersal mechanisms, such as ballooning, though human-mediated transport cannot be discounted. Like other large-bodied orb-weavers, *T. clavata* captures and feeds on flying insects and potentially other small animals, and we suggest thirteen co-occurring spider species that should be monitored for competition with *T. clavata* for resources and web-building sites. Since *T. clavata* is spreading across both natural and urban habitats, management options are limited. Overall, very little is known about this species in its new North American range, especially its impacts within this novel ecosystem. Thus, we advise journalists and experts alike against exaggerating its potential environmental impact or uncritical acceptance of the spider as ecologically harmless. Instead, *T. clavata*'s rapid spread should be carefully monitored, and we should take a cautious, evidence-based approach when determining next steps.

Keywords Dispersal · Ecological impacts · Invasive species · Media · Native species · Nephilinae

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Introduction

U.S. news headlines in early 2022 were awash with sensational reports of a pending apocalypse: giant spiders from distant lands were spreading throughout the country, dropping from the sky! A veritable invasion was underway by the Jorō spider, *Trichonephila clavata* (L. Koch, 1878), which had already established a stronghold in at least four southeastern states. Many media outlets speculated these hand-sized spiders would continue to spread, terrifying unsuspecting New Englanders and potentially wreaking havoc once they arrived. In times of panic and uncertainty, there is great value in slowing down to evaluate the facts around non-native species and make sober predictions about the future.

Spiders have historically received low attention in invasion research (Hulme 2009), possibly because none have yet achieved the level of ecosystem-wide damage and conspicuous community turnover emblematic of more infamous invasive species such as kudzu [*Pueraria montana* var. *lobata* (Willd.) Maesen & S. M. Almeida ex Sanjappa & Predeep], lionfish (*Scorpaena volitans* Bloch), zebra mussels [*Dreissena polymorpha* (Pallas)], or emerald ash borers (*Agrilus planipennis* Fairmaire). This lack of attention to invasive spiders means relatively little is known about their ecological or human-related impacts. Further, their economic costs are likely vastly underestimated, since a recent estimate of invasive arachnid costs only includes a single spider species (the woodlouse spider, *Dysdera crocata* C.L. Koch, 1838) (Renault et al. 2022). It is likely that the number of spider introductions and invasions will parallel increasing commodity movement worldwide, warranting greater attention to this understudied group of organisms within invasion research.

Given its intense media coverage, we review what is currently known about *T. clavata* in the context of its recent North American introduction. We consider this an invasive species as it is established, reproducing without human assistance in natural habitats, and spreading (sensu Richardson et al. 2000), though negative impacts are not yet known (Davis 2009). We review its biology in the context of its invasion, potential impacts, and suggest management strategies. We strongly advise experts and journalists against making hasty conclusions about its future impact or spread before more is known. Finally, we make suggestions for future research as very little is known about this new invasive species in North America.

Biology

Trichonephila clavata (Araneae: Araneidae) is part of a pantropical group of spiders in the genera *Trichonephila* and *Nephila* colloquially called golden orb-weavers, a reference to the shiny golden silk used to make their webs. Often suspended between trees or structures high above the ground, *Trichonephila* webs typically span ~ 1600 cm^2 in area (Kuntner et al. 2019) making these the largest orb-weaver webs found in North America. Correspondingly, *Trichonephila* and *Nephila* are the largest bodied groups of orb-weavers in the world. As extreme examples of female gigantism and sexual size dimorphism, female *Trichonephila* and *Nephila* spiders dwarf not only other web-building species but males of their own species; female *T. clavata* have a total body length of ~ 2.8 cm and males are less than a quarter of that size (Kuntner et al. 2019). Mature *T. clavata* females are generally characterized by having a bright yellow abdomen with five horizontal silver or bluish-green dorsal bands, pink to red ventral markings near the spinnerets, and black legs with yellow bands (Hoebeke et al. 2015), although variation exists in these markings and leg coloration (Fig. 1A, B). Thus, most observations of these spiders are of the brightly colored females and not of the more elusive and nondescript reddish-brown males (Fig. 1C).

In their native range, spanning from India to Japan (Fig. 2A), *T. clavata* produce between 400 and 500 eggs encased in a single golden, silken egg sac (Kim et al. 1999). Oviposition in the native range occurs between mid-October to November, with females surviving until late fall or early winter. Eggs overwinter and spiderlings (Fig. 1D, E) are observed by early summer. We know very little about *T. clavata* biology in the U.S., but authors DRN and DRC both observed spiderlings in early to mid-May during 2022, and by late summer mature adults are commonly observed (Hoebeke et al. 2015; Davis and Frick 2022).

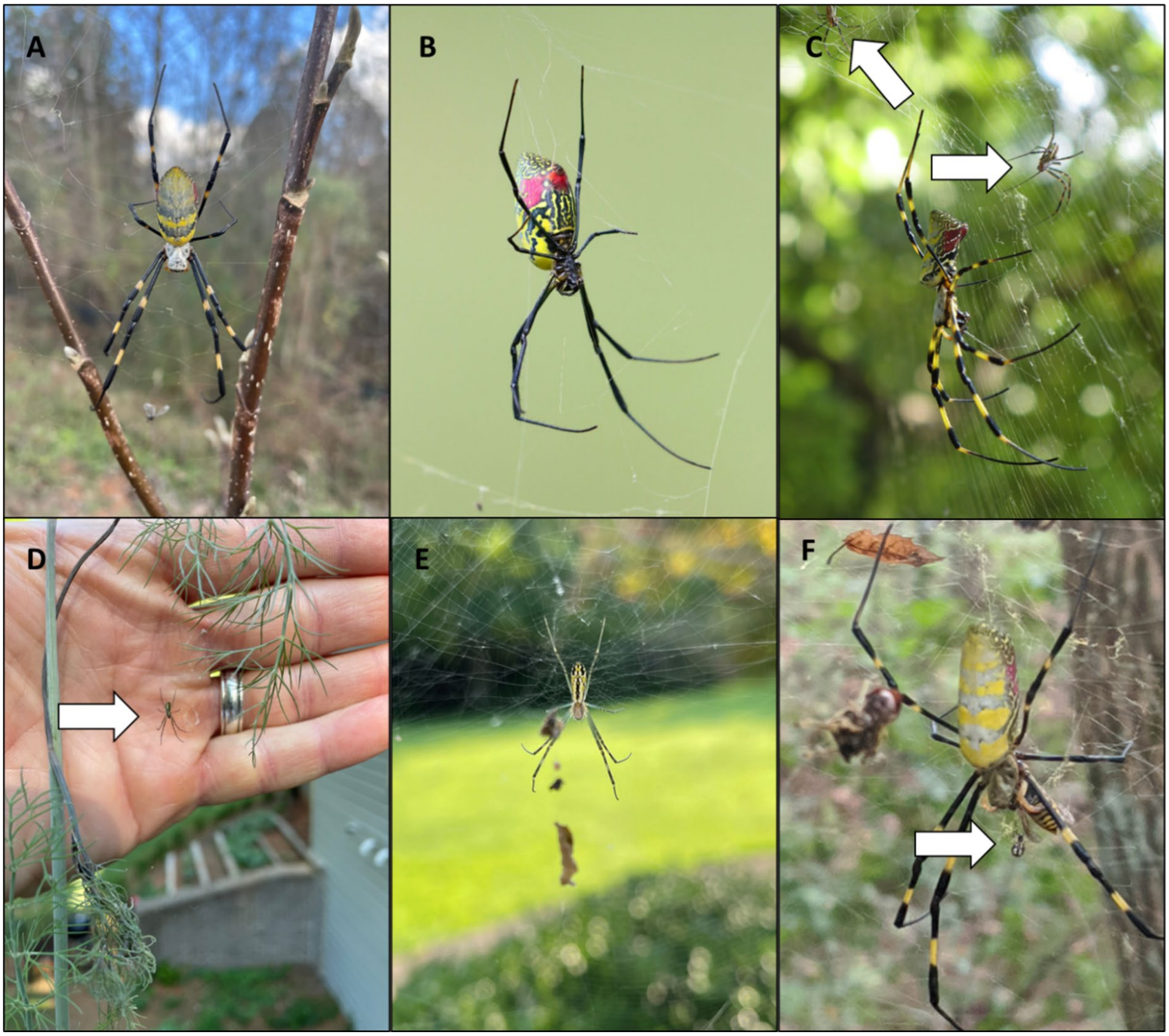

Fig. 1 Mature female *Trichonephila clavata* (A and B) were present beginning in September, and even as late as warm periods in December. Males (indicated by arrows) are much smaller and less colorful than females but can often be seen in the web (C). Spiderlings in May (D, indicated by arrow) had a legspan of ~ 10 mm, and in July had a legspan of ~ 20 mm (E). A small, likely theridiid kleptoparasite (F) was observed in a web (indicated by arrow) just below the prey of a female *T. clavata*. Figs. A and D by DRC; Fig. B by JFD; Fig. C by Micha L. Rieser, permission granted to use by Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Nephila-clavata-f-eating-and-2-m.jpg); Fig. E by DRN; Fig. F by MIS

Invasion history and current range in the U.S.

It is often difficult to establish a clear chronology and origin for spider introductions. This is likely because their human-assisted movement, especially over international borders, is largely unintentional. Their small size, inconspicuousness, and ubiquity makes them not only difficult to detect but very likely to be transported as part of international trade, especially with produce, potted plants, and packaging material (Nentwig 2015). Unlike many agricultural and natural resources pests that can often be detected based on frass or damaged commodities, if a spider has not constructed a web it can easily escape detection. Relatively hospitable environments like storage facilities, logistics centers, and greenhouses may then allow introduced spiders to survive and reproduce, paving the way for establishment in new locations

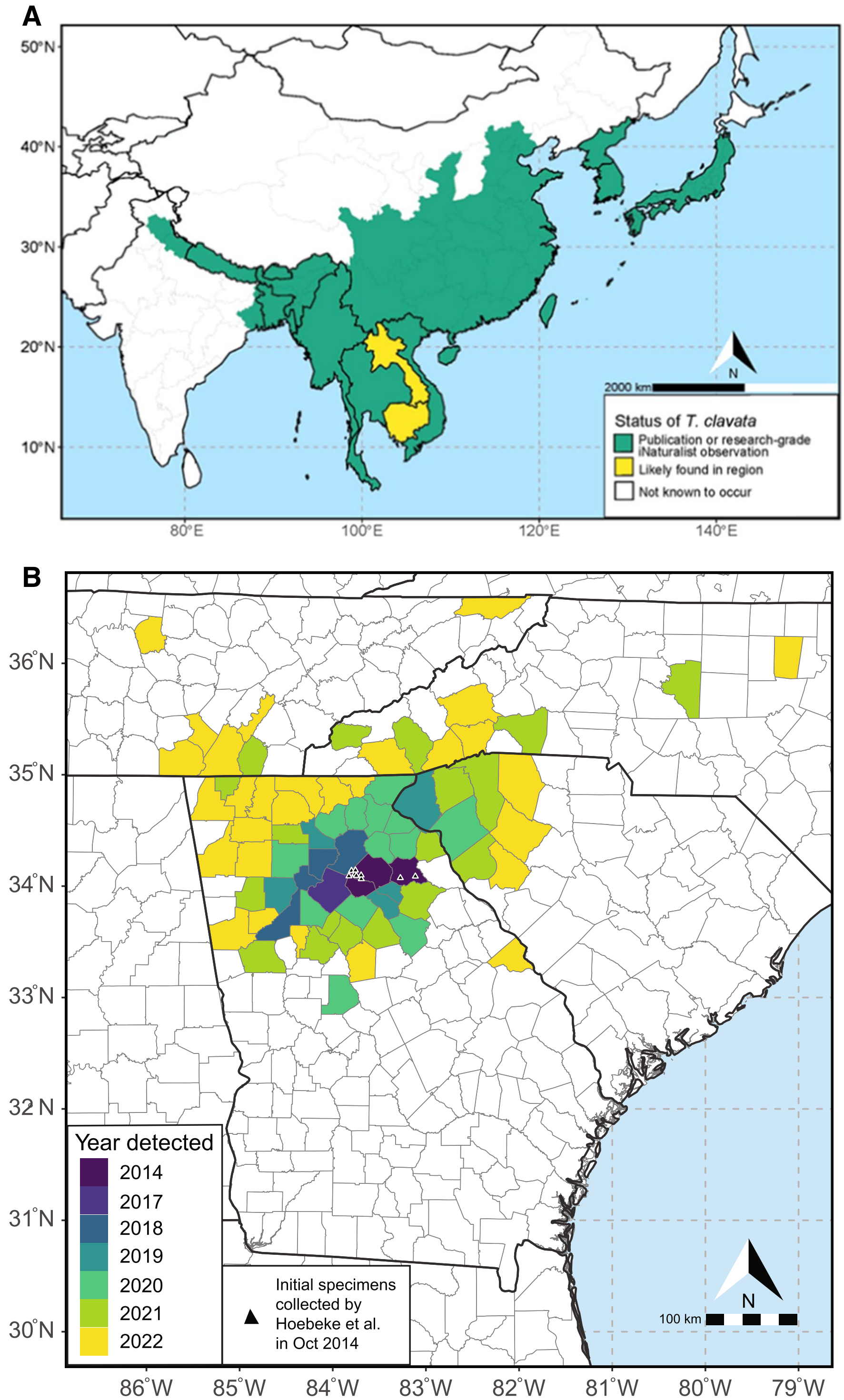

Fig. 2 Native (A) and introduced (B) range of *Trichonephila clavata*. Maps were constructed using research-grade observations as of 26 October 2022 in iNaturalist (www.inaturalist.org). Map B does not include isolated reports in Alabama, Maryland, Oklahoma, or West Virginia

(Hänggi and Straub 2016). Burgeoning international commerce in recent decades has increased the relative risk of spiders establishing new populations where they are accidentally imported.

Trichonephila clavata's pathway of introduction is unknown, but it is speculated that, like most non-native spiders, it may have been a hitchhiker in international cargo shipments (Hoebeke et al. 2015). Its introduction is relatively recent, as the first observation occurred in September 2014 in Madison County, GA (Hoebeke et al. 2015). By October of that same year, 15 females, two males, and an egg sac were found across nine different locations in three counties of northern Georgia (Hoebeke et al. 2015). *Trichonephila clavata*'s actual arrival likely predates these initial reports, as Hoebeke et al. (2015) reported that at least one of their contacts told them that the spiders had been present around her home for the "past 4 years."

Based on research-grade identifications of iNaturalist (https://www.inaturalist.org/) observations, *T. clavata* had already spread across ~ 321 km^2 by 2014, with the area possibly as large as ~ 751 km^2 based on all available reports (including one iNaturalist entry that had no associated photograph). *Trichonephila clavata* has currently been observed across an area spanning ~120,000 km^2 across four states in the southeastern U.S. This includes counties in Georgia (n = 51), South Carolina (n = 8), North Carolina (n = 9), and Tennessee (n = 7) as of October 26, 2022 (Fig. 2B). Additional isolated iNaturalist reports have occurred in Maryland, Oklahoma, and West Virginia, and a credible report from Alabama was reported on October 7, 2022, though this is not present in the iNaturalist data.

Dispersal

Given the diffusion pattern of spread observed from iNaturalist records over time, most of *T. clavata*'s range expansion is likely by ballooning. Many spiders disperse when young, becoming "aeronauts" capable of traveling hundreds of kilometers (Foelix 2011). Under favorable meteorological and atmospheric conditions, spiderlings may seek out a high point and release silk, leveraging both air currents and atmospheric electric fields to obtain lift-off from forces generated on the silk lines (Cho 2021).

The circumtropical distribution of *Trichonephila* suggests great dispersal capabilities (Kuntner et al. 2019). *Trichonephila clavata* spiderlings have been observed to balloon, which explains low genetic structure between native Korean and Japanese populations separated by over 100 km (Jung et al. 2006). Similarly, gene flow within the native North American congener *Trichonephila clavipes* (Linnaeus, 1767) connects populations in the Caribbean and North America, spanning at least 3,000 km (Čandek et al. 2020). These ranges certainly overlap the observed area of spread of *T. clavata* in North America. Thus, ballooning is likely the main contributor to the spread of *T. clavata* from its original discovery locations in Georgia.

Despite media reports of "giant parachuting spiders," *T. clavata* spiderlings are likely the only life stage to perform this ballooning behavior. Many factors (e.g., habitat availability, atmospheric conditions, temperature) influence ballooning (Suter 1999). Importantly, these factors include spider size, as smaller spiders are predicted to be more successful at ballooning than larger spiders (Suter 1999). In addition to the unfavorable mechanics of lifting large spiders, larger individuals would expend more energy climbing, climb more often to repeat ballooning events, and face greater risk of predation (Suter 1999; Buzatto et al. 2021). We are not aware of any records of *T. clavata* adults ballooning, and sensational reporting of giant spiders invading new areas from the air should be kept in check by our current understanding of the limitations and probabilities of ballooning behavior.

Transportation by human activities is likely rare but could account for long-distance jumps in its future range expansion; there has already been one confirmed case with a single *T. clavata* being transported over 1,000 km to Oklahoma (Davis and Frick 2022). For anthropogenic transportation to be effective in the expansion of this species' range, either a gravid female, multiple individuals, or egg sacs would have to be moved. While these scenarios seem less likely than ballooning dispersal, they are possible. Despite the likely low influence of anthropogenic movement on the continued expansion of *T. clavata*'s range, accidental transportation of a gravid female or egg sac likely provided means for introduction of the species to North America (Hoebeke et al. 2015).

Table 1 Orb-weaver species in the southeastern United States that may compete with *T. clavata* for resources and/or web-building sites. These species were chosen based on body size, their use of similar habitats, and discussions with other arachnologists (see Acknowledgements)

Species	Diel pattern	Total body length (female)	Phenology based on inaturalist observations: range (peak)*
Trichonephila clavata (L. Koch, 1878)	Diurnal and Nocturnal[1]	11–32 mm[10]	May—Dec (Oct)
Trichonephila clavipes (Linnaeus, 1767)	Diurnal and Nocturnal[2]	19–34 mm[4]	Jan—Dec (Aug)
Neoscona crucifera (Lucas, 1838)	Nocturnal[3,4]	8.5–19.7 mm[4]	May—Nov (Sept)
Micrathena gracilis (Walckenaer, 1805)	Diurnal[4,5]	7.0–11.0 mm[4]	June—Nov (Aug)
Micrathena sagittata (Walckenaer, 1841)	Diurnal[4,5]	5.4–8.6 mm[4]	May—Dec (Aug)
Micrathena mitrata (Henz, 1850)	Diurnal[6,7]	4.7–6.0 mm[4]	June—Nov (Sept)
Argiope aurantia Lucas, 1833	Diurnal[4,6]	19–28 mm[4]	Apr—Nov (Aug)
Argiope trifasciata (Forsskål, 1775)	Diurnal[4,7]	15.0–25.0 mm[4]	Jan—Dec (Sept)
Araneus marmoreus Clerck, 1757	Nocturnal[4]	9.0–18.0 mm[4]	June—Dec (Oct)
Araneus bicentenarius (McCook, 1888)	Nocturnal[8]	21–28 mm[4]	Mar—Oct (July)
Larinioides cornutus (Clerck, 1757)	Nocturnal[4]	6.5–14.0 mm[4]	Jan—Dec (Sept)
Gasteracantha cancriformis (Linnaeus, 1758)	Diurnal[4]	5.8–8.6 mm[4]	Jan—Dec (Sept)
Verrucosa arenata (Walckenaer, 1841)	Nocturnal[4]	5.0–9.5 mm[4]	Apr—Dec (Sept)
Leucauge venusta (Walckenaer, 1841)	Diurnal[9]	3.7–8.0 mm[4]	Mar—Oct (June)

*Research-grade iNaturalist observations were used to identify the range and peak activity periods of these species, and these data are subject to any biases that may be associated with using crowdsourced data

[1]Personal observation, DRN and DRC

[2]Higgins (1987)

[3]Adams (2000)

[4]Bradley (2019)

[5]Magalhães and Santos (2012)

[6]Harwood (1974)

[7]Blackledge and Wenzel (1999)

[8]Wagner et al. (2022)

[9]Kelly et al. (2019)

[10]Takasuka (2021)

Interactions with and impacts on native fauna

The scant number of case studies show that invasive spiders can prey on, displace, and invade the webs of native spiders (Bednarski et al. 2010; Houser et al. 2014). Their presence has also been associated with overall reduced abundance and diversity of native spider communities (Jakob et al. 2011), though this is not always the case (Burger et al. 2001). As generalist predators, *T. clavata* likely compete with native spiders for both prey and web-building sites. Several orb-weaver species may share an ecological niche and overlap phenologically with *T. clavata* (Table 1); we suggest these are the spider species most likely to be impacted as *T. clavata* spreads in the southeastern U.S. and thus warrant further monitoring. While we currently do not know how or if *T. clavata* impacts native spiders, any potential impacts will likely depend on resource limitation (i.e., prey availability) and habitat use patterns.

As generalist predators that use a large, aerial web to capture prey, *T. clavata* are likely to interact with a wide variety of flying insects and, potentially, small animals. For example, the congener *T. clavipes* primarily captures lepidopterans, hymenopterans, dipterans, and coleopterans – a diet that likely reflects the relative availability of different prey and includes both pests and beneficial insects (Higgins 1987). If *T. clavata* has a comparably broad diet, it is difficult to predict the impact on native arthropod populations and ecosystem function. There may even be no appreciable impact on prey populations if *T. clavata* outcompetes native spiders and fills a similar ecological niche.

Major predators of *T. clavata* in the U.S. are unknown, and predation on spiders in this genus may be relatively infrequent (Higgins 1987). Closely-related *T. clavipes* in the southern U.S. face low rates of mortality from mantispid (i.e., mantis lacewing, Insecta: Neuroptera: Mantispidae) egg parasites and predation from other spiders including mimetids (i.e., pirate spiders, Arachnida: Araneae: Mimetidae) and theridiids (i.e., tangle-web spiders, Arachnida: Araneae: Theridiidae) (Moore 1977), though birds are also likely predators (Rypstra 1984). In its native range, *T. clavata* contends with kleptoparasitic theridiid spiders and an ectoparasitic ichneumonid wasp (Insecta: Hymenoptera: Ichneumonidae) (Takasuka 2021). One of us (MIS) observed a likely kleptoparasitic theridiid in a *T. clavata* web in Marietta, GA (Fig. 1F) and *T. clavata* have been found as prey in mud dauber wasp nests (E.R. Hoebeke and L.A. Taylor, personal communication), indicating native species are already taking advantage of the invasion. Non-native spiders may be less susceptible to specialist natural enemies, such as parasitoid wasps (Mowery et al. 2022), though this remains to be seen in *T. clavata*.

Management

The first step in any management plan is to accurately identify the pest species. While specimens of *T. clavata* have several physical characteristics (e.g., size, coloration) that distinguish them from most spiders, they may be confused with other large, yellow spiders in some areas, such as garden spiders (*Argiope* spp.) and the native golden orb-weaver, *T. clavipes*. Thus, we encourage people to participate in community science by reporting incidences of these spiders to legitimate online crowdsourcing sites (e.g., iNaturalist). Free crowdsourcing sites can be extremely beneficial for pest identification (Unger et al. 2021), making new species detections (e.g., Mesaglio et al. 2021), and recording species' range expansions (e.g., Hahn et al. 2016; Cull 2022). With a species such as *T. clavata*—which appears to be spreading relatively rapidly—obtaining accurate location information is a critical piece of data needed for management.

Management of spider populations in natural or developed areas is incredibly difficult and rarely undertaken. One key exception is the management of spider populations in agricultural or orchard settings (e.g., Marliac et al. 2016), while another pertains to medically relevant species that inhabit dwellings, such as the brown recluse spider, *Loxosceles reclusa* Gertsch & Mulaik, 1940 (Vetter and Hedges 2018). While many spider species commonly reside inside homes (Bertone et al. 2016), *T. clavata* does not. Rather, *T. clavata* tends to build webs on structures such as porches, decks, lawn furniture, houses, and landscape plants. This behavior makes effective management difficult because the homeowner is essentially trying to manage populations of a wild organism on a small landscape scale.

Management options for homeowners do exist, but they are short-term in duration and will likely result in minimal impacts on overall *T. clavata* populations. Although insecticides, hairspray, and other chemicals will likely kill spiders, this approach may be ecologically detrimental and provides a low return on the homeowner's time and money. Further, to be used legally, any pesticide must be labeled for the pest on which it is being used. Webs can be physically removed if they are on unwanted structures (e.g., door frames), but the spider must also be removed, or it will likely rebuild the web in the same general area. Encouraging spider web relocation is probably the most useful tactic, as low prey capture success is a key factor in web site fidelity (Rittschof and Ruggles 2010). Limiting nighttime lighting around homes (e.g., turning off a porch light) may also lead to fewer spiders building webs on or near homes since prey are typically attracted to nighttime lights (e.g., Gomes 2020). Under no circumstances do we recommend using fire, gasoline, or other explosive or unapproved pest management approaches, as these typically have a high likelihood of causing personal injury or property damage (Gott 2020). Regardless of tactic used, these will only provide temporary reprieve, as more spiders are likely to move into these areas. We know of no effective long-term management strategies for

T. clavata in natural areas, and any attempts to control them in these areas are unlikely to be effective.

The need for evidence-based journalism

Trichonephila clavata received an enormous amount of media attention in late 2021 and early 2022 from several national media outlets. Intense media attention can be both a blessing and a curse, as it gives both journalists and experts a chance to disseminate accurate information. Unfortunately, nearly half of the news reports on spiders skew towards sensationalism and contain factual errors, with the former driving the spread of misinformation (Mammola et al. 2022). Thus, we strongly urge both journalists and experts to exercise caution in how they frame this species and its range expansion, given how little is known thus far.

Importantly, projecting large-scale future range expansion based on a single laboratory study (Davis and Frick 2022) is problematic. Likewise, to extrapolate that "parachuting spiders will invade the east coast" based simply on their ballooning ability ignores several important details described above. A panic-inducing conclusion like this does not consider the conditions required for *T. clavata* to establish and spread; it also promotes negativity towards spiders in general.

While we should not fearmonger about big, scary spiders, we also caution against an attitude of welcoming *T. clavata* with open arms. Some articles in early 2022 highlighted the potential beneficial impacts of *T. clavata* in gardens, encouraging the public to embrace them. Similarly, lack of known negative ecosystem effects associated with the invasion is insufficient justification to conclude a lack of impacts, considering no studies have been completed to date. It is unlikely that *T. clavata* will pose any medical risks to people or pets, but we cannot confidently predict the impacts of *T. clavata* on our native fauna. Until our understanding of the invasion develops further, we stress the need for a measured, evidence-based media approach for this species.

Future directions and conclusions

Trichonephila clavata has become a high-profile invasive spider, at once highlighting how little we know about spider invasions in general as well as motivating new research as it gains a foothold in the southeastern U.S. From an invasion perspective, this situation provides a rare opportunity to track an invasion in near real-time, as these spiders are large and easily seen by the general public [similar to the spotted lanternfly, *Lycorma delicatula* (White)]. Immediate research priorities should focus on better understanding the specifics of its range expansion and potential impacts on its surrounding native community and ecosystem. Learning how far and how quickly *T. clavata* may expand its range can have broad impacts on other research avenues. In the absence of alternate data, we used occurrence data from iNaturalist to represent the best current understanding of *T. clavata*'s range, and we acknowledge the limitations of crowdsourced data and its potential biases (e.g., observations may be more likely where human density is higher). Thus, we stress the need for follow-up surveys and updated range expansion estimates. Genetic analyses could help determine if *T. clavata*'s introduction was a single gravid female or egg sac, group of individuals, or multiple introduction events. We also know little about *T. clavata*'s biology and ecology in the U.S. Field and laboratory experiments are needed to better understand interactions with native species (i.e., competition with its native congener, *T. clavipes*, and other orb-weavers in similar habitats; Table 1) and how they might impact potential prey populations. Current management tactics for *T. clavata* have not been studied, but are likely short-term, local in scale, and largely ineffective.

We also urge researchers—and especially journalists—to exercise caution and moderation when discussing *T. clavata* in popular media. The fact remains there is much we still do not know about *T. clavata* and its potential impacts, and ongoing efforts to understand and communicate about U.S. populations of *T. clavata* should build upon what is already known and avoid unfounded sensationalism. This species is firmly established in the U.S. and still spreading; eradication is unlikely. In short, *T. clavata* is here to stay. While the thought of a new, large spider appearing in yards and on homes is unpalatable to many, we encourage people to adopt a more informed attitude towards the situation: this spider is unlikely to pose a threat to people or pets and represents an opportunity to better understand our native ecosystems as well as our impacts on the natural world. We are still experiencing the beginning stages of *T.*

clavata's invasion, and our ultimate interpretation of this situation will depend on the outcomes of current and future research.

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Declarations

Conflict of interest The authors declare that we have no conflict of interest to disclose.

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