7.1 Friend or Foe: The Role of Native, Natural Enemies in the Biological Control of Winter Moth

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Natural enemies that cross over from related native species to invasive species mediate invasions in complex ways (Strauss *et al.*, 2012; Dearborn *et al.*, 2016; Faillace *et al.*, 2017). They have the potential to slow down invasions and aid in biological control efforts (Kenis *et al.*, 2008; Vindstad *et al.*, 2013; Dearborn *et al.,* 2016). In the northeastern United States, the European winter moth, *Operophtera brumata* L. (Lepidoptera: Geometridae) is an invasive, forest pest causing widespread defoliation in rural and urban settings (Elkinton *et al.*, 2014). Following successful biological control of winter moth in Nova Scotia and British Columbia using the tachinid fly, *Cyzenis albicans* (Fallén) (Diptera: Tachinidae) (Embree 1966; Murdoch *et al.*, 1985; Roland and Embree, 1995), similar efforts are underway in the northeastern United States (Elkinton *et al.*, 2015).

While biocontrol shows promising results, success likely depends on additional mortality from native natural enemies. In the northeast U.S., the closest relative to winter moth is Bruce spanworm, *O. bruceata* (Hulst) (Lepidoptera: Geometridae). The two are congeners and can hybridize (Gwiazdowski *et al.*, 2013; Havill *et al.*, 2017), thus it is likely that natural enemies from Bruce spanworm as well as other generalists could cross over to cause mortality to the winter moth population. However, little is known about the identity or impact of these native species in this system or other systems.

To learn more about the role of native pathogens, parasitoids, and predators, we employed a suite of field and laboratory studies. Over the span of four years, we collected caterpillars of winter moth and Bruce spanworm. From these collections, we quantified mortality in rearing and determined the source of mortality. We then used a subsample of the surviving cohort, to deploy as pupae in the field to determine rates of predation and parasitism in pupae. Remaining live samples were used for lab trials of pathogen and parasitoid host range.

Our results suggest that in its introduced range, winter moth is not affected by pathogens from native congener species (Broadley *et al.*, 2017; K. Donahue and H.J. Broadley, 2017, unpublished results). While Bruce spanworm experienced mortality rates three or more times higher than that of winter moth from virus and microsporidia, we found no evidence that winter moth shares viral or microsporidian pathogens with Bruce spanworm. The rates of mortality on Bruce spanworm were particularly high when Bruce spanworm was at high densities. While pathogens do not seem to be shared between the

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two species, we found that generalist predators and a native parasitic wasp, *Pimpla* sp. (Hymenoptera: Ichneumonidae) cause high levels of mortality, both of which have increased significantly over the four years of the study (H.J. Broadley, 2017, unpublished results). In particular, we expect predation to be density dependent and to play a larger role when winter moth has been reduced to low density populations by the biocontrol agent, *C. albicans* (Roland and Embree, 1995; H.J. Broadley, 2017, unpublished results). We suggest that the recruitment of native predators and parasitoids, in concert with the biocontrol agent, may manage winter moth populations. At the same time, we note that native natural enemies can hinder our biological control efforts. While we have found native parasitoids to overall, have a beneficial effect, we have found that native hyperparasites may hinder biocontrol efforts with *C. albicans* (E. Kelly and H.J. Broadley, 2017, unpublished results). By evaluating the mortality rate and source of mortality on pupae parasitized by *C. albicans*, we found that mortality of *C. albicans* was surprisingly high and primarily due to predation, but also due to hyperparasitism from the generalist Ichneumonid wasps *Phygadeuon* sp., *Pimpla* sp. and *Gelis* sp. (Hymenoptera: Ichneumonidae).

Overall, this research improves our understanding of the relationship between introduced and native natural enemies and their relative contribution to successful biocontrol.

References

Broadley, H.J., Boucher, M., Burand, J.P. and Elkinton, J.S. (2017) The phylogenetic relationship and cross-infection of nucleopolyhedroviruses between the invasive winter moth (*Operophtera brumata*) and its native congener, Bruce spanworm (*O. bruceata*). *Journal of Invertebrate Pathology*, 143, 61–68.

Dearborn, K.W., Heard, S.B., Sweeney, J. and Pureswaran, D.S. (2016) Displacement of *Tetropium cinnamopterum* (Coleoptera: Cerambycidae) by Its Invasive Congener *Tetropium fuscum*. *Environmental Entomology*, 45, 848–854.

Elkinton, J.S., Boettner, G.H., Liebhold, A. and Gwiazdowski, R. (2015) *Biology, Spread, and Biological Control of Winter Moth in the Eastern United States*. USDA Forest Service, Forest Health Technology Enterprise Team, Morgantown, West Virginia, USA, FHTET-2014-07.

Elkinton, J.S., Liebhold, A., Boettner, G.H. and Sremac, M. (2014) Invasion spread of *Operophtera brumata* in northeastern United States and hybridization with *O. bruceata*. *Biological Invasions*, 16, 2263–2272.

Embree, D.G. (1966) The role of introduced parasites in the control of the winter moth in Nova Scotia. *The Canadian Entomologist*, 98, 1159–1168.

Faillace, C.A., Lorusso, N.S. and Duffy, S. (2017) Overlooking the smallest matter: viruses impact biological invasions. *Ecology Letters*, 20, 524–538.

Gwiazdowski, R.A., Elkinton, J.S., Dewaard, J.R. and Sremac, M. (2013) Phylogeographic Diversity of the Winter Moths *Operophtera brumata* and *O. bruceata* (Lepidoptera: Geometridae) in Europe and North America. *Annals of the Entomological Society of America*, 106, 143–151.

Havill, N.P., Elkinton, J.S., Andersen, J.C., Hagen, S.B., Broadley, H.J., Boettner, G.J. and Caccone, A. (2017) Asymmetric hybridization between non-native winter moth, *Operophtera brumata* (Lepidoptera: Geometridae), and native Bruce spanworm, *Operophtera bruceata*, in the Northeastern United States, assessed with novel microsatellites and SNPs. *Bulletin of Entomological Research*, 107, 241–250.

Kenis, M., Roy, H.E., Zindel, R. and Majerus, M.E.N. (2008) Current and potential management strategies against *Harmonia axyridis*. *Biocontrol*, 53, 235–252.

Murdoch, W.W., Chesson, J. and Chesson, P.L. (1985) Biological-Control in Theory and Practice. *American Naturalist*, 125, 344–366.

Roland, J. and Embree, D.G. (1995) Biological-control of the winter moth. *Annual Review of Entomology*, 40, 475–492.

Strauss, A., White, A. and Boots, M. (2012) Invading with biological weapons: the importance of disease-mediated invasions. *Functional Ecology*, 26, 1249–1261.

Vindstad, O.P.L., Schott, T., Hagen, S.B., Jepsen, J.U., Kapari, L. and Ims, R.A. (2013) How rapidly do invasive birch forest geometrids recruit larval parasitoids? Insights from comparison with a sympatric native geometrid. *Biological Invasions*, 15, 1573–1589.