Annotated Bibliography on the
Ecology and Management of Invasive species:

Operophtera brumata
Winter Moth

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for the Garry Oak Ecosystems Recovery Team

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Peer-reviewed sources

Boulton, T.J., I.M. Otvos, K.L. Halwas and D.A. Rohlfs. 2007. Recovery of nontarget Lepidoptera on Vancouver Island, Canada: one and four years after Gypsy Moth eradication program. Environmental Toxicology and Chemistry 26 (4): 738-748.

Abstract: The Gypsy Moth (*Lymantria dispar*) is a destructive defoliator that is not established in British Columbia, Canada, because of successful eradication programs involving the microbial insecticide *Bacillus thuringiensis* var. *kurstaki* (*Btk*). In 1999, three aerial applications of *Btk* were made over two areas, totaling 12,805 ha, on southern Vancouver Island, Canada. The impacts of these *Btk* applications on nontarget Lepidoptera were studied from 1999 to 2004 on Garry Oak (*Quercus garryana*) and Common Snowberry (*Symphoricarpos albus*). In 1999, lepidopteran larvae were collected from *S. albus* foliage at 24 urban parks and from *Q. garryana* foliage at 28 oak dominated habitats. The initial impacts (i.e., 1999 data) were published previously, and the present paper is a continuation of the same study. We tested two hypotheses: Reductions of non target Lepidoptera would be more severe at 12 to 13 months postspray than at one to two months post spray, and recovery would be significant, though not necessarily complete, at four years post spray. The total number of nontarget Lepidoptera on *S. albus* and *Q. garryana* was significantly reduced in the treatment sites in each year of the study: the reduction was greatest in 2000. Relative to the reference sites, each of 11 species that were initially reduced by the *Btk* applications showed an increase in the treatment sites between 2000 and 2003, by which time only four species remained significantly reduced in the treatment sites. The uncommon species were significantly reduced in 1999 and 2000 but not in 2003, indicating that some recovery had occurred. Limitations and economic implications of the present study are discussed.

Elkington, J. S., G.E. Boettner, mM Sremac, R. Gwiazdowski, R.R. Hunkins, J. Callahan, S.B. Scheufele, C.P. Donahue, A.H. Porter, A. Khrimian, B.M. Whited and N.K. Campbell. 2010. Survey for Winter Moth (Lepidoptera: Geometridae) in Northeastern North America with pheromone baited traps and hybridization with the native Bruce spanworm (Lepidoptera: Geometridae). Annuals of the Entomological Society of America 103 (2): 135-145.

Abstract: We used pheromone-baited traps to survey the distribution of Winter Moth, *Operophtera brumata* (L.) (Lepidoptera: Geometridae), a new invasive defoliator from Europe in eastern New England. The traps also attracted Bruce Spanworm, *Operophtera bruceata* (Hulst) (Lepidoptera: Geometridae), native to North America. We distinguished between the two species by examining male genitalia and sequencing the mitochondrial cytochrome oxidase subunit 1 (COI) gene, the DNA barcoding region. In 2005, we recovered Winter Moths at sites stretching from eastern Long Island, southeastern Connecticut, all of Rhode Island, eastern Massachusetts, coastal New Hampshire, and southern coastal Maine. At sites further west and north we captured only Bruce Spanworm. In 2006, we confirmed that both Winter Moth and Bruce Spanworm are present in Nova Scotia and in coastal Maine, but only Bruce Spanworm was recovered in coastal New Brunswick, Canada; Pennsylvania; Vermont; or Quebec City, Canada. In 2007, we collected Bruce Spanworm, but no Winter Moths, in New Brunswick and the interior areas of Maine, New Hampshire, and New York. Winter Moth and Bruce Spanworm differed in the COI sequence by 7.45% of their nucleotides. The prevalence of intermediate genitalia in the zone of overlap suggested that hybridization between the two species may be occurring. To confirm the presence of hybrids, we sequenced the nuclear gene, glucose-6- phosphate dehydrogenase (G6PD). We identified six nucleotides that routinely distinguished Winter Moth and Bruce Spanworm, of which three were always diagnostic. We showed that eggs produced by hybridizing the two species in the laboratory contained copies of both species at these six sites. We found that most of the moths collected in the field with intermediate genitalia had Winter Moth CO1 and G6PD sequences and thus were not hybrids (or at least F1 hybrids). We found three hybrids out of 158 moths with intermediate genitalia in the region where both species were caught. We conclude that hybrids occur in nature, but are not as common as previously reported. Introgression of genes between the two species may still be significant.

Heisswolf, A., M. Kaar, T. Klemola and K. Ruohomaki. 2010. Local outbreaks of *Operophtera brumata* and *Operophtera fagata* cannot be explained by low vulnerability to pupal predation. Agricultural and Forest Entomology 12: 81-87.

Abstract: 1 One of the unresolved questions in studies on population dynamics of forest Lepidoptera is why some populations at times reach outbreak densities, whereas others never do. Resolving this question is especially challenging if populations of the same species in different areas or of closely-related species in the same area are considered. 2 The present study focused on three closely-related geometrid moth species, autumnal *Epirrita autumnata*, winter *Operophtera brumata* and northern Winter Moths *Operophtera fagata*, in southern Finland. There, winter and northern Winter Moth populations can reach outbreak densities, whereas autumnal moth densities stay relatively low. 3 We tested the hypothesis that a lower vulnerability to pupal predation may explain the observed differences in population dynamics. The results obtained do not support this hypothesis because pupal predation probabilities were not significantly different between the two genera within or without the *Operophtera* outbreak area or in years with or without a current *Operophtera* outbreak. 4 Overall, pupal predation was even higher in winter and northern Winter Moths than in autumnal moths. Differences in larval predation and parasitism, as well as in the reproductive capacities of the species, might be other candidates.

Horgan, F.G., J.H. Myers and R. Van Meel. 1999. *Cyzenis albicans* (Diptera: Tachinidae) does not prevent the outbreak of Winter Moth (Lepidoptera: Geometridae) in birch stands and blueberry plots on the lower mainland of British Columbia. Environmental Entomology 28 (1): 96-107.

Abstract: In the late 1980s, a new outbreak of the introduced Winter Moth, *Operophtera brumata* (L.), occurred in Richmond, on the lower mainland of British Columbia. This was accompanied by the introduced parasitoid, *Cyzenis albicans* (Falle´ n). Populations were monitored at 2 birch woodlands and 2 blueberry plots between 1989 and 1993. Parasitism by *C. albicans* and predation by generalist predators were important mortality factors during the outbreak. Predation of moth pupae increased at all sites between 1989 and 1990. Parasitism by *C. albicans* caused significant mortality each year reaching a maximum in 1991 and remaining high through to 1993 at birch sites. The Winter Moth populations collapsed simultaneously in 1992 at all study sites, despite different levels of parasitism and 2 very different host plants. As the outbreak collapsed at Richmond, the moth continued to increase in numbers and cause severe defoliation of birch at new sites in southern Vancouver where parasitism remained low. *C. albicans* is unable to prevent the initial outbreak of Winter Moth even when the 2 species are introduced simultaneously. The parasitoid requires high density host populations before becoming well established, but may contribute sufficient additional mortality to prevent subsequent prolonged outbreaks. The control of high density Winter Moth populations in North America by *C. albicans* supports the hypothesis that natural enemies that are rare in their native habitat will be effective control agents when released into exotic habitats without competitors or their own natural enemies.

Horgan, F.G. and J.H. Myers. 2004.Interactions between predatory ground beetles, the Winter Moth and an introduced parasitoid on the Lower Mainland of British Columbia. Pedobiologia 48: 23-35.

Abstract: This study describes assemblages of predatory ground beetles in native birch forest and derived blueberry farms on the Lower Mainland of British Columbia and investigates their role in the successful biological control of Winter Moth *(Operopthera brumata* L.) by the parasitoid *Cyzenis albicans*. Pitfall traps at four sites in 1991 and 1992 indicated that natural birch forest was dominated by native carabid species, while open blueberry was dominated by introduced species and some native xerophilous species. Predation by generalist invertebrates was an important mortality factor for both winter moth and *C. albicans* at all sites and was greatest in the first 2 weeks after pupation. Ground beetles including *Harpalus affinus* (Schrank) and *Pterostichus* spp. consumed Winter Moth pupae in arenas but adult beetles rarely consumed *C. albicans* pupae. Much of the overall predation was due to smaller invertebrates including beetle larvae. Predators actively searched for buried pupae and selected among pupal types based on condition (dead, parasitised or healthy) and size. Prey-selection differed among sites but *C. albicans* pupae were preferred at three of the four sites. At the remaining site, an organic blueberry farm, over 90% of both parasitised and healthy pupae were consumed. High levels of predation did not affect the levels of parasitism by *C. albicans* at the sites. This herbivore–parasitoid– predator system demonstrates the importance of naturally occurring predatory invertebrates for successful integrated pest management, even where they prey upon a biological control agent.

Jepsen, J.U., S.B. Hagen, R.A. Ims and N.G. Yoccoz. 2008. Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forest: evidence of a recent outbreak range expansion. Journal of Animal Ecology 77 (2): 257-264.

Abstract: 1. Range expansions mediated by recent climate warming have been documented for many insect species, including some important forest pests. However, whether climate change also influences the eruptive dynamics of forest pest insects, and hence the ecological and economical consequences of outbreaks, is largely unresolved. 2. Using historical outbreak records covering more than a century, we document recent outbreak range expansions of two species of cyclic geometrid moth, *Operophtera brumata* Bkh. (Winter Moth) and *Epirrita autumnata* L. (autumnal moth), in subarctic birch forest of northern Fennoscandia. The two species differ with respect to cold tolerance, and show strikingly different patterns in their recent outbreak range expansion. 3. We show that, during the past 15-20 years, the less cold-tolerant species O. brumata has experienced a pronounced north-eastern expansion into areas previously dominated by E. autumnata outbreaks. Epirrita autumnata, on the other hand, has expanded the region in which it exhibits regular outbreaks into the coldest, most continental areas. Our findings support the suggestion that recent climate warming in the region is the most parsimonious explanation for the observed patterns. 4. The presence of O. brumata outbreaks in regions previously affected solely by E. autumnata outbreaks is likely to increase the effective duration of local outbreaks, and hence have profound implications for the subarctic birch forest ecosystem.

Knauf, W., H.J. Bestmann and O. Vostrowsky. 1984. Responses of male Winter Moths (*Operophtera brumata*) to their sex attractant (3Z, 6Z, 9Z)-1,3,6,9 nonadecatetraene and to some structural analogues. Entomologia Experimentalis Et Applicata 35 (2): 208-210.

Abstract: *3Z,6Z,9Z*)-1,3,6,9-nonadecatetraene, the synthetic sex pheromone of the female of *O. brumata* is highly active in attracting males of this species in the field (Germany and Switzerland). No analogous compounds possessing attractivity to *O. brumata* males have been found up to now, nor did they show any inhibitory effects to the same species. Therefore (*3Z,6Z,9Z*)-1,3,6,9-nonadecatetraene (I) can be recommended as a good attractant in the prognosis or monitoring of this lepidopteran pest.

Roland, J. 1994. After the decline: what maintains low Winter Moth density after successful biological control? Journal of Animal Ecology 63: 392-398.

Abstract: 1. Life-table data for Winter Moth are analyzed for an 8-year period following introduction of parasitoids for biological control in British Columbia, Canada. 2. Winter Moth density declined in 1984, and has remained low since 1985 at an average density of approximately 1 20 adults per M2. 3. Introduced parasitoids contributed to mortality during the decline, and have a weak, delayed density-dependent effect at the new low density. 4. Mortality of unparasitized pupae in the soil (primarily by predation) is strongly, and directly density-dependent at the new low density, and is the factor which is most strongly regulatory. 5. Analysis indicates that the strong regulation of Winter Moth numbers by generalist predators allows parasitism levels to vary greatly after suppression without the eruption of Winter Moth populations; if parasitism were absent, winter moth populations would erupt to pre-biocontrol levels.

Roland, J., K.E. Denford and L. Jiminez. 1995. Borneol as an attractant for *Cyzenis albicans*, A tachinid parasitoid of the winter moth, *Operophtera brumata* L. (Lepidoptera: Geometridae). Canadian Entomologist 127(3): 413-421.

Abstract: Volatile compounds were isolated and identified from a crude extract of Garry oak, *Quercus garryana*, foliage which was known to be attractive to the tachinid fly *Cyzenis albicans*. Candidate compounds were identified by the combined use of gas chromatography-mass spectrometry, and infra-red spectroscopy. Specific oak-leaf volatiles were field-tested in 2 different years in an apple orchard. Compounds were applied singly or in combination to individual apple trees; the number of *C. albicans* entering the canopy of each tree was observed and the number of eggs they oviposited on foliage was estimated. Borneol was the only compound that attracted flies when compared with the other treatments, but this did not result in more fly eggs being oviposited on borneol-treated trees. None of the compounds tested resulted in a greater number of *Cyzenis* eggs being oviposited. A greater abundance of borneol in oak foliage than in apple foliage, and its attractiveness to *C. albicans*, may explain the aggregation of flies in response to feeding-damage among oak trees and the absence of this pattern among apple trees.

Roland, J. and D.G. Embree. 1995. Biological control of the Winter Moth. Annual Reviews of Entomology 40: 475-492.

Abstract: The biological control of the Winter Moth in North America, by the introduction of parasitic insects, is reviewed with the aim of identifying the common factors leading to successful control. These patterns are assessed in light of the large literature on the biology of the host insect and its natural enemies, both in the introduced populations and in endemic populations in Britain. Successful control has arisen from the combined effect of added mortality from the introduced agents and a suppression of the pest to the level where generalist predators already in the system regulate the Winter Moth at a new, low density.

Roland, J. and J.H. Myers. 1987. Improved insect performance from host-plant defoliation Winter Moth on oak and apple. Ecological Entomology 12 (4):409-414.

Abstract: 1. We test the hypothesis that defoliation has short-term and long-term negative effects on performance of Winter Moth *Operophtera brumata* L. on two species of food plants: Garry oak (*Quercus garryana* Dougl.) and apple (*Malus domestica* L.). 2. Pupal weight (and hence potential fecundity of females) decreased with increased defoliation in the current year on both tree species. 3. Pupal weight increased, however, with increased level of defoliation in the previous year. 4. Increased weight of pupae from larvae which had fed on previously defoliated trees may buffer population decline by increasing fecundity of moths in the next generation.

Tomalak, M. 2003. Biocontrol potential of entomopathognic nematodes against Winter Moths (*Operophtera brumata* and *O. fagata*) (Lepidoptera: Geometridae) infesting urban trees. Bicontrol Science and Technology 13(5): 517-527.

Abstract: Infectivity and biocontrol potential of entomopathogenic nematodes against Winter Moths (*Operophtera brumata* and *O. fagata*) pupating in the soil were examined in laboratory, semi-field and field conditions. A pilot experiment conducted in the field showed that *Steinernema feltiae* was completely ineffective against pupae of these moths in the soil. Subsequent laboratory tests revealed that none of the tested species (i.e. *S. feltiae, S. affinae, S. carpocapsae, Heterorhabditis megidis* and *H. bacteriophora*) could colonise the pupae, while mature larvae descending to the soil for pupation and prepupae were highly susceptible to nematode infection. No differences were observed between *O. brumata* and *O. fagata* in susceptibility to nematodes. In laboratory experiments *H. megidis* applied at 1.5×10^5 infective juveniles (IJ) m^{-2} infected almost 100% of insects exposed for 6 days in the soil. It was significantly more infective than *H. bacteriophora* (73-77%) and *Steinernema* species (29-50%). *H. megidis* was also highly effective in semi-field conditions when applied at an even lower dose, i.e. 10^5 m^{-2}. After a 45-day experiment, only 3% of insects descending for pupation survived in the soil pre-treated with this species. This was significantly less than in soil with *S. feltiae* (43%) and control treated with water only (59%). Very high efficacy of *H. megidis* and a relatively easy method for its field application through ground spraying gives some promise for environmentally safe and successful biological control of winter moths during their pupation in the soil. The low application rate required and recycling in the host could be additional advantages for economic and long lasting protection of high value trees, particularly those in urban parks and forests.

Other sources

Humble, L.M. and E.A. Allen. 2004. Alien Invaders: non-indigenous species in urban forests. 6th Canadian Urban Forest Conference October 19 -23, 2004. Kelowna, BC.

Abstract: Recent establishments of invasive insect pests across Canada have highlighted the threat that such incursions pose to the urban and natural forests of the country. The impacts of non-indigenous introductions generally first occur in urban environs, as a direct result of the importation of a wide range of commodities. Once established in the urban environments, pest populations can expand into the adjacent natural forests. One of the earliest introduced pests, beech bark disease, arrived in Halifax, NS in 1890; and has since spread across the range of beech in Canada and the northeastern United States. Dutch elm disease was first discovered in Quebec in 1945. Since then it has devastated the urban and native elms in the Maritimes and central Canada and is now present in Manitoba and Saskatchewan. Currently, eradication programs are underway in urban forests for three recently introduced wood-boring pests: brown spruce longhorn beetle in Halifax, NS; Asian longhorn beetle in Toronto and Vaughn, ON; and emerald ash borer in Windsor and Essex County, ON. British Columbia has maintained its gypsy moth free status through active eradication of incursions of the pest from eastern North America and Asia for more than 25 years. The likelihood of success of eradication programs against new incursions of invasive forest pests is greatly enhanced by early detection of any introduction. Because introduced forests pests first establish in urban forests and parks, the managers of these urban forests and trees can play a significant role in the early detection of invasive alien species. This role and the impacts of recent invasive introductions in urban forests are reviewed and Canadian and international strategies to prevent the influx of alien invasive species, to monitor for their presence, and attempts to control established populations are discussed.

Online sources

Berries Northwest. 2009. Pest Management Detail: Winter Moth / Bruce Spanworm in raspberries. In: Pest Management. www.berriesnw.com. Peerbolt Crop Management. Portland, OR.

Canadian Forest Service. May 27, 2010. Winter Moth. In: Insects and Diseases of Canada's Forests. http://imfc.cfl.scf.rncan.gc.ca/accueil-home-eng.html. Natural Resources Canada. Ottawa, ON.

Childs, R.D., D.C. Swanson and J. Elkington. 2009. The Winter Moth. UMass Extension. www.uri.edu/cels/ceoc/documents/wm_overview_09.pdf. United States Department of Agriculture. 4pp.

City of Victoria. November 19, 2008. Media Advisory: Tree Banding Helps Prevent Winter Moth Damage in Spring. In Press Room. www.victoria.ca/cityhall. The City of Victoria. Victoria, BC.

City of Victoria, Parks Division, Department of Parks, Recreation and Community Development. May 21, 2009. Winter Moth, *Operophtera brumata* – An Alien Invasive Species. www.victoria.ca/cityhall/pdfs/compar_prkipm_wntrmt2.pdf. City of Victoria, Victoria, BC.

Department of Conservation and Recreation Massachusetts. December 1, 2005. Pest Alert: Winter Moth. www.mass.gov/dcr/news/winter_moth.pdf. Department of Conservation and Recreation Massachusetts. Boston, MA.

Evans, S. and T. Murray. Winter Moth. In: The Ten Most Un-Wanted Pests. Lake Friendly Gardening: Tips for Homeowners Living in the lake Whatcom Watershed. http://lakewhatcom.wsu.edu/gardenkit/INDEX.HTML. Washington State university Cooperative Extension, Whatcom County Water Resources and the Lake Whatcom Water Management Program. Whatcom County, WA.

Forestry Practices Branch, Ministry of Forests and Range. August 24, 2009. Bruce Spanworm, *Operophtera bruceata* / Winter Moth, *Operophtera brumata.* In: Field Guide to Forest Damage in British Columbia. Heningham, J., T. Ebata, E. Allen, J. Westfall and A. Pollard (Eds.) March 2001, Second Edition, MOF/CFS Joint Publication Number 17. www.for.gov.bc.ca/hfp/publications/00198/index.htm. Forestry Practices Branch. Ministry of Forests and Range. Government of British Columbia. Victoria, BC.

Garry Oak Ecosystems Recovery Team. Oak Pests and Diseases. In Planting and Caring For Garry Oak Trees. In: Gardening and Restoration. www.goert.ca. Garry Oak Ecosystems Recovery Team. Victoria, BC.

Gilkeson, L.A. and R.W. Adams. 2000. Tree Bands for Winter Moths. In Chapter Three, Integrated Pest Management Manual for Landscape pests in British Columbia www.env.gov.bc.ca/epd/ipmp/publications/manuals/landscape_pests/toc.htm. British Columbia Ministry of Environment. Victoria, BC.

Massachusetts Introduced Pest Outreach Project. Winter Moth. In: Fact Sheets. www.massnrc.org/pests/index.htm. Massachusetts Dept. of Agricultural Resources and the UMass Extension Agriculture and Landscape Program. [Accessed February 8, 2011].

Murray, T. Winter Moth. In: Garden Friends or Foes. http://whatcom.wsu.edu/ag/homehort/pest/wintermoth.htm. [Accessed September 9, 2010].

New York Cooperative Agricultural Pest Survey. Winter Moth Pest Alert. In Fruit and Vegetable Invaders. New York State Department of Agriculture and Markets.Albany, NY. Available online: www.agmkt.state.ny.us/CAPS/pdf/Winter%20Moth%20Pest%20Alert.pdf. [Accessed September 23, 2010].

Ovsyannikova E.I., I.Ya. Grichanov. *Operophtera brumata* L. –Winter Moth. In: Pests. www.agroatlas.ru/en/. Agro Atlas: Interactive Agricultural Ecological Atlas of Russia and neighbouring Countries, Economic Plants and their Diseases, Pests and Weeds.

Russell Integrated Pest Management. Winter Moth. In: Pheromone Monitoring Systems.www.russellipm-agriculture.com/pheromoenmonitoringsystem.php?lang=en&KT_az=ALL Russell Integrated Pest Management. Flintshire, UK.

Story, M. June 2008. *Operophtera brumata* (Linnaeus, 1758) (Winter Moth). In: BioImages – Virtual Field-Guide. www.bioimages.org.uk/index.htm.

University of Connecticut Integrated Pest Management. 2009. A New Pest Concern in New England: Winter Moth Update 2009. www.hort.uconn.edu/ipm/general/biocntrl/wintermoth.htm.University of Connecticut Integrated Pest Management. Storrs, CT.