Warmer and wetter might not be better – Short review

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ABSTRACT: As the climate continues to change, gaps in our understanding of how the altered environment will affect forest hosts and their pathogens widen. In some areas pathogens thought to be present for centuries are changing their behaviour. Dothistroma needle blight caused by the fungus *Dothistroma septosporum* in northwest British Columbia (BC), Canada, is a good example. In this area both the pathogen and the host, lodgepole pine (*Pinus contorta* var. *latifolia*), are considered native species, but here *Dothistroma* has been responsible for killing mature host trees, which is unprecedented. A plausible link between warmer, wetter summers and directional climate change has been suggested as the primary driver. Those environmental conditions appear to be affecting the host/pathogen relationship for other diseases in the neighbouring central interior of BC including comandra blister rust (*Cronartium comandrae*). Disrupted host/pathogen relationships tend to favour the short-lived more adaptable pathogens rather than their long-lived hosts. These changes in forest health have not been well accounted for in fields of forest science that have been built on stability and predictability.

Keywords: climate change; *Cronartium comandrae*; *Dothistroma*; host/pathogen instability

Evidence of climate change and the role that humans play in it is all but incontrovertible (IPCC 2013). As this global process unfolds, our understanding of the behaviour of forest hosts and pathogens under changing environmental conditions must try to keep pace. This poses a significant challenge as we cannot rely on past experience to the extent we are accustomed, we are in a new world (Millar et al. 2007). Native forest pathogens with long established stable host-pathogen relationships appear to be acting in some areas as if they were invasive introduced alien species. The Dothistroma needle blight outbreak in northwest British Columbia, Canada, caused by the pathogen *Dothistroma septosporum* could be seen as an example of this (Welsh et al. 2009). Directional climate change as first suggested by Woods et al. (2005) continues to be the most plausible explanation for the apparent change in that pathogen's behaviour. The same environmental trends associated with the Dothistroma outbreak in British Columbia (BC), warmer and wetter summers, have been forecast to increase lodgepole pine productivity provided that seed sources are optimized (Wang et al. 2006). Such forecasts ignore biotic disturbance agents like Dothistroma needle blight and their impacts and presume that we can assist the movement of tree species populations to optimize their growth in isolation of these biological realities. Short-lived organisms, whether damaging insects or pathogenic fungi, can adapt to new environmental conditions far more quickly than their long-lived hosts (Harvell et al. 2002). One of the most sobering aspects of the *Dothistroma* example in northwest BC is that compared to the forecast changes to come both globally (IPCC 2013) and regionally (Walker, Sydneysmith 2008), the climate has not changed dramatically.

Increases in incidence and severity of a number of forest diseases over those from earlier records are comparatively obvious, despite relatively subtle changes in environmental conditions seen in long-term weather records for climate stations in BC (Anonymous 2002). The trend of increasing

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incidence and severity seen in Dothistroma needle blight also appears to be occurring for comandra blister rust (*Cronartium comandrae*) (Woods 2011), a canker causing the rust of lodgepole pine (Ziller 1974). Overnight minimum temperatures have been identified as having a critical influence on *Cronartium ribicola* on five needle pine (van Arsdel et al. 1956). Optimal environmental conditions for *Cronartium ribicola* spore production and germination are similar to those for *Cronartium comandrae* (Powell 1974). It thus seems logical given the similarities in life history (Mielke et al. 1968) that the increases in overnight minimum temperatures experienced in central BC could have a positive influence on the closely related pathogen *Cronartium comandrae*. A close relationship between comandra blister rust outbreaks and environmental factors has been well known for a considerable time (Krebill 1965).

Evidence of increases in comandra blister rust incidence in the central interior of BC can be found at both the stand and landscape level. A comandra blister rust resistance trial established in 2004 suffered infection rates of between 70% and close to 80% in two of the three trial installations over an eight-year period. Highly detailed assessments of these sites have shown three consecutive years of high infection in 2004, 2005 and 2006 (Reich, personal communication). Earlier reports of this pathogen in central BC suggested that the disease was uncommon, though capable of considerable damage where present (van der Kamp, Spence 1987). Comandra blister rust infections are reported to occur in wave years (Mielke et al. 1968) but three consecutive wave years of infection in this rust trial represent a possible change in disease behaviour from that observed elsewhere (Jacobi et al. 2002). The extent to which this phenomenon has played out on the larger landscape is not yet known but experiences like this cast doubt on the future health and productivity of lodgepole pine plantations in the region.

On the landscape scale, three surveys of 60 or more randomly selected juvenile lodgepole pine stands in the west central interior show an almost three-fold increase in combined hard pine rust incidence and a six-fold increase in the proportion of stands with rust incidence over 20% between two surveys conducted in the late 1990s and a subsequent survey of the same population in the late 2000s (Woods 2011). Had the landscape level incidence of comandra blister rust been as high in the past as it appears to be today, we might have planted less of the susceptible host species. Warmer and wetter conditions and their effect on forest pathogens are forcing forest managers to consider the assisted migration of species such as Douglas-fir (*Pseudotsuga menziesii*) and western larch (*Larix occidentalis*) that are ecologically suitable to the new environment and immune to comandra blister rust.

The warmer and wetter conditions in the central interior of BC represent a general trend in the important environmental drivers of foliar diseases and hard pine rusts. There are other biological disturbance agents that respond to extremes and it appears that the forests of central BC are also being challenged by these. A recent widespread occurrence of top dieback in lodgepole pine in the central interior may in part be linked to an abrupt (40°C) drop in temperature in the fall of 2010, following a drier than average summer. That combination of environmental conditions is considered a trigger for C*enangium ferruginosum* (Sinclair, Lyon 2005) and this opportunistic pathogen is believed to be at least in part responsible for the extent of top dieback in lodgepole pine in the western portion of BC's central interior. This example further emphasizes how an environmental change can drive biotic disturbances leading to unforeseen forest conditions in what we have considered a stable predictable forest management system.

Evidence of the combined impacts of abiotic (e.g. wind and snow damage) and biotic damage agents on managed stand productivity is accumulating (Woods et al. 2010; Woods, Coates 2013). It appears we are already in a new, less predictable regime in forest management driven by climate change and its direct and indirect impacts on disturbance agents (Dale et al. 2001). Just as forest genetics forecasts of a potential for improved growth under a changing climate (Wang et al. 2006) appear optimistic, so also do growth and yield model projections that similarly ignore or overlook damage agents. The fundamental tenets at the basis of growth and yield models were developed prior to the knowledge of the impacts of biotic damage agents on managed stand productivity and certainly before knowledge of climate change (Woods, Coates 2013). Sustainable forest management is one of the most effective means of mitigating climate change (Nabuurs et al. 2007) but to achieve any success there we must manage forests in a more holistic sense incorporating the influence of biotic and abiotic disturbances. A greater emphasis must be placed on monitoring forest conditions and on incorporating that monitoring information into more flexible, adaptable managed stand growth models.

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