Western Forest Diseases and Climate Relations: General Considerations, Dwarf Mistletoe and Stem Rusts

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Abstract

This is a preliminary, draft outline for organizing information on the relation of climate to western forest diseases. The question is how to assess the threat of these diseases under a regime of climate change. Although forest diseases are often important, assessment of disease–climate relations is a challenging problem due to the multiple values at risk and the complexity of these systems. Several approaches are described and illustrated with examples for mistletoes and stem rust. Only a sampling of examples is given to illustrate a variety of concepts; many additional examples are to be found in the literature. Knowledge gaps are identified.

I. FOREST DISEASE–CLIMATE RELATIONS ARE IMPORTANT BUT CONFOUNDING

A. At times and places, forest diseases are important forest ecosystem drivers.

B. The hosts, pathogens, and associated organisms have complex relations with the atmospheric environment represented by climate and weather.

1. Climate refers to averages and regimes…
2. Extreme weather events (rare or occasional) are very influential.
3. Primary factors for consideration of forest pathogens are heat and moisture.
4. Secondary factors include carbon dioxide concentration, ozone, radiation, etc.
5. Direct effects influence the epidemiology (dispersal and survival) of the pathogen, e.g., high temperature lethal to pathogen spores during dispersal.
6. Some indirect effects are mediated by host, e.g., on host physiology with changes in balance of growth and defense.
7. Other indirect effects are mediated by associated organism, e.g., changes in the abundance of vectors natural enemies, etc
8. Effects and consequences may be positive or negative and with or without feedback
9. Expression may be reduction in disease or emergence of latent pathogens (shift to pathogenic behavior).

C. Forest diseases are classified as abiotic or biotic.

1. Abiotic diseases are often decline syndromes with multiple and complex predisposition and inciting factors.
2. Biotic diseases involve a host and pathogen in a conducive environment.
   a. Vectors, symbionts, or collateral species usually also associated or affected.
   b. Host and pathogen have each their own genetics and distribution (constraints, metapopulation, interaction networks).

II. VALUES AT RISK ARE ECOLOGICAL, SOCIAL AND ECONOMIC

A. Impacts range from direct, rapid and obvious to indirect, cumulative, subtitle, and cascading.

B. Quantifiable measures of more direct impacts include estimates of disease losses, of management/control costs, and area at risk.

C. Effects of more indirect nature include altered fire regime, nutrient cycling, hydrology, and energy budgets and changes in abundance or survival of native species and their genetic integrity.

III. FOREST DISEASE–CLIMATE RELATIONS ARE EMBEDDED IN COMPLEX SYSTEMS

Paradigm determines what is considered relevant and how study is conducted. Older observations and literature may be useful but need careful re-interpretation and re-phrasing to be relevant for the present question.

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1. 20th Century paradigms pervade much of the older literature.
   a. Climatic, climax vegetation and plant associations are seen as important; disturbance is considered a transient deviation.
   b. The historic range of variability assumed to provide an adequate reference frame.
   c. Evolutionary time is thought to run slower than ecological time.
   d. The forest pathology perspective is that weakened, understory trees and poorly managed forests deteriorate and decline over time because of numerous insults from biotic and abiotic agents.
   e. The defined purpose of forest pathology is to reduce immediate economic losses.
2. 21st Century paradigms appear infrequently in older literature and more commonly in recent literature.
   a. Disturbance and recovery is seen as pervasive; long persisting associations are rare.
   b. Rapid change and regime shifts are expected.
   c. Especially at population levels which become a greater focus genetic/phenotypic change is seen over generational times and as responses to ecological events.
   d. The forest pathology perspective is for declines and disease to function in reference to stabilizing selection—healthy dominant trees in the forest (the survivors) are selectively killed by a combination of specifically ordered factors.
   e. The contribution of forest pathology is for sustaining desirable ecosystems.

B. Complex systems are characterized by nonlinear behavior and hierarchical structure.
   1. Criticality provides a potential link between spatial pattern and phase shift.
   2. Concepts of scale and hierarchy give a framework for describing complex systems in which different processes dominate at different scales.
      a. Scale topics include: translation from regional climate to a topographic mesoclimate, mapping spatial gradients and quantifying temporal rates of change.
      b. Hierarchical topics help explain cross-scale interactions as fast, bottom-up mechanisms and slow, top-down constraints.
   3. Feedbacks refer to connections which amplify or dampen dynamics.
   4. Emergent properties/synergism are not predicted because the whole acts as more than sum of parts.

C. The study of forest disease–climate relations for assessing potential direct and indirect effects on future ecosystems benefits complexity science.
   1. Only broad trends may be foreseeable.
      a. ID of specific, controlling factor and consequent, predictable response is unlikely
      b. Plural approaches and perspectives are needed.
   2. Species respond individually; network analysis may prove useful.
   3. Present communities are transient; a biogeography viewpoint of system states (distribution and abundance) and dynamics processes (migration, extinction, and evolution) is practical.
   4. Adaptive plasticity and systemic-induced resistance may affect host balance between growth and defense.
   5. Novel abiotic–biotic interactions under climate change are to be expected.
   6. Disturbance induces heterogeneity at multiple scales.
   7. Identifying alternative states (desirable or undesirable) and vulnerability to regime shift are goals.
   8. Biodiversity functions in ecosystem persistence.
   9. Slow, higher-level, larger-scale ecosystem processes constrain dynamics at faster, smaller-scale, lower levels.
   10. A focus on re-organization after disturbance/shift should consider:
      a. model action (disease type)
      b. pathogen virulence, aggressiveness, and host range
      c. host importance, uniqueness, and phytosociology.

IV. MULTIPLE APPROACHES ARE AVAILABLE AS OBSERVATION SOURCES AND INSPIRATION FOR HYPOTHESES.

A. Paleoecology provides an alternative, temporal perspective of different climates and communities.
B. Biogeography and invasive biology provide spatial perspectives on ecological and evolutionary processes

with emphasis on population, species, and community levels.

1. Invasive biology is a model for emergent diseases (new climate like a new habitat); both describe series of steps (dispersal, establishment, lag, spread, replacement/assimilation).
    a. There does appear to be a link between life history traits and invasiveness (statistical evidence in support).
    b. The importance of phenotypic plasticity, habitat difference (rate of change), and genetic variation are mostly unknown at this time.
    c. Lag phase processes involve adaptive evolution or sorting of adaptive genotypes.
    d. Dispersal and reproduction determine spread, persistence, and abundance of invasive/emergent.
    e. Community dynamics after emergence (impacts, feedbacks) determine the consequences.

C. Fundamental biology as epidemiology, ecophysiology, phytopathology, genetics, and other disciplines provide a mechanistic perspective with emphasis on life histories and pathogen–host interactions.
    1. Life histories, pathogen–host interactions, and ecology are core subjects.
    2. Information on variability and constraint (e.g., optimal and tolerable temperature ranges) are core data.

D. Synthesis of information involves the organization and presentation of information for addressing specific issues.
    1. Climate mapping is useful but requires proper interpretation.
    2. Modeling is very useful but has limitations. For example, caution in predicting forest dieback from growth models arises from several shortcomings.
        a. Tree growth is based on the realized rather than the fundamental niche.
        b. Life spans of trees in the models are too low.
        c. Vegetative reproduction is not incorporated.
        d. Tolerance of climatic fluctuations is given inadequate attention.
        e. The unique niche of fire-tolerant species is not considered.
        f. The protected position of species growing under unique edaphic conditions is not included.

V. DWARF MISTLETOES (*ARCEUTHOBIUM*) ARE DAMAGING AERIAL PARASITES OF CONIFERS.

A. The paleoecology record of pollen and microfossils of mistletoes is long and relatively rich.
    1. The presence of lodgepole pine dwarf mistletoe is a as mean annual temperature marker.
    2. Mistletoe distributions have changed over eons.

B. The biogeography of mistletoes is relative well documented.
    1. An example from historical biogeography is the speculation that favorable climate in Europe for mistletoe contributed to its increase and destruction of European forest
    2. Mistletoe elevational distribution more restricted than that of host
    3. Ponderosa pine mistletoe is absent in Black Hills but host is susceptible.
    4. On South Rim of Grand Canyon, distribution of southwestern dwarf mistletoe near the rim is due to either climate gradient or recent introduction history.
    5. The distributions and associations with site and stand factors is known for many species.
        a. Inferences are made that direct climate effects, host condition, and mistletoe capability are responsible
        b. More southwestern dwarf mistletoe is observed on ridges than slopes than bottoms but no difference observed in same study for Douglas-fir dwarf mistletoe.

C. There is a large body of science on the fundamental biology of mistletoes.
    1. Information is weakest in genetics but there are some relevant observations.
        a. By inference from contrasts of pinyon-juniper systems on different soils, stressed-environments may provide a reserve of more stress-tolerant genotypes
        b. Beyond species immunity, little known of differential, resistance with a genetic basis (not a gene-for-gene system).
    2. Life history focuses on epidemiology and ecophysiology.
        a. Mistletoes are perennial, long-lived, slow reproducing with moderately abundant seeds and short dispersal distance.

b. Response to temperature varies by species; examples are
   i. extreme cold lethal, ice-nucleation/undercooling
   ii. dormancy and chemical inhibitor on germination
   iii. shoot growth related to temperature (+).
c. Rain/snow effect seeds in multiple ways, such as
   i. rain moves seeds to safe sites
   ii. heavy storms can remove seeds (not protected under snow).
d. Light effects mistletoe seed germination and shoot production.
e. Greater host vigor can result in great mistletoe shoot growth and reproduction..
f. High C02 may inhibit germination.
g. Pollination is by entomophily and anemophily, therefore
   i. cold and wet may reduce insect visitation
   ii. but is reproduction pollen limited?

3. Host-pathogen interactions determine disease progress.
   a. Rapid height growth and physiological vigor of host affects mistletoe increase (complex +/- feedback).
   b. Severe mistletoe infestation increases host vulnerability to drought, bark beetles, and other diseases but killing host eliminates the infection.
   c. Host density and non-host interception affect spread.
   d. Historical increase in seral species may have promoted mistletoe abundance and distribution.
   e. Host-mistletoe water relations are key and well studied.
   f. Mistletoe-infected trees may have reduced root systems.
4. Ecology and community interactions influence disease and impacts.
   a. There are strong, bi-directional fire-mistletoe interactions.
   b. The linkage with bark beetles varies by host-beetle combination.
   c. Stem canker fungi, foliage herbivores, mycorrhiza, and various tritrophic interactions also involved.
   d. The relation of mistletoe infection and severity with drought is often cited.

D. Both distribution and forest-stand simulation models have been developed for many mistletoe species.
   1. The Mark-Hawksworth model for southwestern dwarf mistletoe is based on climate.
   2. The Robinson-Geils epidemiological model is linked to FVS and TASS.
   3. Various distribution/severity models are based on plant association.

VI. STEM RUST OF PINE (*CRONARTIUM*) ARE AERIALLY-DISPERSED FUNGAL PATHOGENS.

A. The fossil record for fungi is meager but phylogeography promises to provide a long-term, Evolutionary perspective.

B. The biogeography of stem rusts is relatively well studied but could benefit from additional synthesis.
   1. The lack of apparent climate signal for white pine blister rust in BC may indicate it's all-favorable there.
   2. The spread of white pine blister rust into regions formerly considered unfavorable indicates either
      a. greater adaptability than recognized b. more microsites favorable that thought?
   3. Yellowstone region was described as too dry and too cold for severe white pine blister rust.
   4. Observed reduction in white pine blister rust near smelter indicate flume gases may affect rust directly or through effect on needle retention.
   5. Provenance and screening tests reveal host population differences.
   6. Several years of extreme cold purged ponderosa pine population of comandra blister rust at Mink Creek, Idaho.

C. There is a large body of science on the fundamental biology of stem rusts.
   1. Information is moderately extensive in genetics.
      a. Selection and resistance are related.
      b. There is a concern that selection for rust resistance resulted in decrease in cold hardiness.
   2. Life history focuses on epidemiology and ecophysiology.
      a. Stem rust life cycle includes alternating between annual host and perennial host. Although stem rust

are not especially long-lived, potentially, populations an expand rapidly with large number of spores dispersed at scales from meters to mega-meters.

b. Strong environmental effects on rate of development (spore development, dispersal, germination) are due to effects of
    i. temperature
    ii. humidity
    iii. air flow (local and synoptic)
    iv. as well studied in western gall rust, comandra blister rust, white pine blister rust.
c. Wave year phenomena demonstrates importance of and sensitivity due to weather, especially that:
    i. regional climate and annual/monthly statistics may not be sufficient
    ii. hot and dry weather may decrease infection by effect on rust and on defoliation of alternate host
d. Loss of uredinial stage for stalactiform blister rust observed in dry regions where spread on repeating host is not climatically favorable.

3. Host-pathogen interactions determine disease progress.
    a. Infection is through open stomates so whatever affects stomates affects infection.
    b. Foliage susceptibility differs over time and age.
4. Ecology and community interactions influence disease and impacts.
    a. Western gall rust and terminal weevil are associated.
    b. Spermatization is insect mediated.
    c. Various insects and fungi are associated with cankers and host necrosis, but their importance is variable and disputed.
    d. Rust trees may provide habitat for non-outbreak bark beetles.
    e. The spatial connection of alternate host populations is important.
    f. Nearby sites may have very different microclimates.
    g. Comandra blister rust outbreak was postulated as result of increase in comandra not change in climate, but this assertion has also been refuted.
    h. Lodgepole pine severely cankered by comandra blister rust have lower sugar levels than non-cankered trees which may be related to susceptibility to mountain pine beetle.

D. Hazard models and epidemiological simulation models are developed for several stem rusts.
    1. Stalactiform blister rust distribution is predicted from elevation/habitat type.
    2. Western gall rust incidence is related to topographic position and elevation.
    3. Comandra blister rust is related to weather and site factors.
    4. White pine blister rust predicted for many regions, scales, approaches. For example, the McDonald model is used to assess differences in epidemiology under contrasting climates, northern Idaho and southern California.
    5. The TASS model used to assess volume loss of rusts of lodgepole pine.

VII. KNOWLEDGE GAPS AFFECT THE ABILITY OF SCIENCE-BASED MANAGEMENT TO ASSESS AND MITIGATE THREATS.

A. The nature of threat assessment and mitigation of forest diseases and their changes under future climates require adaptive ecosystem management, element of which are:
    1. Integration, communication, and uncertain decision-making in multiple, biased environments
    2. Long-term, ecosystem-wide strategy rather than a tactical approach focused on battling individual, emerging disease
    3. Anticipating interactions between emerging diseases and other global change processes
    4. Distributed information systems that deliver information on risks, identification, and response strategies.
B. Multiple perspectives are needed from global to site-specific scales, including:
    1. Global assessment methodologies
    2. Integrating invasive species/emergent diseases into sustainable forestry frameworks such as the Montreal Process and forest certification programs
    3. Developing suitable approaches for ecosystem and landscape management.

C. Surveillance and monitoring are key elements for effective control that would benefit from improved technologies, especially:
   1. Baseline conditions (taxonomic-genetic identification and georeference)
   2. Advancing technologies for molecular identification, expert systems, and remote sensing
   3. Improved cost estimates to inform choices about international trade and pest suppression efforts.
D. Several examples illustrate specific needs and concerns.
   1. Whether assisted migration is required or prudent depends on:
      a. Estimation and monitoring of species distributions
      b. Biogeographical modeling
      c. Community interactions
      d. Long-distance dispersal
      e. Genetic diversity.
   2. BC is very concerned over potential maladaptation in forest tree planting using seed zone and standards that no longer match the current environment.