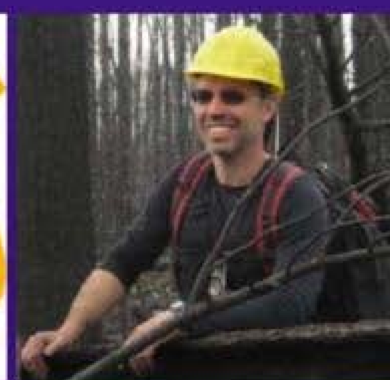
Research update on eastern spruce budworm: insights from a decade-long Canada-USA collaboration

Dr. Brian Sturtevant



Dr. Barry J. Cooke

Ministry of Natural Resources

Canadian
Forest
Service

Forest Health Session
Thunder Bay
March 22, 2017

Berryman (1986)

TABLE 4.3
Key to the Outbreak Classes

Class	Outbreak characteristics	Outbreak Class
1a	Spread out from local epicenters to cover large areas of forest and usually last for several to many insect generations.	*Eruptions*
1b	Do not spread far from their points of origin and are associated with particular sites or major disturbances, but the latter always subside when the environment returns to normal.	*Gradients*
2a	Go through a single pulselike cycle at any one place, often being terminated by food depletion, host-defensive reactions, or natural enemies.	
2b	Persist at high densities for several to many years at any one location, and host plants only die after many years of attack if at all (Fig. 4.12c_4).	*Sustained eruption*
3a	Occur at regular intervals, often 8–11 years apart, and never cause severe or widespread mortality to the host plant population (Fig. 4.12c_3).	*Cyclical eruption*
3b	Occur at irregular intervals and often cause severe and rapid mortality to the host plant population or are quickly terminated by natural enemies (Fig. 4.12c_1).	*Pulse eruption*
4a	Occur at irregular intervals following major environmental disturbances or are permanently associated with particular site and/or stand conditions.	
4b	Occur at regular intervals, usually every 8–11 years, rarely cause extensive morality to the host plant population, are often associated with particular site and/or stand conditions, and are usually terminated by host-defensive responses or natural enemies (Fig. 4.12b).	*Cyclic gradient*
5a	Occur more or less continuously on particular sites and/or stands (Fig. 4.12a).	*Sustained gradient*
5b	Occur at irregular intervals, following major environmental disturbances or outbreaks of other organisms and subside soon after the environment returns to normal.	*Pulse gradient*

Berryman (1986)

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4b	Occur at regular intervals, usually every 8–11 years, rarely cause extensive morality to the host plant population, are often associated with particular site and/or stand conditions, and are usually terminated by host-defensive responses or natural enemies (Fig. 4.12b).	*Cyclic gradient*
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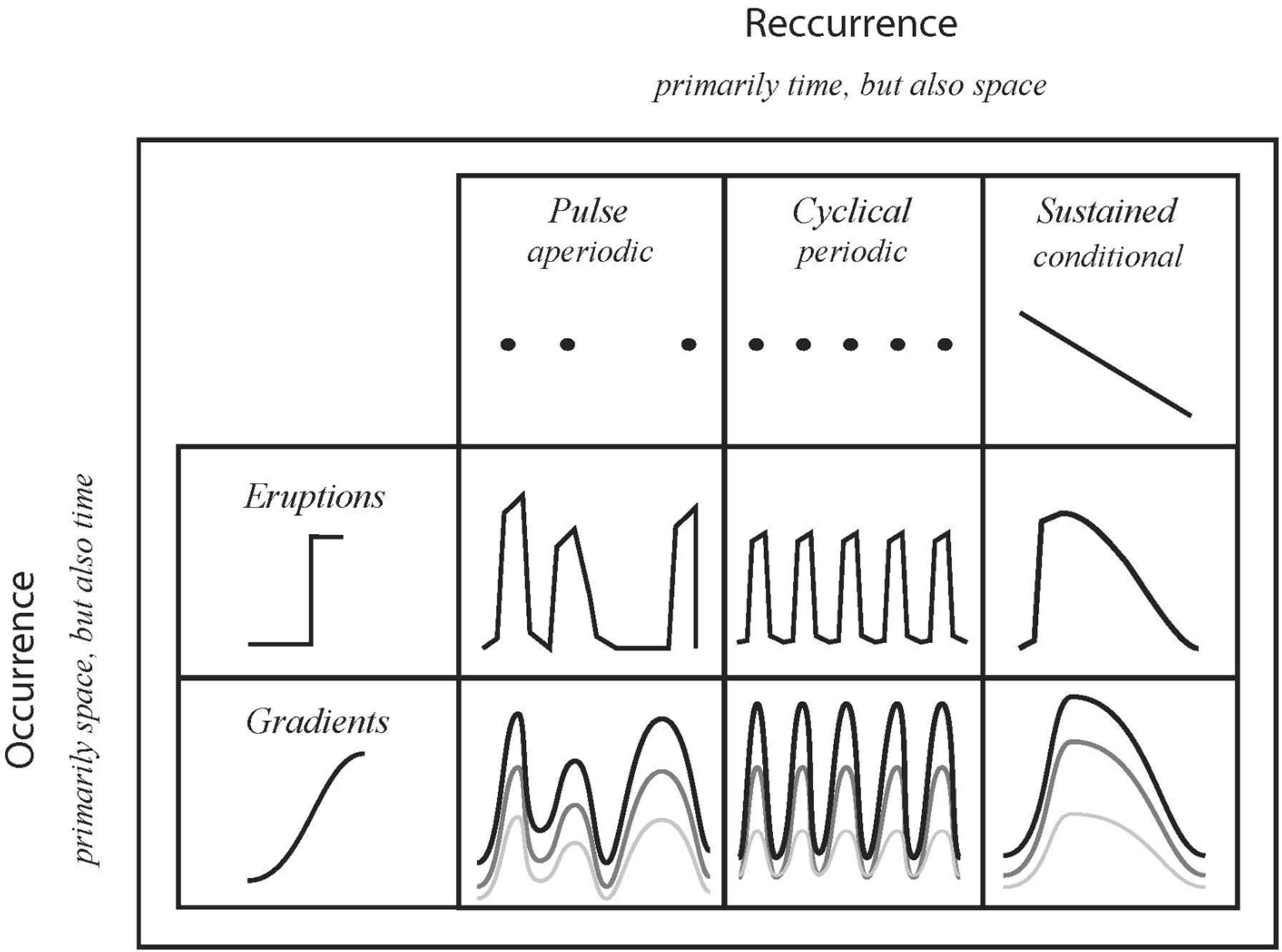
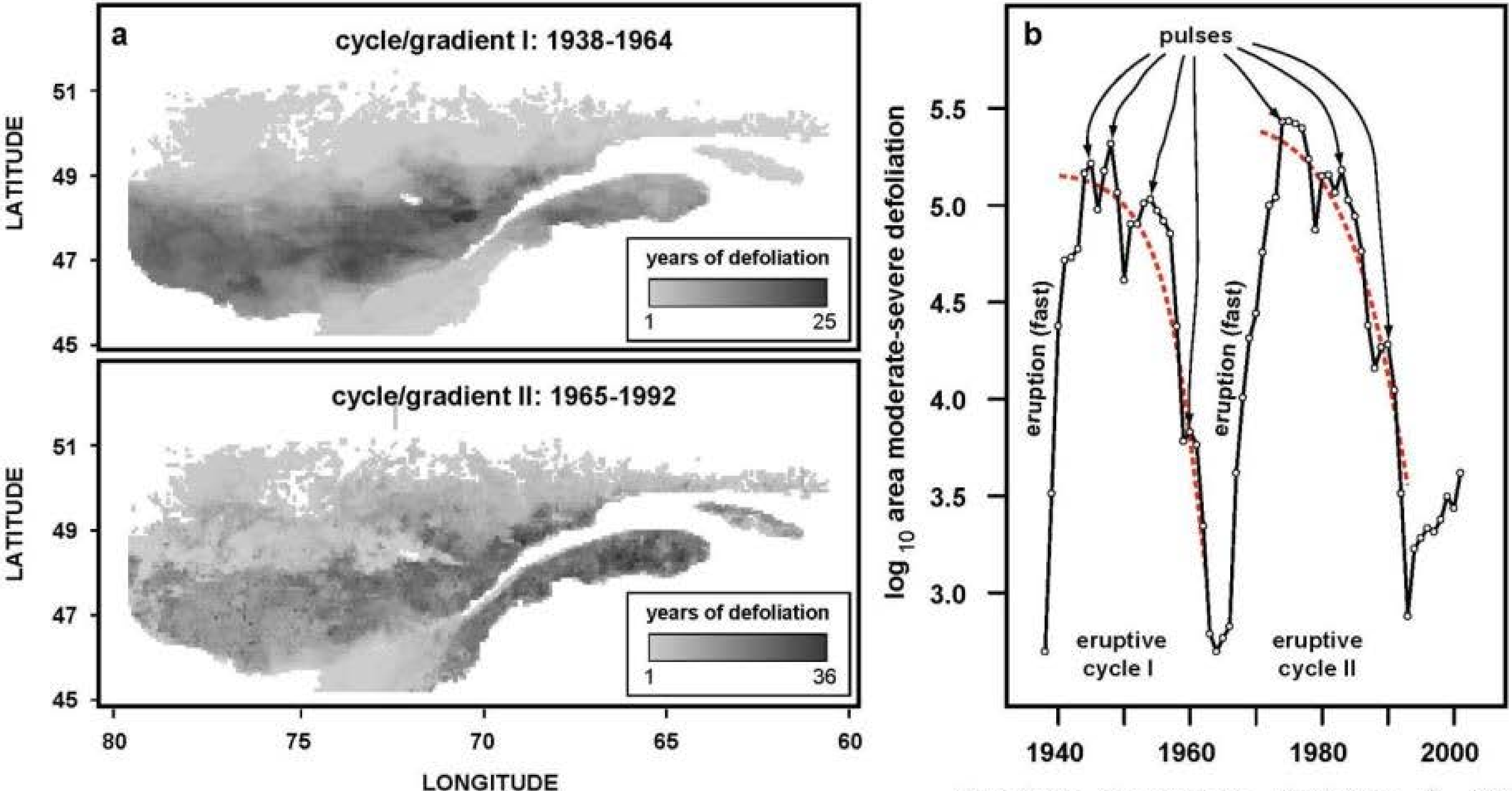
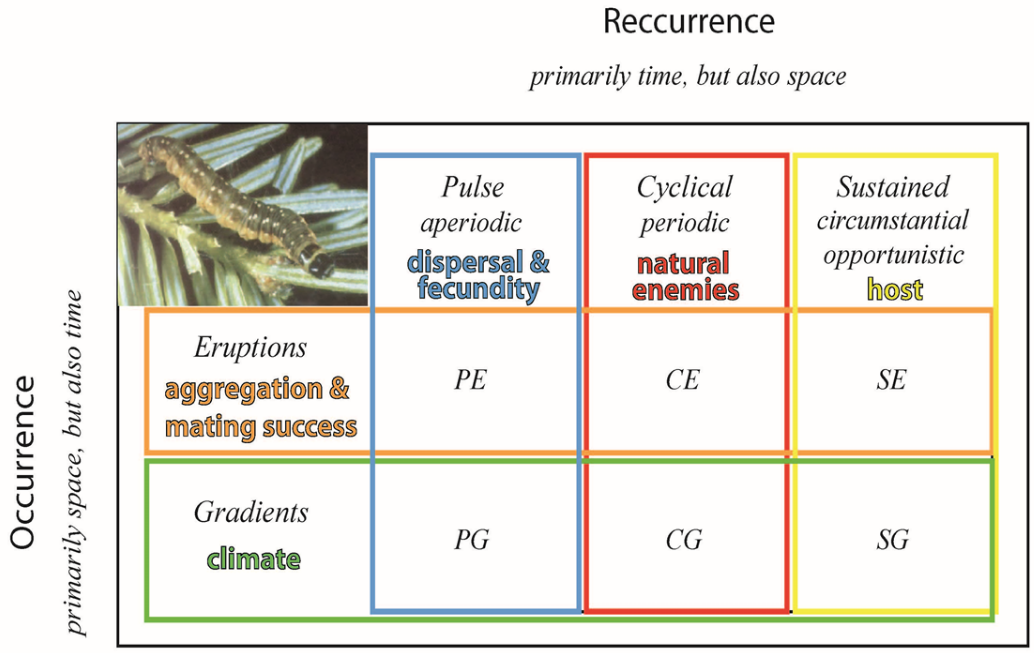
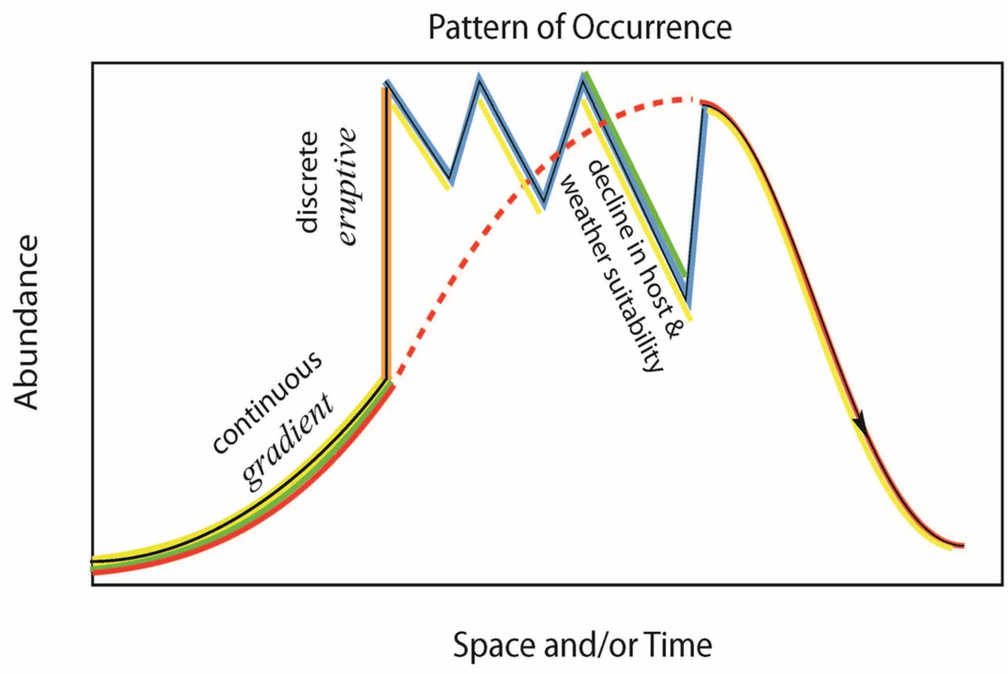

Reccurrence
primarily time, but also space
Pulse
aperiodic
Cyclical
periodic
Sustained
conditional
Eruptions
Gradients
Occurrence
primarily space, but also time



Kneeshaw, Sturtevant, Cooke et al. 2015


Reccurrence
primarily time, but also space
Pulse
aperiodic
dispersal & fecundity
Cyclical
periodic
natural enemies
Sustained
circumstantial
opportunistic
host
Occurrence
primarily space, but also time
Eruptions
aggregation & mating success
PE
CE
SE
Gradients
climate
PG
CG
SG

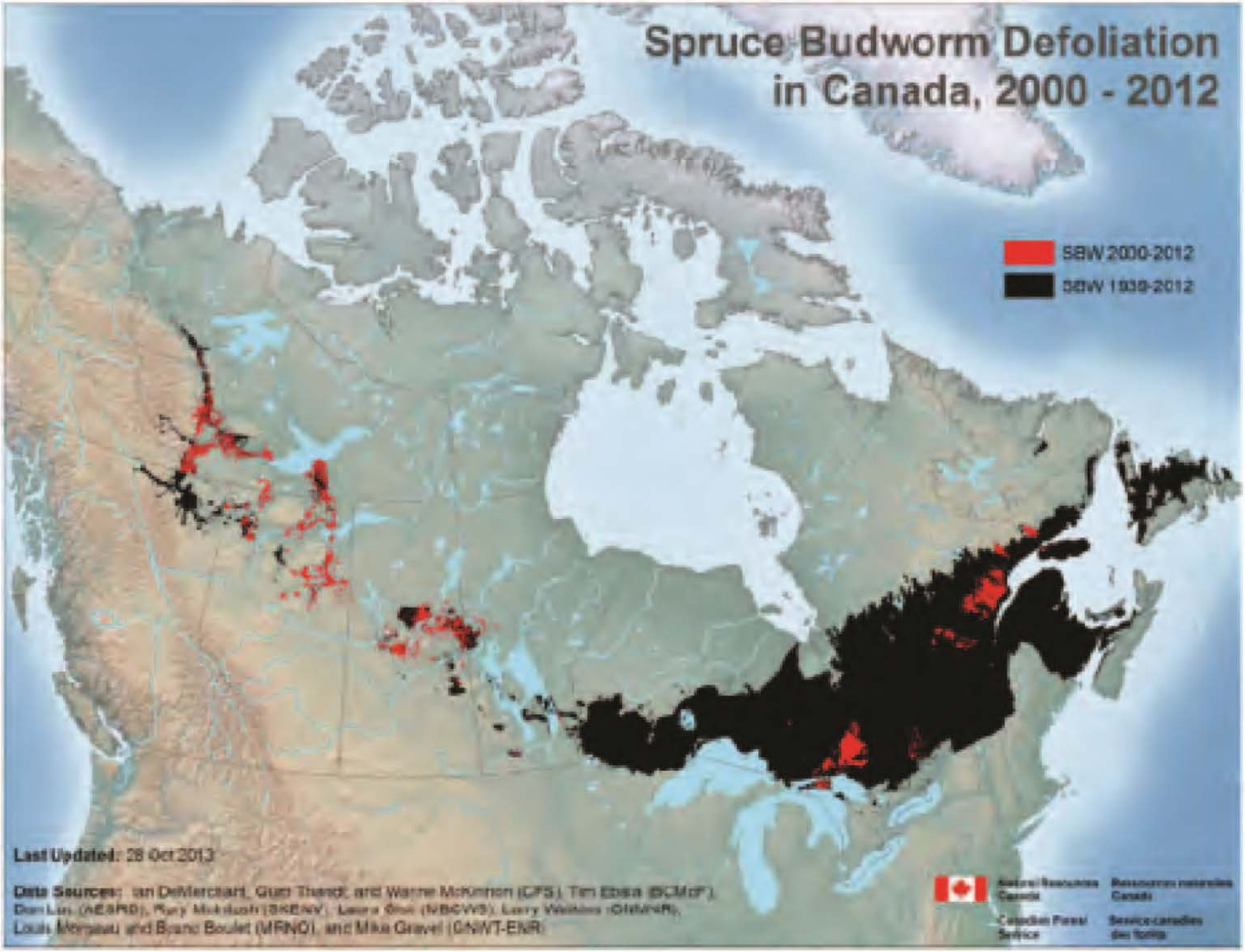

Pattern of Occurrence
Abundance
discrete
eruptive
decline in host & weather suitability
continuous
gradient
Space and/or Time

WHO WANTS TO BE A

BUDWORM MODELER

Which *one* phrase best describes patterns of outbreaks of the spruce budworm in the boreal forest?

- **A:** cyclic
- **B:** eruptive
- **C:** gradient
- **D:** pulse


Spruce Budworm Defoliation
in Canada, 2000 - 2012
SBW 2000-2012
SBW 1938-2012
Last Updated: 28 Oct 2013
Data Sources:

What next?

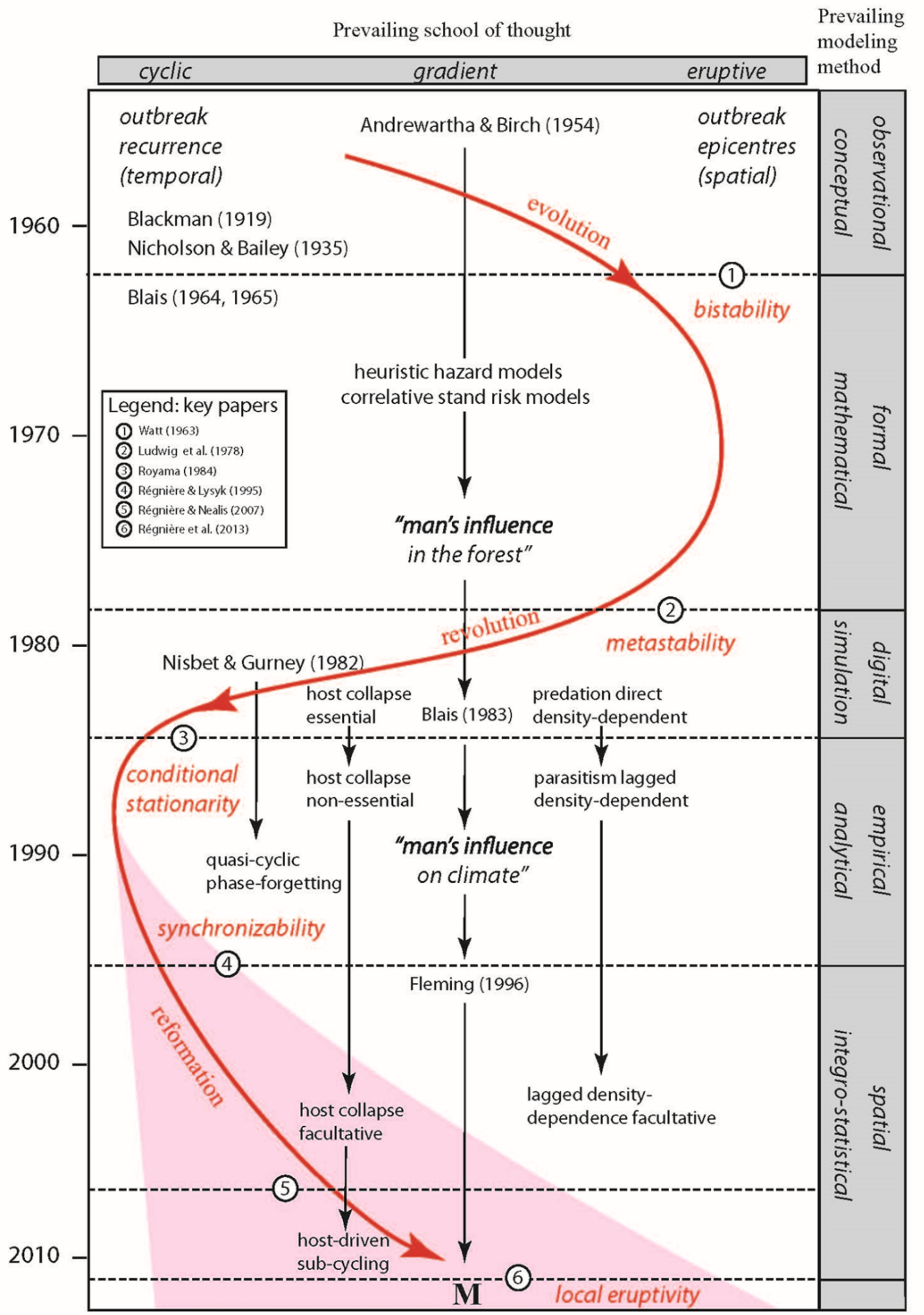
Spruce Budworm Defoliation in Canada, 2000 - 2012
SBW 2000-2012
SBW 1938-2012
Last Updated: 28 Oct 2013
Data Sources:

What next?

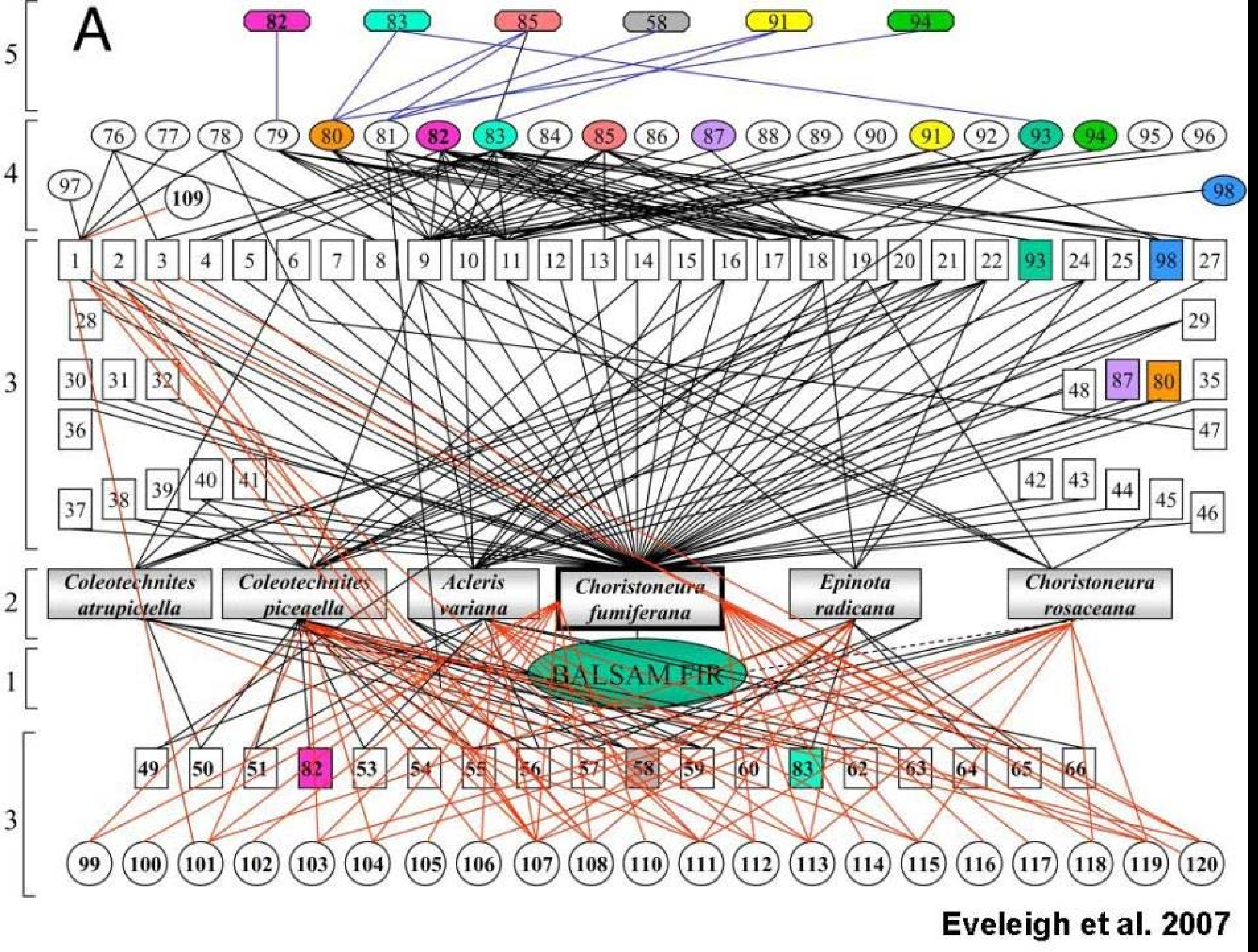
Climate?

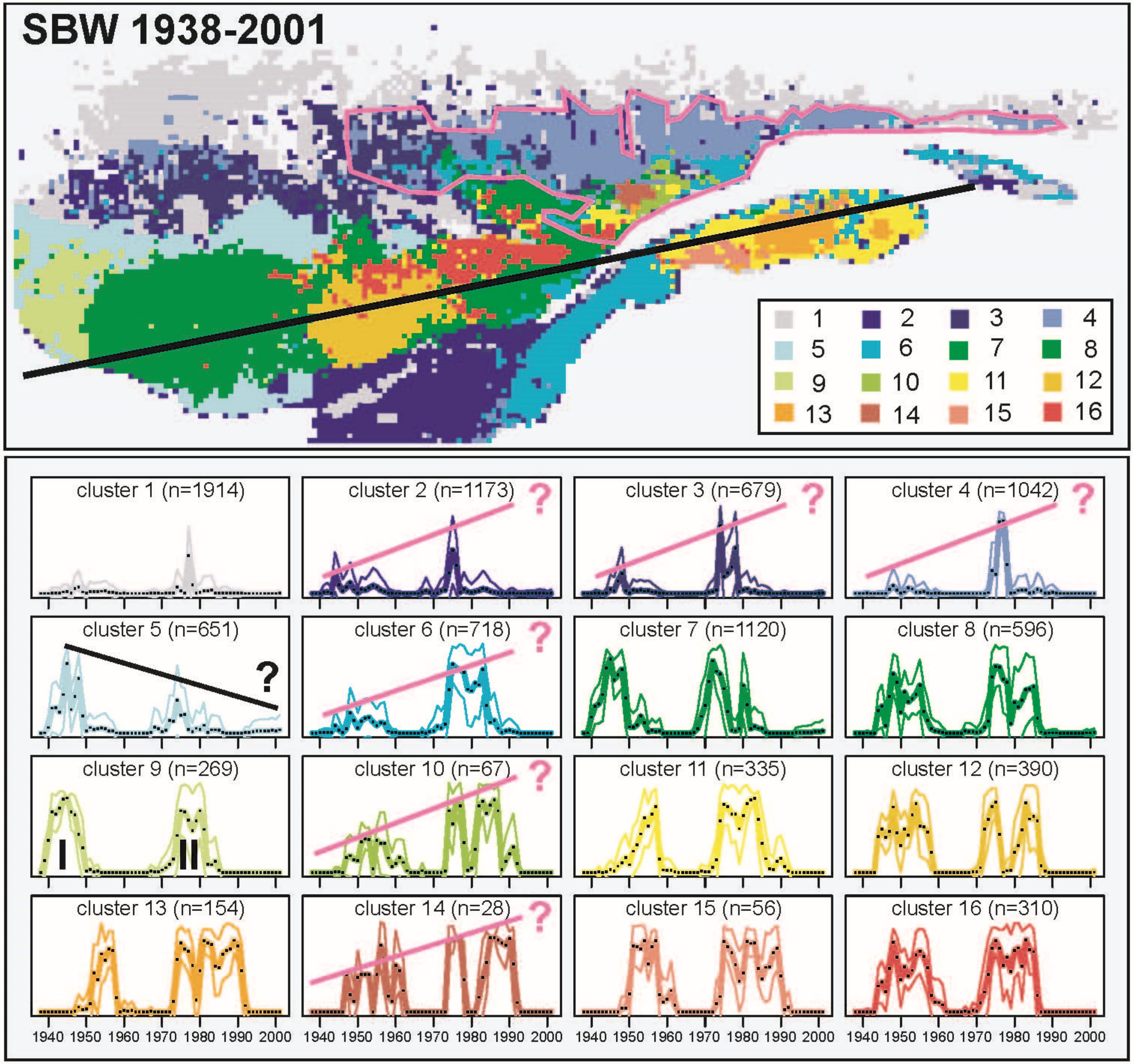
Forest?

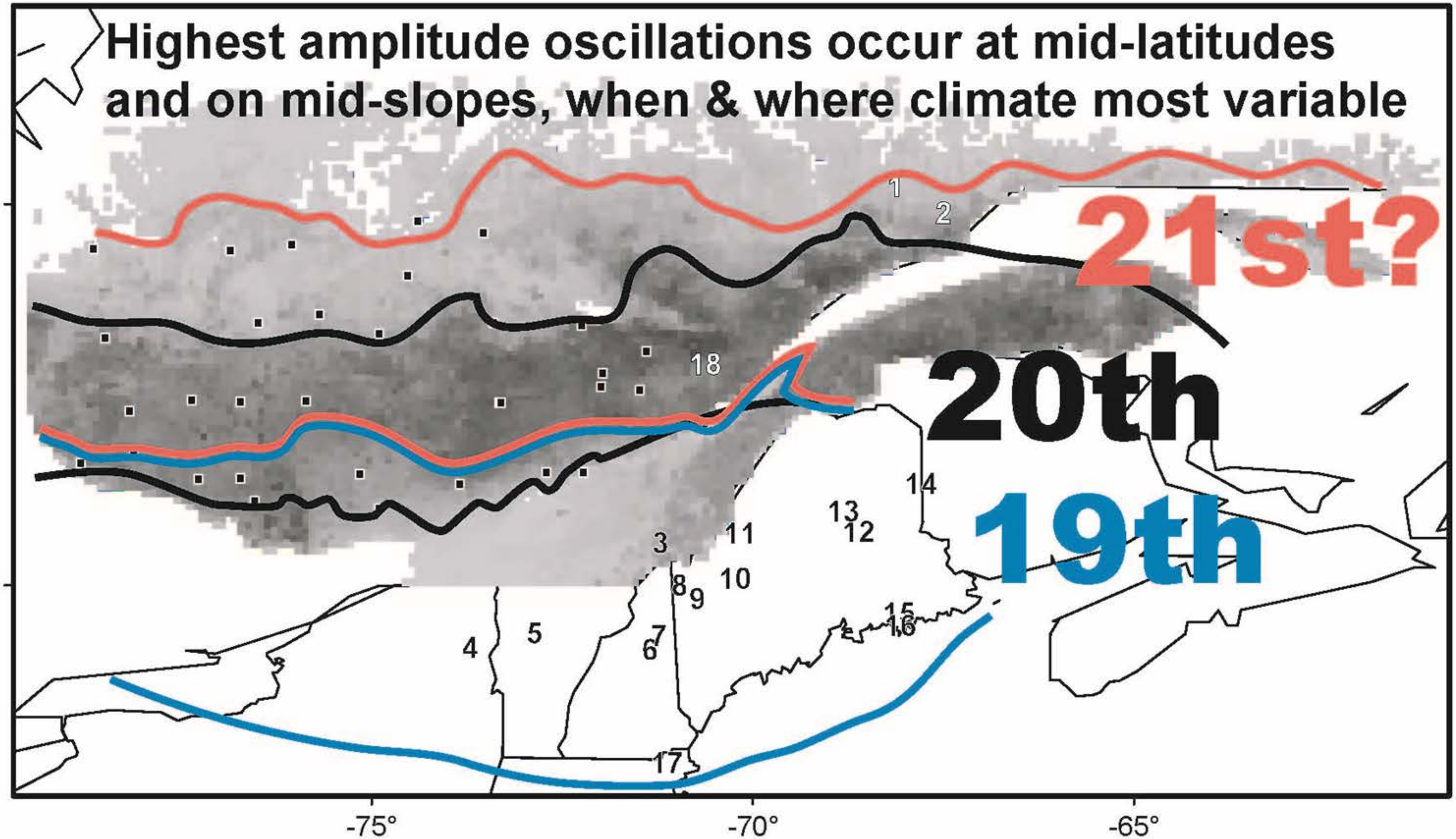
Natural enemies?

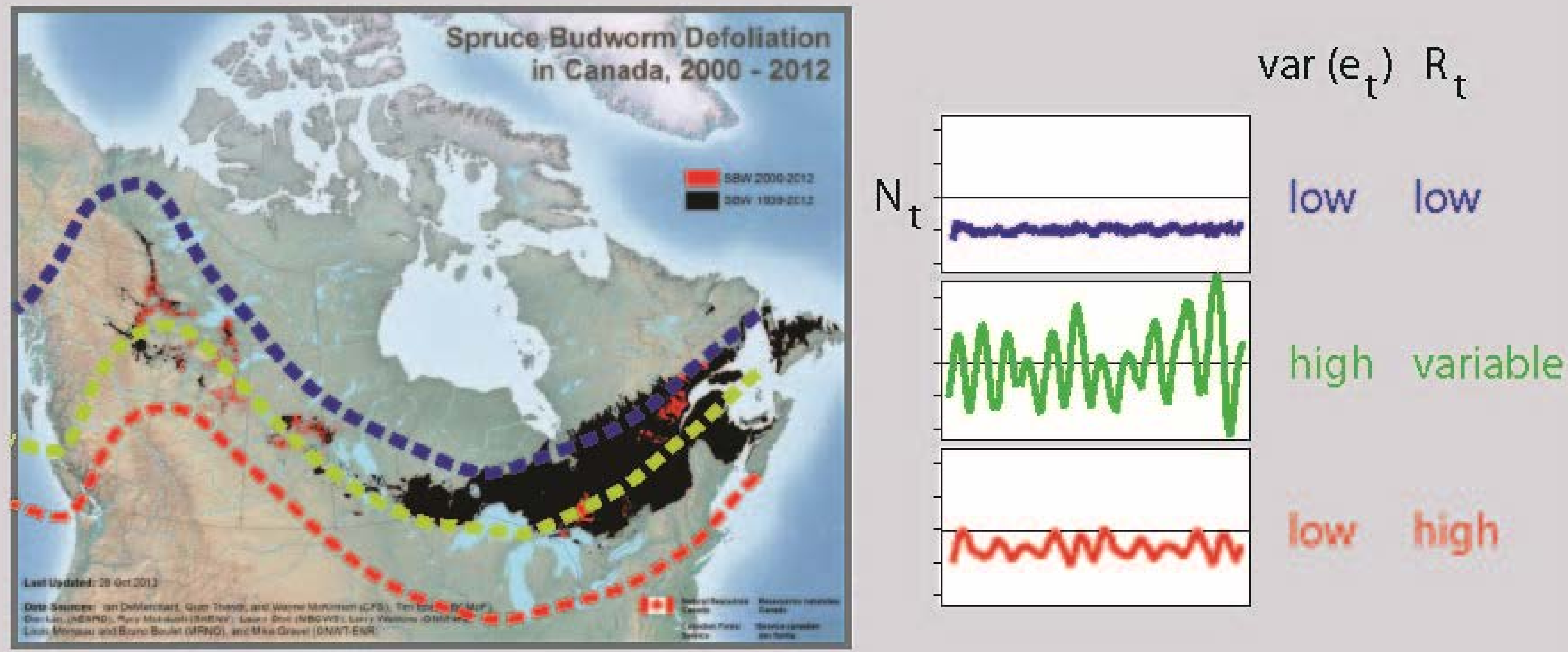


Toward a modern synthesis (M): trends in modeling methodology and prevailing wisdom over time.


A
5
4
3
2
1
3
Coleotechnites atrupictella
Coleotechnites piceaella
Acleris variana
Choristoneura fumiferana
Epinota radicana
Choristoneura rosaceana
BALSAM FIR
Eveleigh et al. 2007


SBW 1938-2001
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
cluster 1 (n=1914)
cluster 2 (n=1173)
cluster 3 (n=679)
cluster 4 (n=1042)
cluster 5 (n=651)
cluster 6 (n=718)
cluster 7 (n=1120)
cluster 8 (n=596)
cluster 9 (n=269)
cluster 10 (n=67)
cluster 11 (n=335)
cluster 12 (n=390)
cluster 13 (n=154)
cluster 14 (n=28)
cluster 15 (n=56)
cluster 16 (n=310)
I
II
?
1940 1950 1960 1970 1980 1990 2000

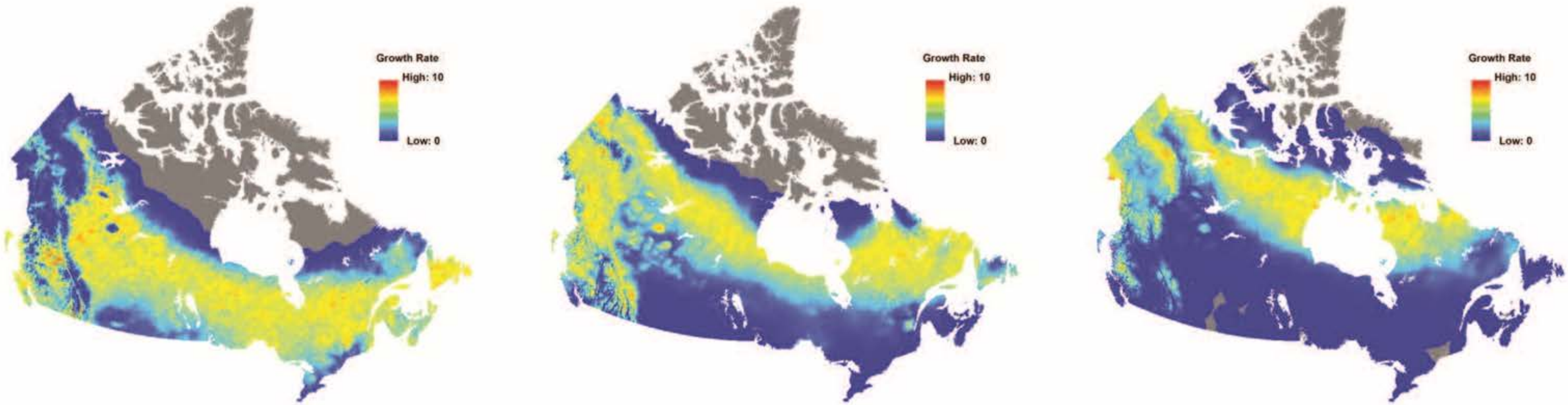

Highest amplitude oscillations occur at mid-latitudes
and on mid-slopes, when & where climate most variable
21st?
20th
19th
50°
45°
-75°
-70°
-65°
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18



Spruce Budworm Defoliation
in Canada, 2000 - 2012
var (e_t) R_t
N_t
low low
high variable
low high

Spruce Budworm Relative Growth Rates

Climate Change Scenario RCP 8.5



1961-1990 **2041-2070** **2071-2100**

* generated using BioSIM-SBW Régnière et al. (2012)

Spruce Budworm Relative Growth Rates

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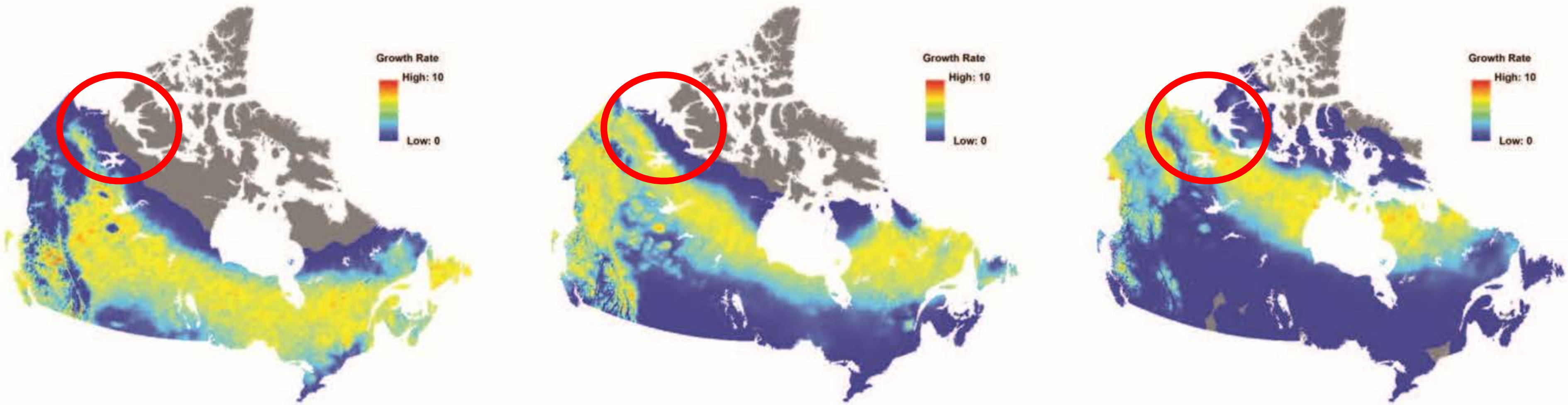
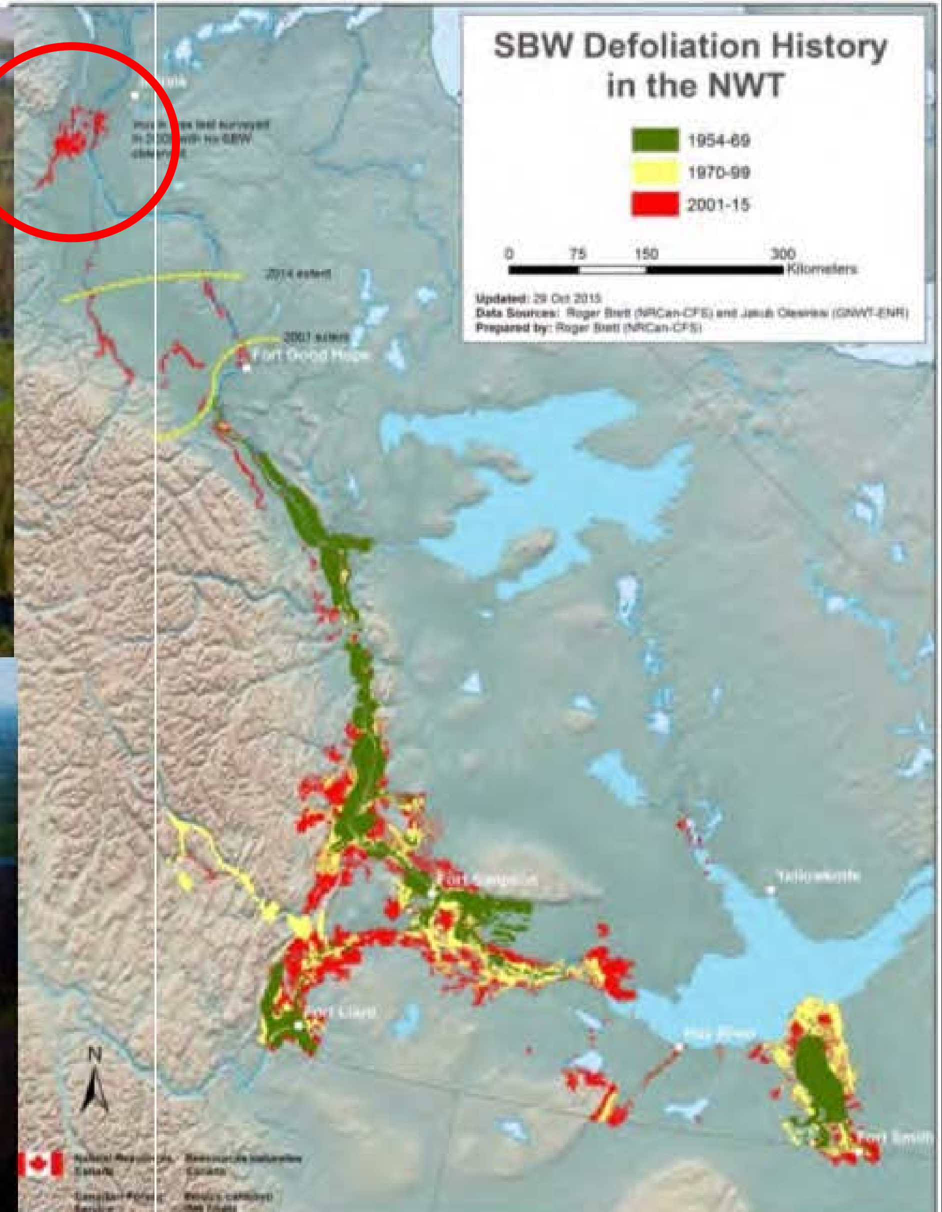
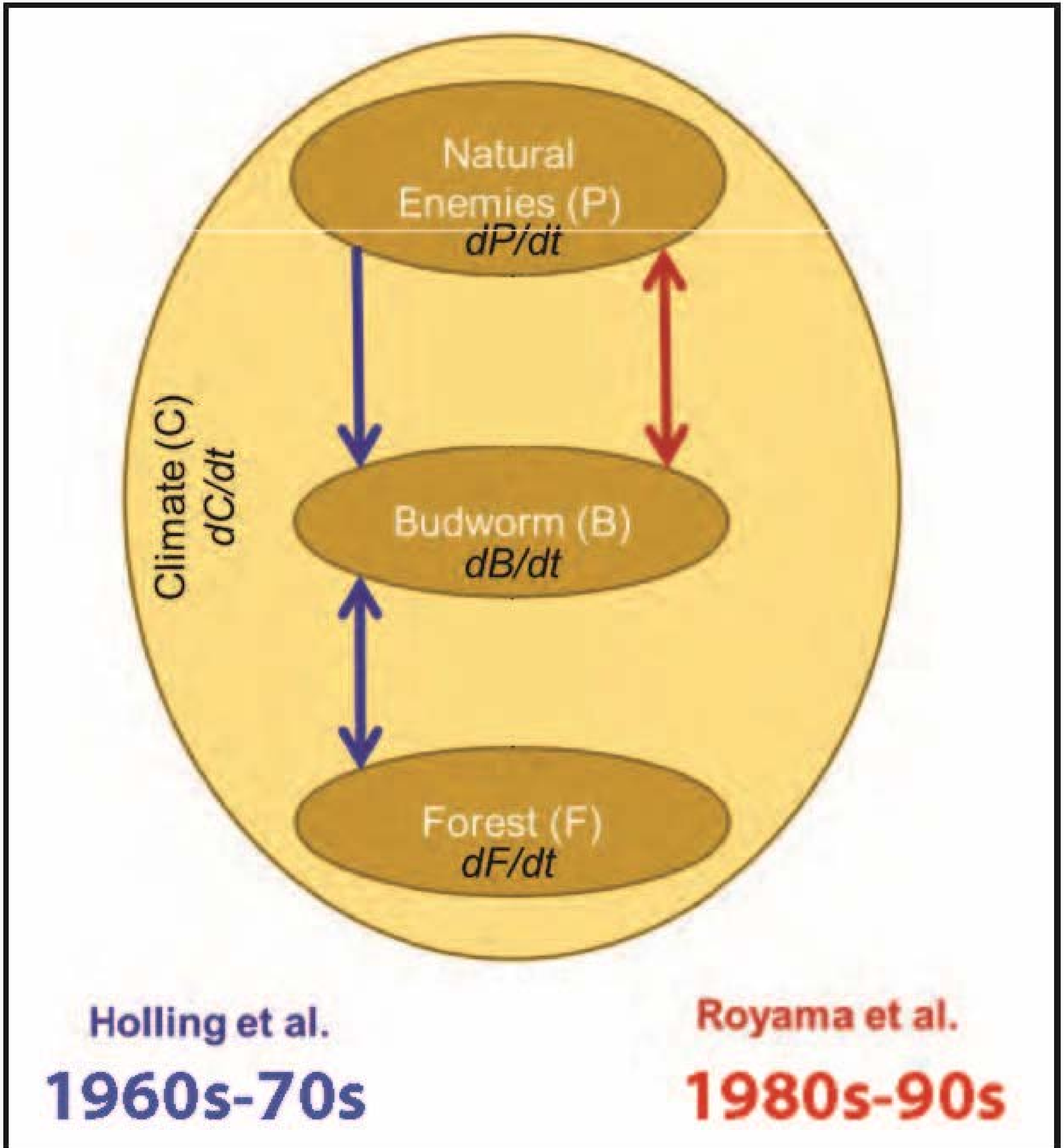


1961-1990 **2041-2070** **2071-2100**

* generated using BioSIM-SBW Régnière et al. (2012)

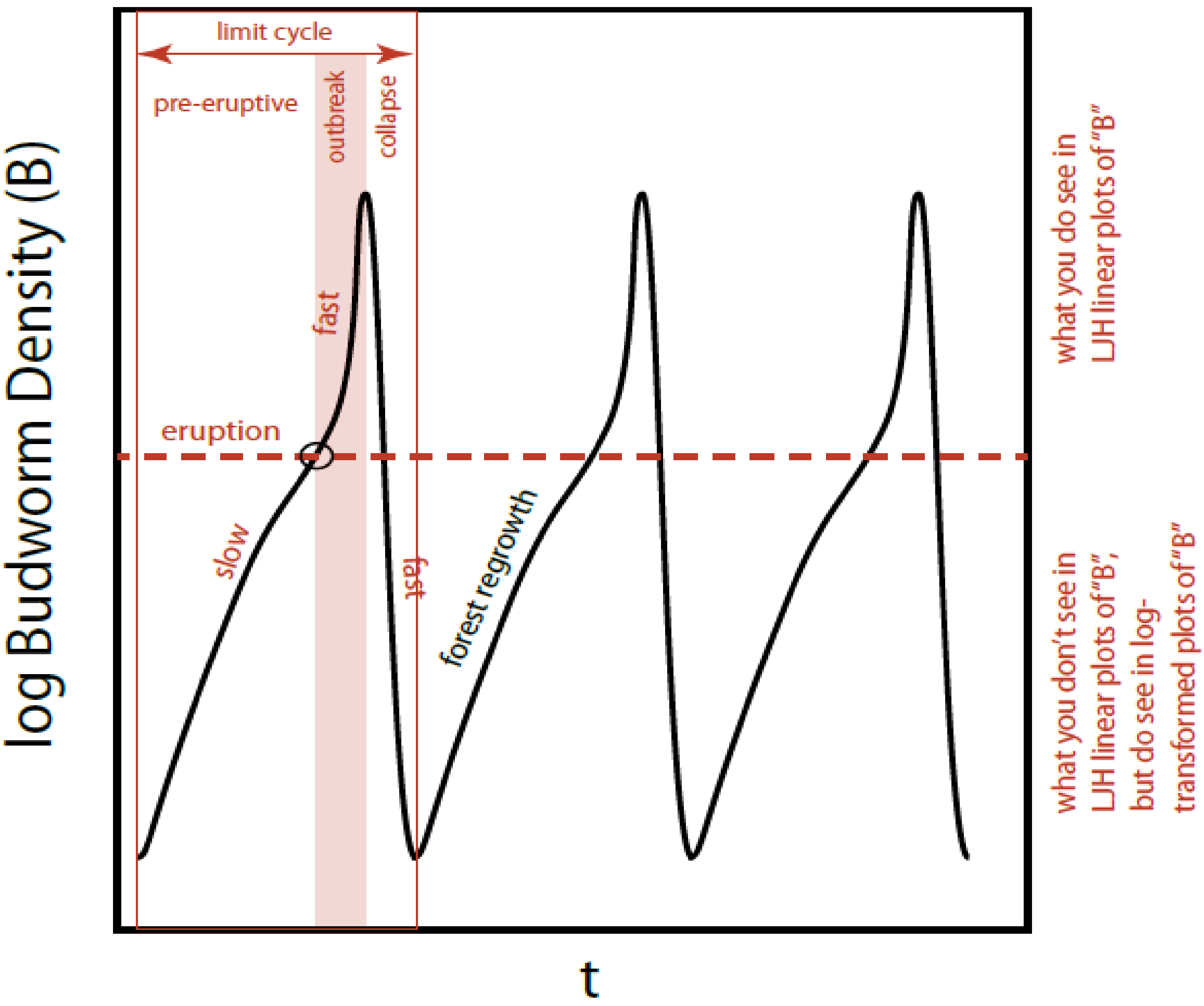
Northward expansion of Spruce Budworm defoliation





Natural Enemies (P)
dP/dt
Climate (C)
dC/dt
Budworm (B)
dB/dt
Forest (F)
dF/dt
Holling et al.
1960s-70s
Royama et al.
1980s-90s

Output from the Fowler (1997) implementation of the Ludwig-Jones-Holling (LJH) spruce budworm model



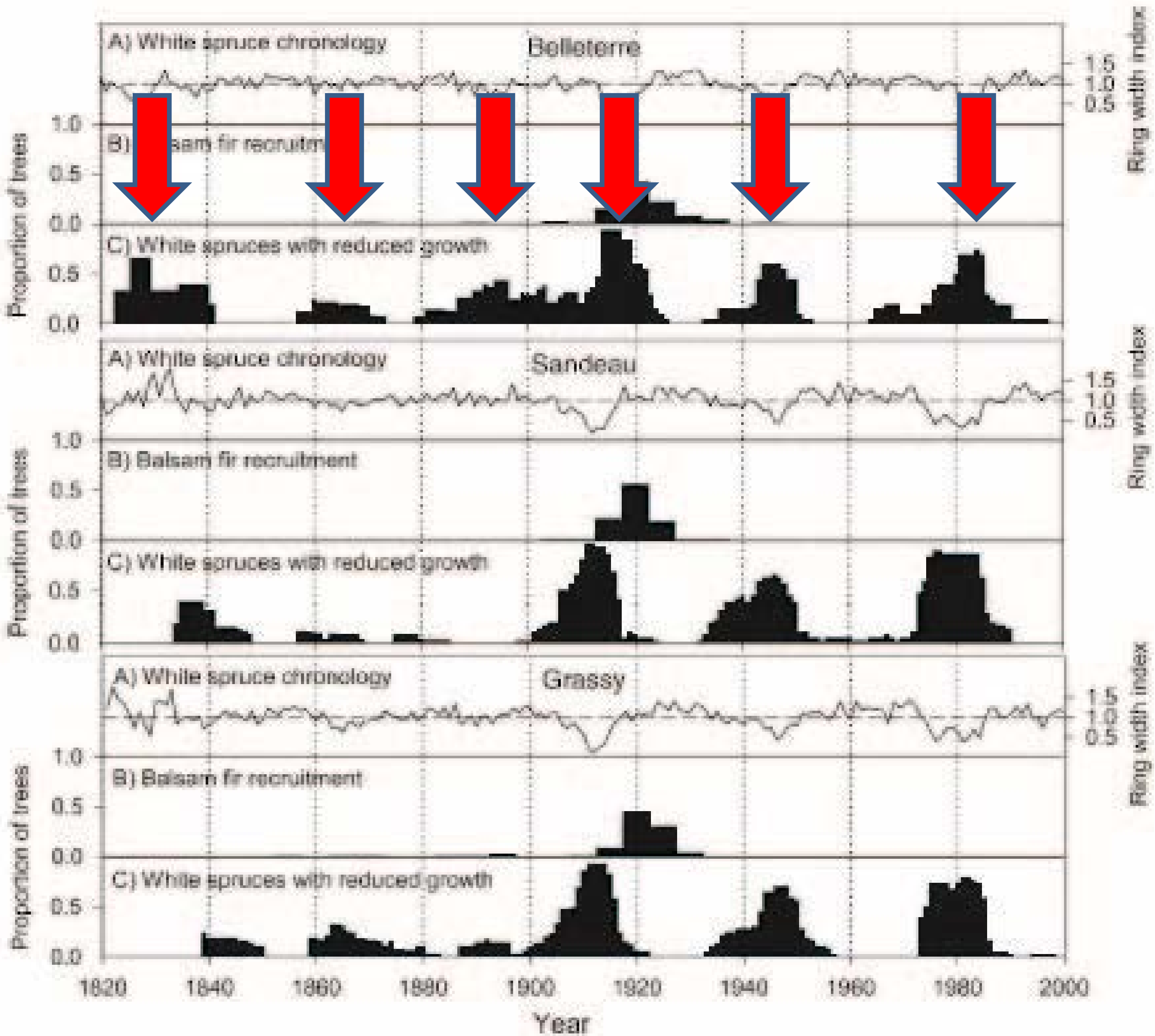
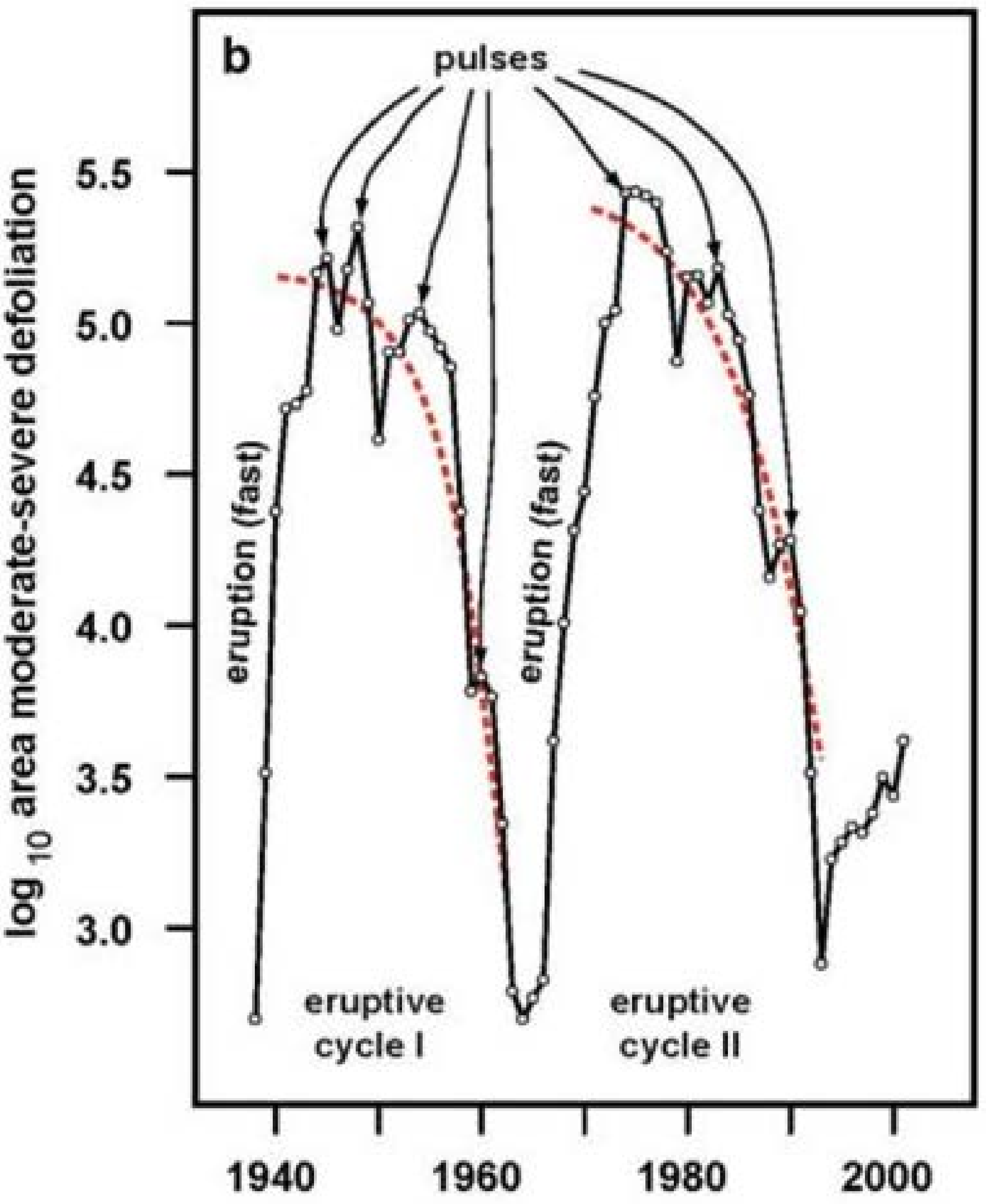


FIG. 2. For each study area, (A) white spruce standardized ring width indices, (B) proportion of balsam fir trees that recruited (first tree ring at 1-m height) during a given five-year period, and (C) proportion of white spruce trees showing significant growth reductions (i.e., five consecutive years with growth inferior to mean standardized ring width, including at least one year with growth below the mean standardized ring width by ≥1.28 SD).

Bouchard et al. 2006



Kneeshaw, Sturtevant, Cooke et al. 2015

insect-weather interactions & stochastic dynamics

deterministic

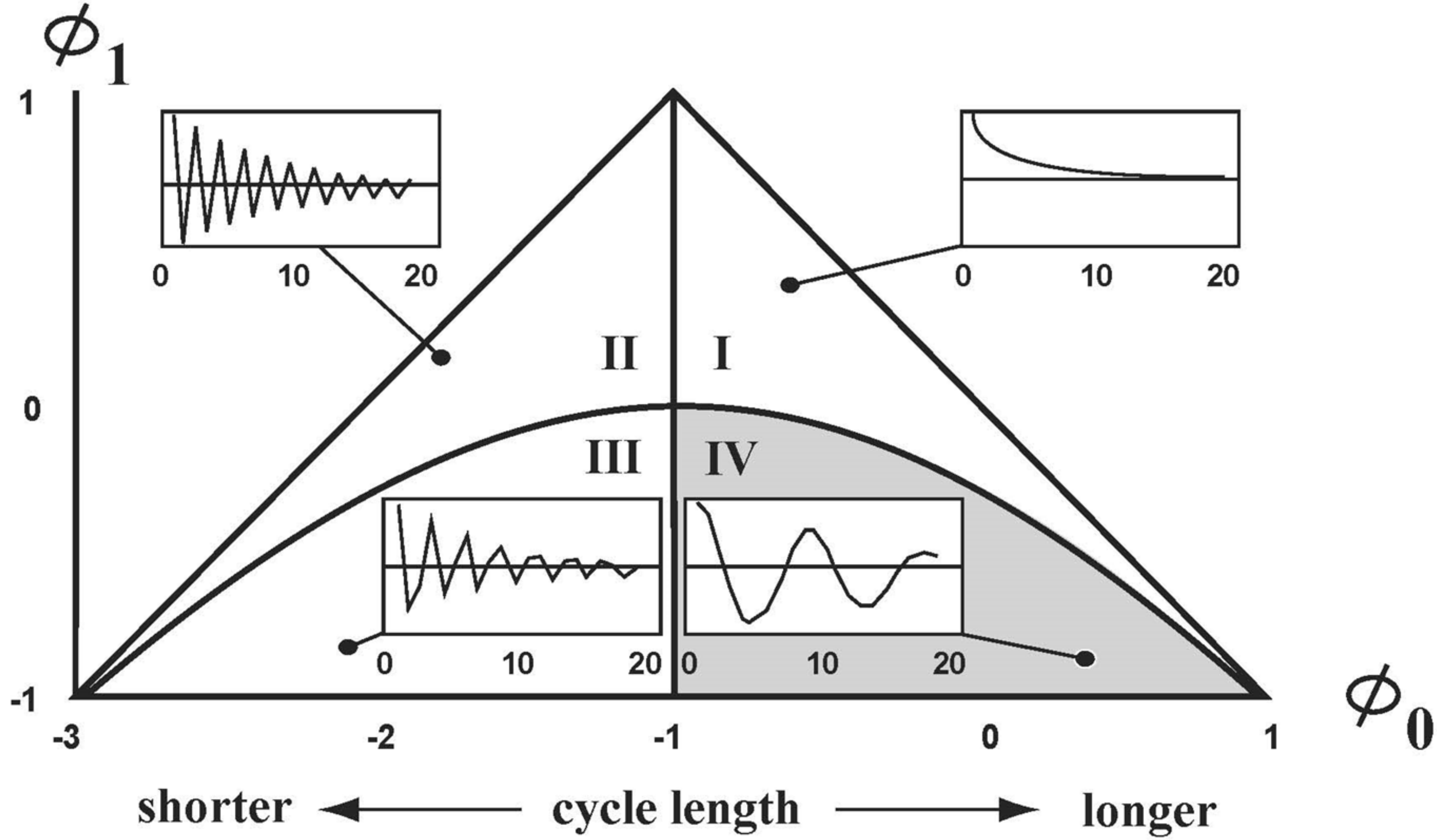
$$R_t = \phi_0 N_t + \phi_1 N_{t-1} + e_t$$

recruitment		perturbation
budburst synchrony	←	late spring weather
larval development time	←	summer weather *
moth dispersal, egg viability	←	late summer weather
overwintering survival	←	winter weather **

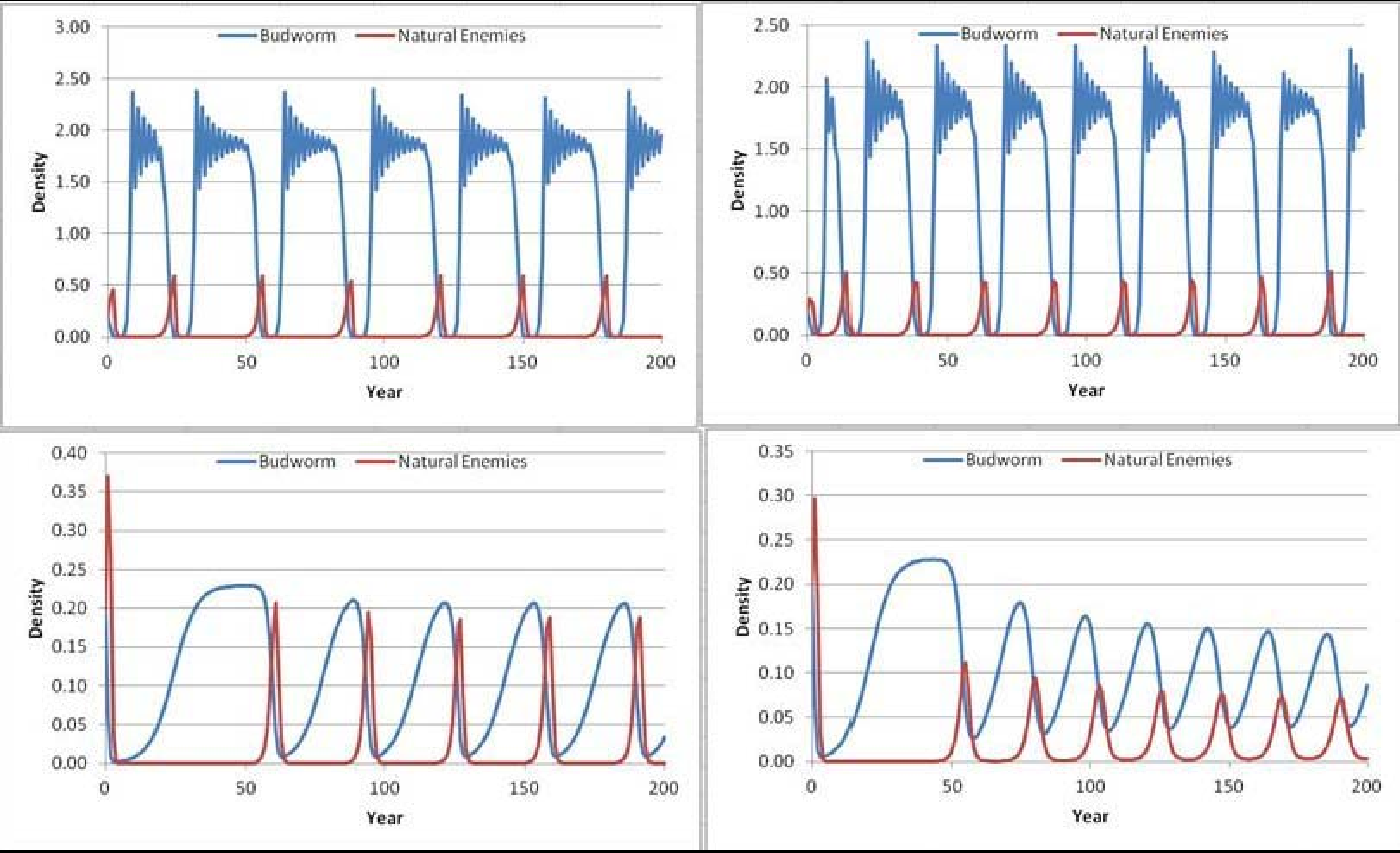
* SBW

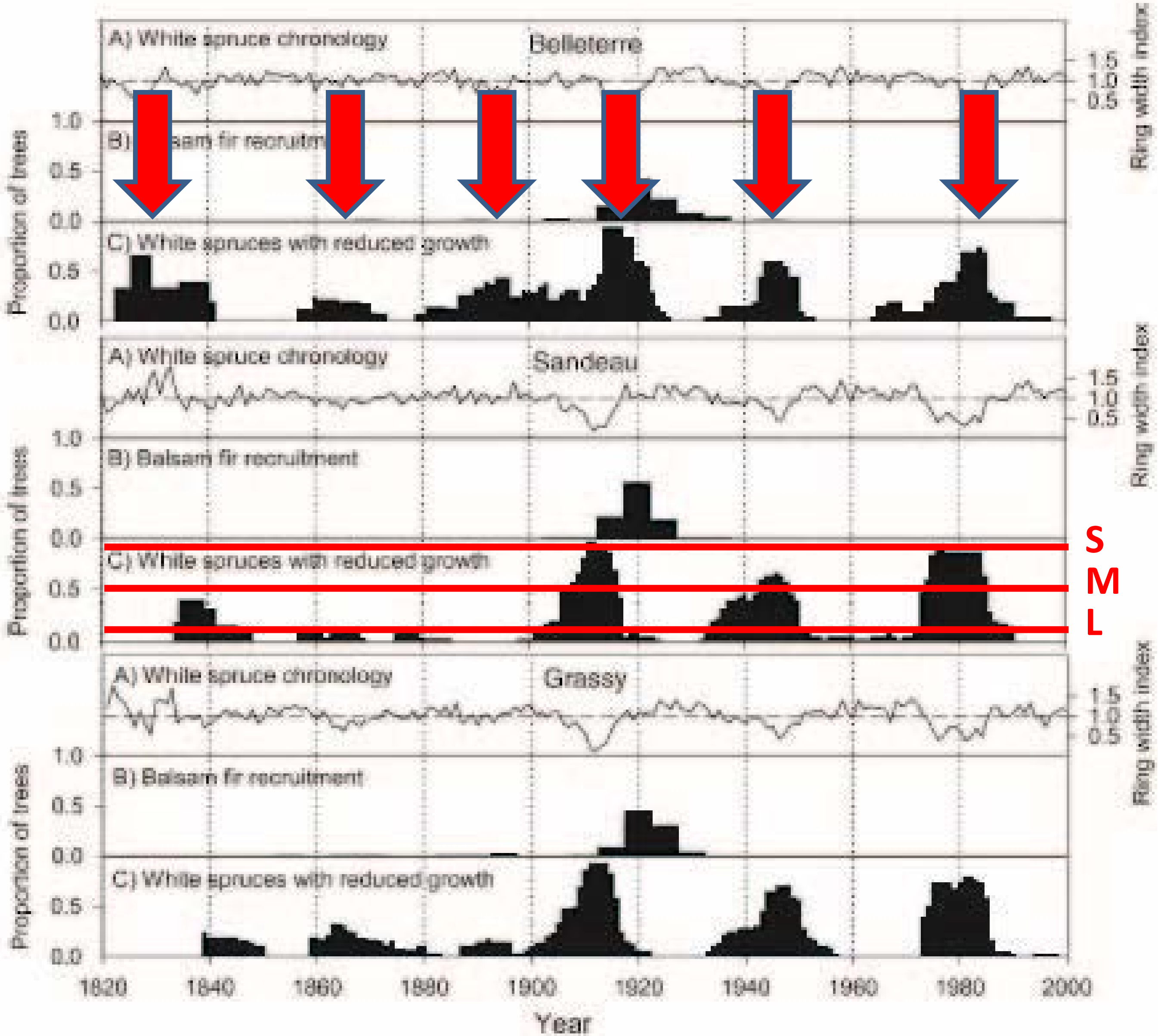
** FTC

Canadian Forest Service



ϕ_1
1
0
-1
-3
-2
-1
0
1
ϕ_0
II
I
III
IV
0
10
20
0
10
20
0
10
20
0
10
20
shorter
cycle length
longer


Budworm
Natural Enemies
Density
Year
Budworm
Natural Enemies
Density
Year
Budworm
Natural Enemies
Density
Year
Budworm
Natural Enemies
Density
Year



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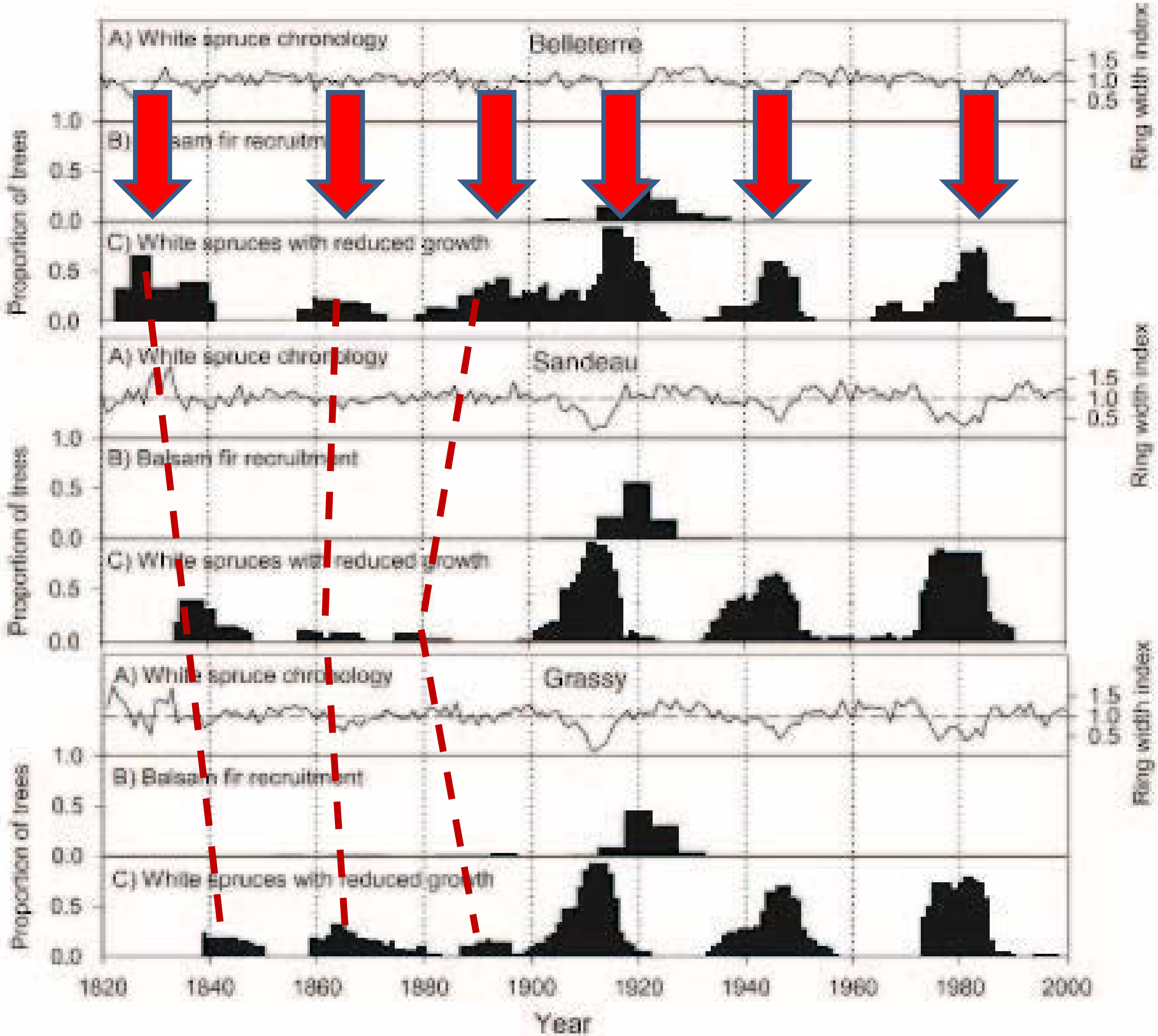

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Bouchard et al. 2006

forest insect population models

Ludwig et al. (1978) budworm-forest

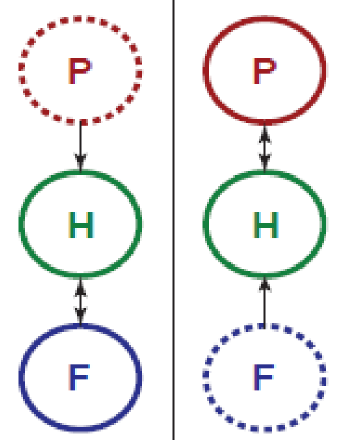
Equations 20-22

$$\frac{dB}{dt} = r_B B \left(1 - \frac{B}{K'S}\frac{T_E^2 + E^2}{E^2}\right) - b\frac{B^2}{(aS)^2 + B^2}$$

$$\frac{dS}{dt} = r_S S \left(1 - \frac{S}{E}\frac{K_E}{K_S}\right)$$

$$\frac{dE}{dt} = r_E E \left(1 - \frac{E}{K_E}\right) - P'\frac{B}{S}\frac{E^2}{T_E^2 + E^2}$$

B = Budworm density
S = Surface area of foliage
E = Energy content of foliage



P = Predator density
H = Herbivore density
F = Foliage availability

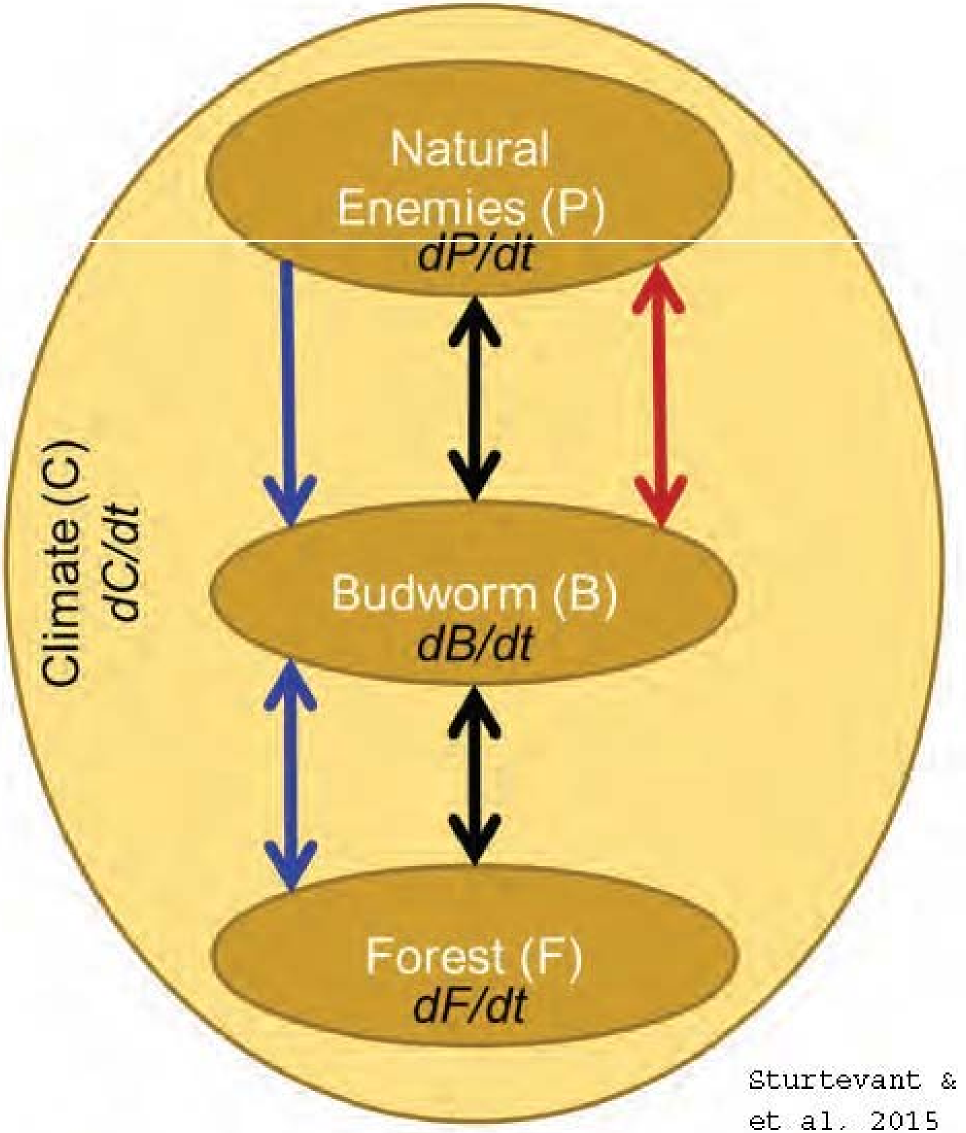
Royama (1992) predator-prey

Equations 5.17 a,b

$$r_t = r_m[1-\exp(-by_t)]\exp(-cx_t)$$

$$r'_t = r'_m \exp[-(b'y_t + c'x_t)]$$

r = Predator recruitment
r' = Herbivore recruitment
x = Predator density
y = Herbivore density



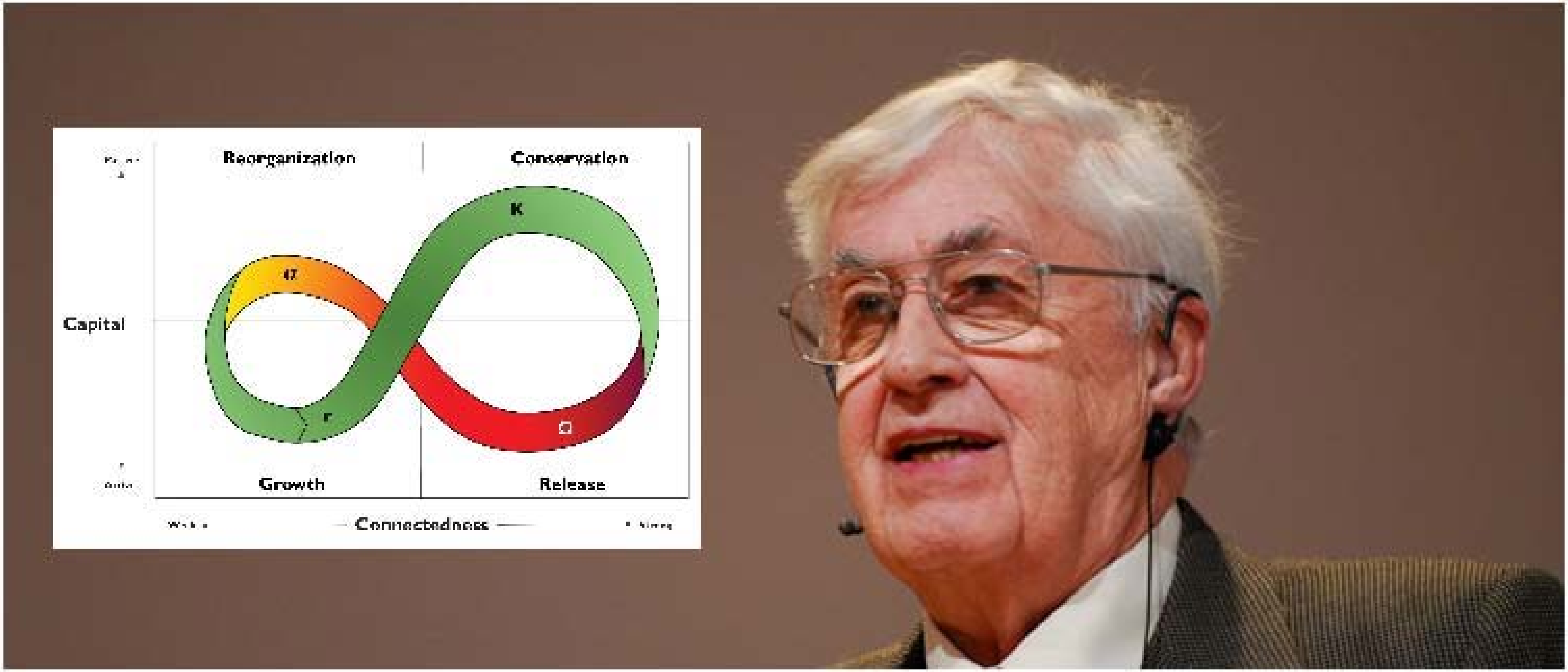
Sturtevant & Cooke et al. 2015

Holling et al.
1960s-70s

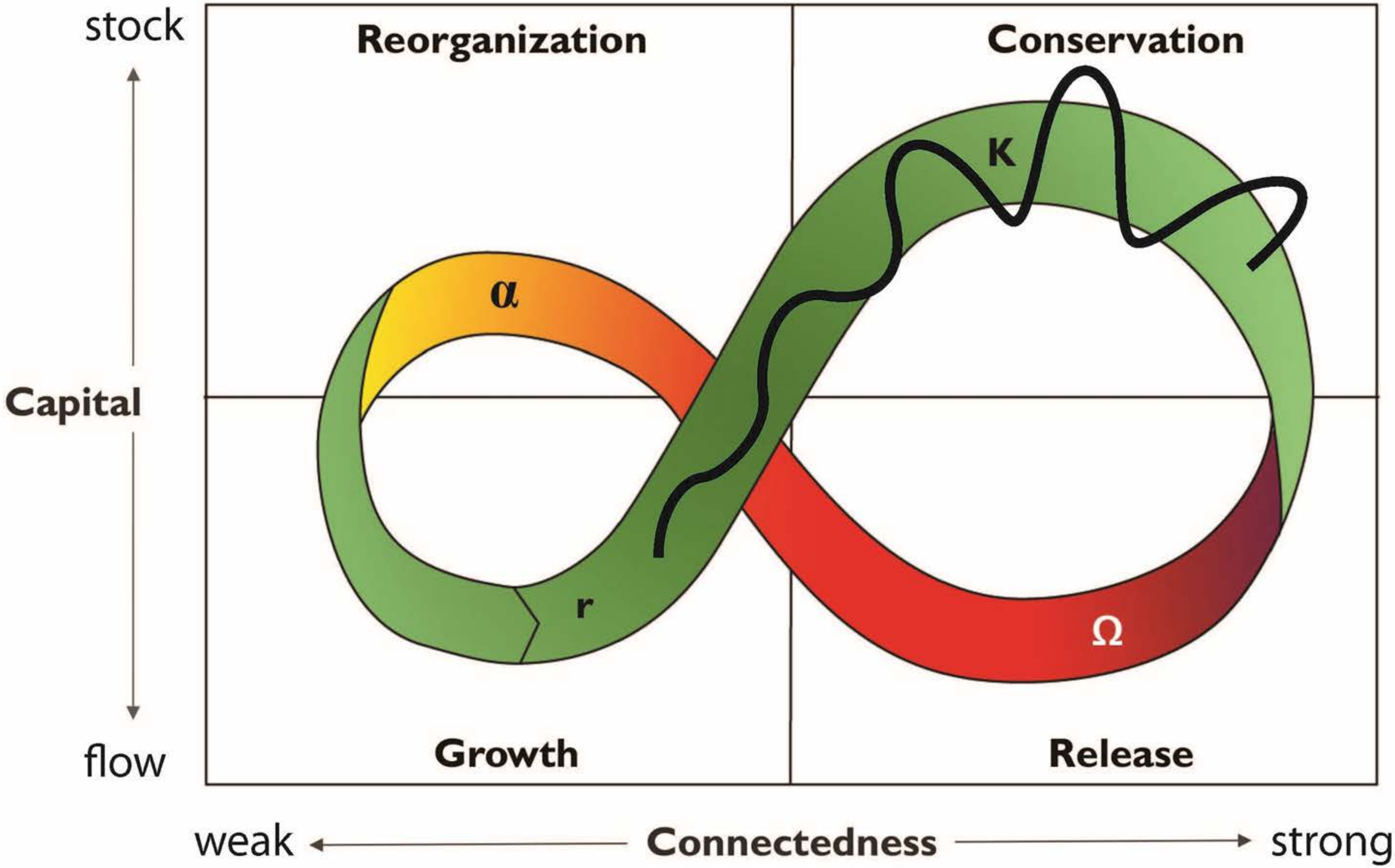
Modern Synthesis

Royama et al.
1980s-90s

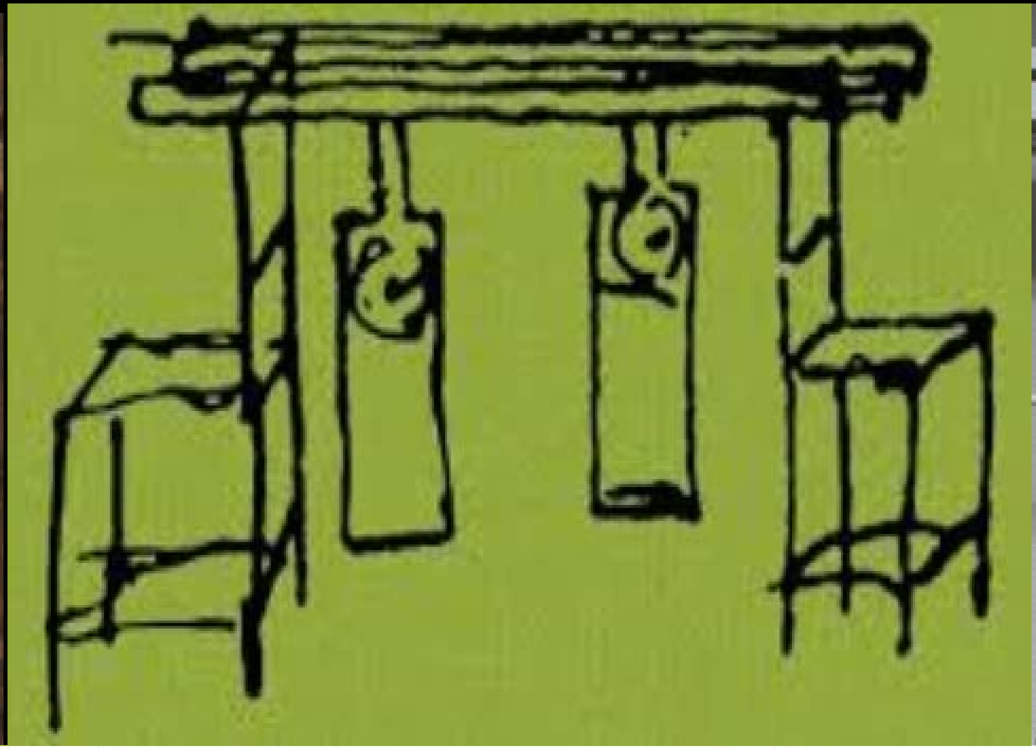
Global Forest Ecosystem Function

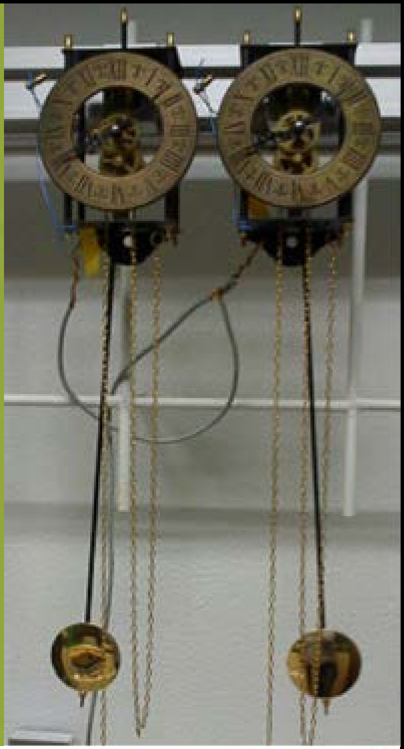


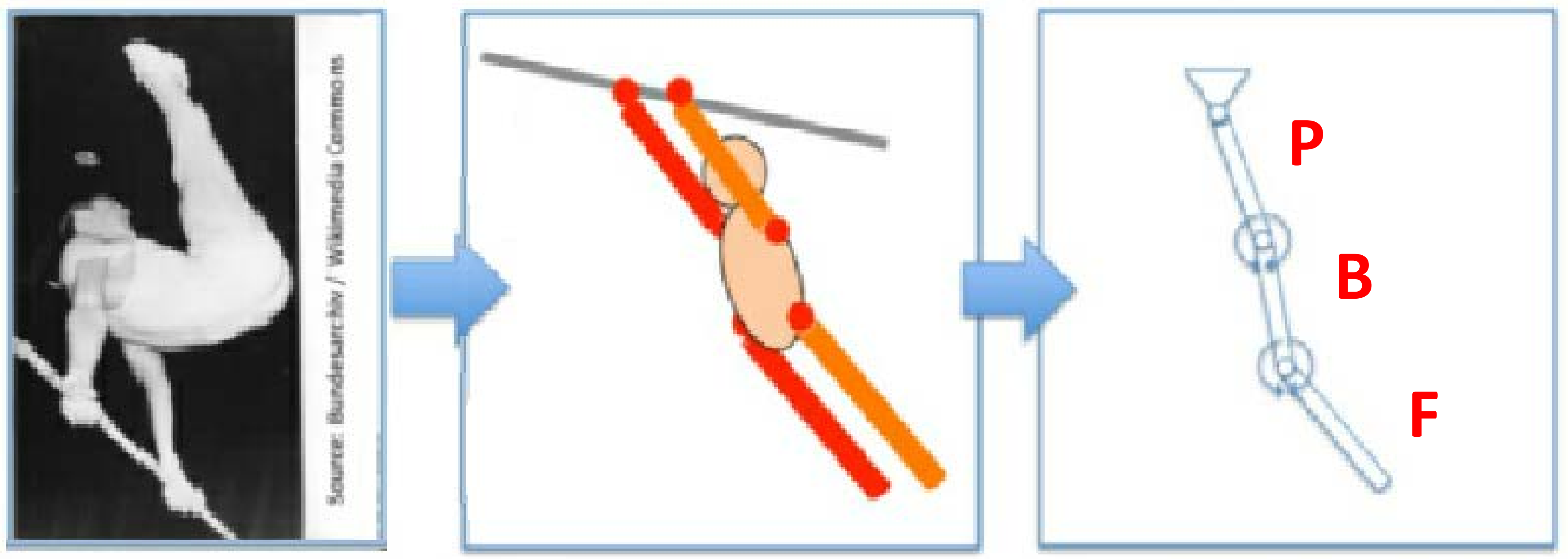
Big Questions - Limited Resources



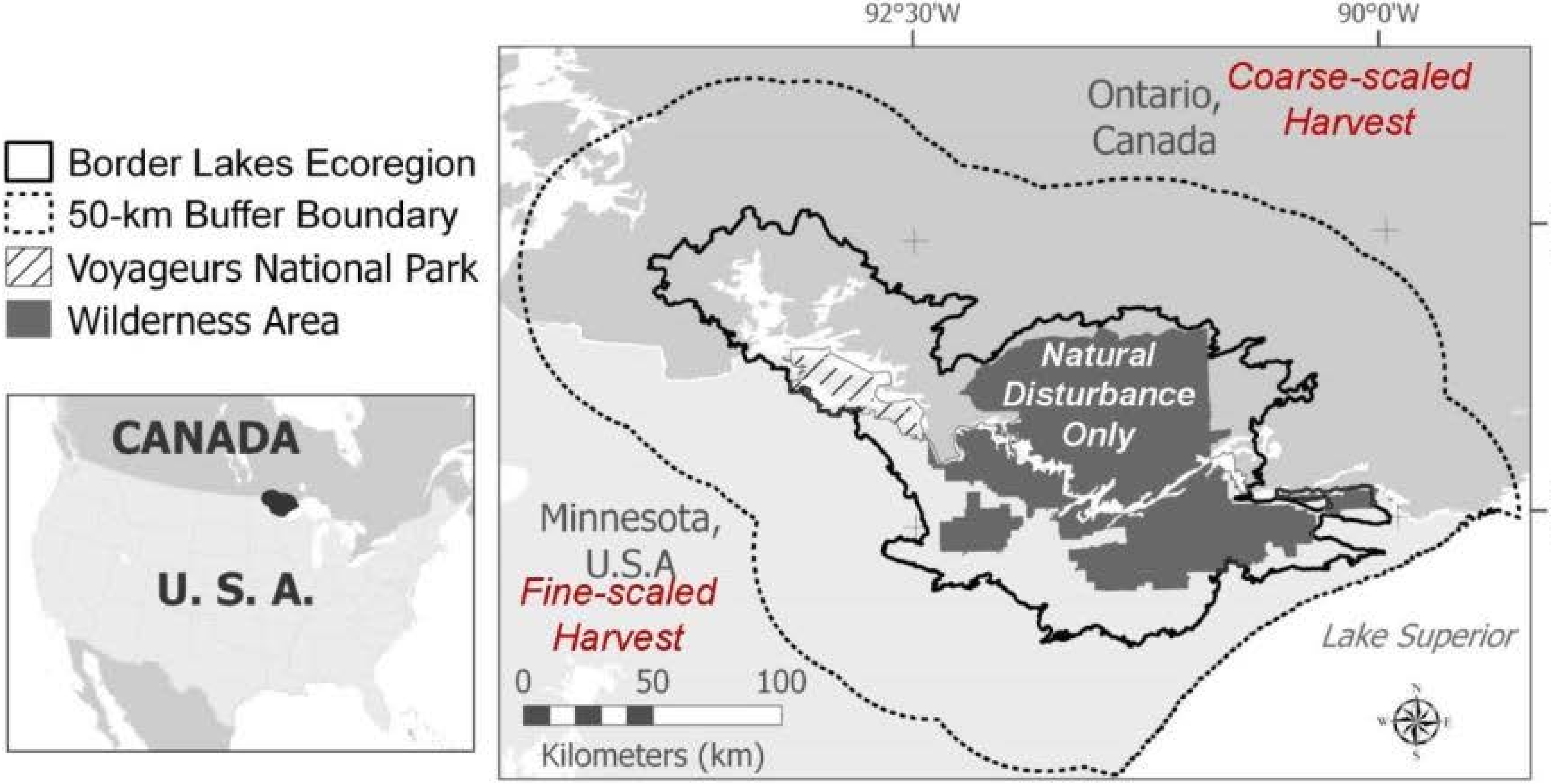
stock
Reorganization
Conservation
K
α
Capital
r
Ω
flow
Growth
Release
weak
Connectedness
strong






Source: Bundesarchiv / Wikimedia Commons
P
B
F

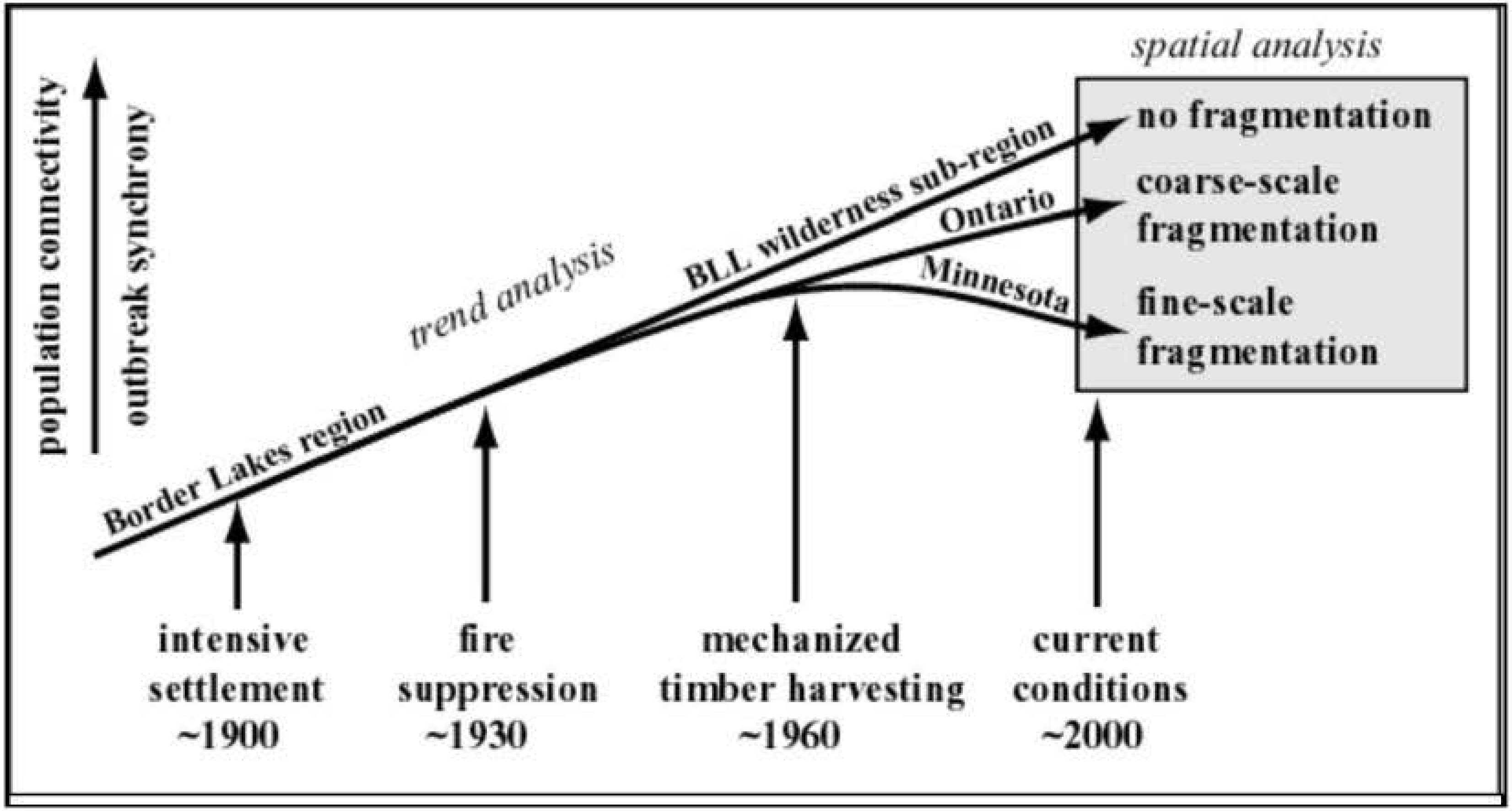
Spruce Budworm Research Program
Border Lakes Landscape Project

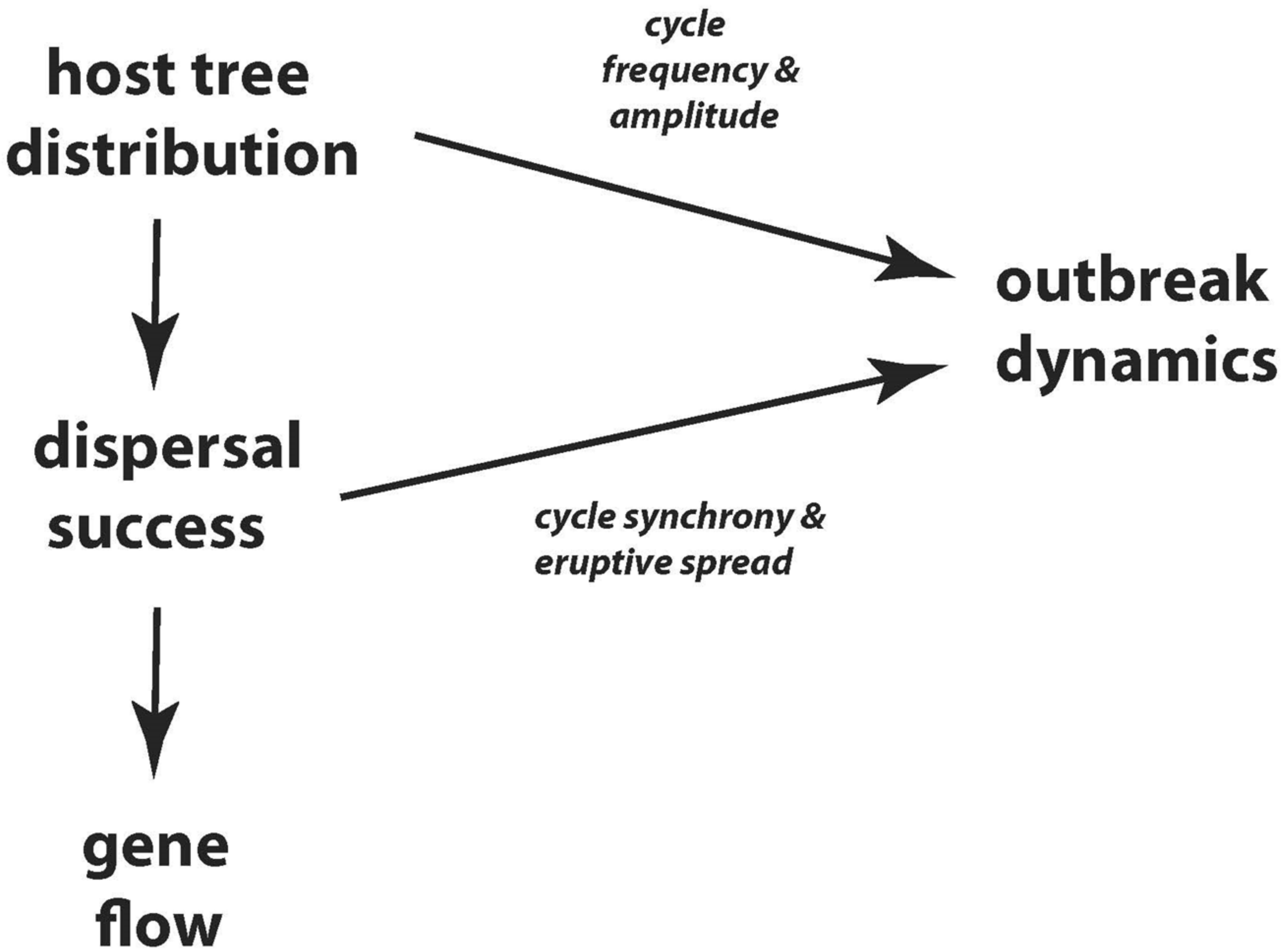


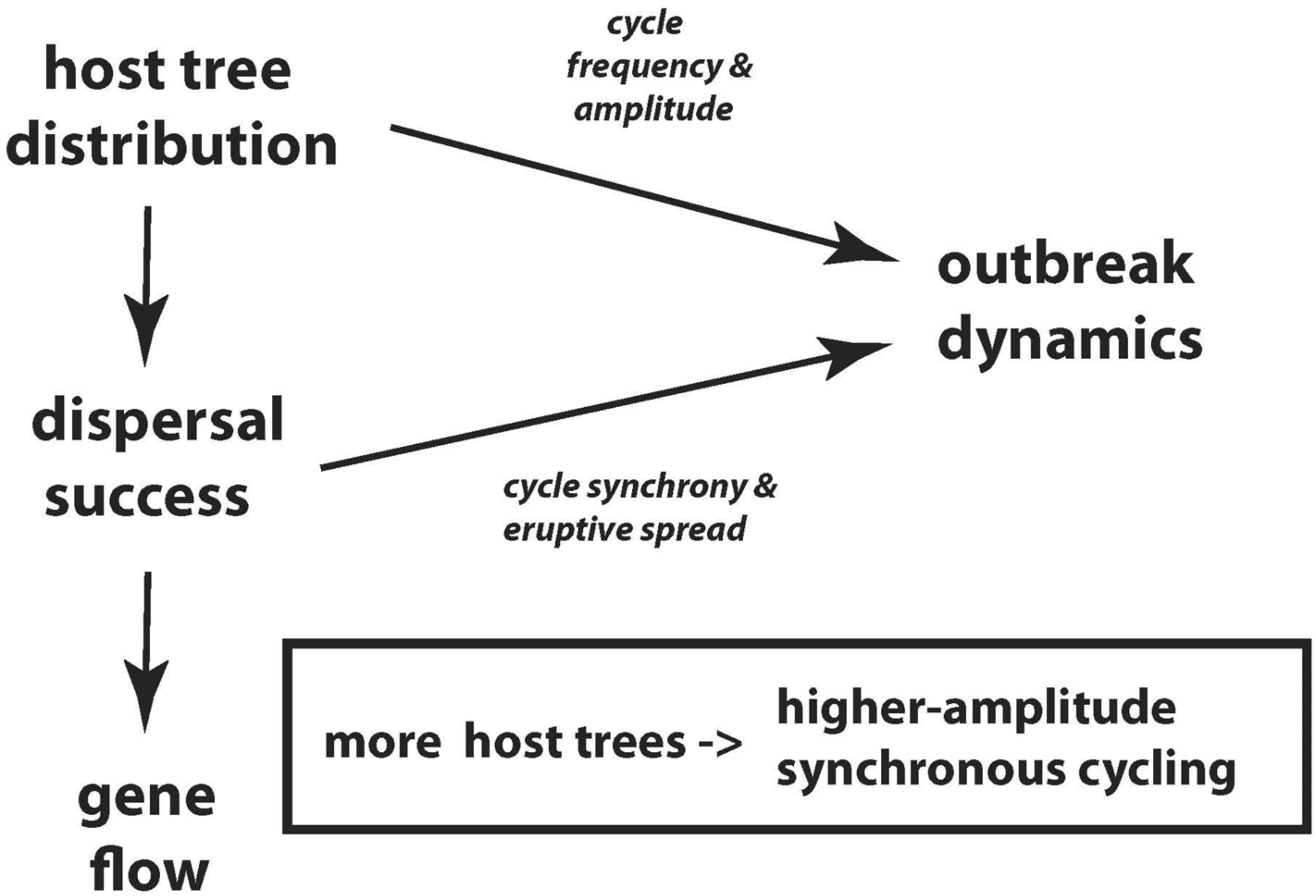
Brian Sturtevant
bsturtevant@fs.fed.us

http://www.nrs.fs.fed.us/people/Sturtevant

Hypothesized Outbreak Behavior

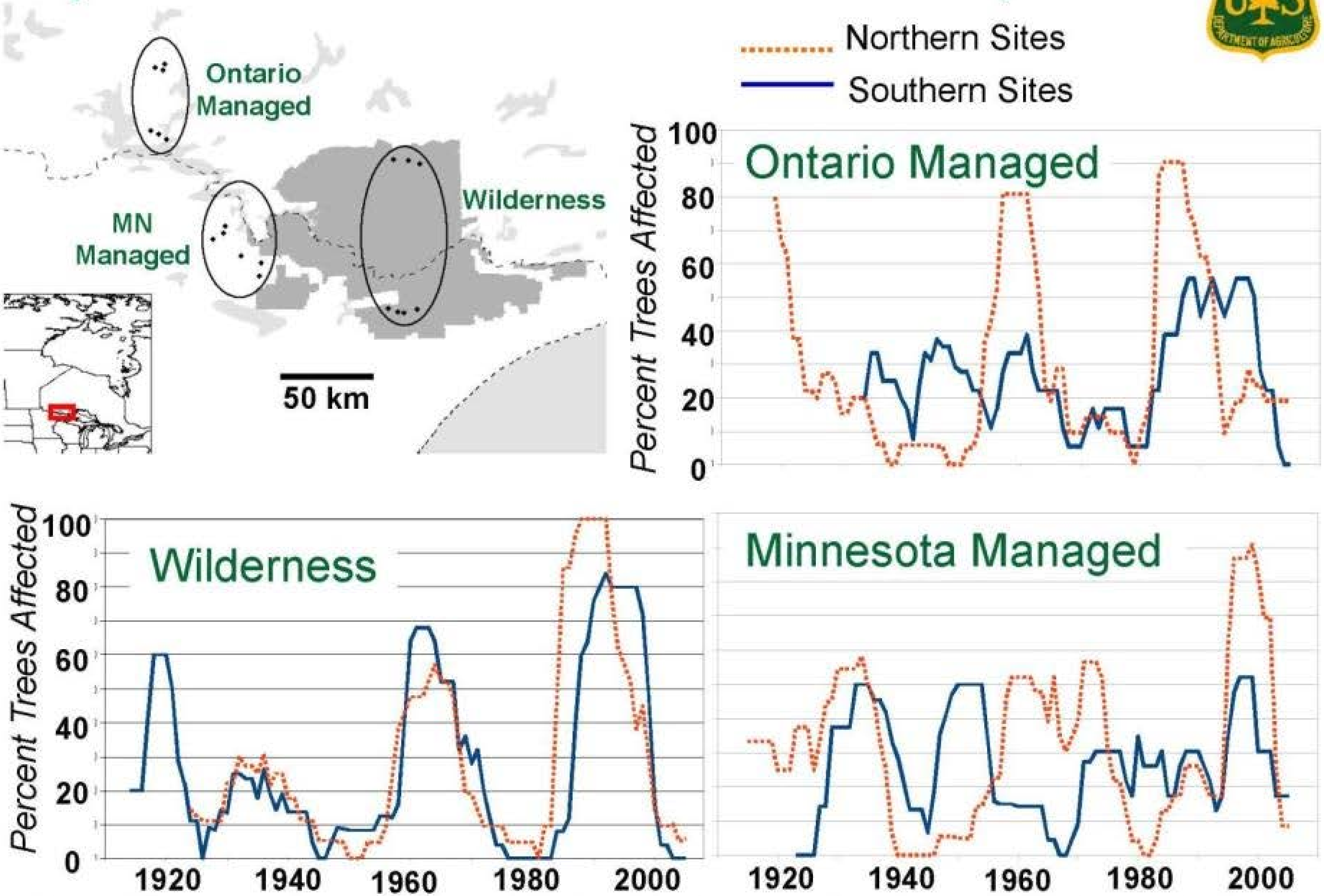



host tree distribution
cycle frequency & amplitude
outbreak dynamics
dispersal success
cycle synchrony & eruptive spread
gene flow

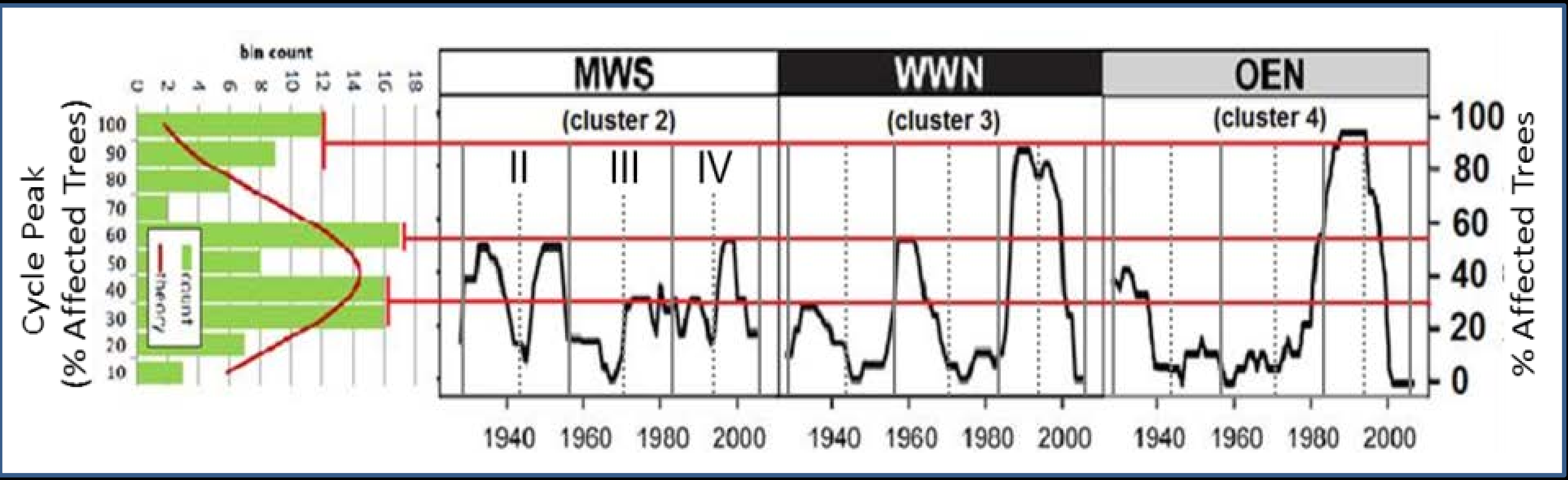


host tree distribution
cycle frequency & amplitude
outbreak dynamics
dispersal success
cycle synchrony & eruptive spread
gene flow
more host trees ->
higher-amplitude synchronous cycling

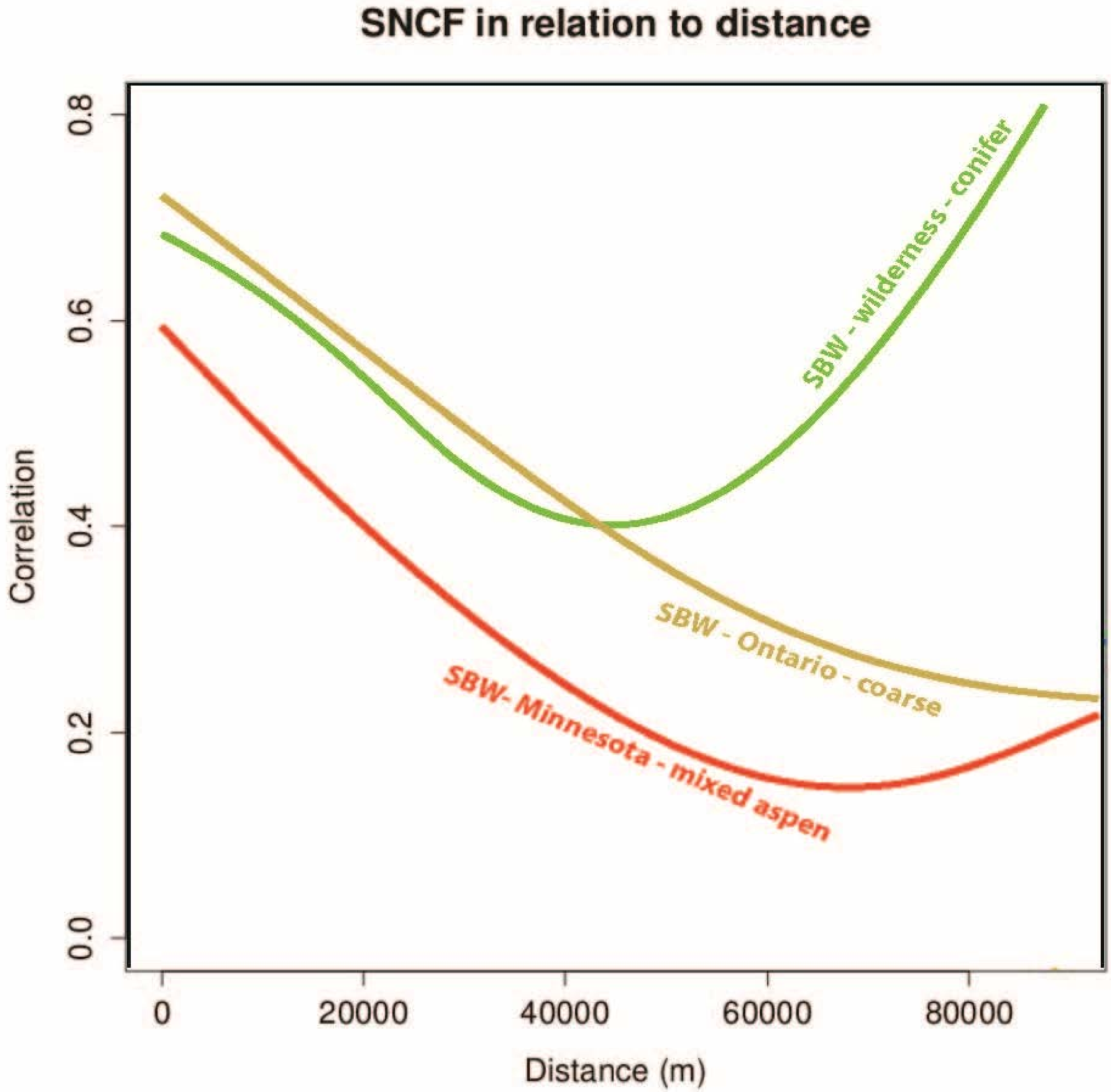
Spruce budworm disturbance history



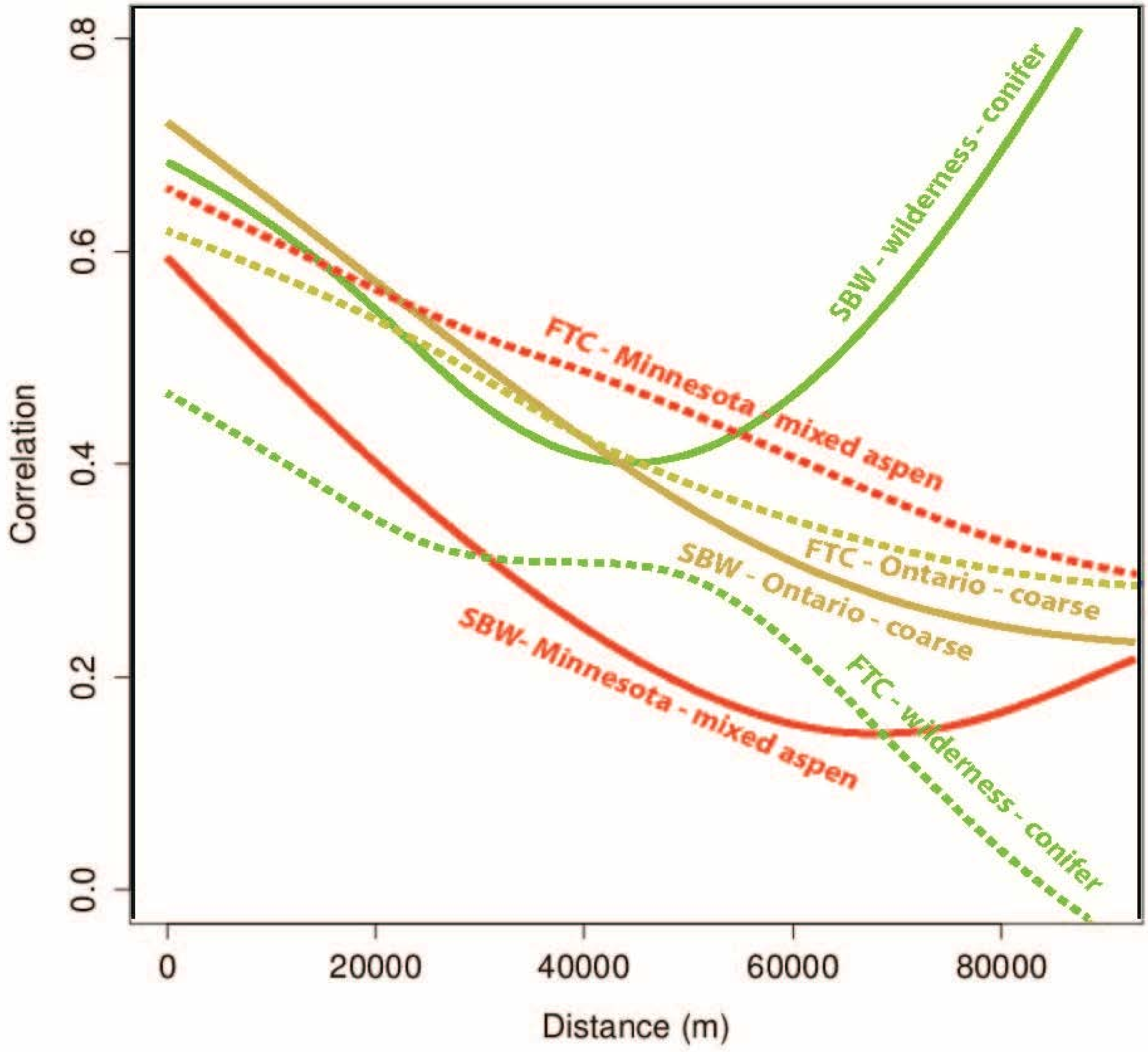
Robert, L. E., D. Kneeshaw, and B. R. Sturtevant. 2012. Effects of forest management legacies on spruce budworm outbreaks. Canadian Journal of Forest Research **42**:463–475.

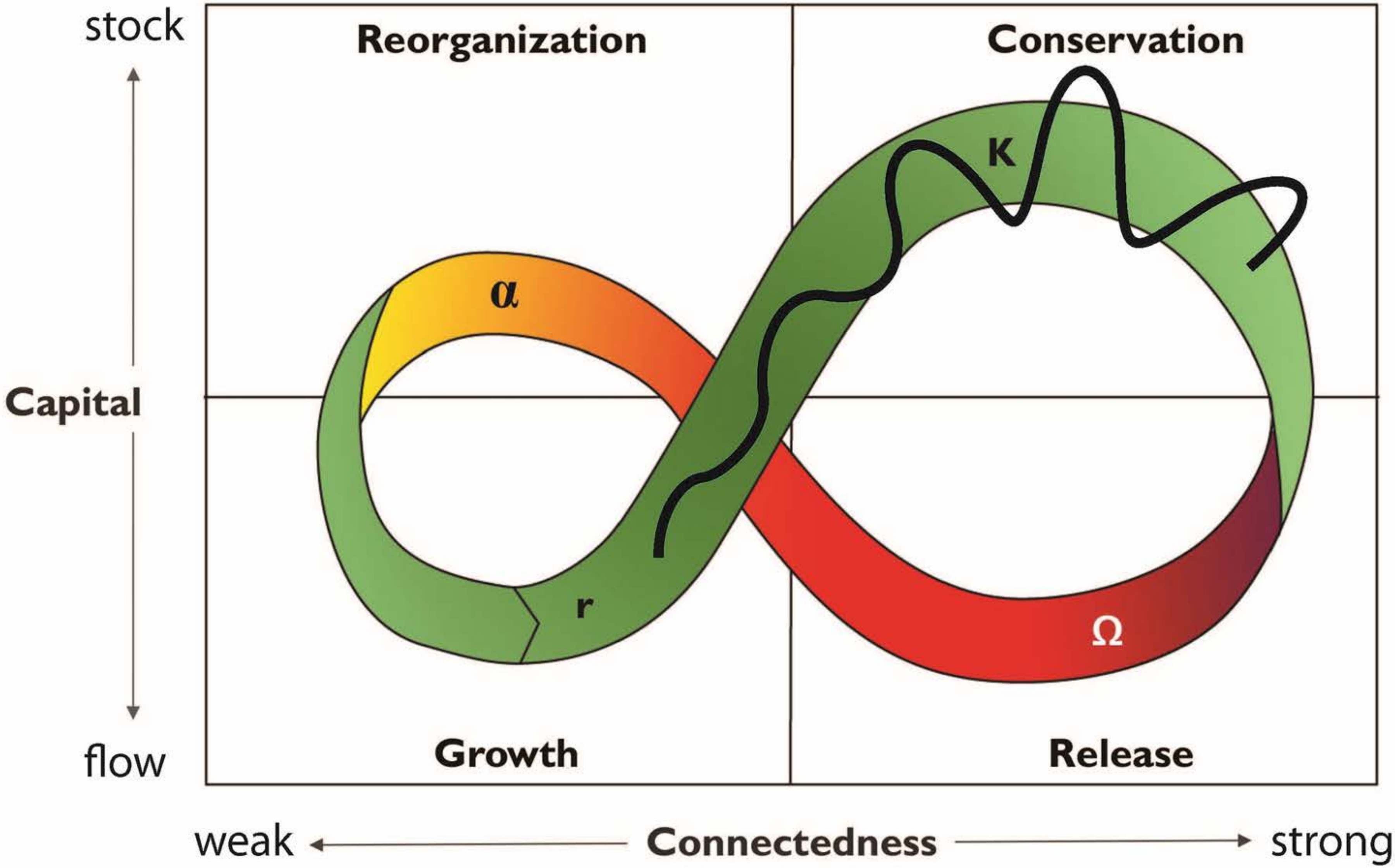


bin count
Cycle Peak (% Affected Trees)
count
theory
MWS
WWN
OEN
(cluster 2)
(cluster 3)
(cluster 4)
II
III
IV
% Affected Trees


SNCF in relation to distance
Correlation
0.0
0.2
0.4
0.6
0.8
Distance (m)
0
20000
40000
60000
80000
SBW - wilderness - conifer
SBW - Ontario - coarse
SBW- Minnesota - mixed aspen

SNCF in relation to distance




stock
Reorganization
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