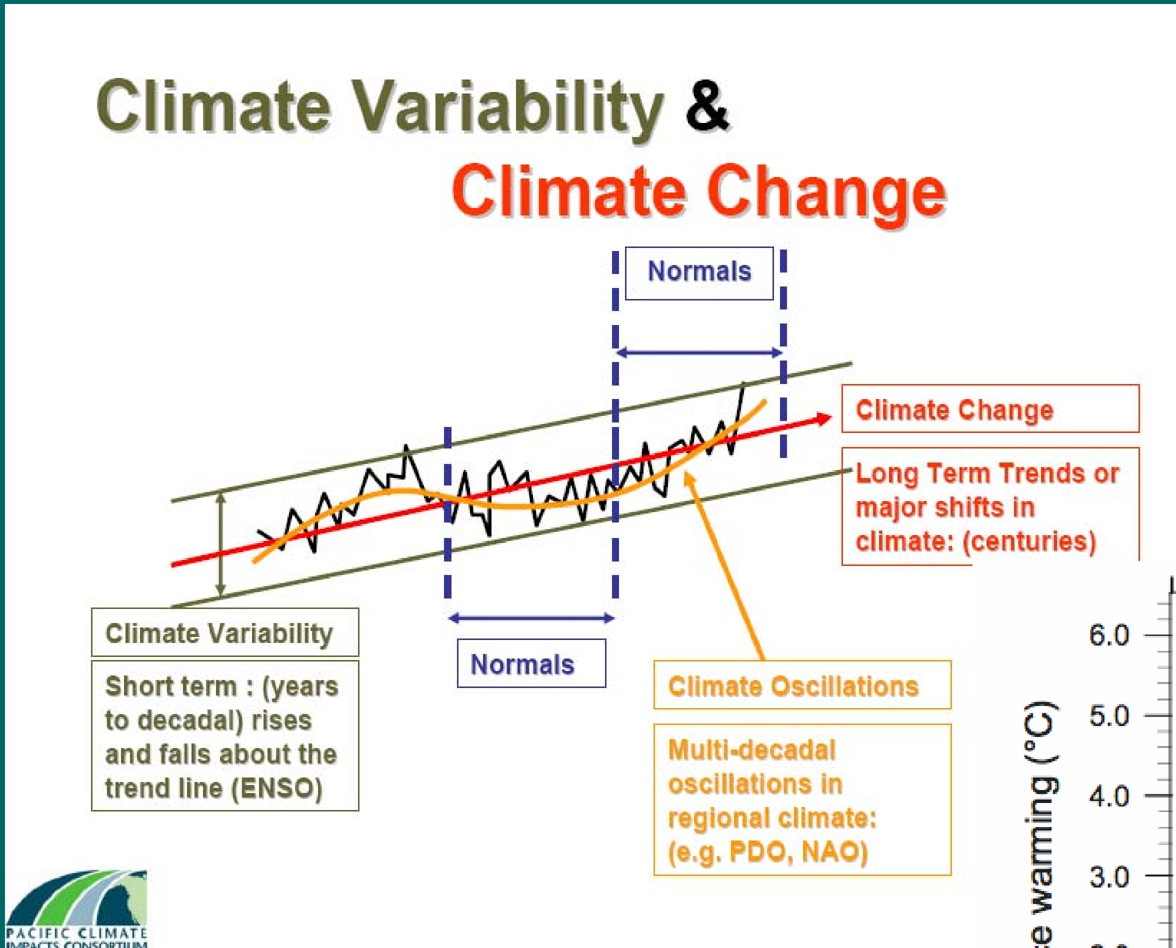
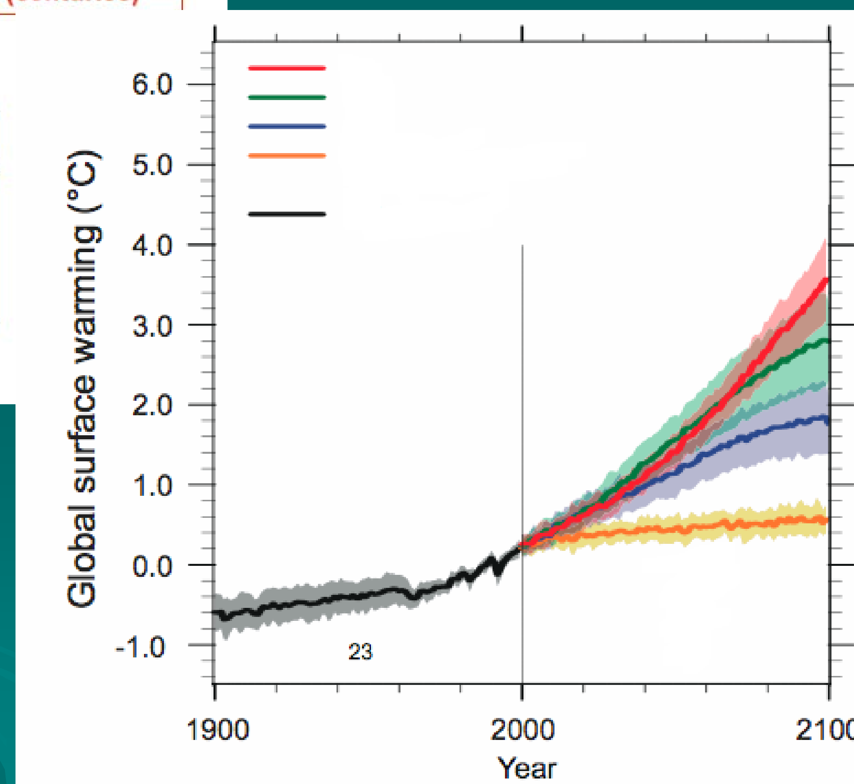




Simulated change in global mean temperature from 1980-1999 mean value. From 2000 to 2100 the simulation uses selected emissions scenarios (red, green, and dark blue lines). The orange line indicates effect of an immediate total cut in emissions. Shading around each line represents ± 1 SD on a range of annual means from 16 to 21 GCMs. Retrieved from Spittlehouse (2008).

It's A Different Box

- Dr. Tim Kittel, Institute of Arctic & Alpine Research, U of Colorado, at Alaska–Yukon–BC conservation workshop 8-9 May 2007, Haines Junction, YT, sponsored by Nature Conservancy Canada.

- Dr. Kittell acknowledged uncertainty about the rate, dimensions and projected impacts of climate change. But he declared,

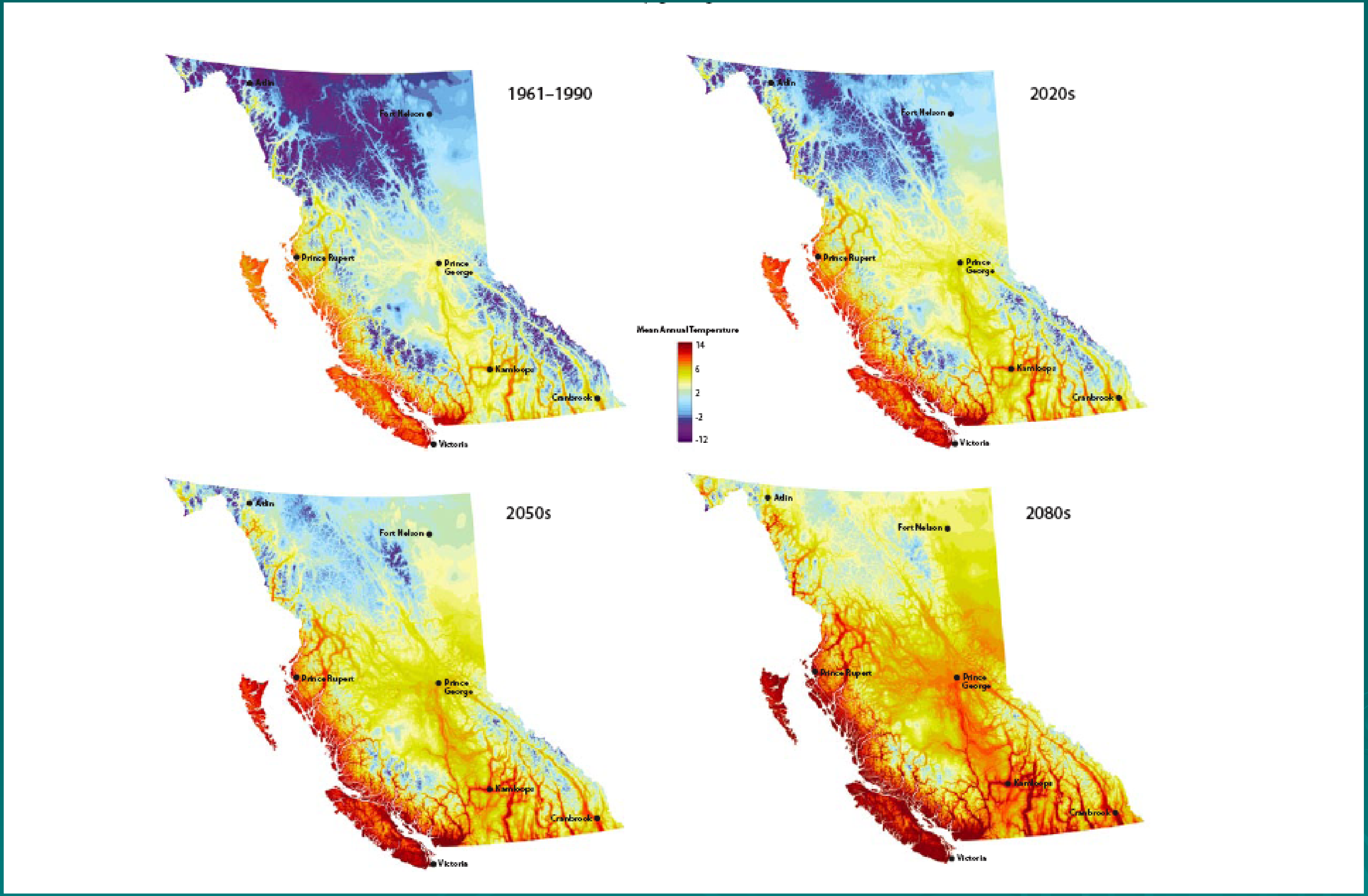
  "the magnitude of what ***<u>is</u>*** *certain will change everything."*

Climate Change Realities

- Fastest climate change in 750,000 years
- Is real & largely human-caused (IPCC)
- Portions of n N Am (including n BC) have greatest temperature increase globally, over past 30-50 years

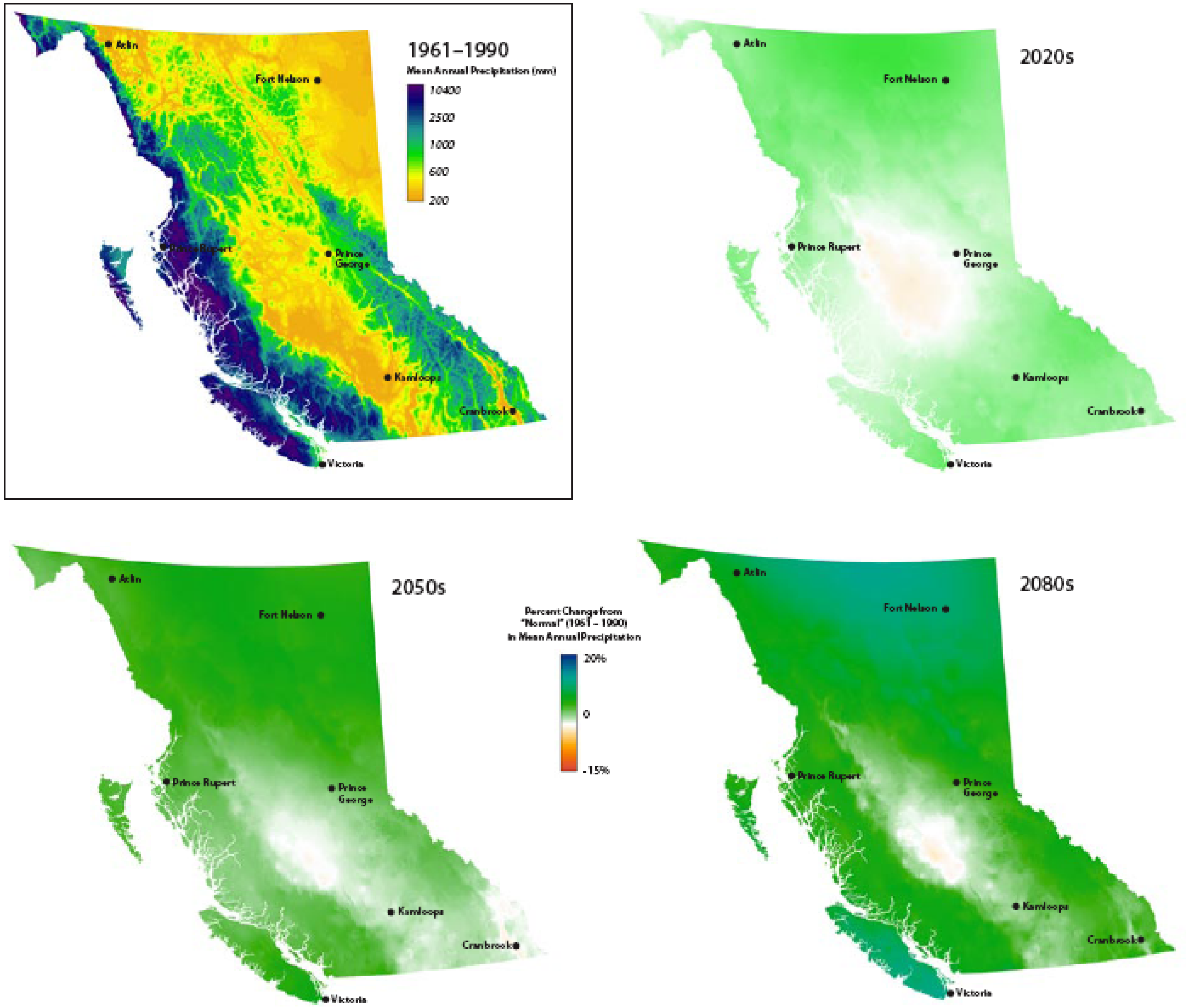
- B.C. has warmed up, esp. winters. Winter T up 3-3.5^{o}C at Dease Lake since 1950
- Frost-free period ↑ by 21 days between 1950 and 2004.
- Annual precipitation ↑ 22% on ave. over past 100 years; significant seasonal & regional variation. Mostly reduced winter P, increased summer P over past 50 years.
- Water T in rivers rising; peak summer T on Fraser R main stem up 1.5 °C since 1940.

Mean Annual Temperature



Spittlehouse, D. 2008. Climate Change, Impacts and Adaptation Scenarios: Climate change and forest and range management in British Columbia. Technical Report 45. BC Ministry of Forests and Range, Victoria, B.C. 38 p.

Mean Annual Precipitation



Retrieved from Spittlehouse (2008).

Temperature

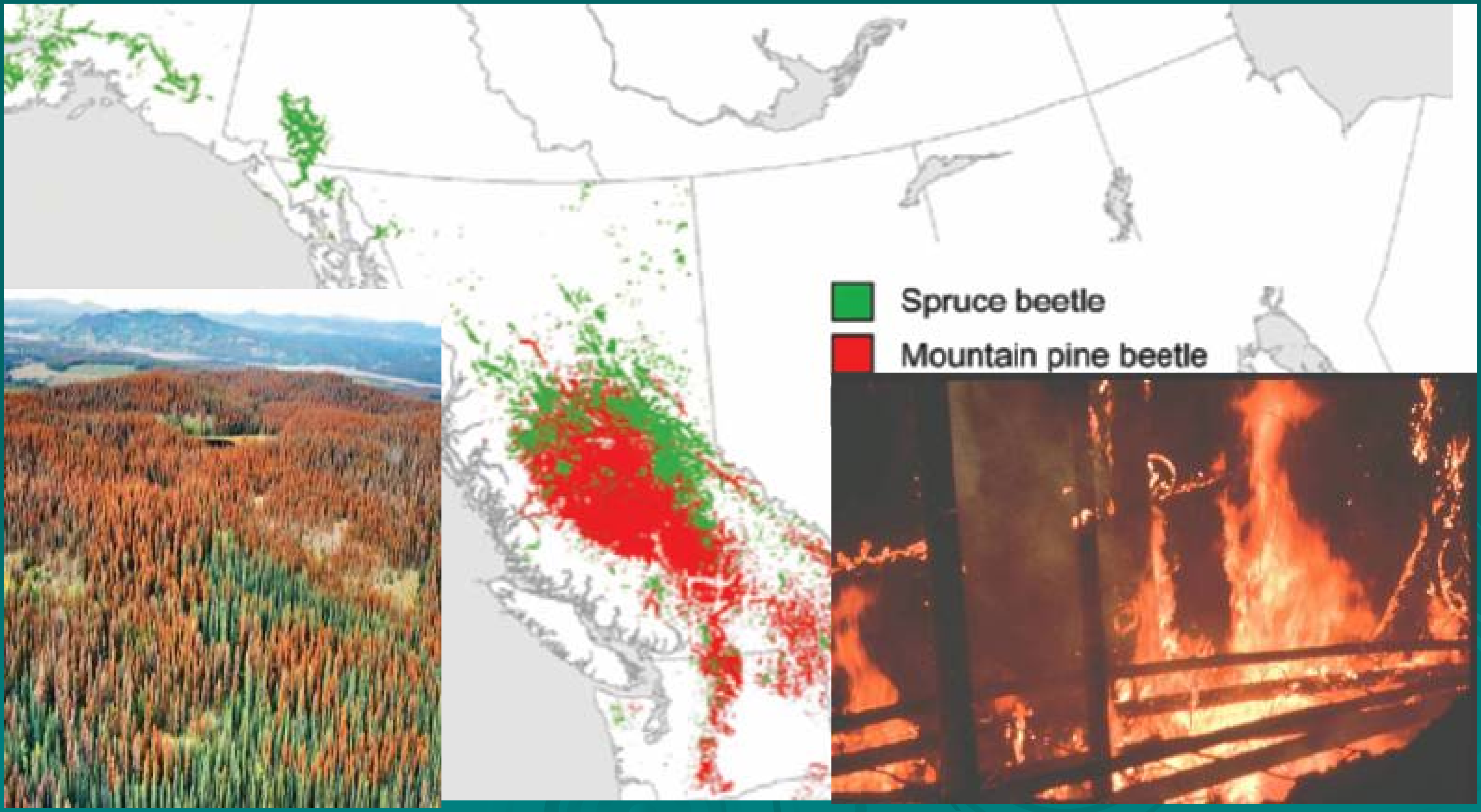
- MAT warming by 3 to 5°C by 2100.
- Winters warming faster than summers.
- Lakes and rivers ice-free earlier in spring, at least the larger bodies of water freezing over later in winter.

Precipitation

- P up 9-18% by 2100, mostly in winter generally; decreasing summer P in southern 1/2 province.
- Declining snowpack, ultimately in most parts of province.
- Changing snowpack; more frequent thaw-freeze events>>denser snow with more crusts and icy layers.
- Declining summer streamflows in many snow-dominated systems>>warmer water. Glacier-fed rivers the opposite, for as long as ice lasts.
- Amplification of hydrological cycle>>increased cloudiness, latent heat fluxes, & more frequent climate extremes. ↑ risk of drought, heat waves, intense P events and flooding.

Changing Disturbance Regimes

- As agents of change, shifting disturbance regimes & patterns could become as important as increasing T and changing levels of P.
- Landscape-scale disturbances & extreme weather events could determine character of transient and ultimate new ecosystems.



Natural Disturbances

- Insects & fungal diseases - ↑ #, variety, outbreak frequency, influence on forest dynamics
- Wildfire - ↑ #, area burned, severity, fire season length
- Wind - ↑ intensity atmos. convective processes>> ↑ freq & intensity of windstorms
- Invasive species - ↑ #, impact
- ↑ More frequent extreme events—floods, windstorms, deluges, droughts, wildfires, avalanches, landslides
- Disturbance interactions & uncertainty

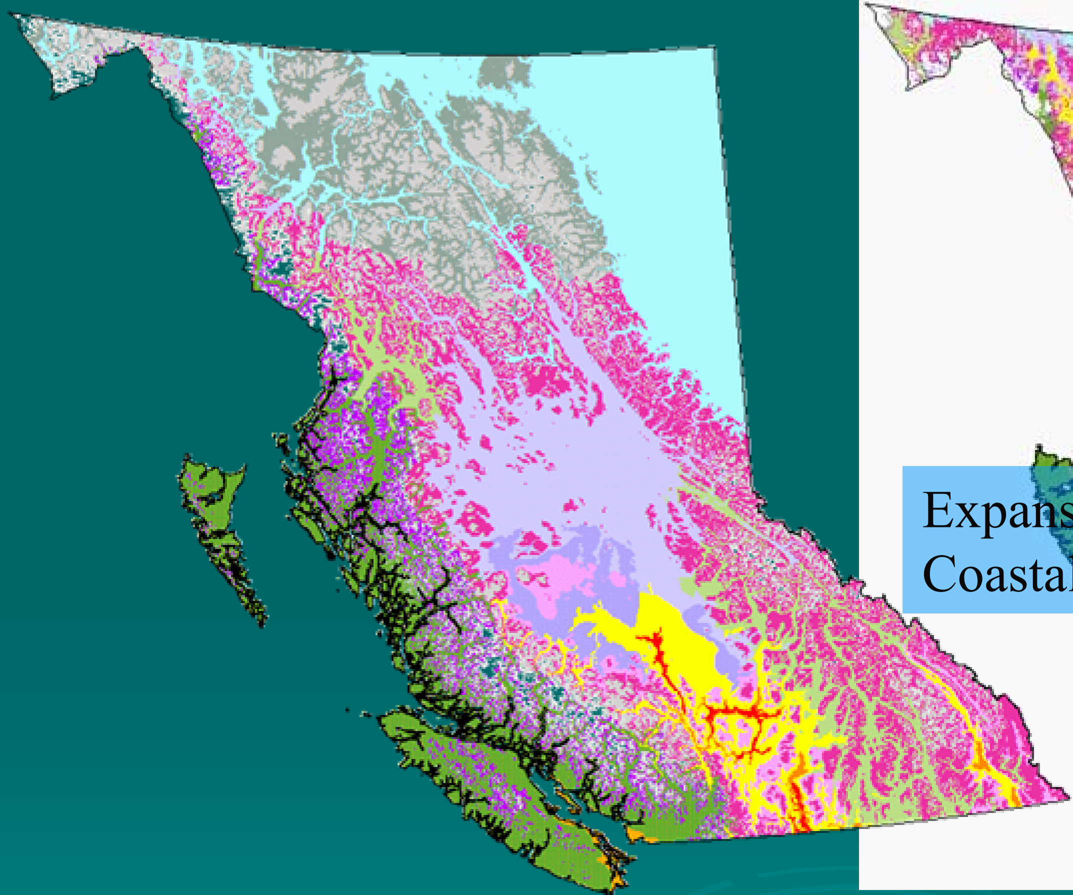
Swiss Fire *BCFS*

Expect Surprises

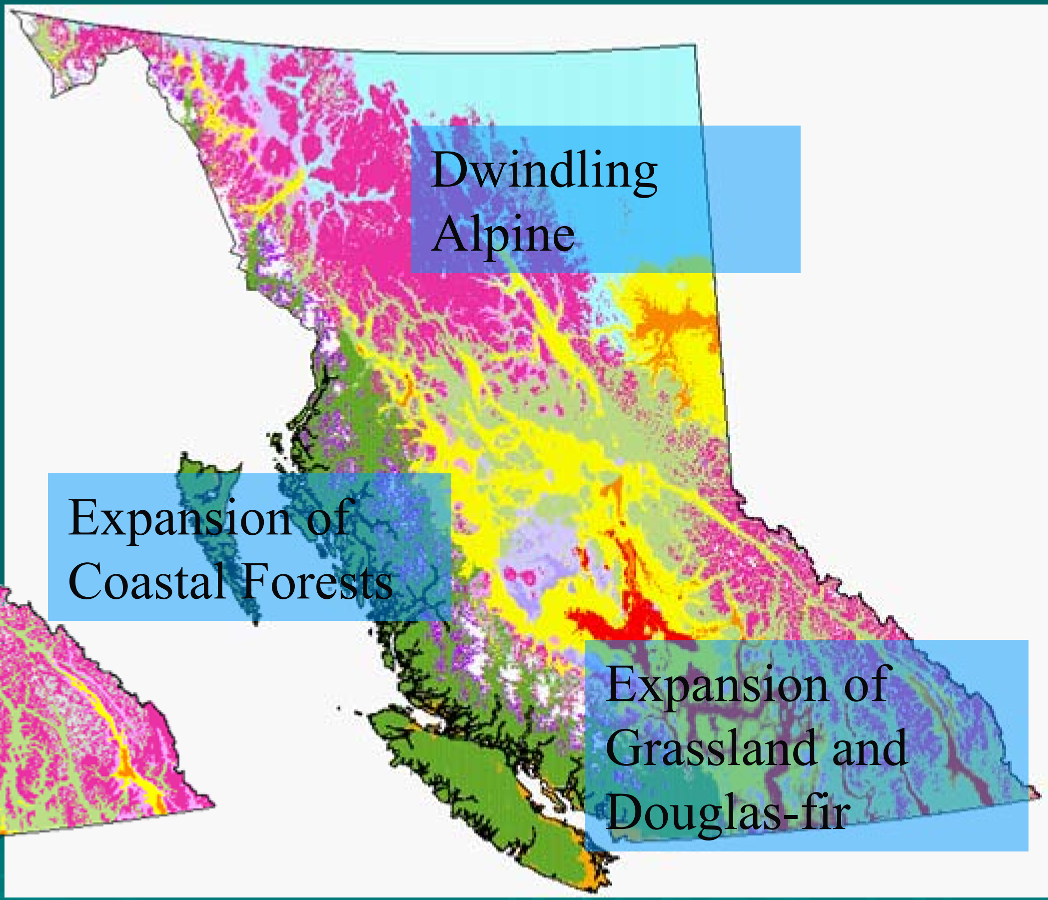
willow stem borer *J. Pojar*

Dothistroma
Kispiox Valley

Shifting Bioclimates



Current

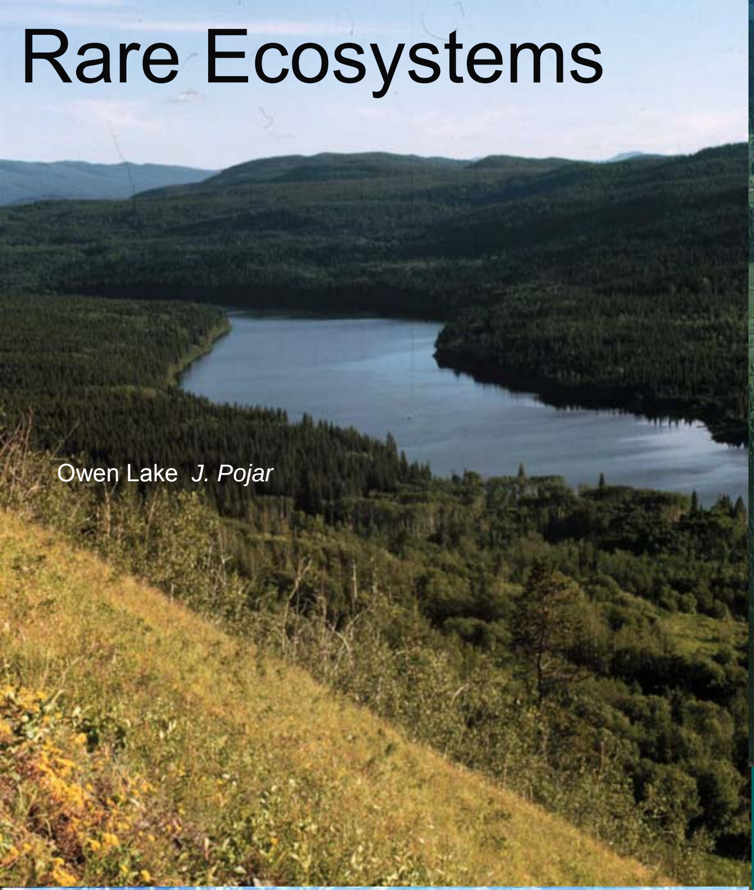


2050

Hamman, A. and T. Wang. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. **Ecology** 87: 2773-2786.

Landscape-level Implications

Rare Ecosystems



Owen Lake *J. Pojar*

Finlay Lk patterned fen *W. Mackenzie*

Nanika Valley *J. Pojar*

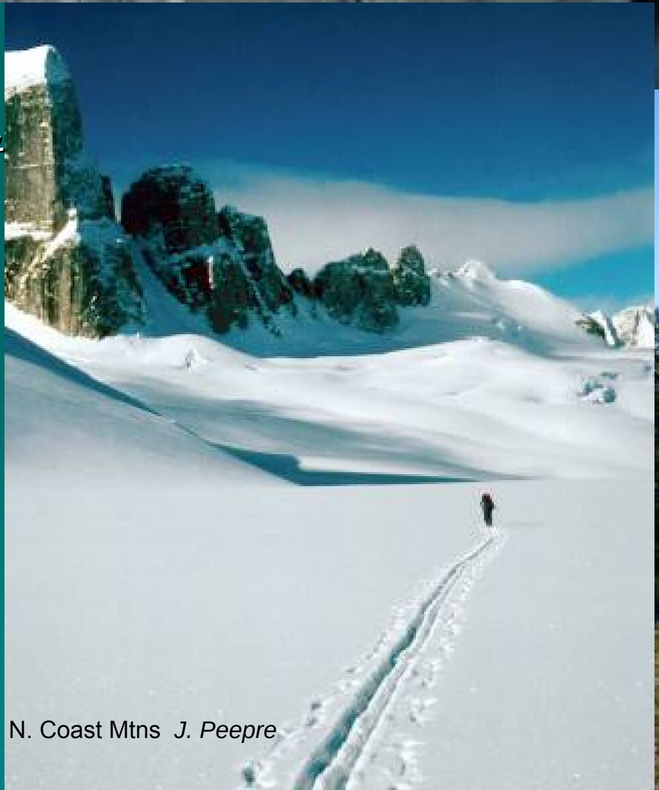
Pa-Pl-Bl-Hm

Old Man Lk from China Nose *J. Pojar*

Tulsequah Glacier *M. Geertsema*

Nadina Mtn *J. Pojar*

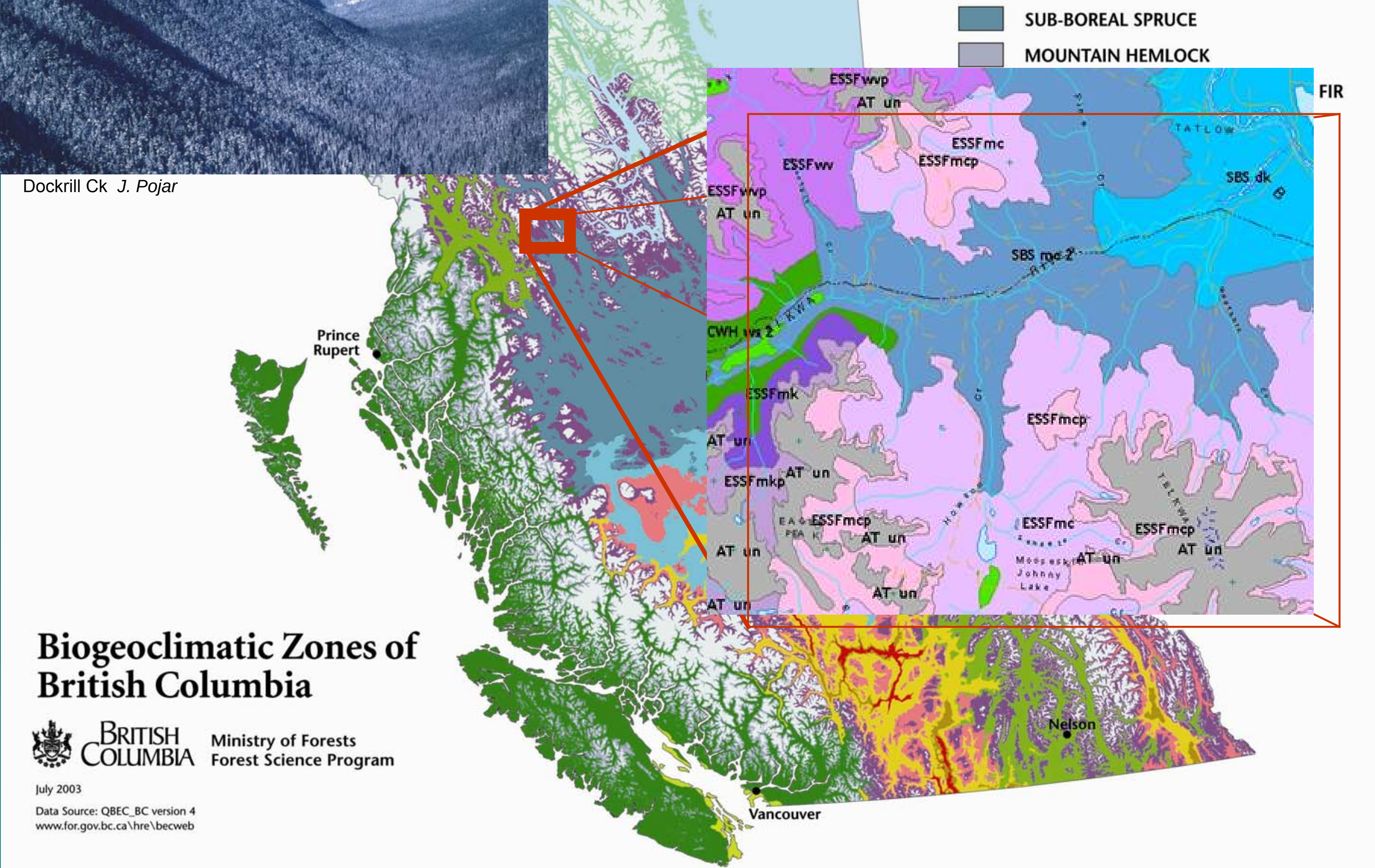
alpine zone, glaciers & icefields dwindle; subalpine forests shift upwards



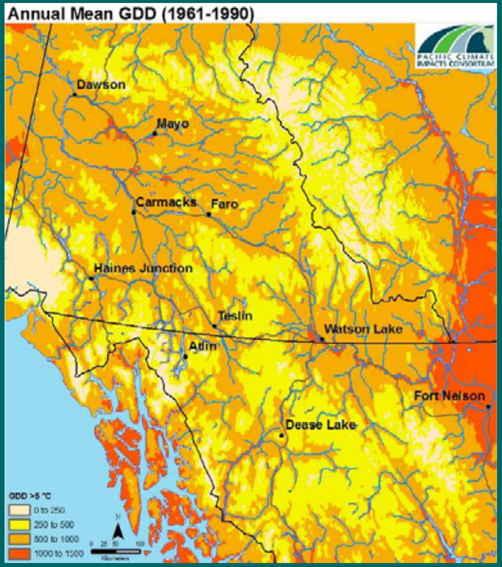
N. Coast Mtns *J. Peepre*

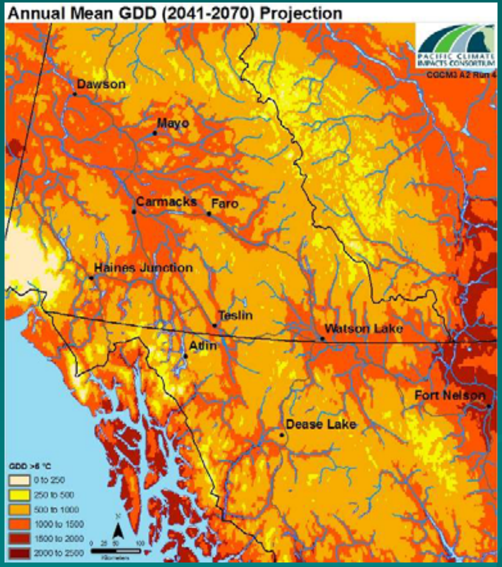
Howson Rge from microwave *J. Pojar*

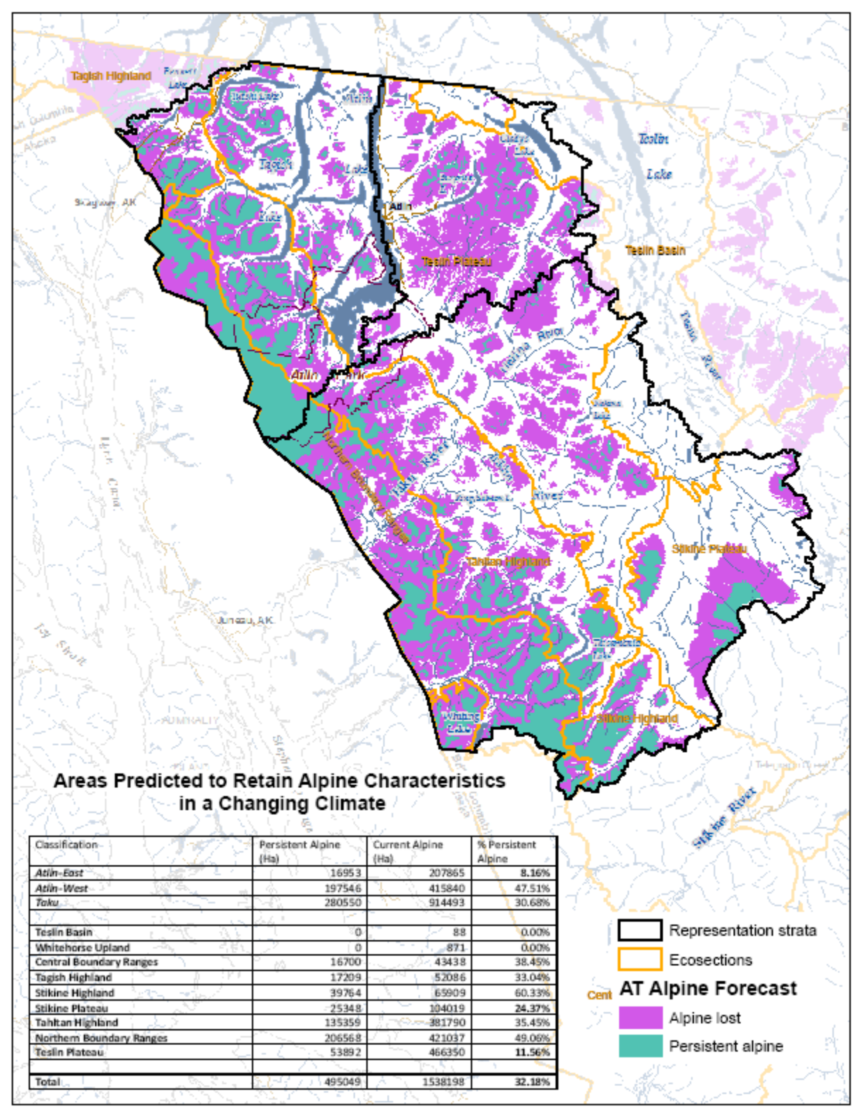
Dockrill Ck *J. Pojar*



Down-scale Climate Change Maps

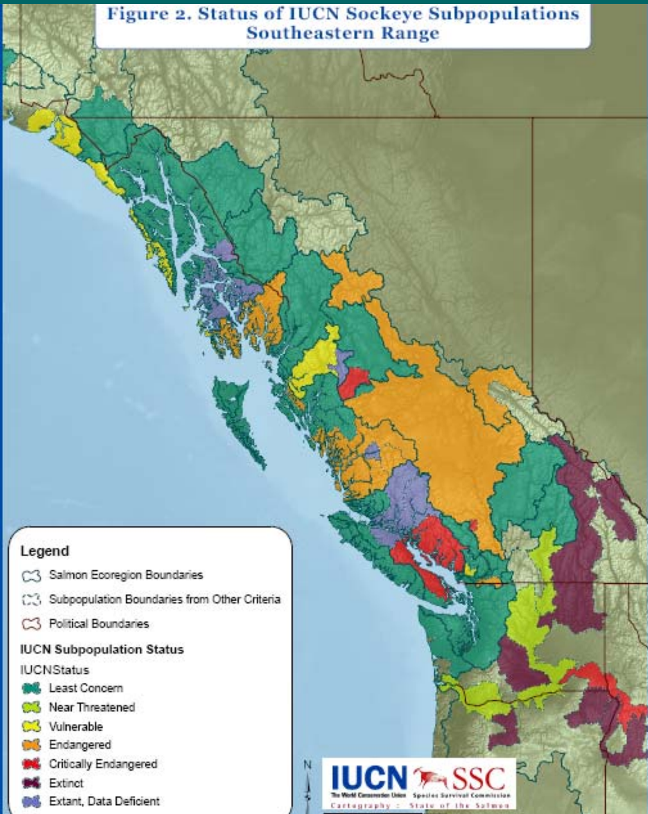






Areas Predicted to Retain Alpine Characteristics in a Changing Climate

Classification	Persistent Alpine (Ha)	Current Alpine (Ha)	% Persistent Alpine
Atlin-East	16953	207865	8.16%
Atlin-West	197546	415840	47.51%
Taku	280550	914493	30.68%
Teslin Basin	0	88	0.00%
Whitehorse Upland	0	871	0.00%
Central Boundary Ranges	16700	43438	38.45%
Tagish Highland	17209	52086	33.04%
Stikine Highland	39764	65909	60.33%
Stikine Plateau	25348	104019	24.37%
Tahltan Highland	135359	381790	35.45%
Northern Boundary Ranges	206568	421037	49.06%
Teslin Plateau	53892	466350	11.56%
Total	495049	1538198	32.18%



D. Mackinnon

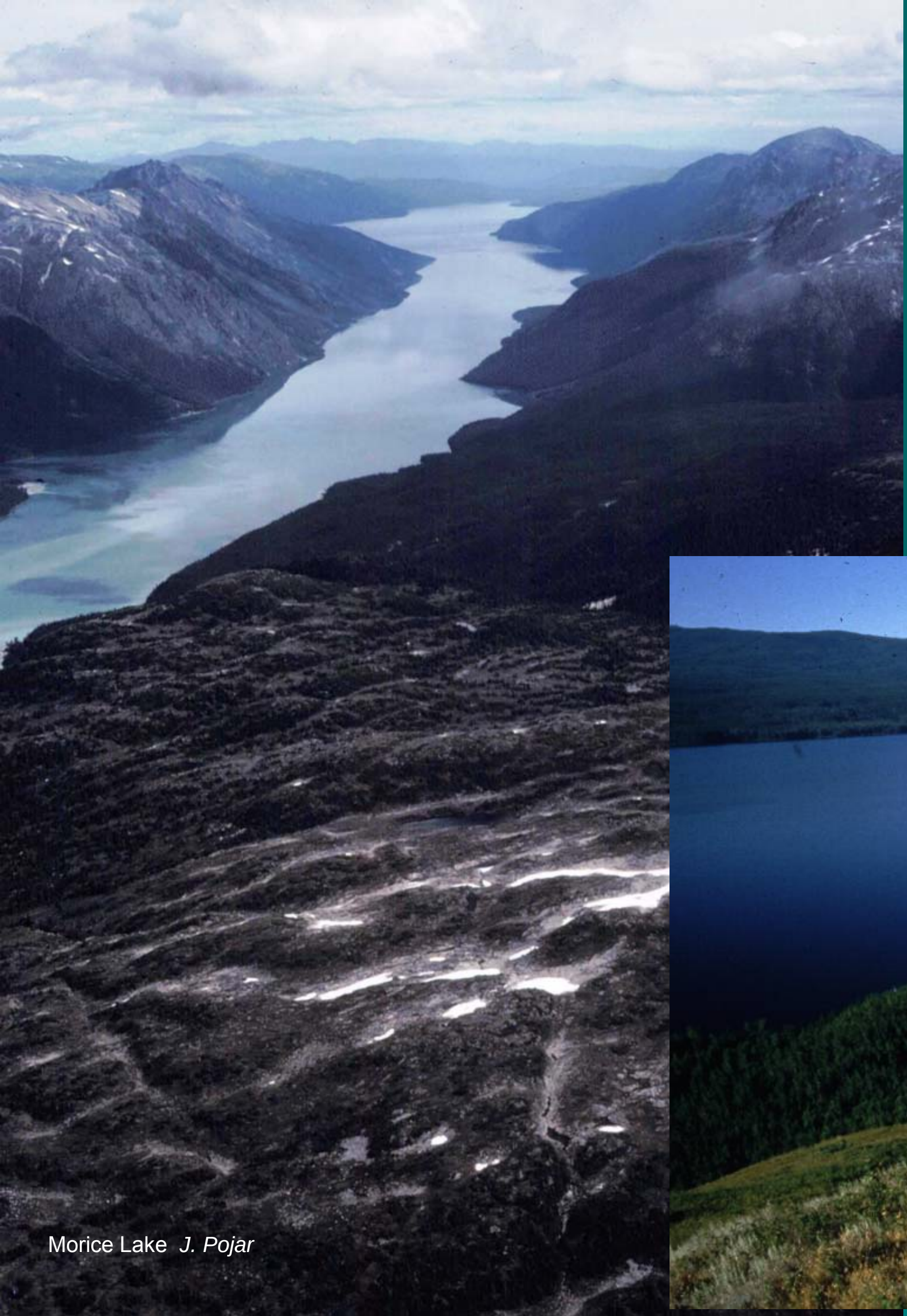
Implications

- ↑ Warmer water in rivers, lakes & ocean
- Cold-water fish decline
- Less snow, more rain (shoulder seasons) >>changes streamflow ---volume & timing
- Glacial systems differ … for a while

Skeena near Temlaham *J. Pojar*

Salmon Streams

- Two of B.C.'s largest rivers
- Large populations of spawning salmonids + steelhead
- Lake-headed salmon streams
- Water T of small lakes & streams such as Nadina, Maxan??



Morice Lake *J. Pojar*

Babine Lake, SE arm *J. Pojar*

*Real structured volumetric systems occupying relatively fixed earth spaces. Layered site-specific systems—a lake, a wetland, a particular landform-based forest—**into and out of which mobile organisms come and go.*** (Stan Rowe)

Figure 6. Changes in understory vegetation and growth of advance regeneration SBSmc2/01c-C10 from 2001 (top) to 2007 (bottom).

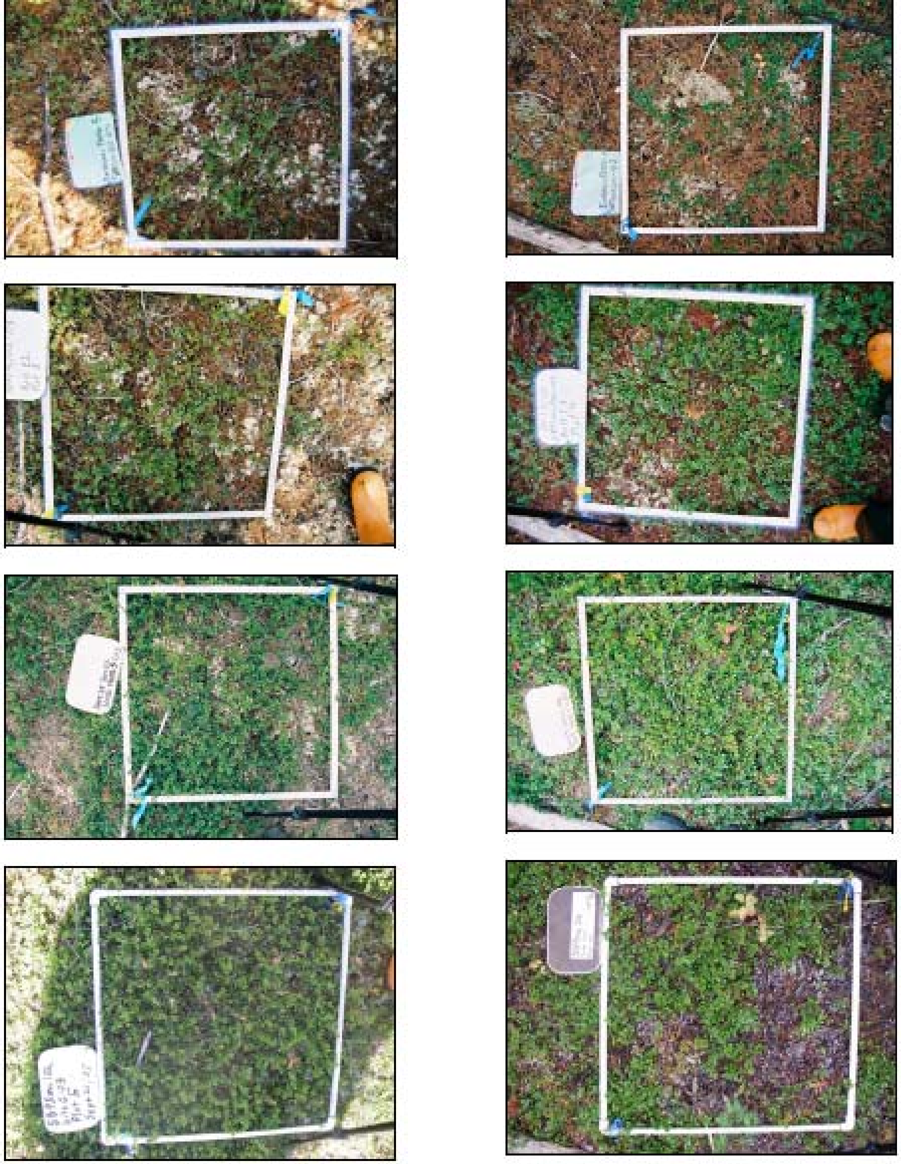


Figure 12. Examples of an increase in kinnikinnick from 2001 to 2007 (left) and an increase in kinnikinnick from 2001 to 2005 and then dieback from 2005 to 2007 (right).

Cichowski, D., P. Williston and S. Haeussler. 2008. The response of caribou terrestrial forage lichens to mountain pine beetles and forest harvesting in the East Ootsa and Entiako Areas. Annual Report – 2007/08 – Year 7. A report to Morice-Lakes Innovative Forest Practices Agreement, Prince George; Bulkley Valley Centre, Smithers; Ministry of Environment, Prince George. 46 p.

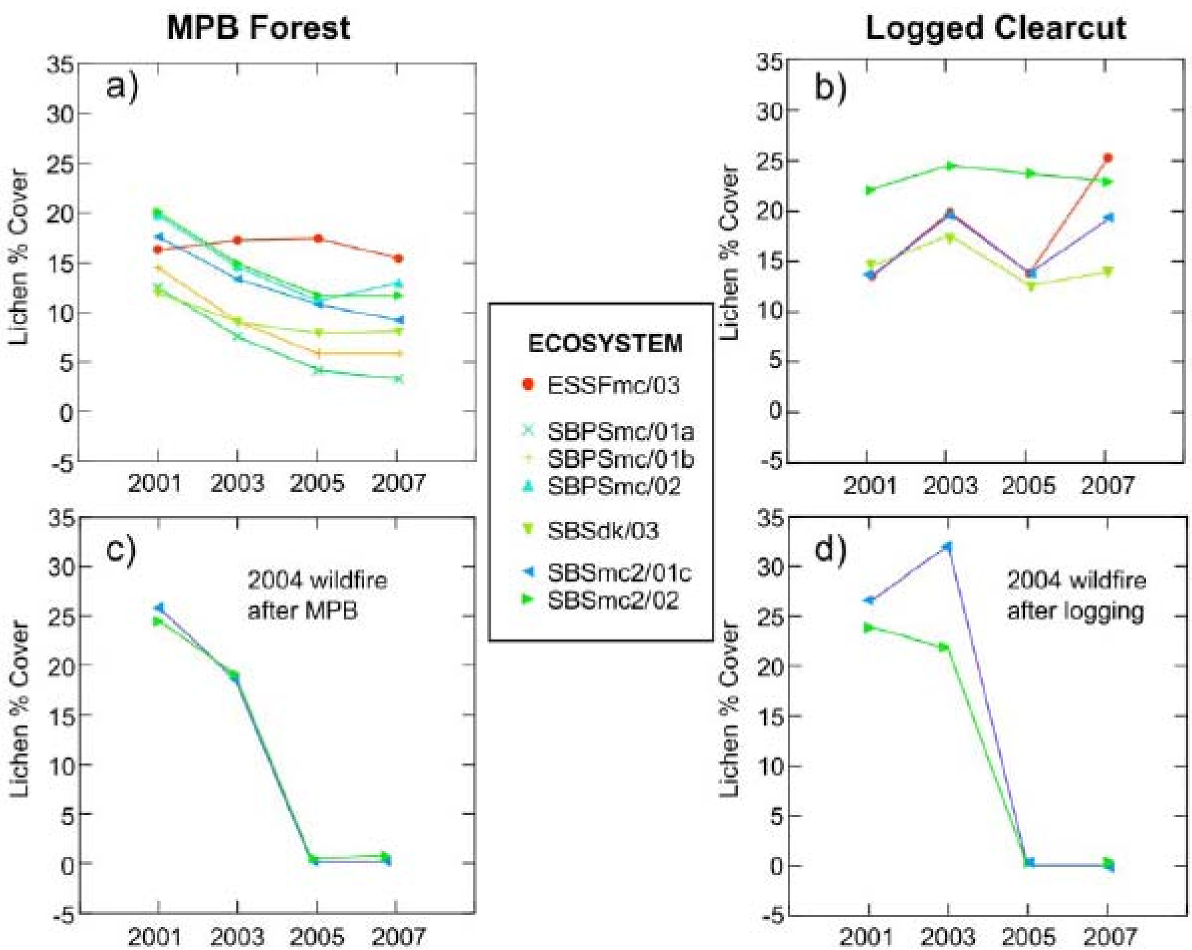


Figure 8. Changes in *Cladina* lichen abundance following mountain pine beetle, forest harvesting and fire disturbance in the East Ootsa and Entiako areas (2001-2007).

Spruce – Huckleberry

SBSmc

W. Hemlock – Step moss

ICHmc

Increased Ecosystem Productivity?

- Longer growing season
- Warmer soils
- Faster decomposition & nutrient cycling
- Elevated levels of CO_2 in atmosphere

But …

- Nitrogen limitation
- Increased moisture stress
- Danger of spring frost damage
- Genetic maladaptation

Ecological Upheaval

1) Ecosystems do not migrate, species do—largely independently.
2) Species confronting rapid environmental change will either a) go extinct or b) survive ----by acclimatizing, evolving, or migrating to suitable habitats elsewhere.
3) Most species cannot move fast enough to keep up with projected changes.

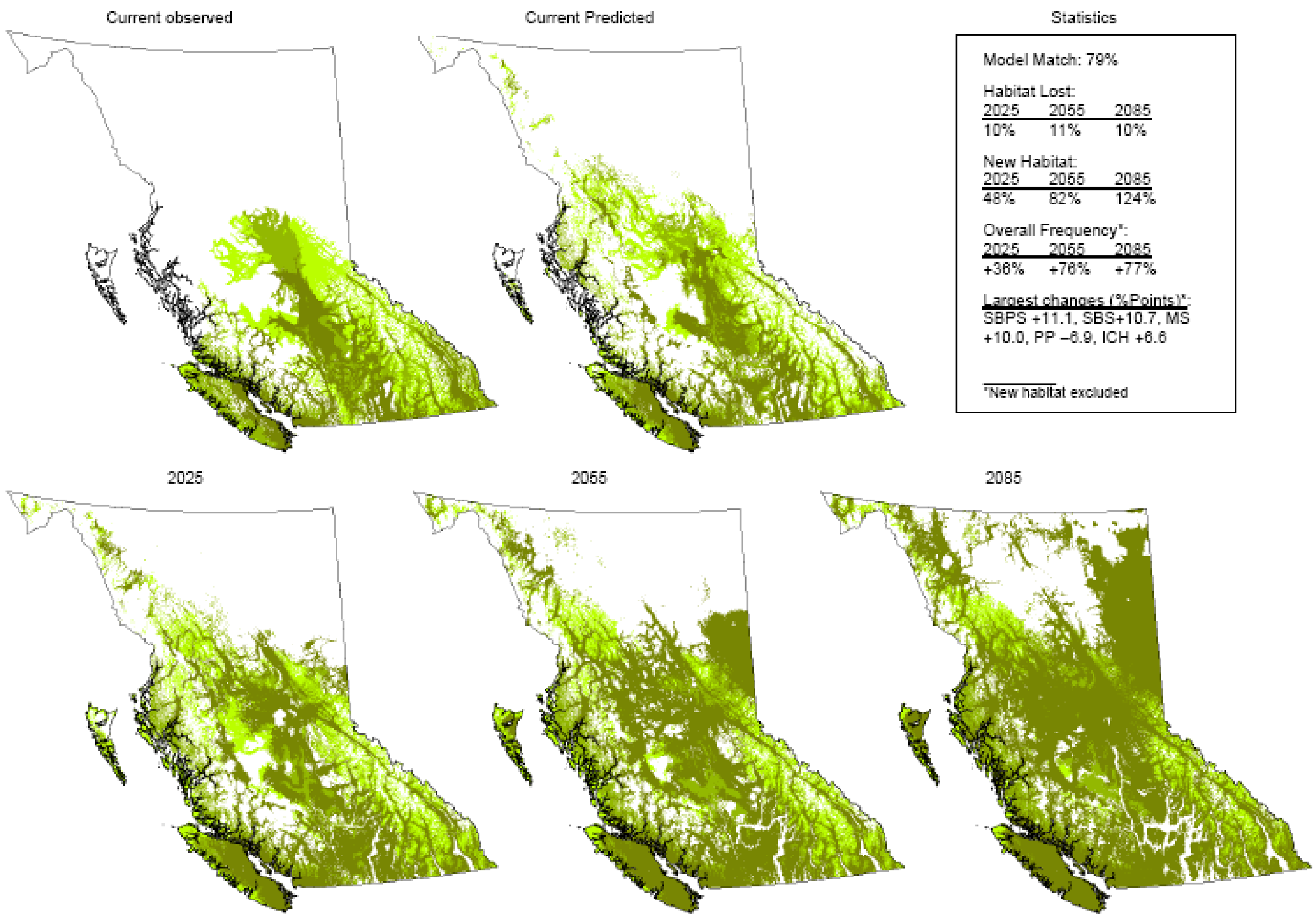
Species-level Implications

- Native species—many will decline, others will increase, some will be lost from the province, some will be new immigrants.
- A few species could stay put. Most species will move—if they can—individualistically; will reassemble in suitable habitats elsewhere, likely in different combinations, some novel.
- Weedy, introduced, invasive species are increasing and will continue to do so.

Climate envelopes of tree species shift ↑ N and ↑up in elevation

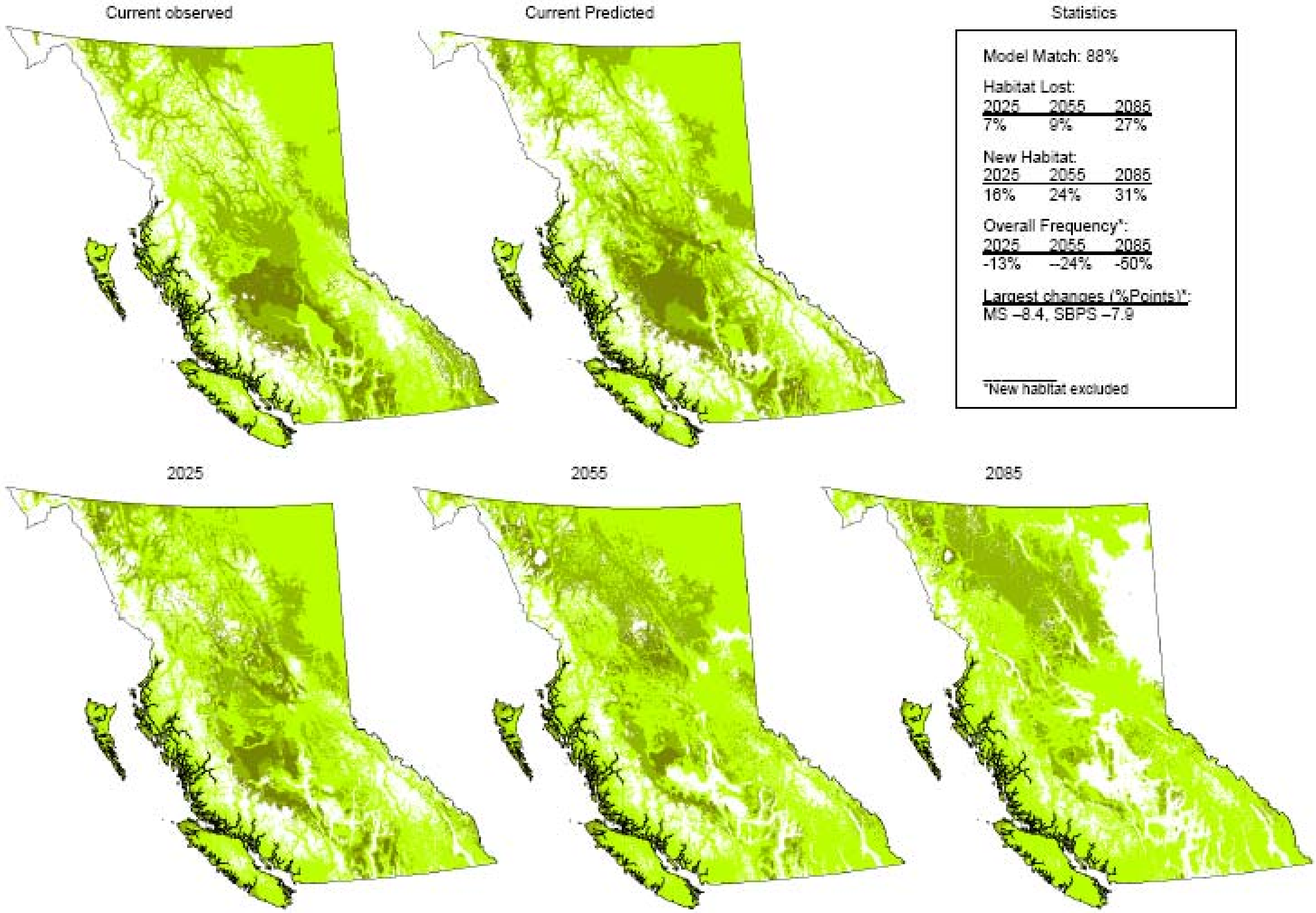
Douglas-fir

FIGURE C14. Observed and predicted range and frequency for *Pseudotsuga menziesii* (Mirbel) Franco - Douglas-fir (■ <5%, ■ 5-10%, ■ >10%).



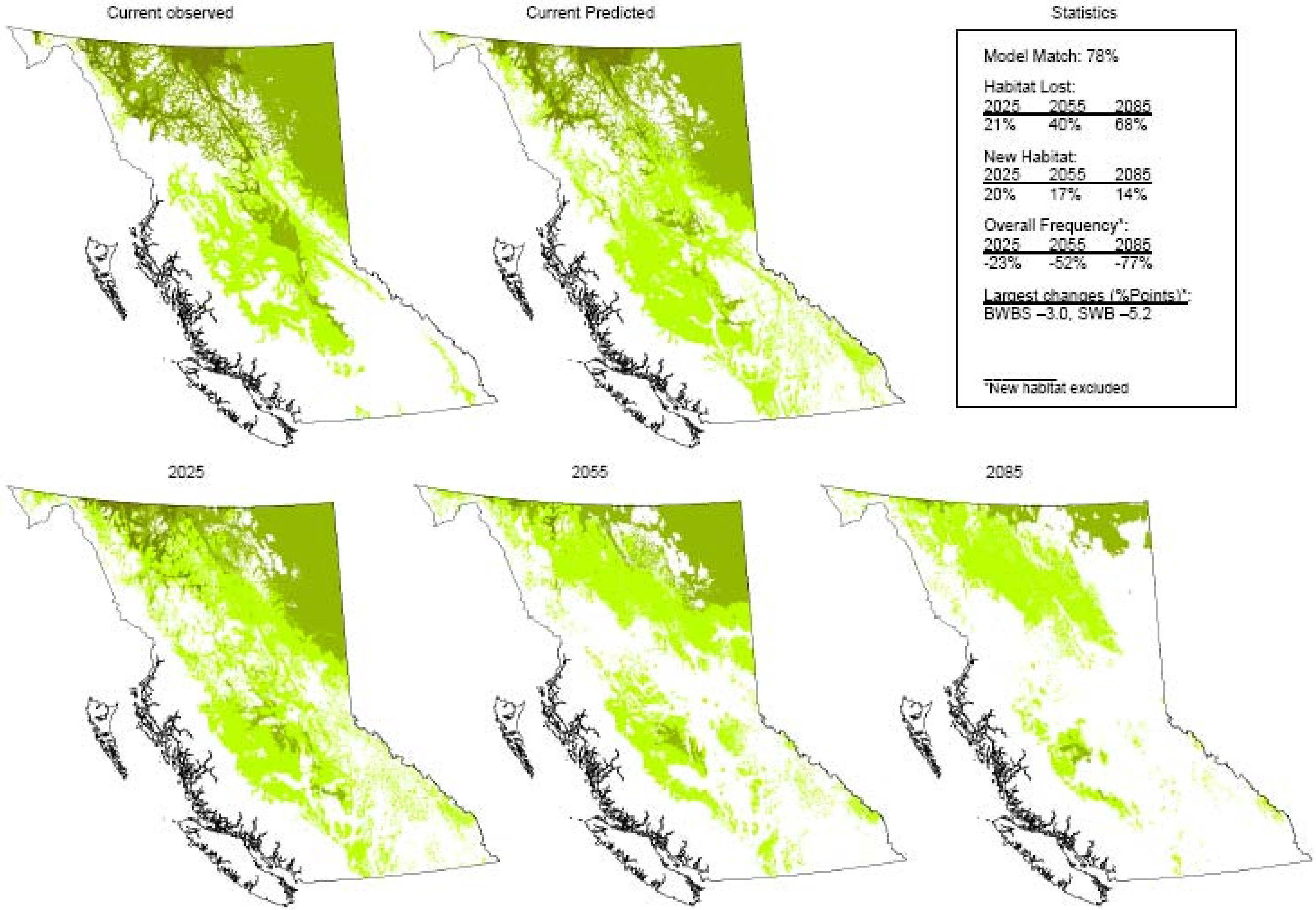
lodgepole pine

FIGURE C12. Observed and predicted range and frequency for *Pinus contorta* Dougl. - Lodgepole pine (■ <5%, ■ 5-10%, ■ >10%).



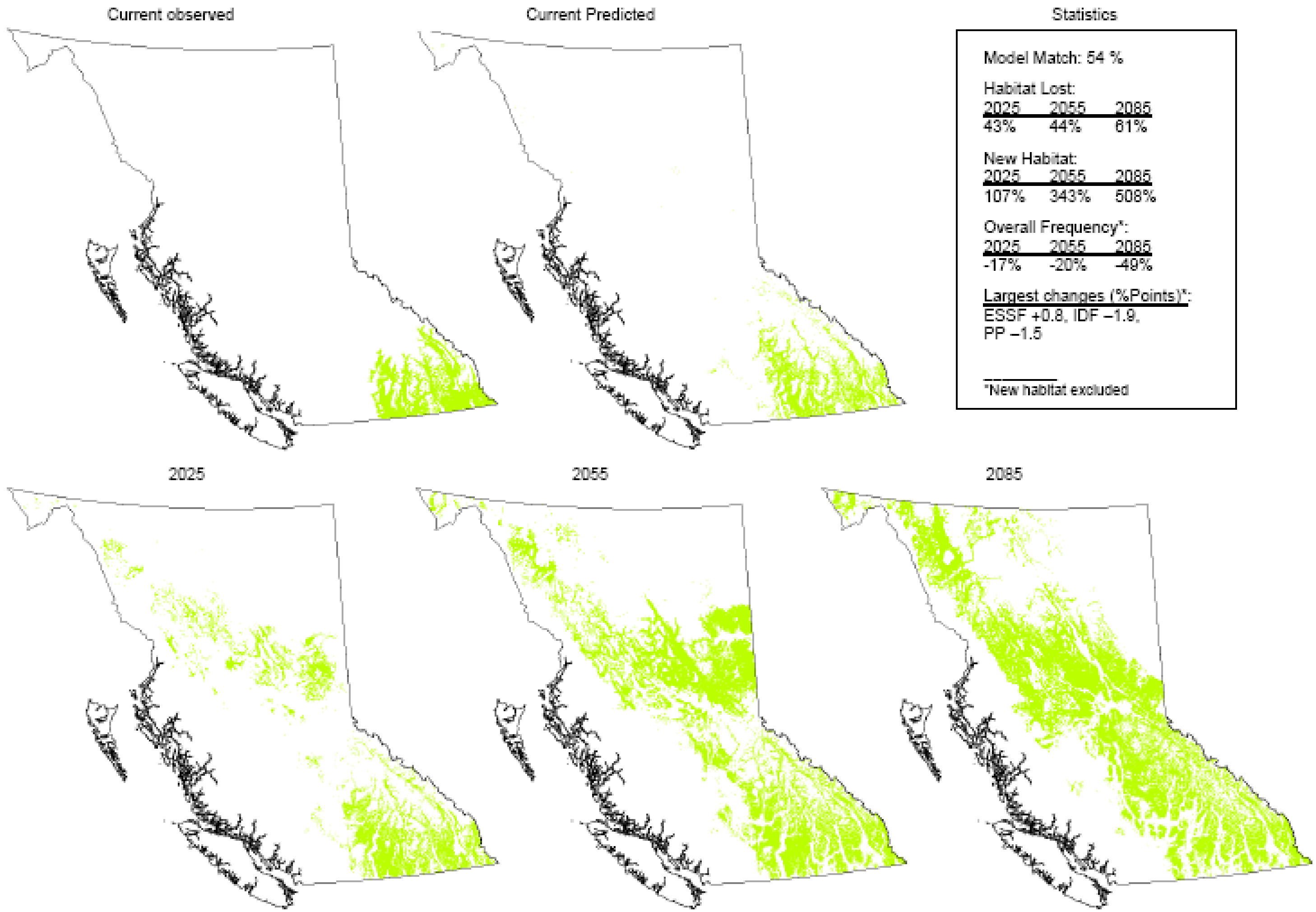
“white” spruce

FIGURE C11. Observed and predicted range and frequency for *Picea glauca* (Moench) Voss - White spruce (■ <5%, ■ 5-10%, ■ >10%).



western larch

FIGURE C10. Observed and predicted range and frequency for *Larix occidentalis* Nutt. - Western larch (■ <2%, ■ ≥2%).

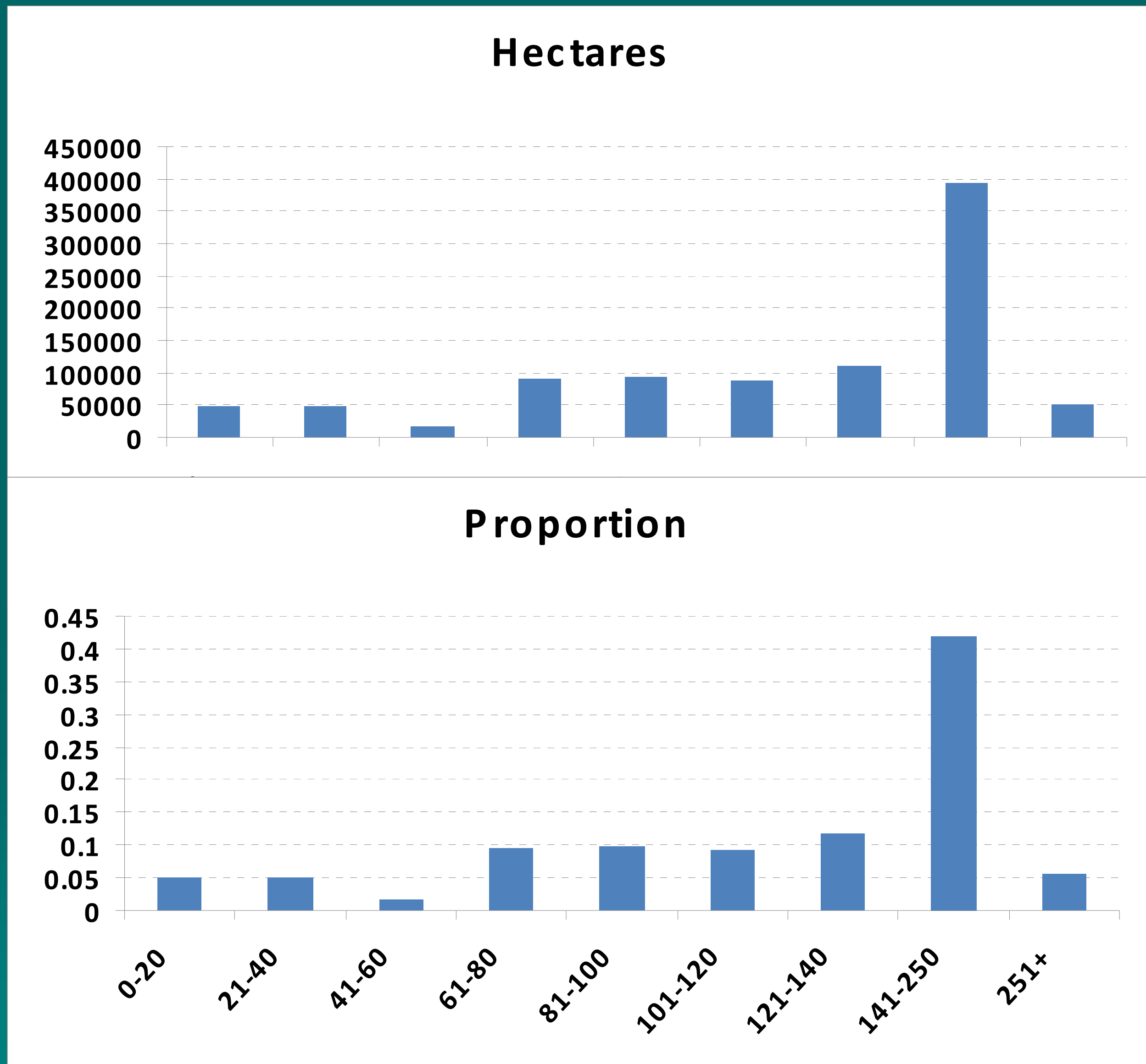


Back to Basics (silvics, autecology)

Assemble & evaluate the life history characteristics of key plant species (including trees)

- Mode of reproduction
- Pollination & dispersal mechanisms
- Response to disturbance; shade tolerance
- Pests and pathogens; herbivores
- Weedy syndrome

Nadina SBSmc circa 2008



Uncertain Future for Woodland Caribou

Fire Flats, Spatsizi Park *J. Pojar*

- changing snowpack, ↓↓availability ground lichens
- increased harassment by biting insects
- ‘trophic mismatch’ in rearing habitat
- less availability/suitability of lakes as winter escape terrain
- increased predation, by wolves (& cougars)
- plus increased mortality (hunting, collisions), stress, & costly avoidance behaviour because of increased access

W. Sawchuk

Adaptive Strategies of Trees

Trade-off between selection for high **growth** potential vs. selection for **hardiness** (high cold tolerance)

Each tree species has different **life history strategy**.

- white spruce: regeneration on a variety of seedbeds, shade tolerance, slow steady growth, extreme cold tolerance, abundant small light seeds that disperse widely

& different **genetic architecture**.

>>Individualistic responses to change

Specialists ↑↑genetic differentiation

- physiological processes attuned to a small range of environments
- phenotype controlled by genotype
- environmental variability & change accommodated by genetic variation .

Generalists ↑↑phenotypic plasticity

- physiological processes attuned to a broad range of environments
- phenotype controlled by environment
- environmental variability & change accommodated by phenotypic variation.

Most B.C. conifers are genetically specialised; Pw and Yc are plastic.

Genetic Implications

Climate warming big trouble for many genetically specialised B.C. conifers because:

- populations locally adapted: cc causes conditions to deteriorate throughout species' range, not just at margins; will push many populations beyond their physiological limits of temperature or moisture tolerances
- mortality induced by extreme events >> losses of genetic diversity
- rate of change too fast for adaptive tracking response by tree species with long generation times and life-spans

These factors could lead to significant genetic erosion and forest decline for several forest generations.

Long-lived specialists will have to migrate to survive, moving if possible to where suitable environments exist.

Genetic Implications

Generalists with lots of phenotypic plasticity will respond to climate change by "attempting" to ride it out within the bounds of their plasticity.

- Individuals of highly plastic species can tolerate wide range of environments, may be less sensitive to climate change.
- Eventually—when changes become intolerable—they too will have to evolve, or migrate but maybe not as far to survive.
- If generalists handicapped by low levels of genetic diversity, as in Pw and Yc, could be more susceptible to pathogens, esp. exotic pathogens like blister rust, or to things like freezing damage.


Big threat not cc acting in isolation; combination cc & other human footprints.
Red Chris exploration camp
Ecosystem responses complex & difficult to predict; reflect combined and synergistic effects of Δs climate, natural disturbances, land & resource uses, and invasive species.
Haida Gwaii
Finlay clearcut *W. Sawchuk*

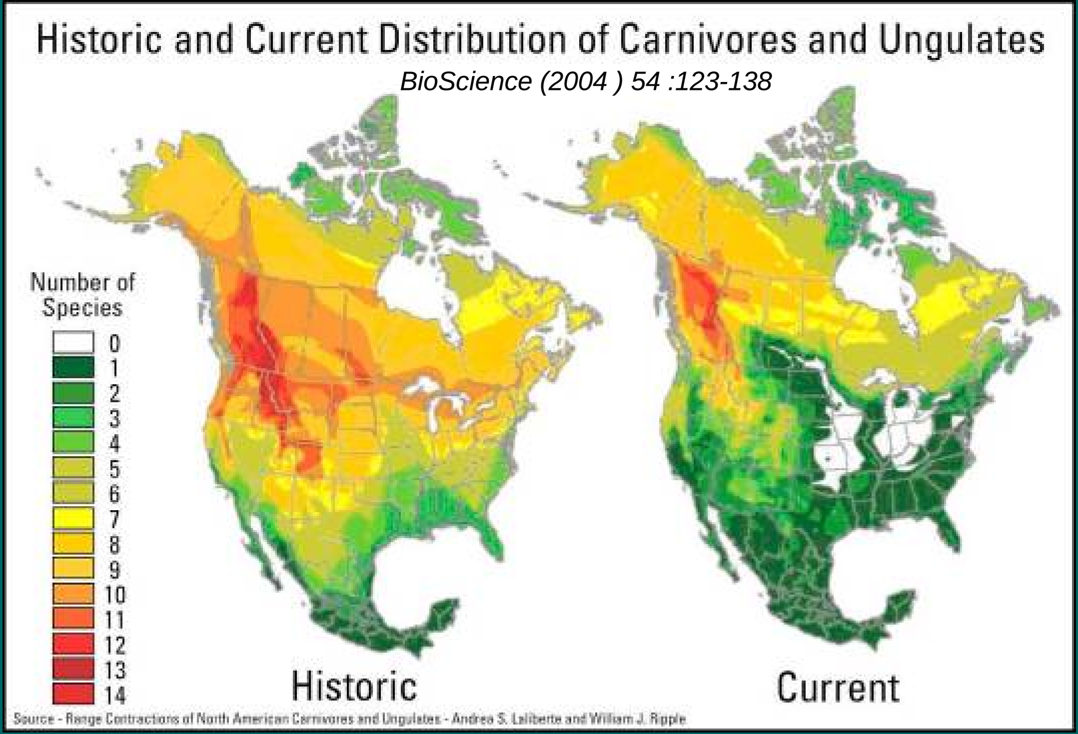
Global Responsibilities

Don't pee in swimming pool

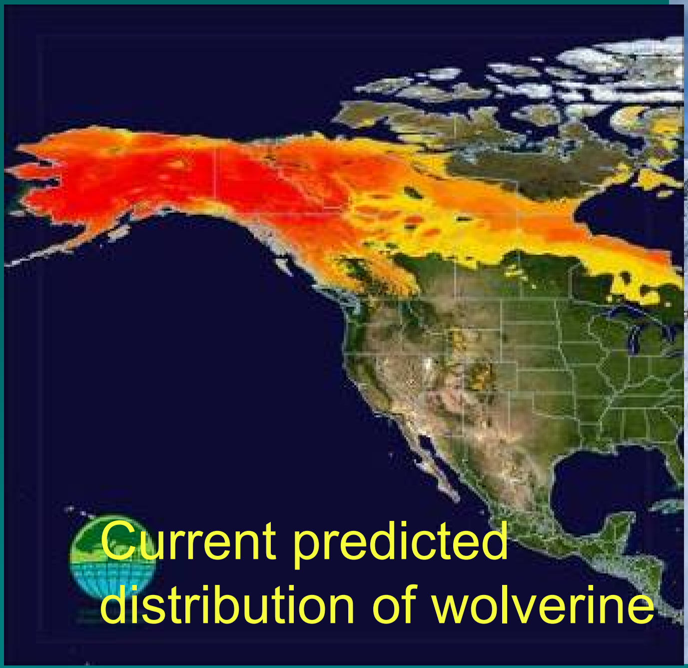
- Limit GHG emissions as our contribution to global reduction

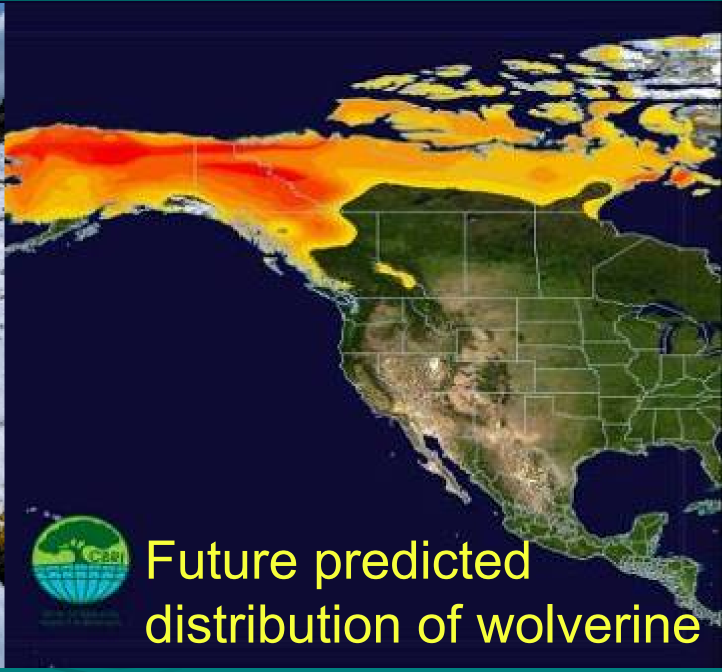
Global stewardship

- grizzly bears, temperate rainforests, wild clean rivers & wild salmon, rich marine ecosystems, endemic species, ecosystem diversity & landscape complexity



North American species ranges collapse toward British Columbia





What We Can Do

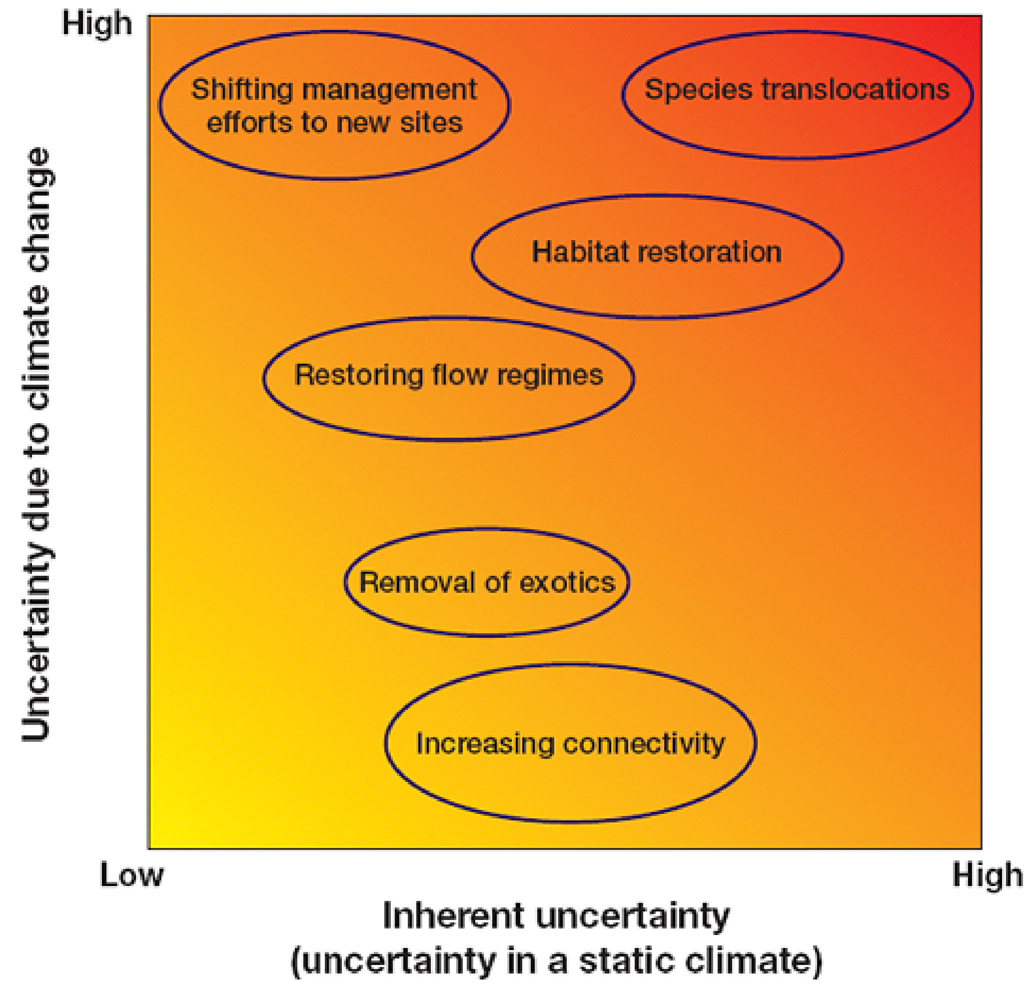
Technology Strategies

- *Mitigation*: get emissions of greenhouse gases (especially CO_2) down fast
- *Adaptation*: engineer infrastructure resilience (e.g., raise level of dikes)

Nature Strategies

- *Sequestration*: capture & store carbon in soils, trees, wetlands
- *Conservation*: sustain web of life/biodiversity; minimize species losses; maintain our Life Support System; optimize ecosystem services

Management Strategies and Uncertainty of Their Outcomes



Lawler, J.J. et al. 2010. Resource management in an uncertain climate. Frontiers in Ecology and Environment 8: 34-43.

Scenarios, Risk Spreading & Conservation Strategies

1) Recovery scenario	Keep existing pops. alive *in situ* in key ‘refugia’ >> *maintain resilience* existing ecosystems
2) Stabilisation scenario	Establish species of lower & warmer elevations & latitudes; *directed transformation*
3) Runaway scenario	Facilitate natural movement of species across landscape; *self-organising transformation*
Regardless of scenario	Do the same thing generally, or for all occurrences of a given ecosystem >> *no regrets*

Revamped Nature Conservation

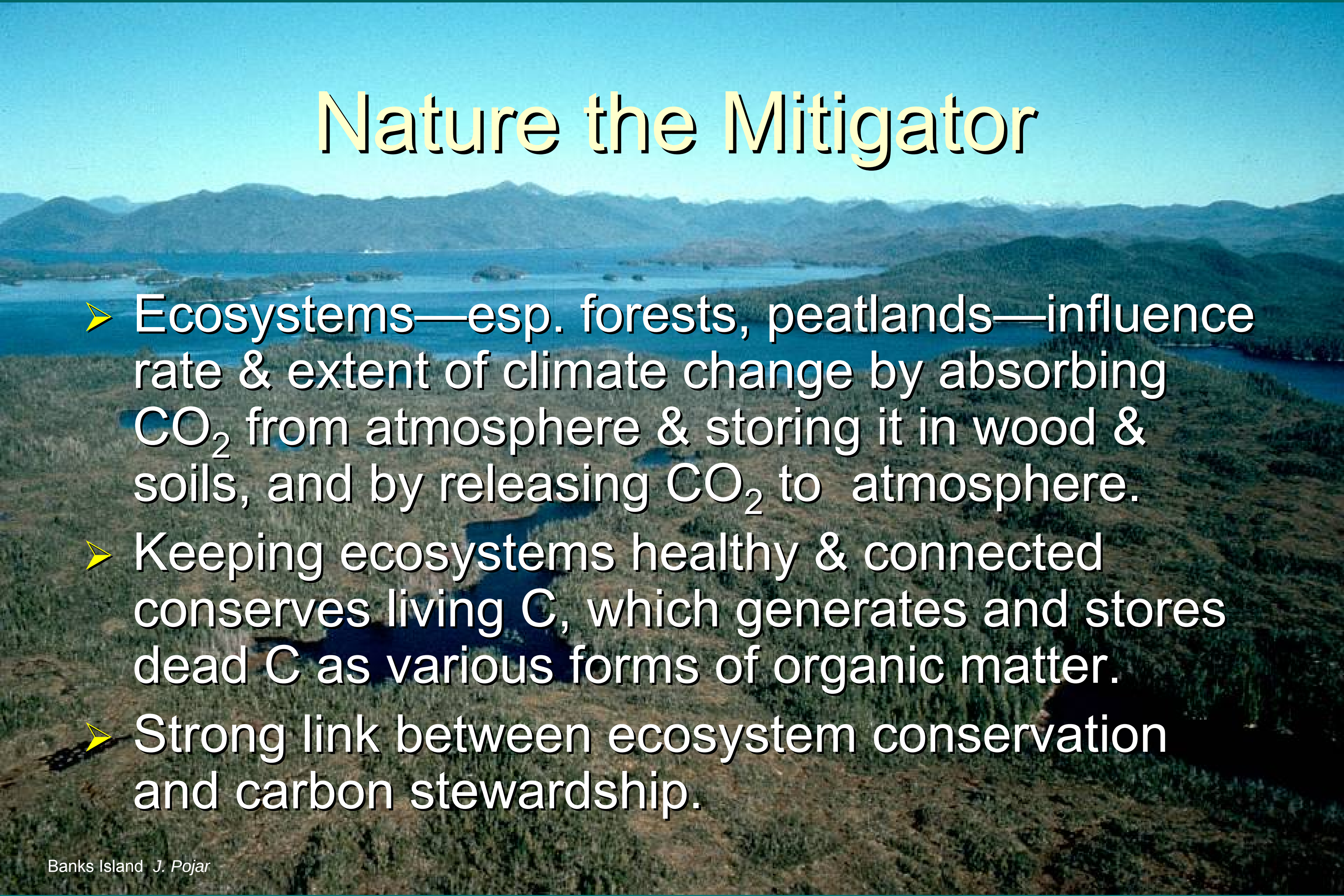
- Risk management approach of eco-portfolio diversification makes most sense.
- Reorientation from trying to maintain historical or *status quo* species distributions and abundances towards:

  a) maintaining well-functioning, resilient ecosystems of sometimes novel composition that continue to deliver ecosystem services;

  b) retaining a diversity of native species and ecosystems;

  c) triage (priorized treatment).

Nature the Mitigator



- Ecosystems—esp. forests, peatlands—influence rate & extent of climate change by absorbing CO_2 from atmosphere & storing it in wood & soils, and by releasing CO_2 to atmosphere.
- Keeping ecosystems healthy & connected conserves living C, which generates and stores dead C as various forms of organic matter.
- Strong link between ecosystem conservation and carbon stewardship.

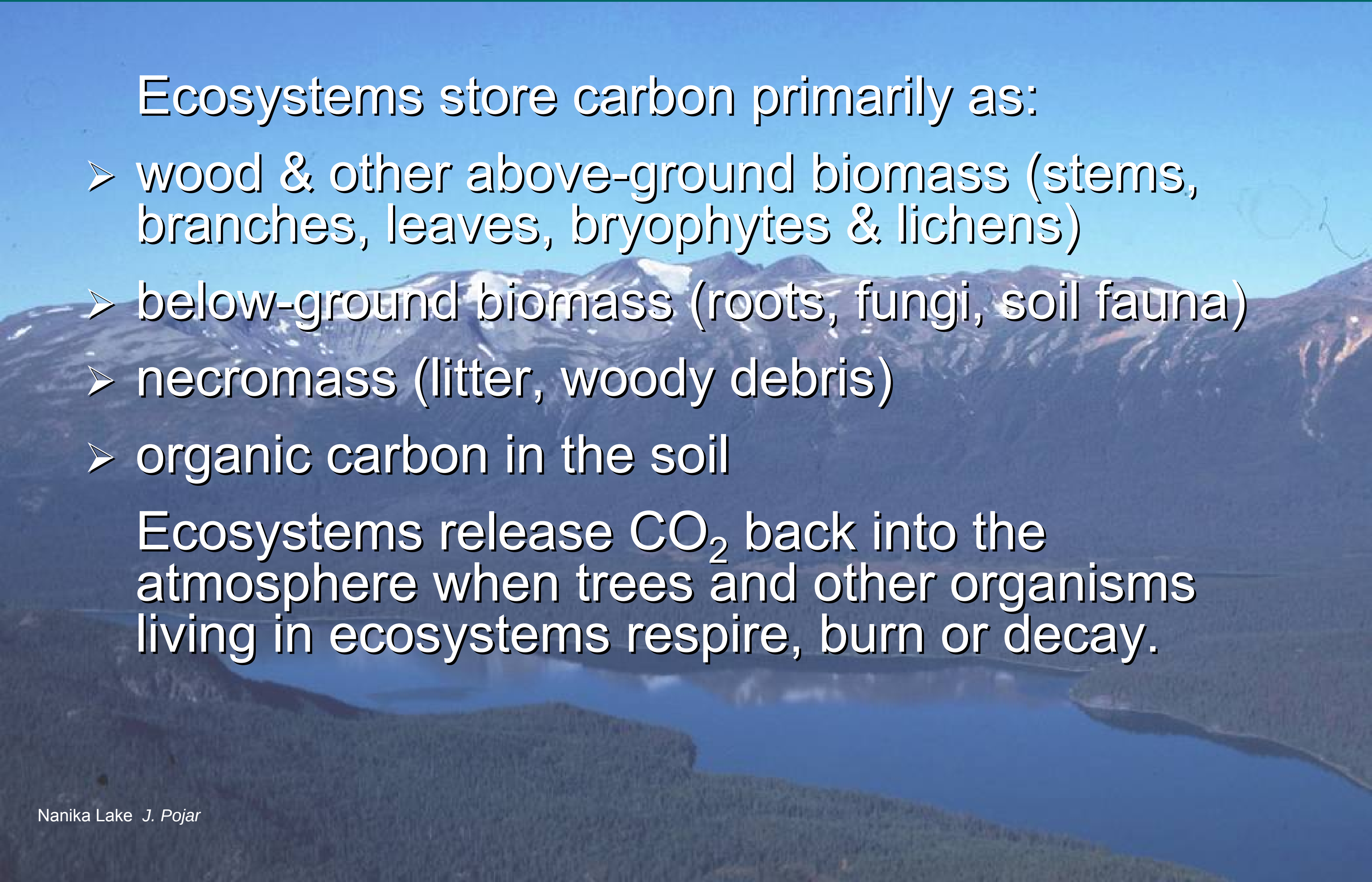
Banks Island *J. Pojar*

$6CO_2 + 6H_2O + \text{☼} <---> C_6H_{12}O_6 + 6O_2$

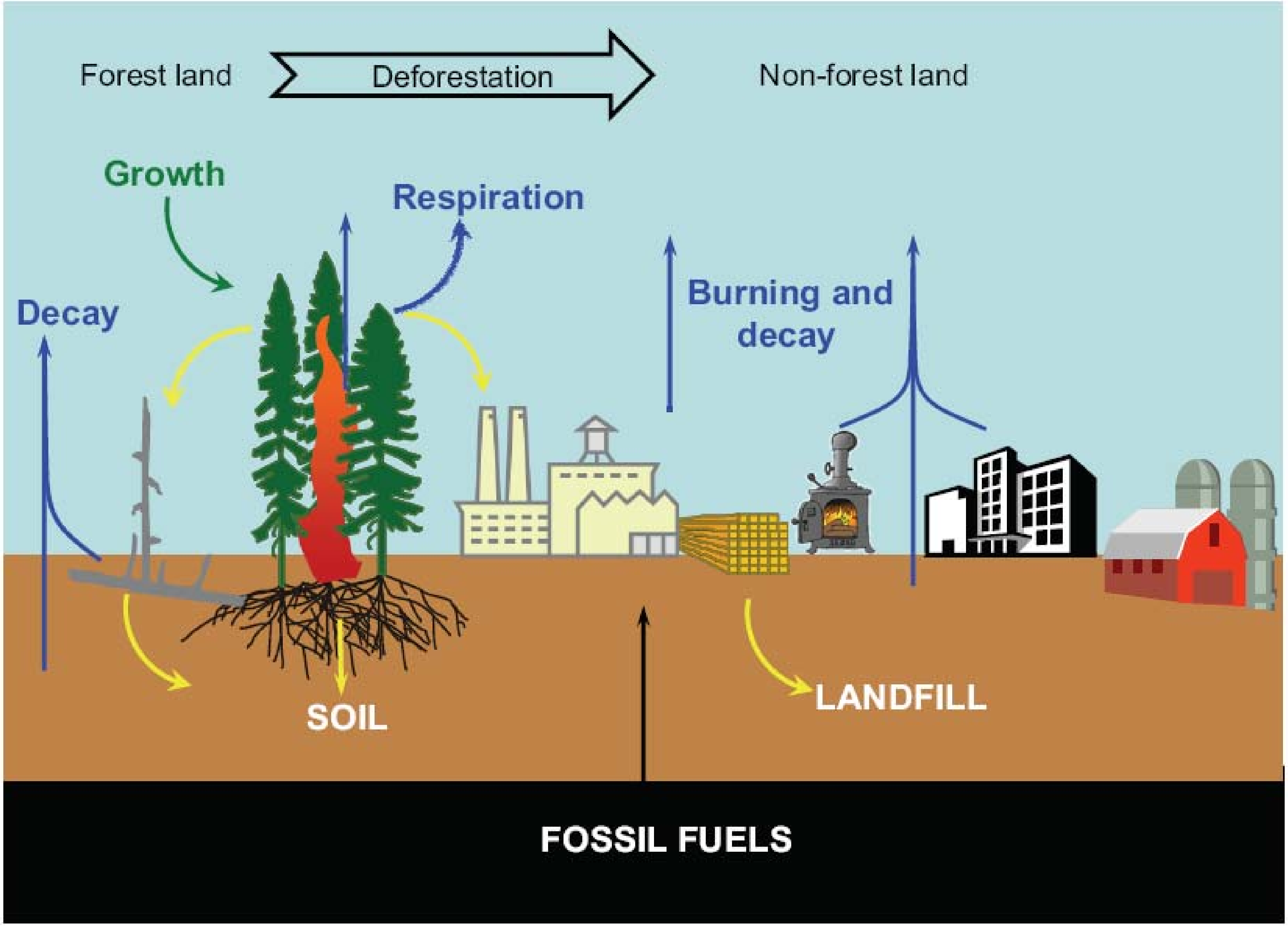
Ecosystems store carbon primarily as:

- wood & other above-ground biomass (stems, branches, leaves, bryophytes & lichens)
- below-ground biomass (roots, fungi, soil fauna)
- necromass (litter, woody debris)
- organic carbon in the soil

Ecosystems release CO_2 back into the atmosphere when trees and other organisms living in ecosystems respire, burn or decay.



Nanika Lake *J. Pojar*



C taken up from atmosphere as plants grow (green arrow). C released back to atmosphere (blue arrows) or transferred within ecosystem or to forest products industry (yellow arrows).

Grieg, M. & G. Bull. 2009. Carbon Management in British Columbia's Forests: Opportunities and Challenges. FORREX Series 24. *Image credit: C. Dymond & M. Apps*

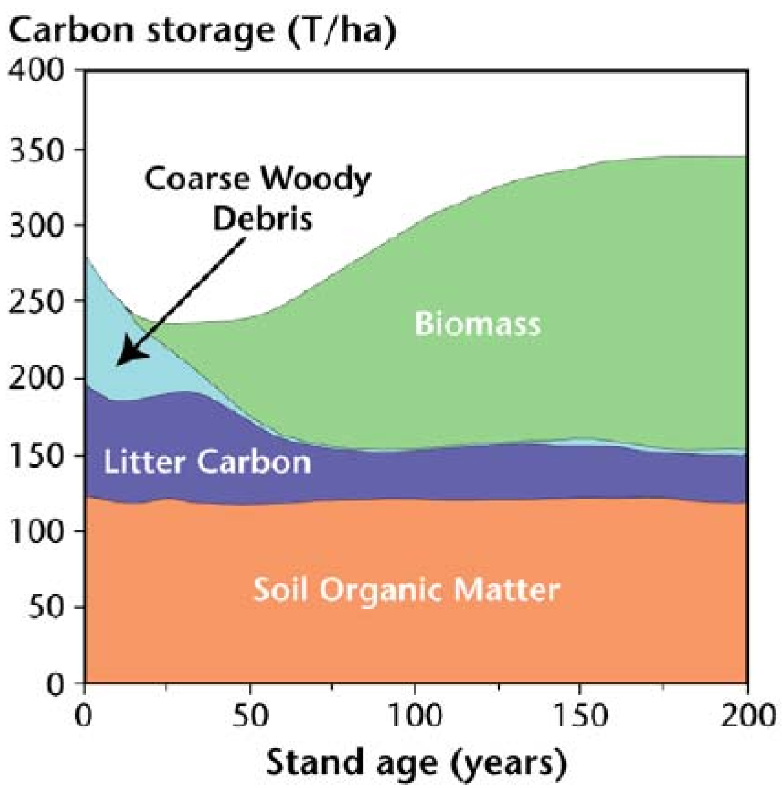


FIGURE 3 *Carbon storage of a forest stand in northeast British Columbia after fire; adapted with permission from B. Seely, Forest Ecosystem Management Simulation Group, University of British Columbia.*

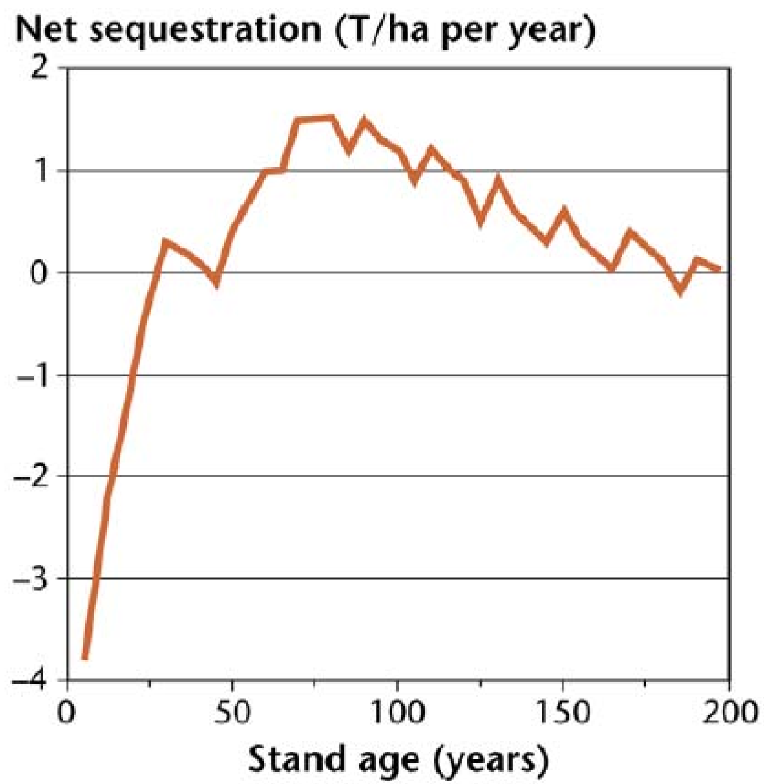
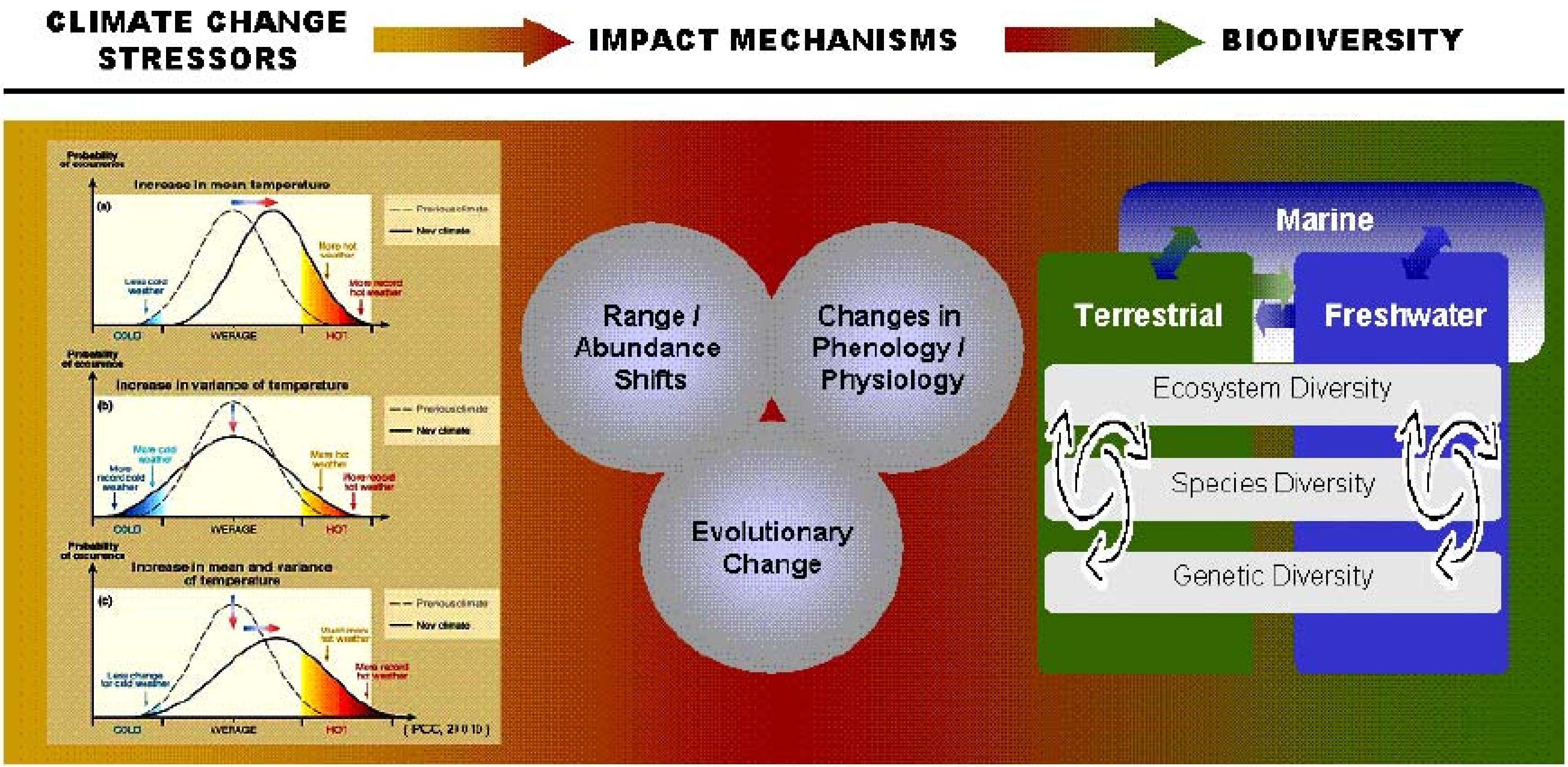


FIGURE 4 *Annual carbon sequestration of a forest stand in northeast British Columbia after fire; adapted with permission from B. Seely, Forest Ecosystem Management Simulation Group, University of British Columbia.*

Grieg, M. & G. Bull. 2009. Carbon Management in British Columbia's Forests: Opportunities and Challenges. FORREX Series 24.

Ecological Resilience

- The capacity of an ecosystem to tolerate disturbance without collapsing/shifting to a qualitatively different state that is controlled by a different set of processes *OR*
- To absorb disturbance, undergo change, and still retain essentially the same functions, structure, identity, and feedbacks *(unlikely given cc projections)*.



Compass Resource Management. 2007. An Assessment of Climate Change Impacts on Biodiversity Management in BC. Report prepared for the Biodiversity BC Technical Subcommittee, for the Report on the Status of Biodiversity in BC. 41 p.