R.G. Pike - Harris Cr. Vancouver Island

Potential Effects of Climate Change on Hydrology, Geomorphology and Aquatic Ecology in BC

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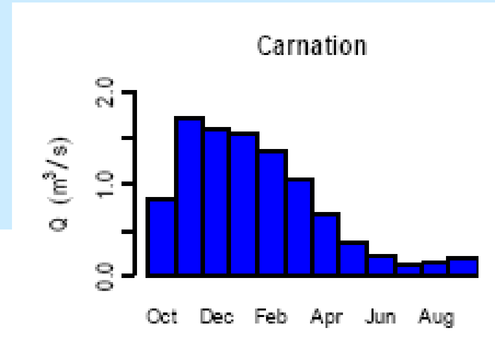
Talk Overview

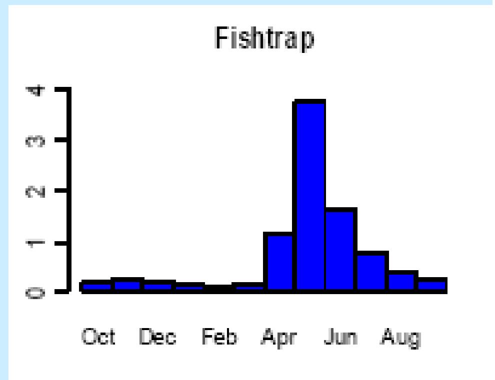
1. Background
   - Hydrologic Systems in BC
   - Projected Climate Changes
2. Hydrologic Changes and Implications
3. Geomorphic Changes and Implications
4. Aquatic Ecology Changes and Implications

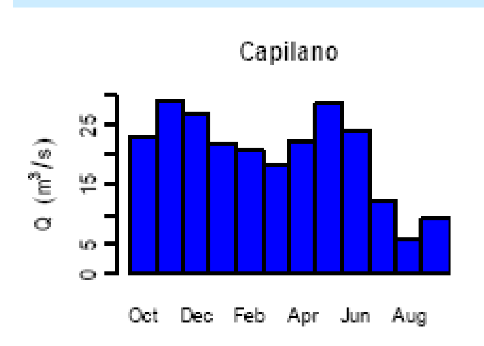
R.G. Pike: Russell Cr. Experimental Watershed.

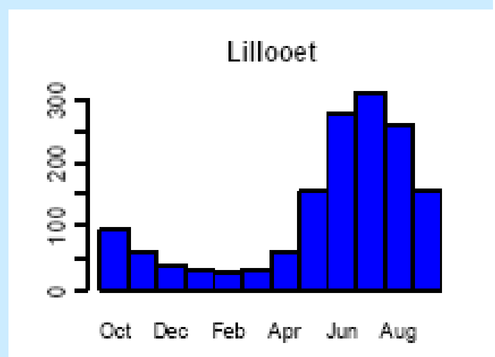
Hydrologic Systems in BC

1. **Rain-dominated regimes**
2. **Snowmelt-dominated systems**
3. **Mixed/hybrid regimes**
4. **Glacier-augmented systems**





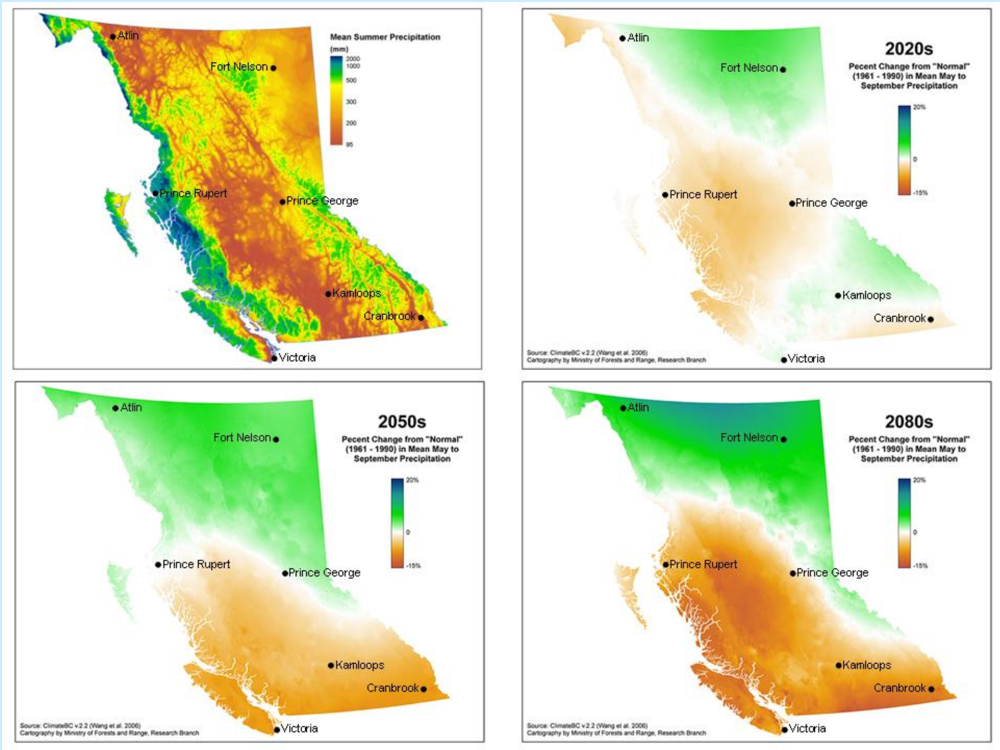




Images: Eaton and Moore 2007

What are the Projected Changes in BC Climate ?

- Increased winter and summer temperatures
- Greater warming in the north vs. southern BC.
- Wetter winters throughout BC.
- Dryer summers in Southern BC
- Wetter summers in northern British Columbia
- Increased intensity and amount of precipitation.
- Reduction in return periods of extreme events.



Source: Pike et al. 2008: pg 5

Part II - Hydrologic Changes and Implications

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Photo: R.G. Pike.

What are the Projected Hydrologic Changes for BC?

1) Increased atmospheric evaporative demand and vegetation changes

2) Decreased snow accumulation and accelerated melt

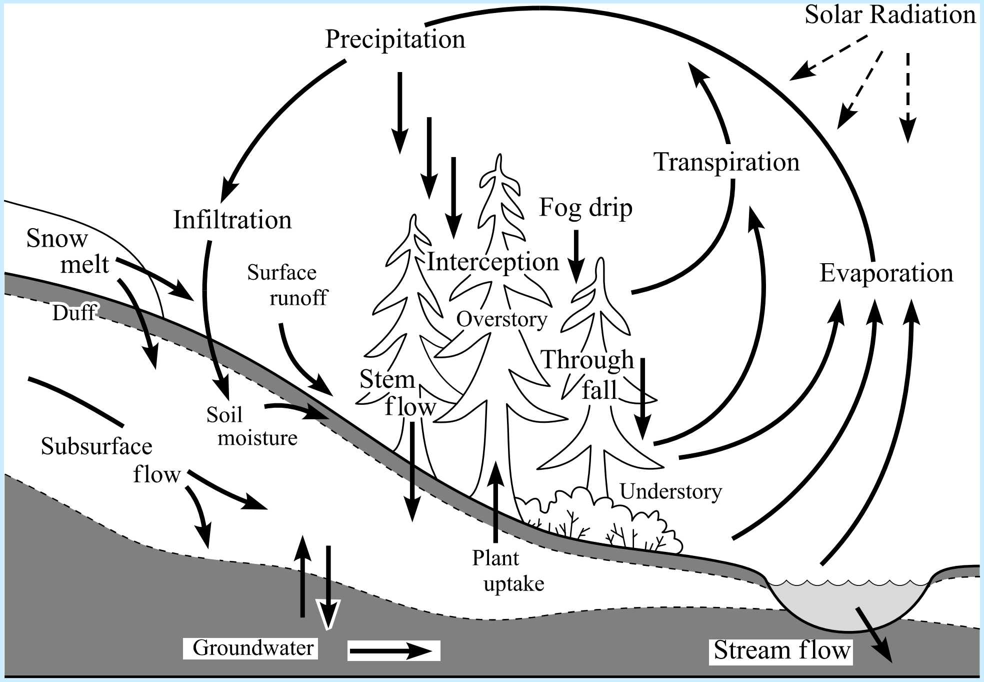
3) Glacier mass balance adjustments

4) Altered timing and magnitude of streamflow

5) Increased levels of storm events and disturbances

6) Accelerated melting of ice

7) Increased water temperatures



Source: Pike 1998

Atmospheric Evaporative Demand and Vegetation Changes

- The atmosphere’s ability to evaporate water will increase.

- Vegetation changes (e.g., interception/ evap characteristics) will alter water balance.

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Hydrologic Implications:

• Increased evaporative losses from water bodies

• Increased water demands

• Reduced vegetation growth and survival

• Increased wildfire risk

Decreased Snow Accumulation and Accelerated Snowmelt

• Average snowlines will migrate north in latitude and higher in elevation in response to increasing temperatures.

• Changes to snow depths may affect ground temperatures and subsequently infiltration rates / runoff.

P. Teti Snow Measurement near Williams Lake

Decreased Snow Accumulation and Accelerated Snowmelt

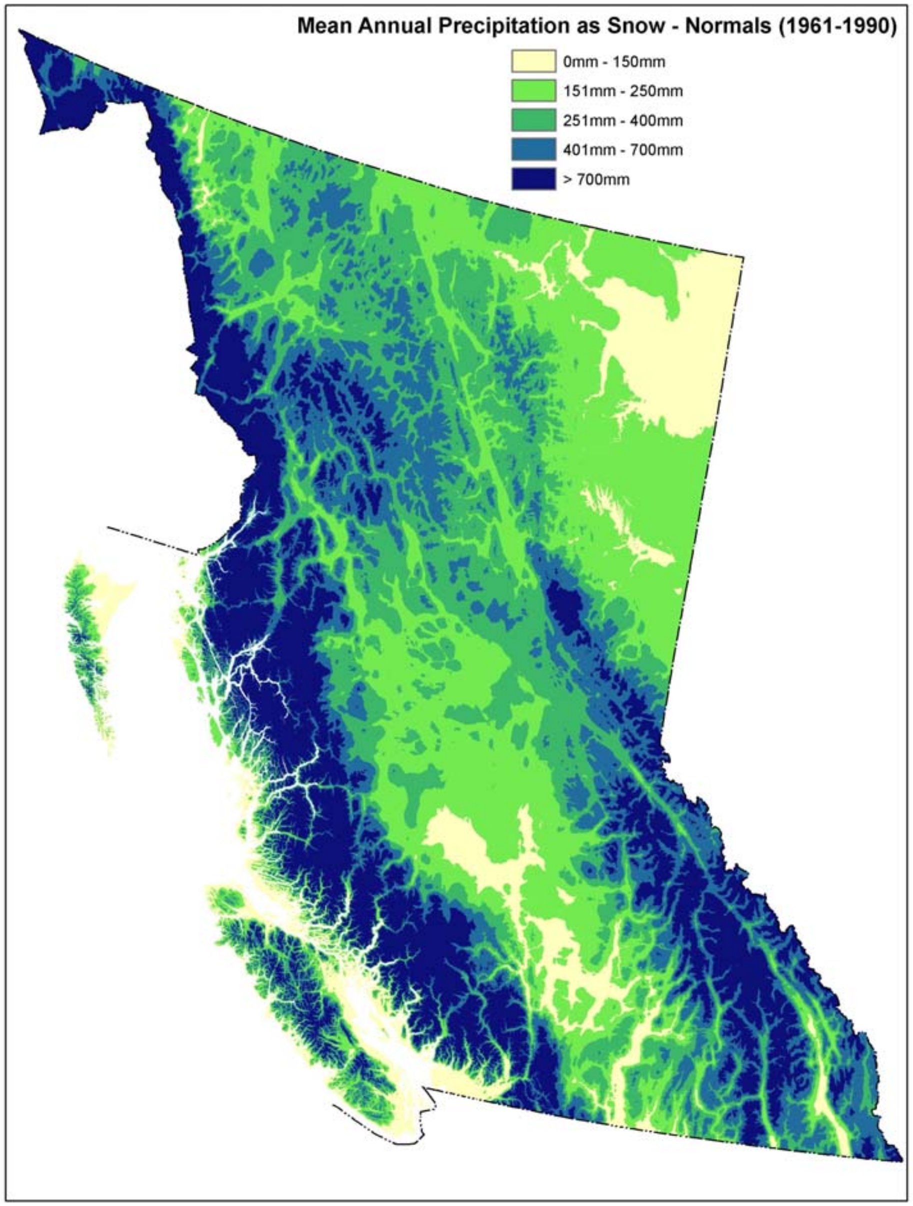
- Average snowlines will migrate north in latitude and higher in elevation in response to increasing temperatures.
- Changes to snow depths may affect ground temperatures and subsequently infiltration rates / runoff.

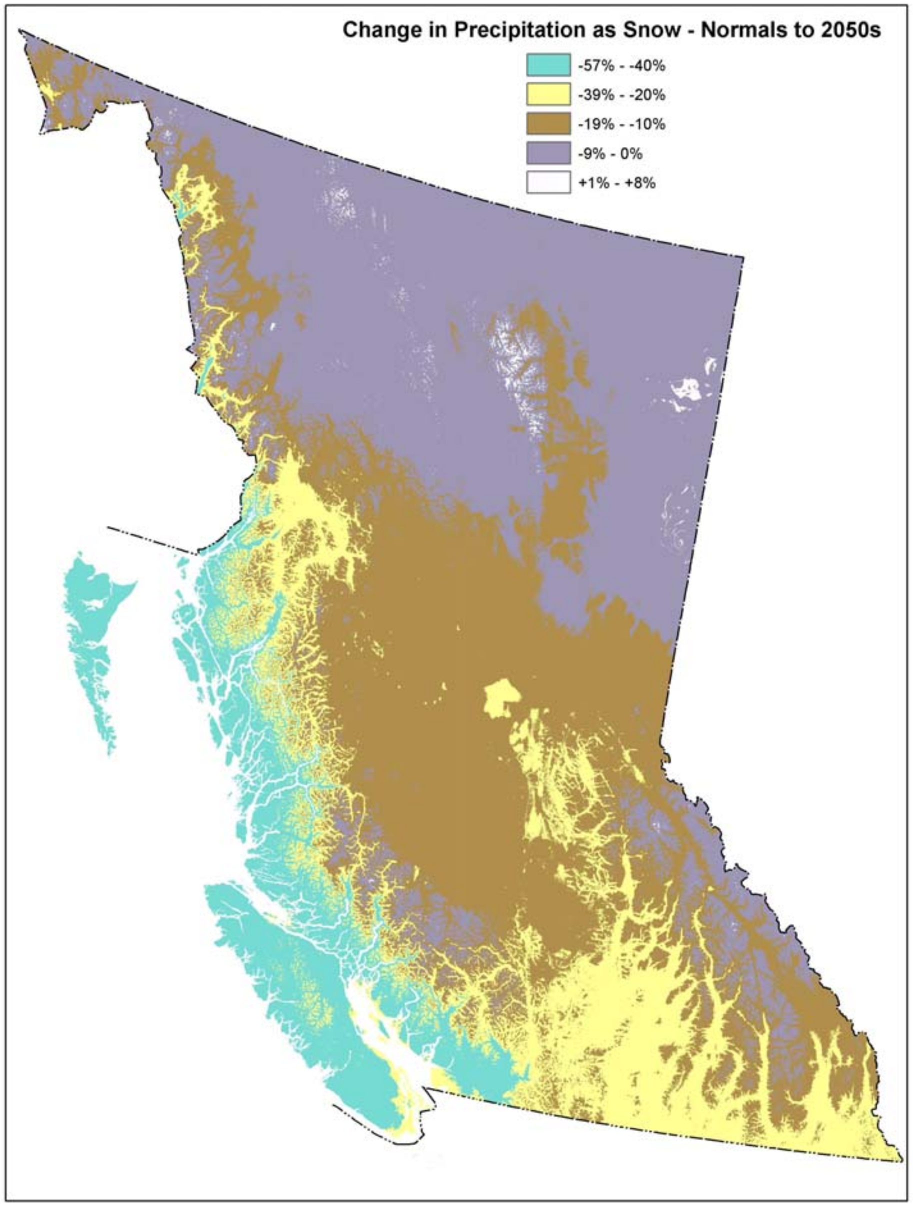
Hydrologic Implications:

- Accelerated timing of snowmelt peaks
- Exacerbated summer low-flows.
- Water supply changes affecting hydroelectric power, fish, aquatic habitat, and winter recreation.

P. Teti Snow Measurement near Williams Lake

Precipitation as Snow: 1961-90 and Change by 2050 for CGCM2-A2

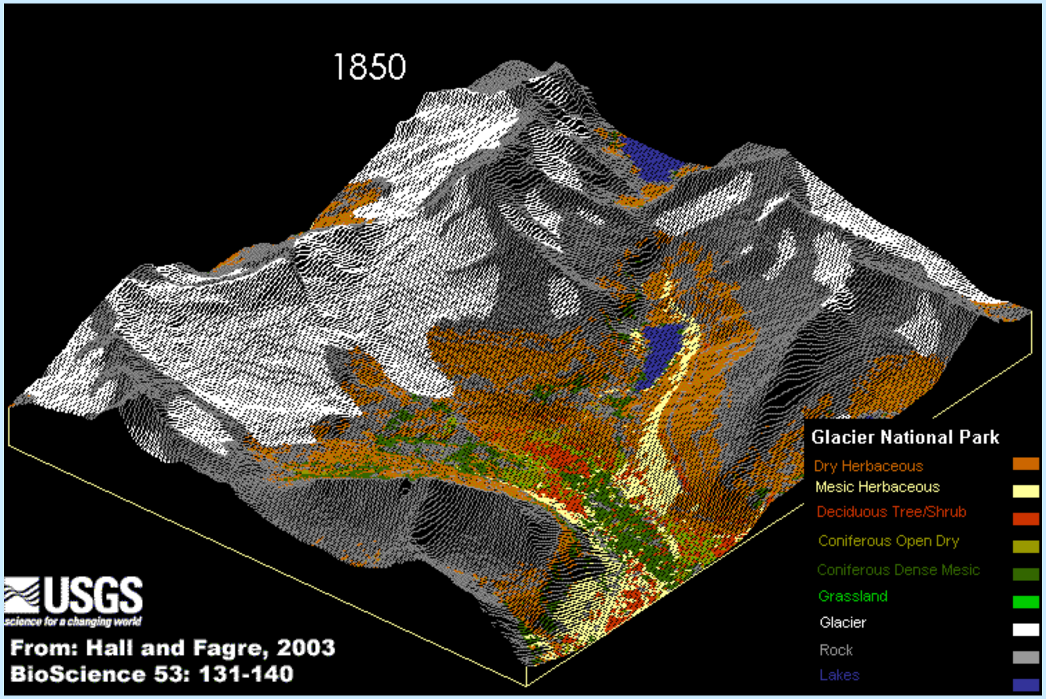




Source: ClimateBC- A. Walton; Wang et al., 2006

Glacier Mass Balance Adjustments (advance/recession)

Glaciers will continue to recede, except those at the coldest locations.



Hydrologic Implications:

• Short-term: less severe low flows (number of days)

• Long-term increases number of low flow days

Altered Timing and Volume of Streamflow (peak flows, low flows)

Preface…

- Storage and release mechanisms (groundwater, wetlands, lakes) importantly control streamflow in many watersheds.

- Climatic changes, therefore, will vary by region depending on the watershed's current sensitivity to regional temperature and precipitation changes **AND** storage and release mechanisms.

Photo: R.G. Pike

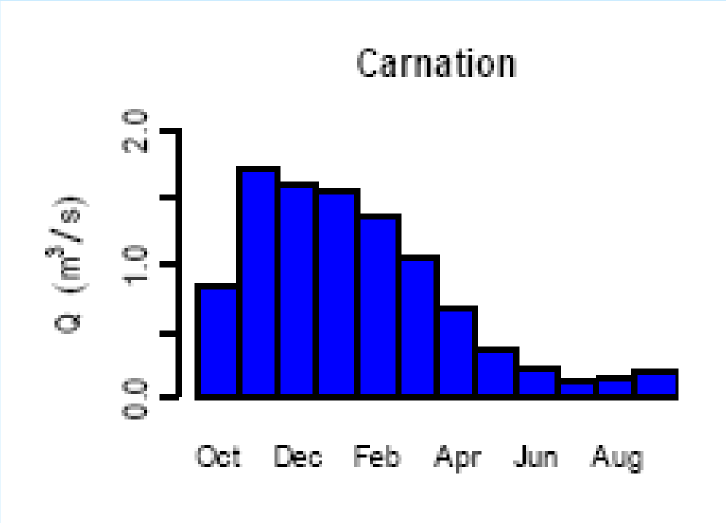
Altered Timing and Volume of Streamflow (peak flows, low flows)

Rain-dominated regimes

• Increased frequency and magnitude of winter storm-driven peak flows

• Drier summers with increased number and magnitude of low-flow days.

• Changes in hybrid snowpacks … potential early indicator?

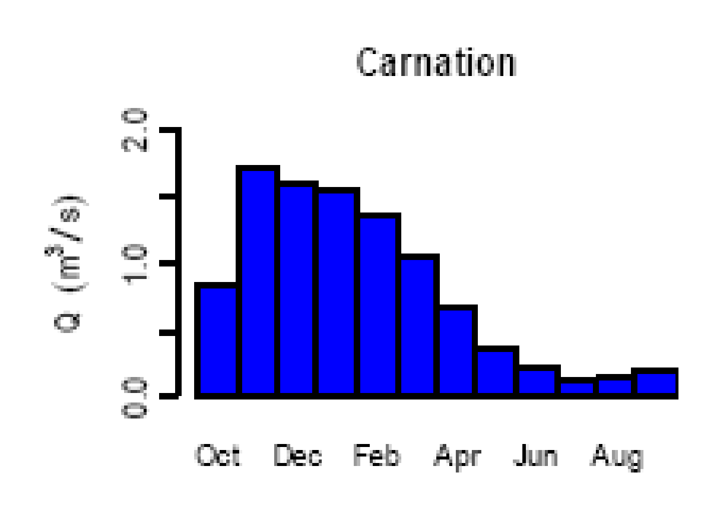


Source: Eaton and Moore 2007

Altered Timing and Volume of Streamflow (peak flows, low flows)

Rain-dominated regimes
- Increased frequency and magnitude of winter storm-driven peak flows
- Drier summers with increased number and magnitude of low-flow days.
- Changes in hybrid snowpacks … potential early indicator?

Snowmelt-dominated systems
- Shorter snow accumulation season
- Earlier start to the spring freshet.
- Shift in period of low flows.
- Plateau SMDR mostly in one elevation band therefore more likely sensitive to changes in snow (abrupt changes).



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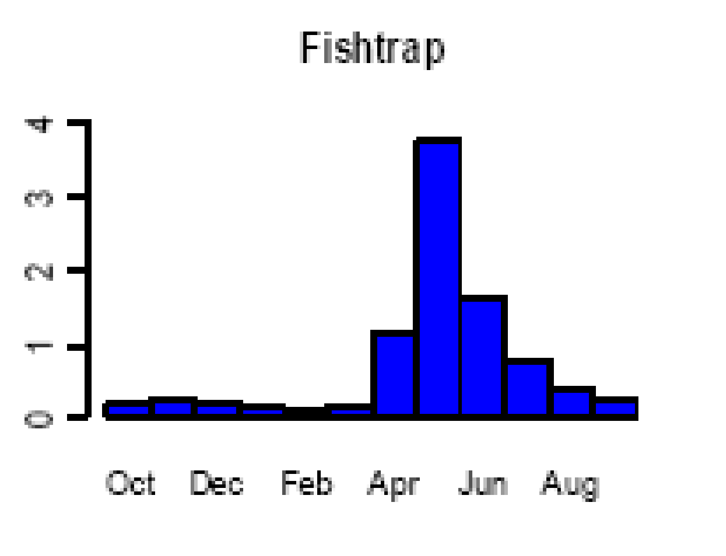
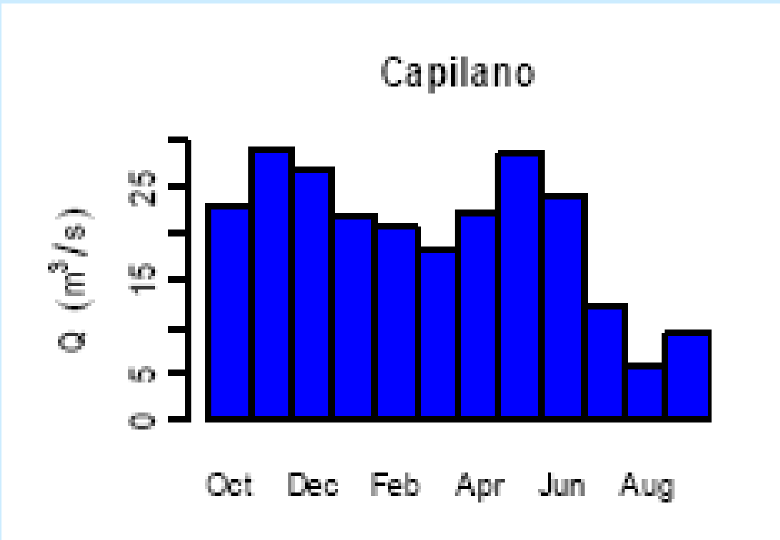


Altered Timing and Volume of Streamflow (peak flows, low flows)

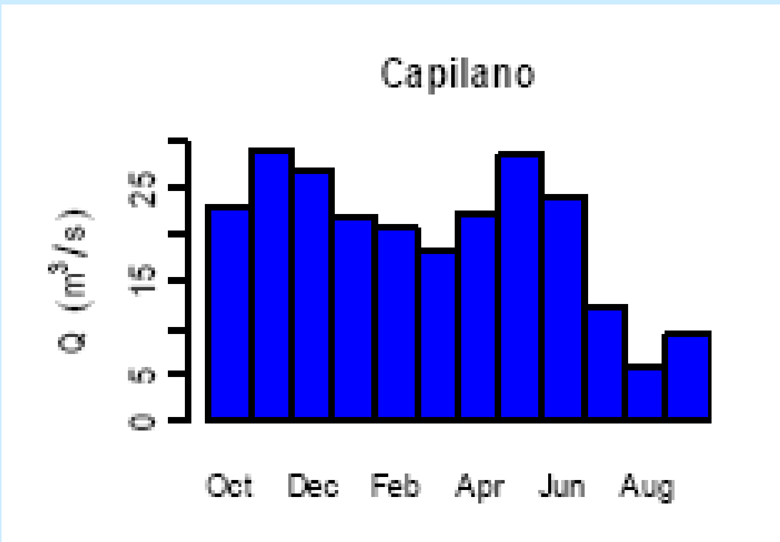


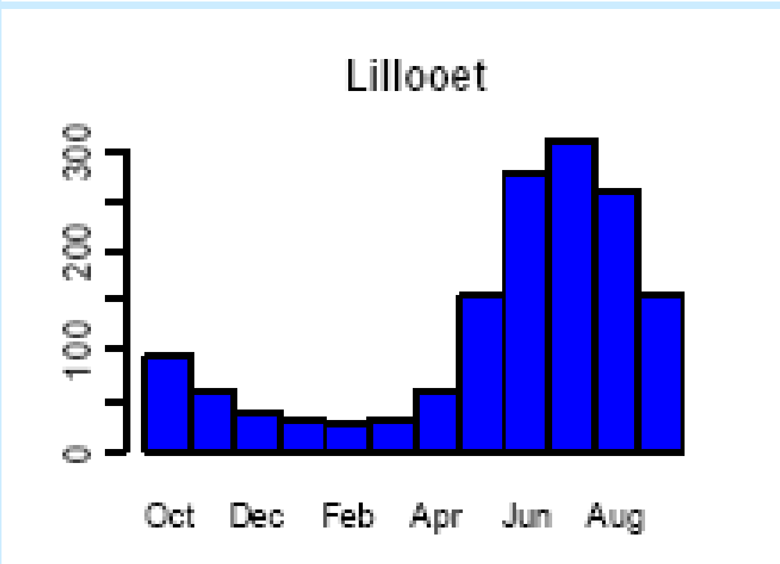
Mixed/hybrid regimes

- Reduced spring peak flows that occur earlier
- Reduced winter low flows (i.e., more water) if precipitation falls as rain instead of snow.

Source: Eaton and Moore 2007

Altered Timing and Volume of Streamflow (peak flows, low flows)





Mixed/hybrid regimes

- Reduced spring peak flows that occur earlier
- Reduced winter low flows (i.e., more water) if precipitation falls as rain instead of snow.

Glacier-augmented systems

- Decrease peak flows occurring earlier, similar to snowmelt-dominated regimes.
- Increased frequency and duration of low-flow days

Source: Eaton and Moore 2007

Management Implications - Hydrology

Hydrologic Implications:

• All hydrologic regimes will see changes in how much and when water is delivered… not just snow!

• More $$ to deal with winter storm-related damage (roads, floods, etc.)

• Decreased summer water availability

• Hydro-power concerns

• Hillslope and fluvial geomorphic interactions

• Increased aquatic concerns re: fish (temperatures, low flows, peak flows, etc.)

Photo: R.G. Pike

Part III - Geomorphic Changes and Implications

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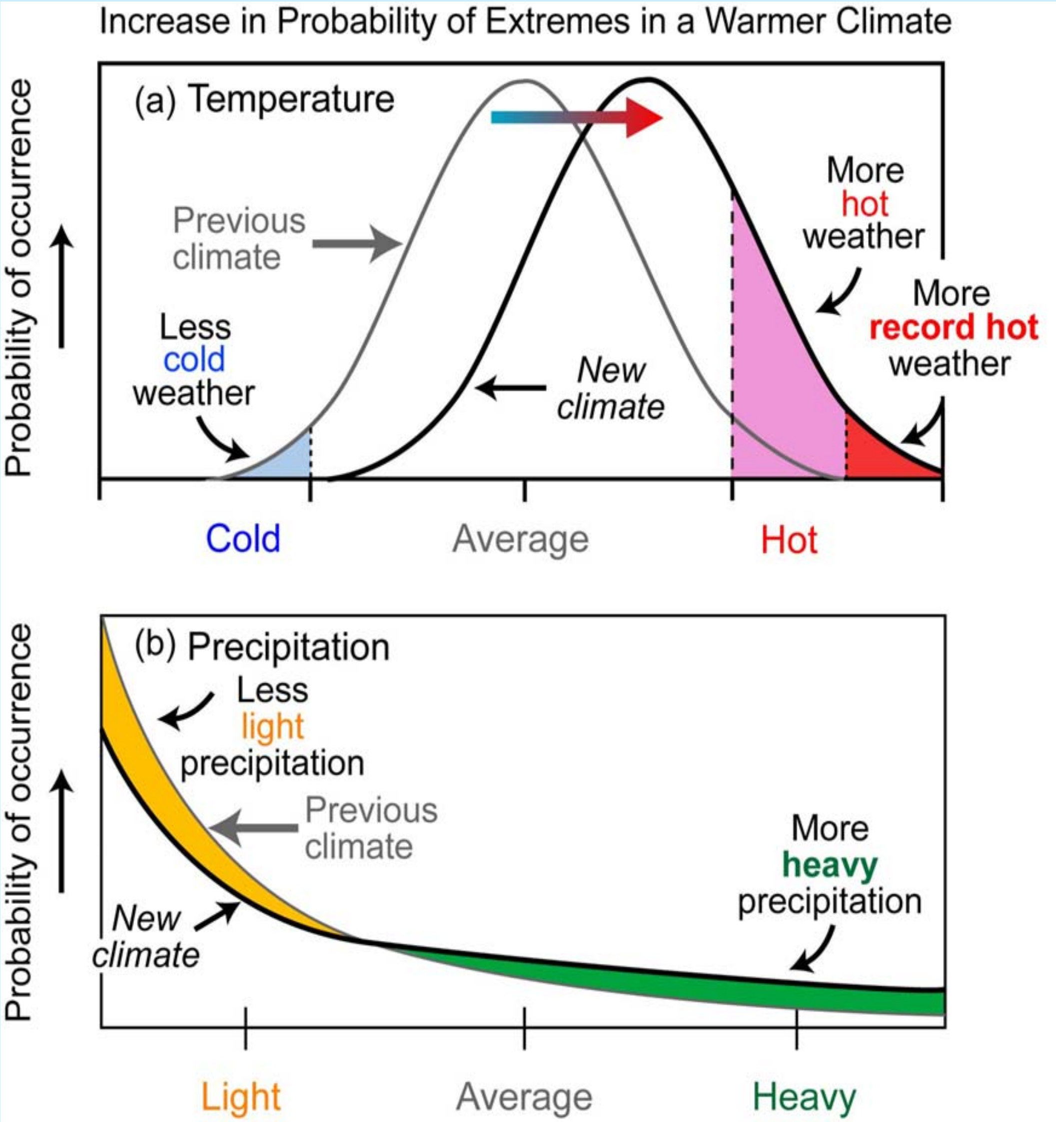
3. **Geomorphic Changes and Implications**
4. Aquatic Ecology Changes and Implications

Photo: J.Schwab



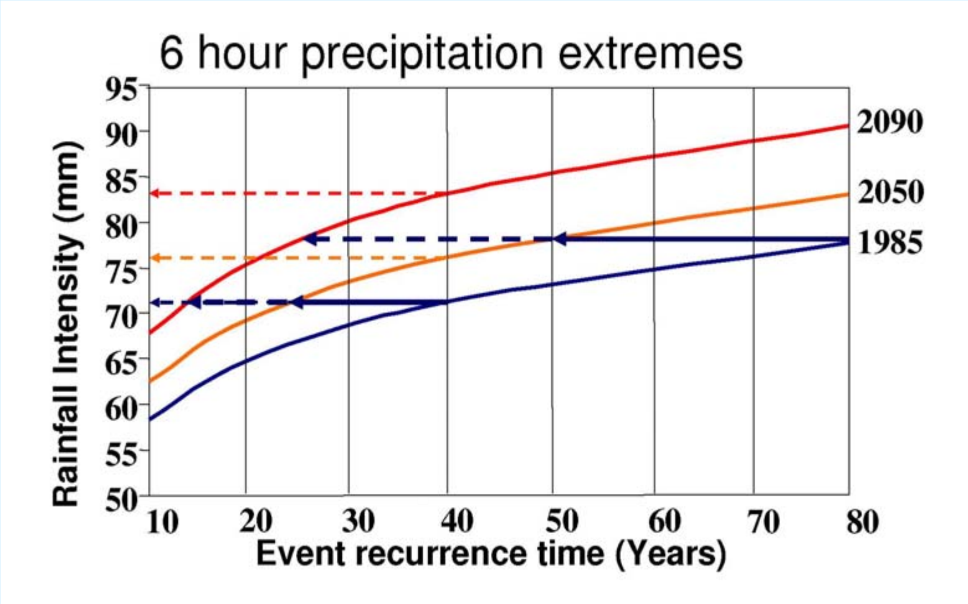
(Cohen, 2008; Graphics from by T. Peterson)

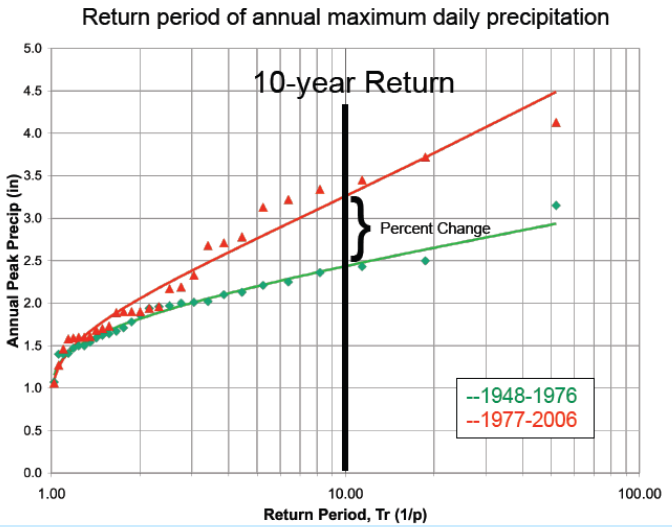
"Stationarity is Dead" (Milly et al., 2008—*Science, 319, 573-574)*

- *Climate change undermines a basic assumption—that natural systems fluctuate within an unchanging envelope of variability*

Storm Frequency-Magnitude

- Increased in both frequency (for a given magnitude) and magnitude (for a given frequency)
- Eg. Salathe 2008 in Washington State -> +5-25% in 10-year event
- November 12-17, 2006 event in SW BC -> Shift from ~100 yr event (pre-1998 data) (Chapman, 2007; IWL 2006) to 20 year event (Miles et al., 2008)
- Variability from decadal-scale (PDO) and multi-year (ENSO) oceanic phenomena are confounding factors





Source: Centralia Station, Washington (Salathe 2008)

Photo: P.Jordan

Photo: T.Millard

Landslides

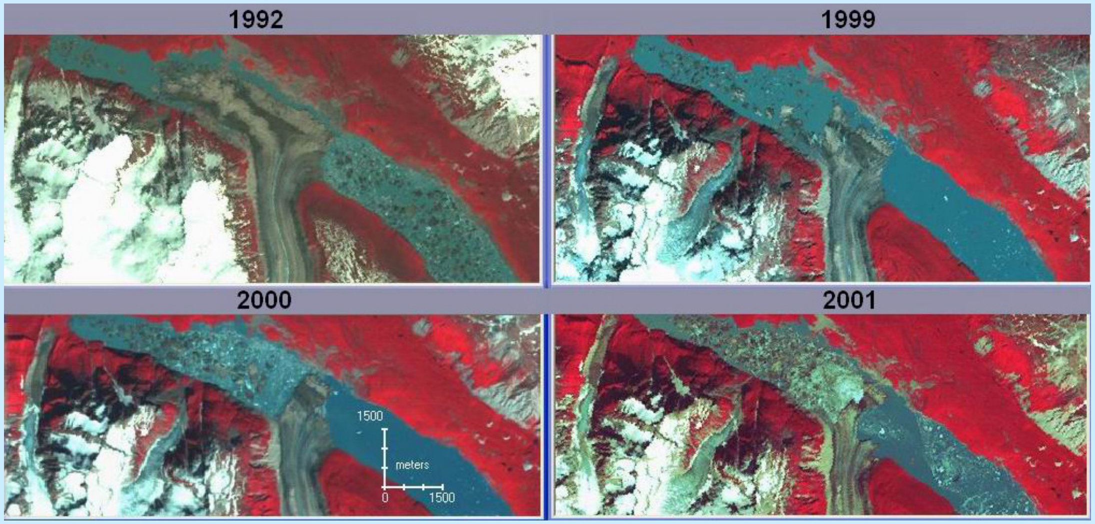
- Precipitation (+/- rain-on-snow component) major landslide driver (e.g. Coast)
- GCM's and Regional Downscaling models have limited capabilities for predicting short duration (24-hr or less) events
- Studies attempt to link annual or seasonal precipitation trends with short-duration events which exceed landslide initiation thresholds (e.g. Miles, 2001; Jakob and Lambert, 2009) or with regional landslide rates (e.g. Guthrie and Brown, 2008)
- ~10%-100% increase in landslide rates projected over 21st century

Landslides

- In Northern BC recent climate shifts have been associated with increased landslide frequency (Geertsema et al. 2007)
- 20th century changes of ~+0.6-1.3C; MAP~+10.2-18.6% (Egginton 2005)
- Both short-term (storm) and long-term (seasonal/annual precip and temp) responses are important
- ~2-3x increase in landslide rates associated with recent change

Photo: P.Teti

Glaciers



Source: Landsat Images Glacial Lake Melbern BC

Photo: D.Campbell

- Glacial recession and thinning
- Changes in geomorphic hazards (moraine-dam outburst floods; de-buttressing and rock slope failures; jökulhlaups)
- High suspended sediment production from glacierized basins=>complex responses to de-glaciation (Moore et al. 2009)
- Paraglacial effects persist over varying time and space scales (Ryder and Church, 1972; Church and Slaymaker, 1989)

Photo: Moore et al. 2009

Permafrost & Snow-Ice Processes

Photo: D.Toews

Photo: Geological Survey of Canada

- Warmer temp (winter/annual)
- Avalanches =>changes in thermal regimes and snow loading (complex responses)
- Permafrost => melting (North & high elevation)
- River ice and ice jams

Implications

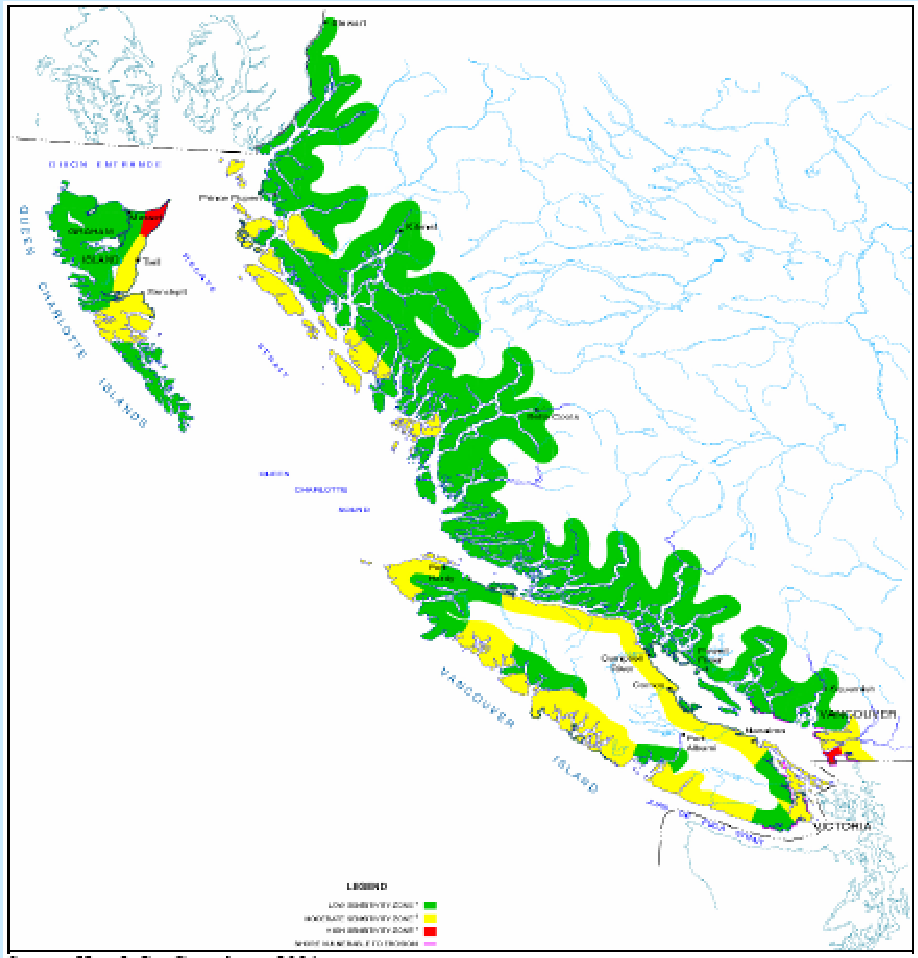
- Altered forest harvest scheduling (operable ground, timing)
- Transportation (reduced use of ice bridges, avalanche safety)
- Increased rates of slope failures
- Increased soil water levels influencing runoff timing and amounts
- Altered recreation (fishing opportunities)

Sea-level Rise & Coastal Erosion

- Projected sea-level rise varies with GCM, and varies with location on the Coast
- ~0.1 to 0.5m rise based on mean projects (Bornhold, 2008)
- Some areas more sensitive than others (e.g. Lower Mainland, NW Haida Gwaii)

Implications

- Increased erosion
- Infrastructure



Source: Hay & Co. Consultants 2004.

Ecological Disturbance

- Linkages and feed-back mechanisms between biological and physical processes
- Fire, windthrow, disease/forest health can play major role in geomorphic processes, particularly for landscape-level disturbances

Implications

- Increased surface erosion (fire)
- Loss of root strength
- Slope instability
- Changes in stream-flow
- Watershed sensitivity
- Altered LWD supply regime and riparian function

Management Implications - Geomorphology

- Impacts to ecosystem values (water, fish, timber, soils)
- Cumulative Watershed Processes
- Public and worker safety
- Risk to infrastructure, property
- Design, maintenance, operational costs
- Liability issues

Management Implications - Geomorphology

- Forest Management vs. Climate Change?
- Terrain Management => improvements over past 20 years; still ~3-5x increase in landslide rates post-harvest (FPB, 2005; Guthrie 2008; Horel 2007)
- Public perception and social acceptability (Guthrie, 2009)

Photo: D.Campbell

Photo: Chen Haining/Xinhua

Part IV - Aquatic Ecology Changes and Implications

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Key drivers:

Thermal regime change - Increased Stream and Lake Temperatures

Hydrology regime – peak and low flows

Increased frequency and magnitude of natural disturbances

- ***Precipitation, storm flows, mass wasting***
- ***Fire, forest pest infestations***

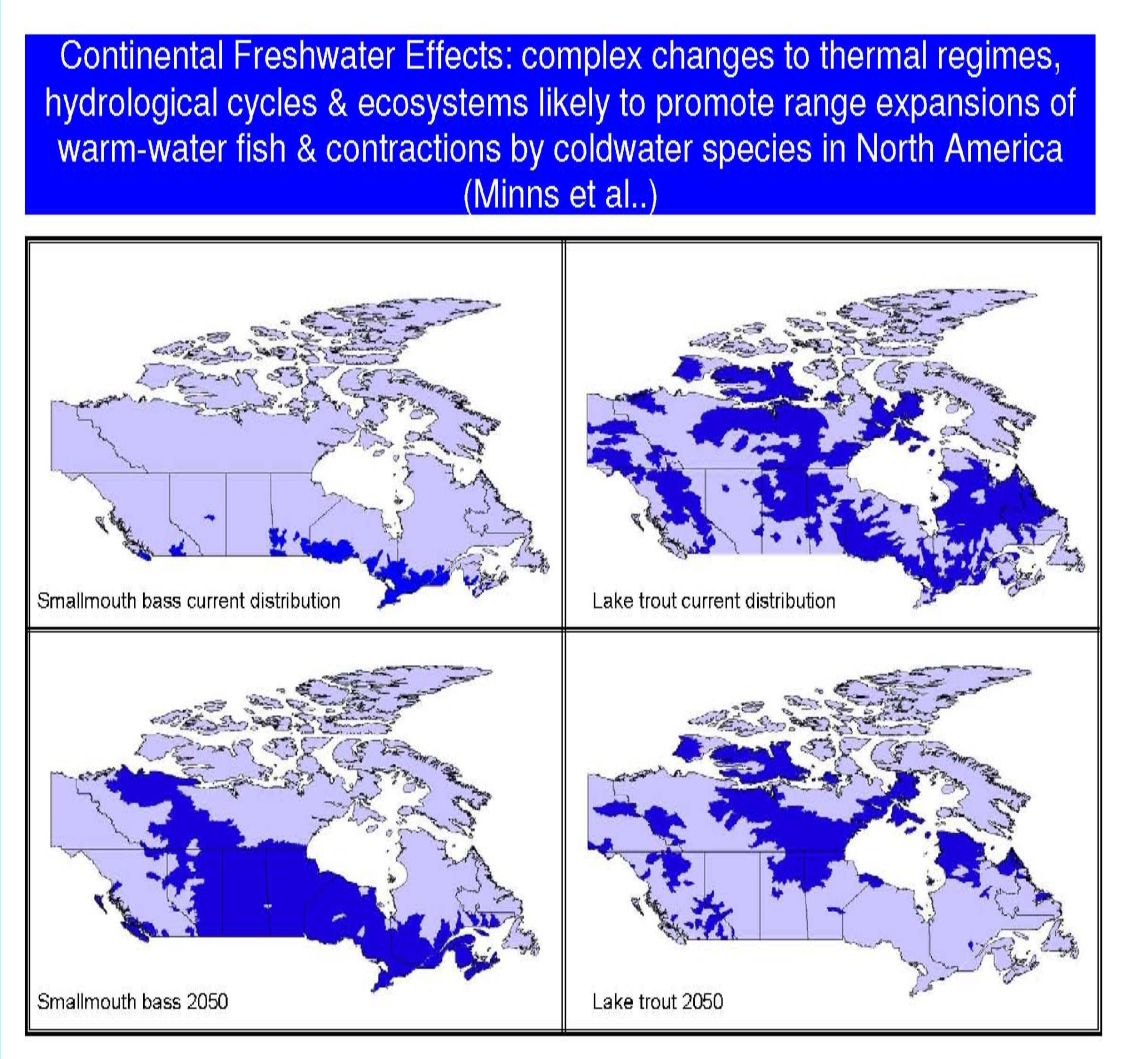
Sea level rise

- ***Loss of coastal estuarine rearing habitats; e.g., coho salmon, cutthroat trout***

Juvenile coho salmon, Carnation Creek

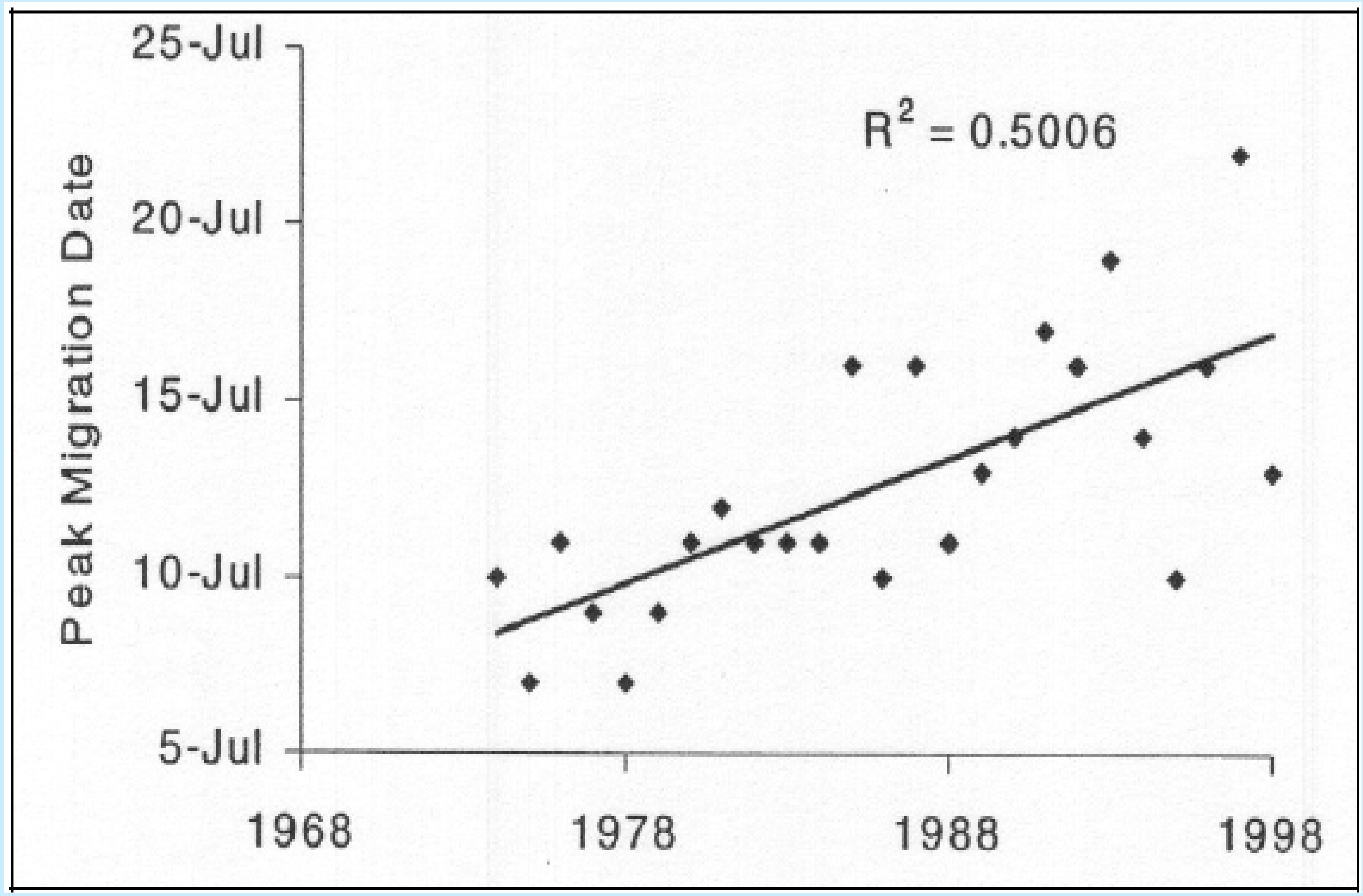
Increased Stream and Lake Temperatures

- **Altered growth, egg & juvenile development**
- **Thermal barriers for both adult and juvenile migrations**
- **Delayed fall spawning and reduced survival**
- **Increased frequencies of disease**
- **Altered species abundance and distribution (e.g., bull trout, rainbow trout)**



Early-Stuart Sockeye Migration Timing

- Migration time has shifted 5 days due to warmer sea surface temperatures
- Corresponds to earlier seasonal maximum river flow
- When flow recedes, water temperature rises to stressful levels causing disease outbreaks

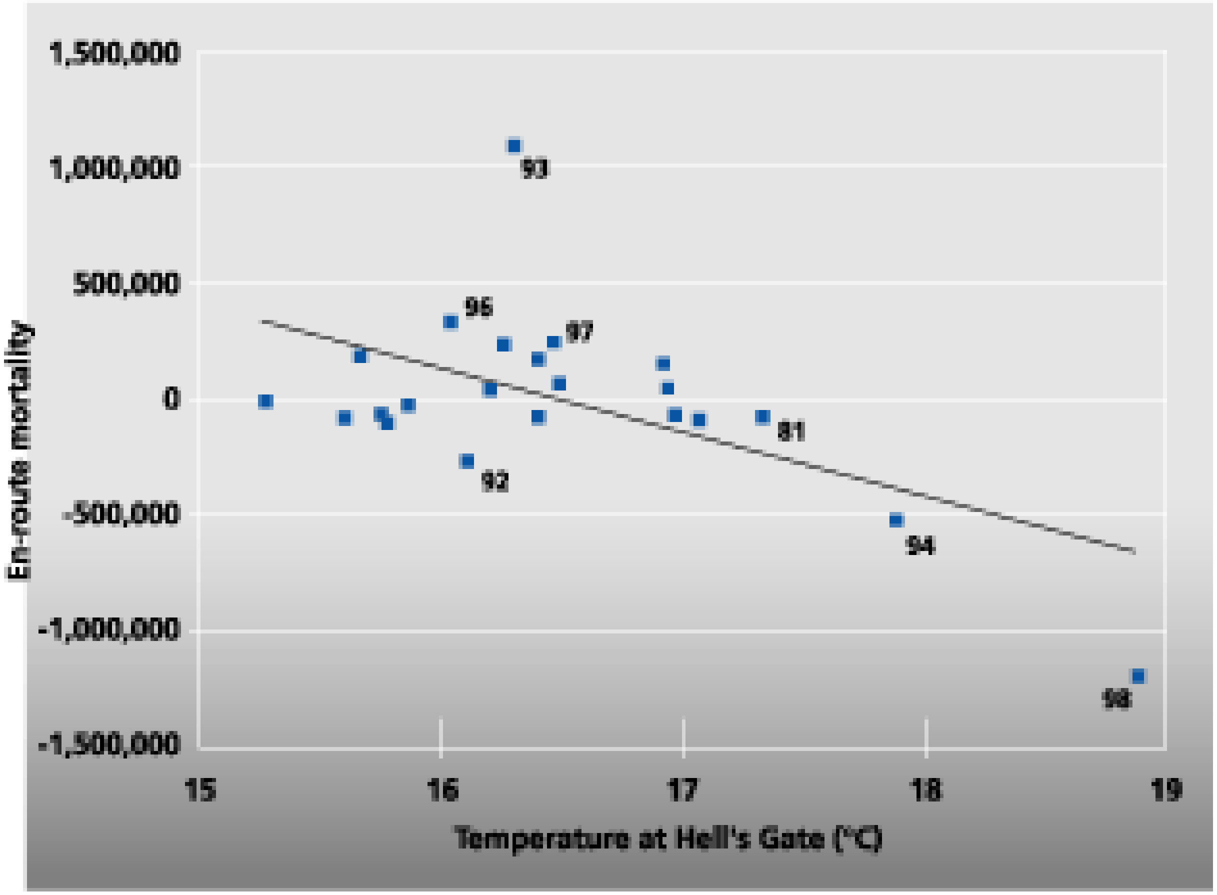


Trend in peak date of passage of Early Stuart sockeye past Hell's Gate (Macdonald et al. 2000)

Anadromous Salmon Migration Success

Summer-Run Sockeye vs. Water Temperature at Hell's Gate 1978-1998

- **Higher temperatures = greater pre-spawning mortality**
- **Increased metabolic demands**
- **Increased disease**



Source: Indicators of Climate Change for BC. MOE (2002)

Anticipated thermal responses - Where will they most likely occur?

- Fish responses will vary: impacts to some… benefits for others
- Cold-water "guild" species likely the most vulnerable (tolerate maximum temps. up to ~24°C); e.g., bull trout
  - Affected most strongly where current conditions are near the maximum levels of thermal tolerance
  - Smaller, more southerly streams and lakes at lower elevations
- Cool-water (e.g., rainbow trout) and warm-water guilds may benefit
  - Faster growth and range/habitat expansions, esp. in the north where large temperature shifts are expected

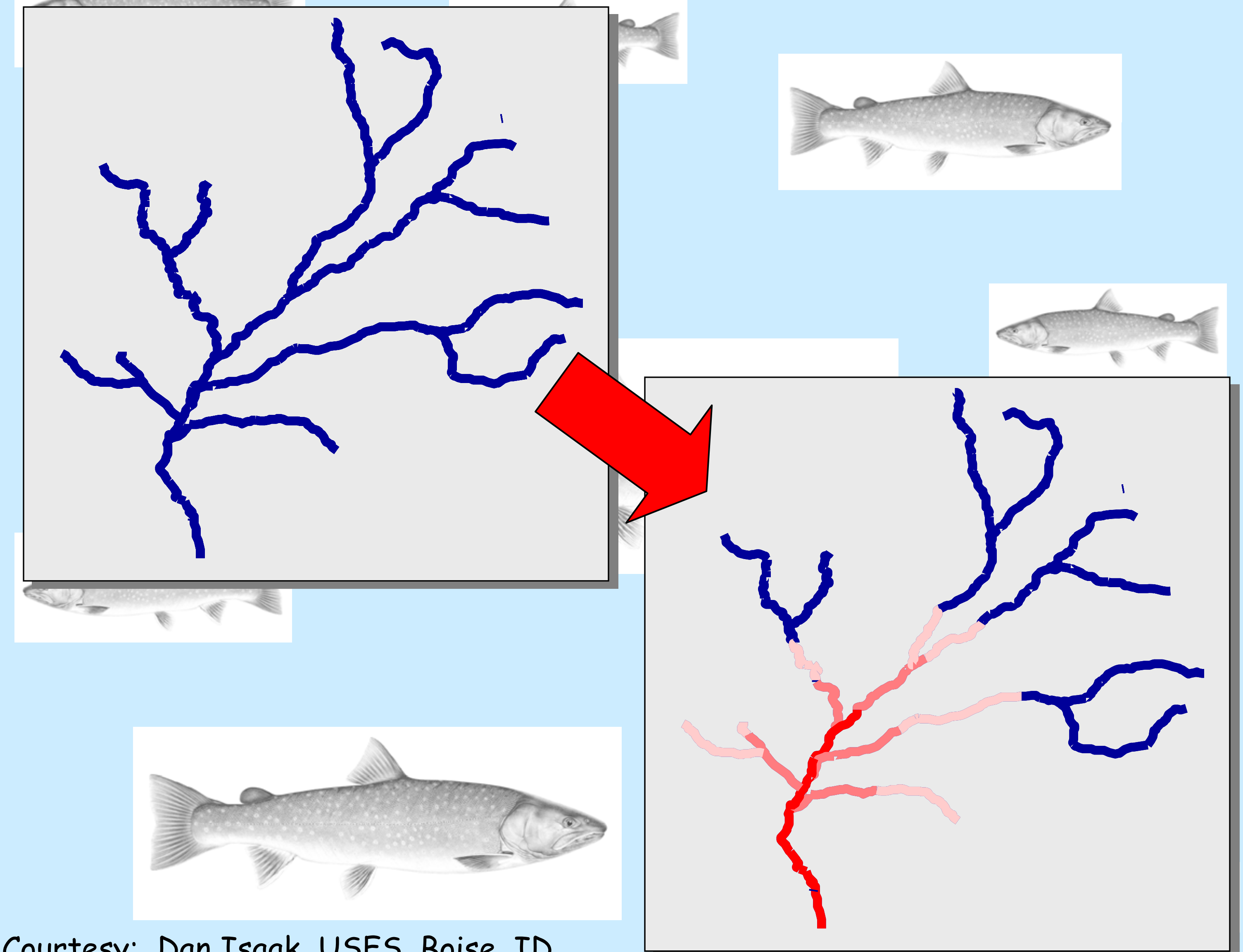
Photo: T. Redding

Range Contractions
Cold-Water Aquatic Guilds

USA Rocky Mt. Region:
Increase in July air temps. of 1, 2, 3, 4, & 5 °C estimated to reduce salmon habitat by 17, 36, 50, 62, and 70% respectively

Thermal Regimes

Air temperature effects



Courtesy: Dan Isaak, USFS, Boise, ID

Lake Communities

Longer ice-free period (up to 2 months in central BC)

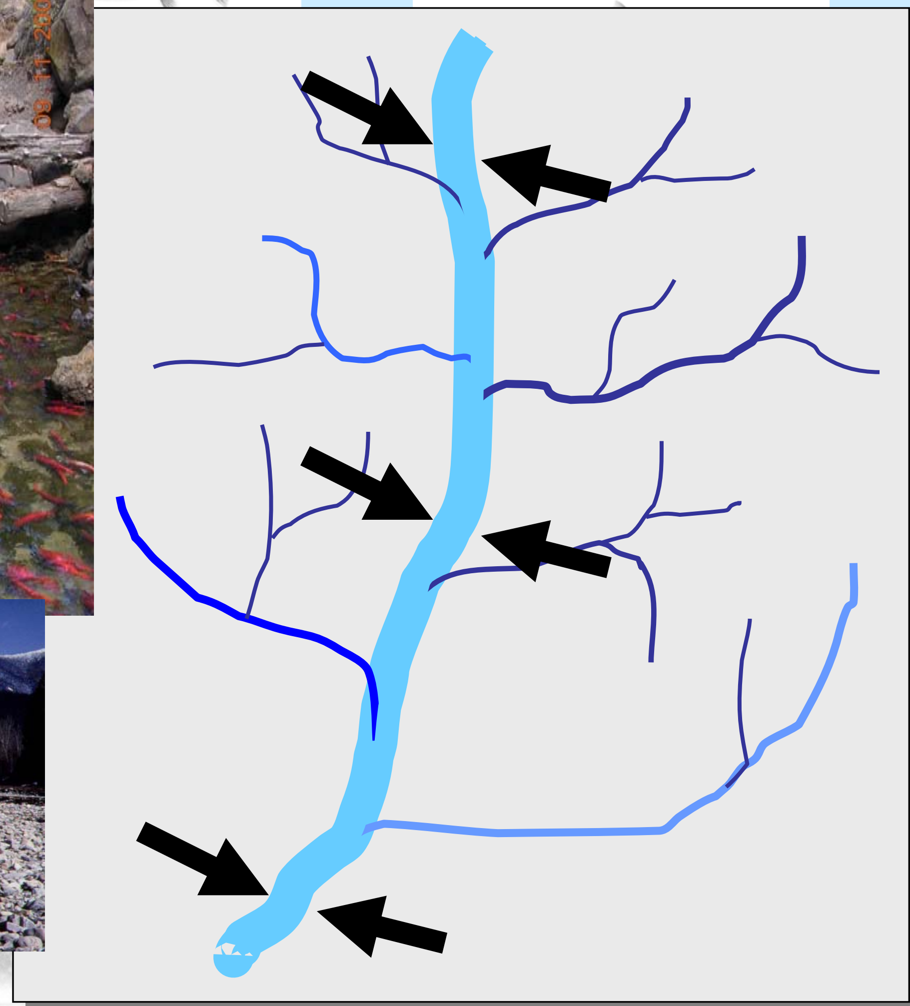
- **Earlier onset of thermal stratification**
- **Changes in depth of thermocline and volume of epilimnion and hypolimnion**
- **Decreased hypolimnetic oxygen concentrations**
- **Increased potential for summer and winter fish kills**
- **Thermal advantages for growth and survival of fish in some northern and higher-elevation lakes**

Lake Communities

- **Effects vary by lake depth, elevation, latitude, and recharge rate**
- **Difficult to predict changes**
- **Where water temperatures increase with only modest precipitation increases:**
  - **Lake levels may drop seasonally or year-round**
  - **May lose some productive shallow lakes in southern areas**
  - **Major impact on littoral-zone spawning and rearing habitats for fish**
  - **Increased productivity where nutrients are not limiting, especially in northern latitudes where ice-free period increases**

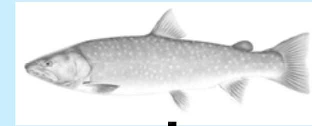
Hydrologic Regimes

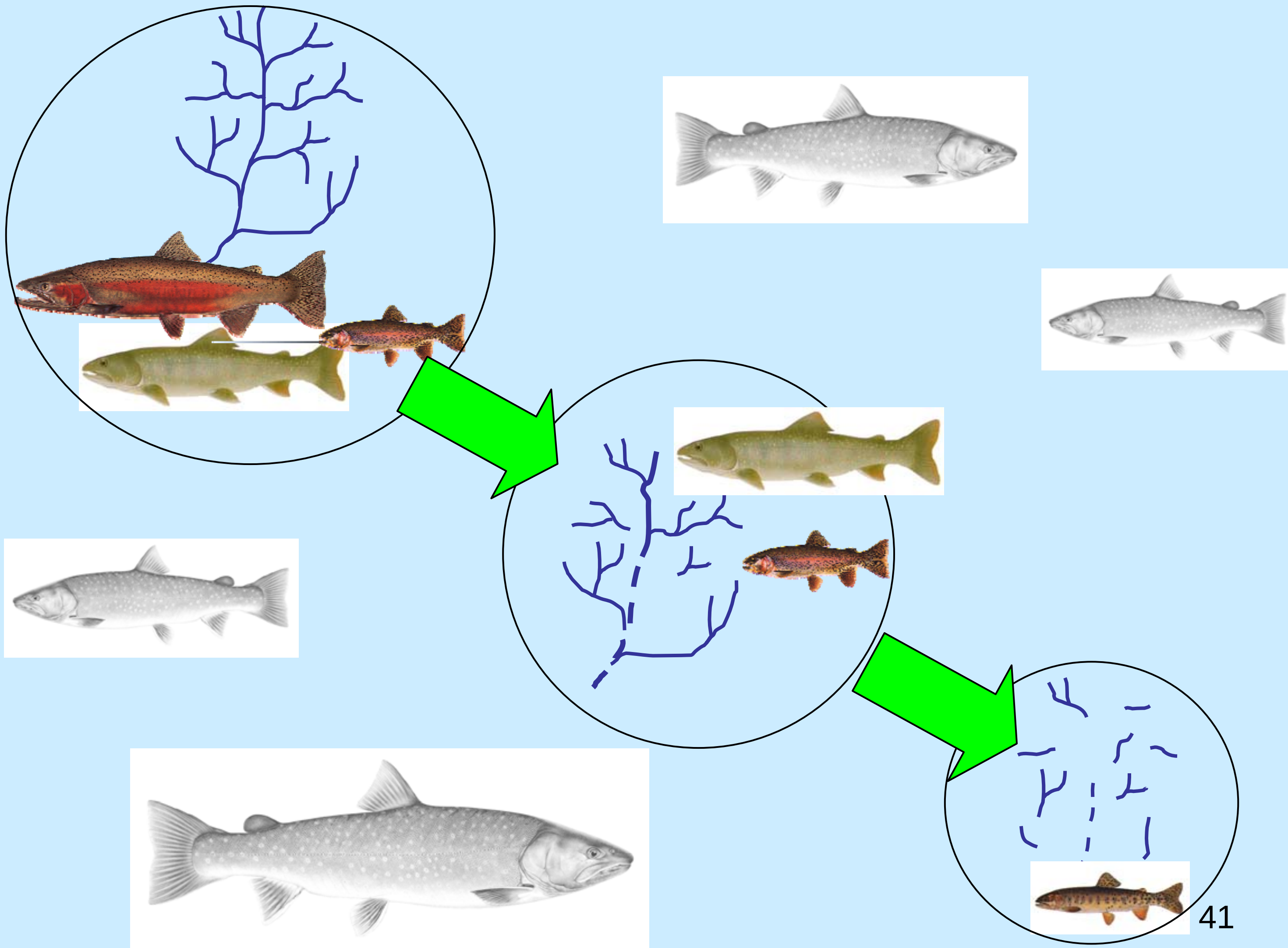
Habitat Restrictions – Summer Low Flows



Courtesy: Dan Isaak, USFS, Boise, ID

Remnant Populations and Fragmented Stream Networks





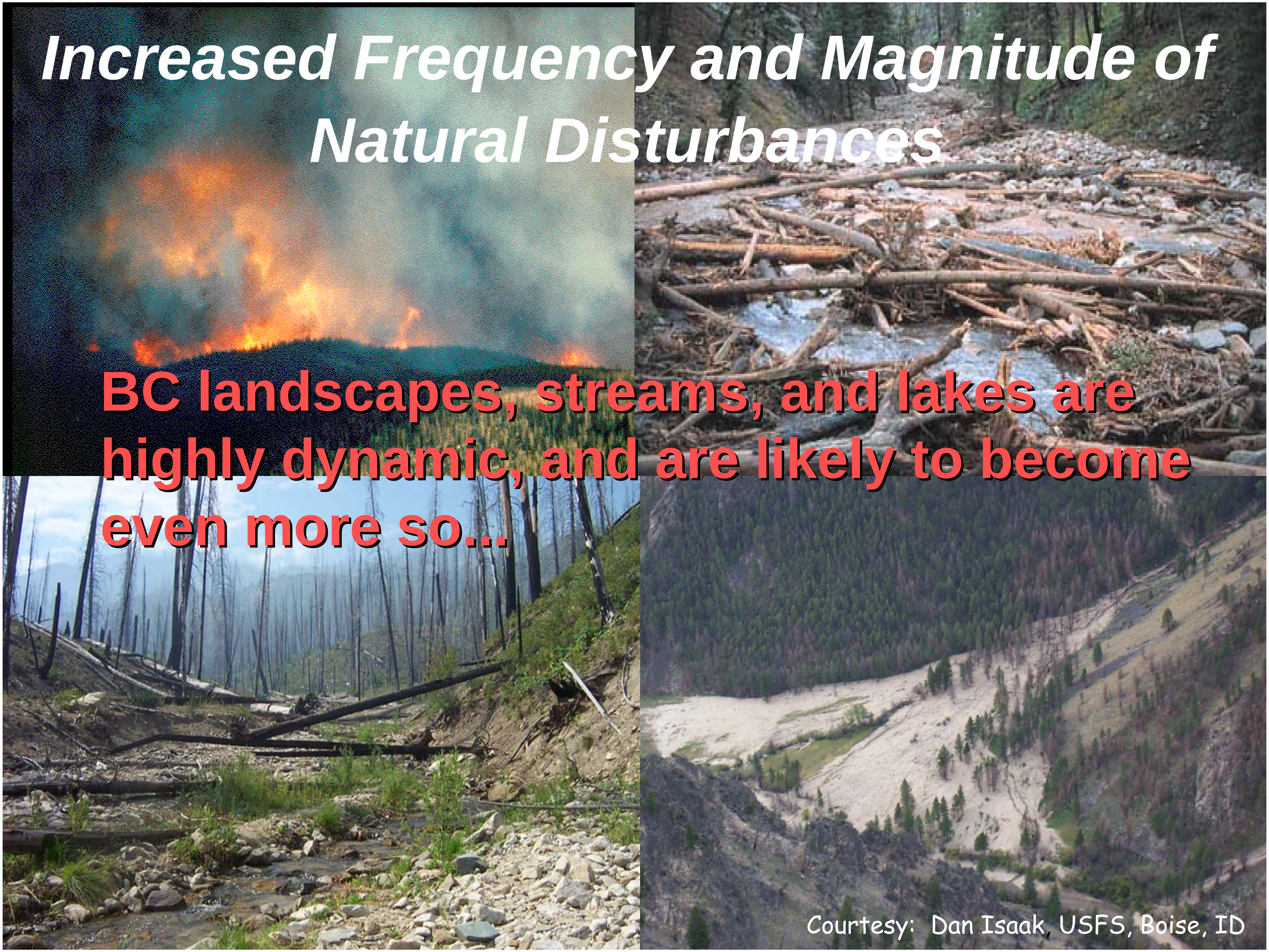
Courtesy: Dan Isaak, USFS, Boise, ID

Hydrologic Regimes

Altered timing and magnitude of storm flows

- Impacts on spawning and rearing habitat
- Impacts on egg and juvenile survival
- Impacts on all life stages of non-migratory fish species
- Scour and bedload movements impact benthic aquatic communities; e.g., periphyton, macroinvertebrates

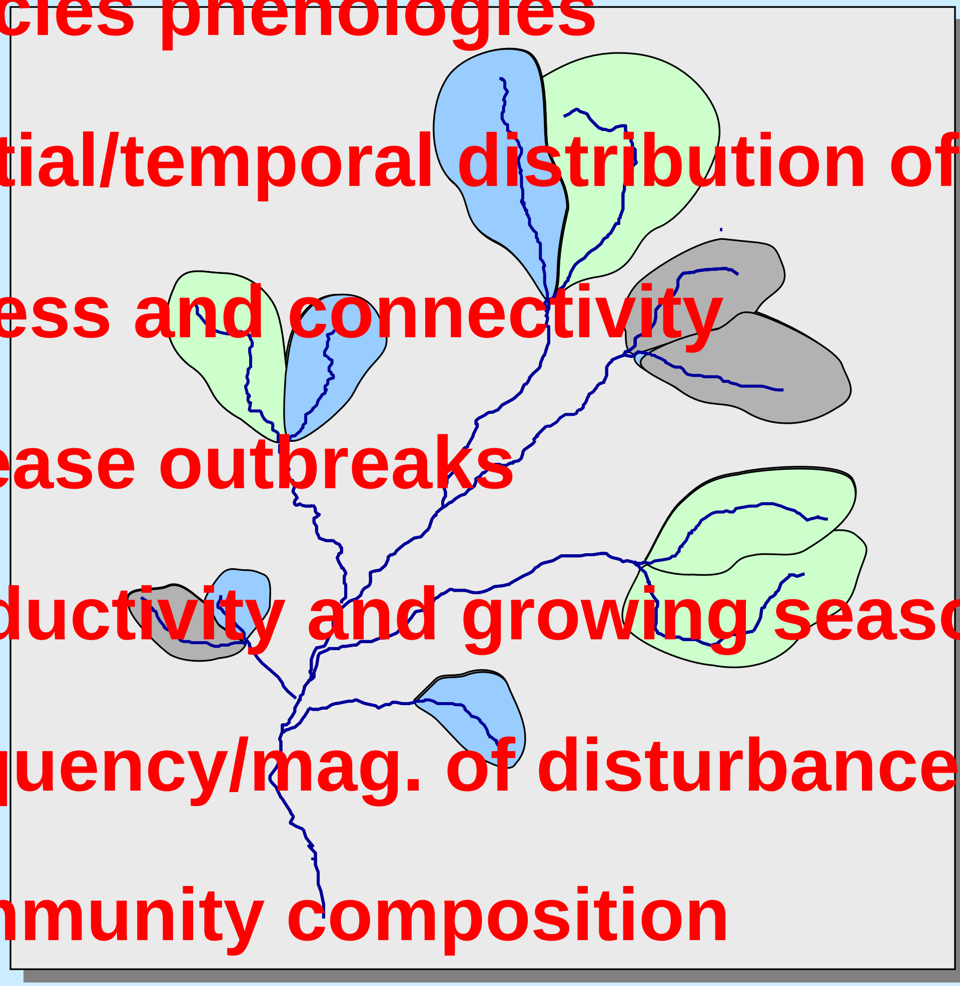
Increased Frequency and Magnitude of Natural Disturbances



BC landscapes, streams, and lakes are highly dynamic, and are likely to become even more so...

Courtesy: Dan Isaak, USFS, Boise, ID

How Will Species React to a Rapidly Changing Environment?

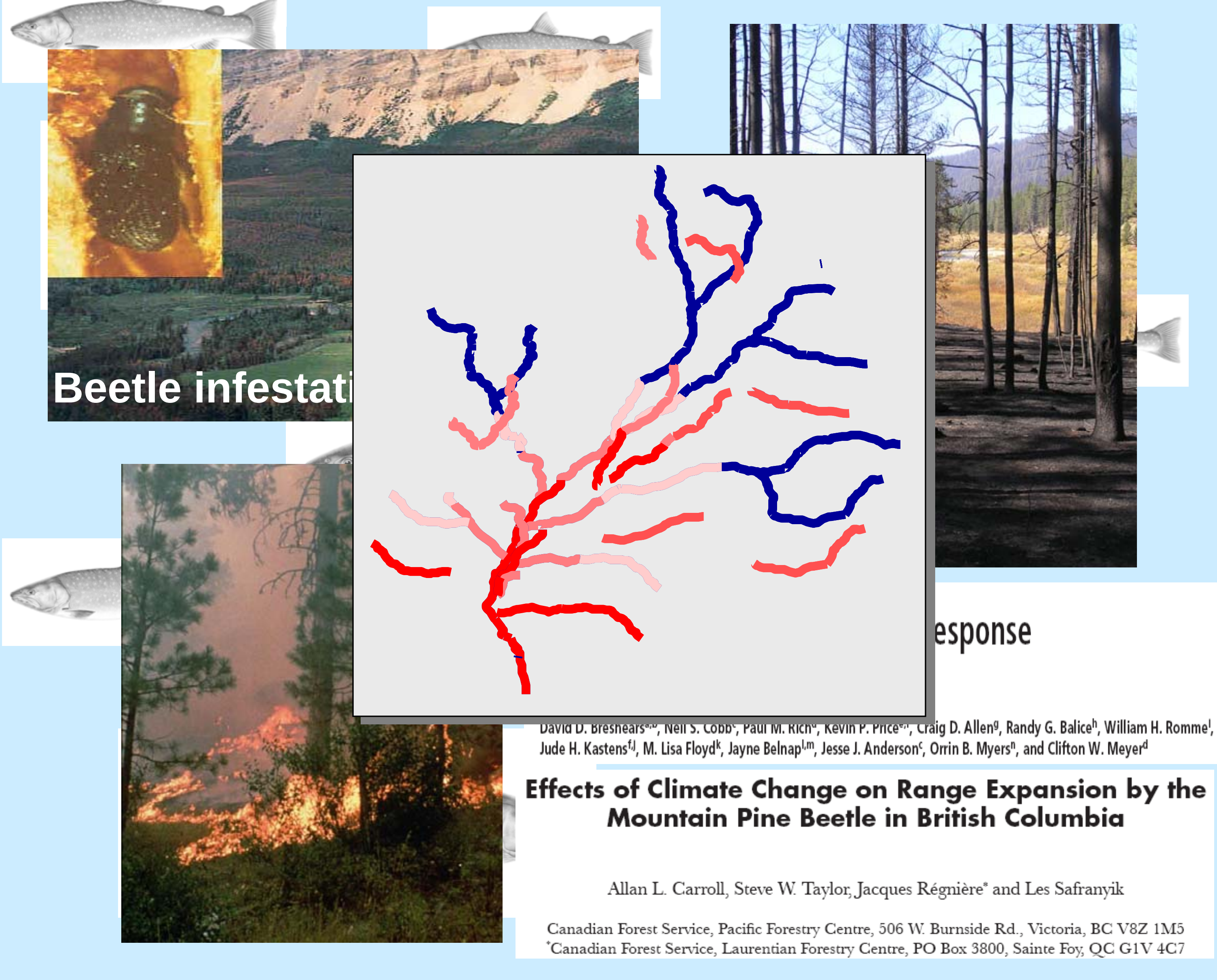


- **Species phenologies**
- **Spatial/temporal distribution of habitats**
- **Access and connectivity**
- **Disease outbreaks**
- **Productivity and growing season**
- **Frequency/mag. of disturbances**
- **Community composition**
- **Effects of invasive species & exotics**

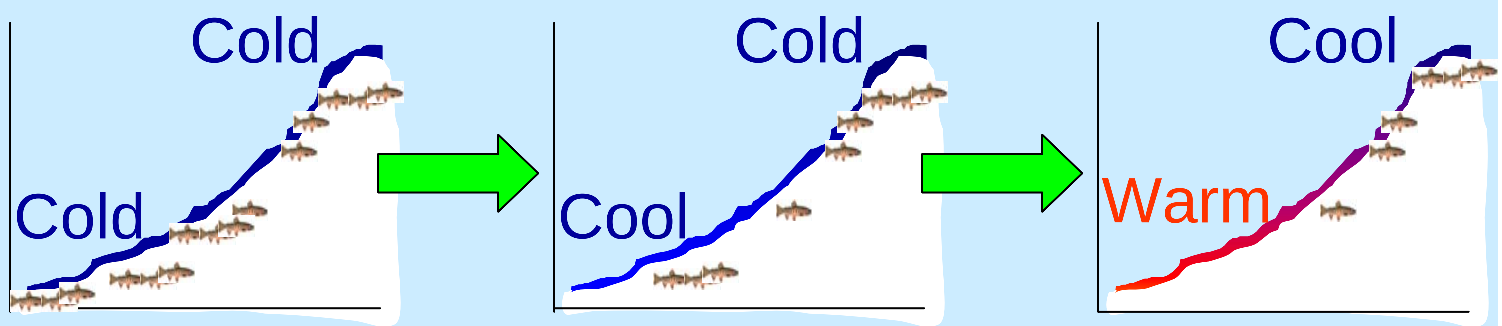
Courtesy: Dan Isaak, USFS, Boise, ID

Thermal Regimes

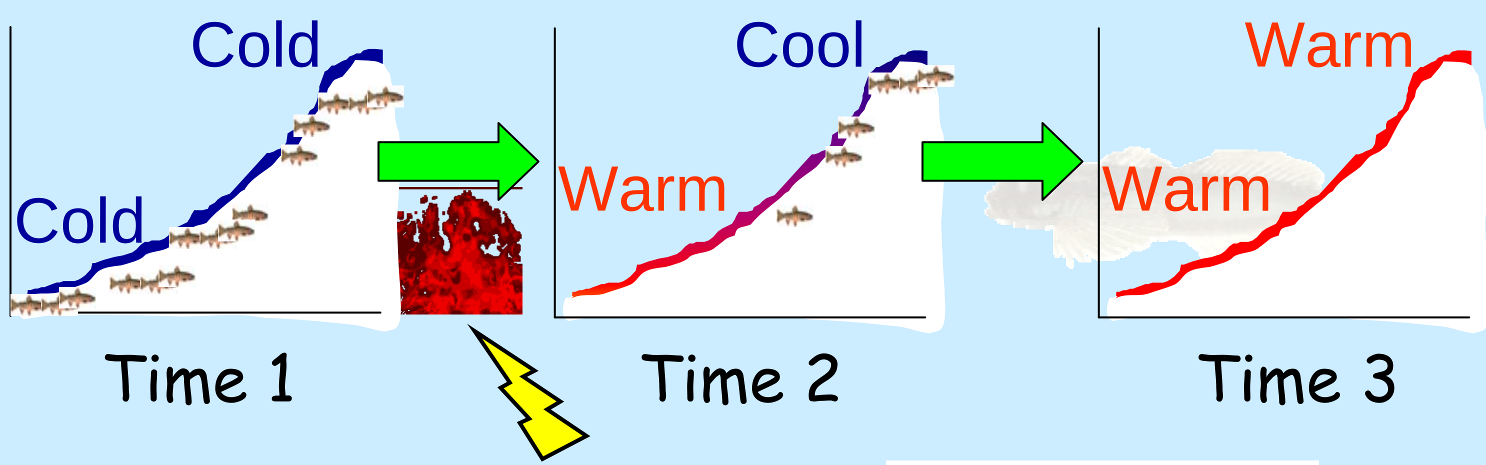
Vegetation & fire effects



Gradual Trends…



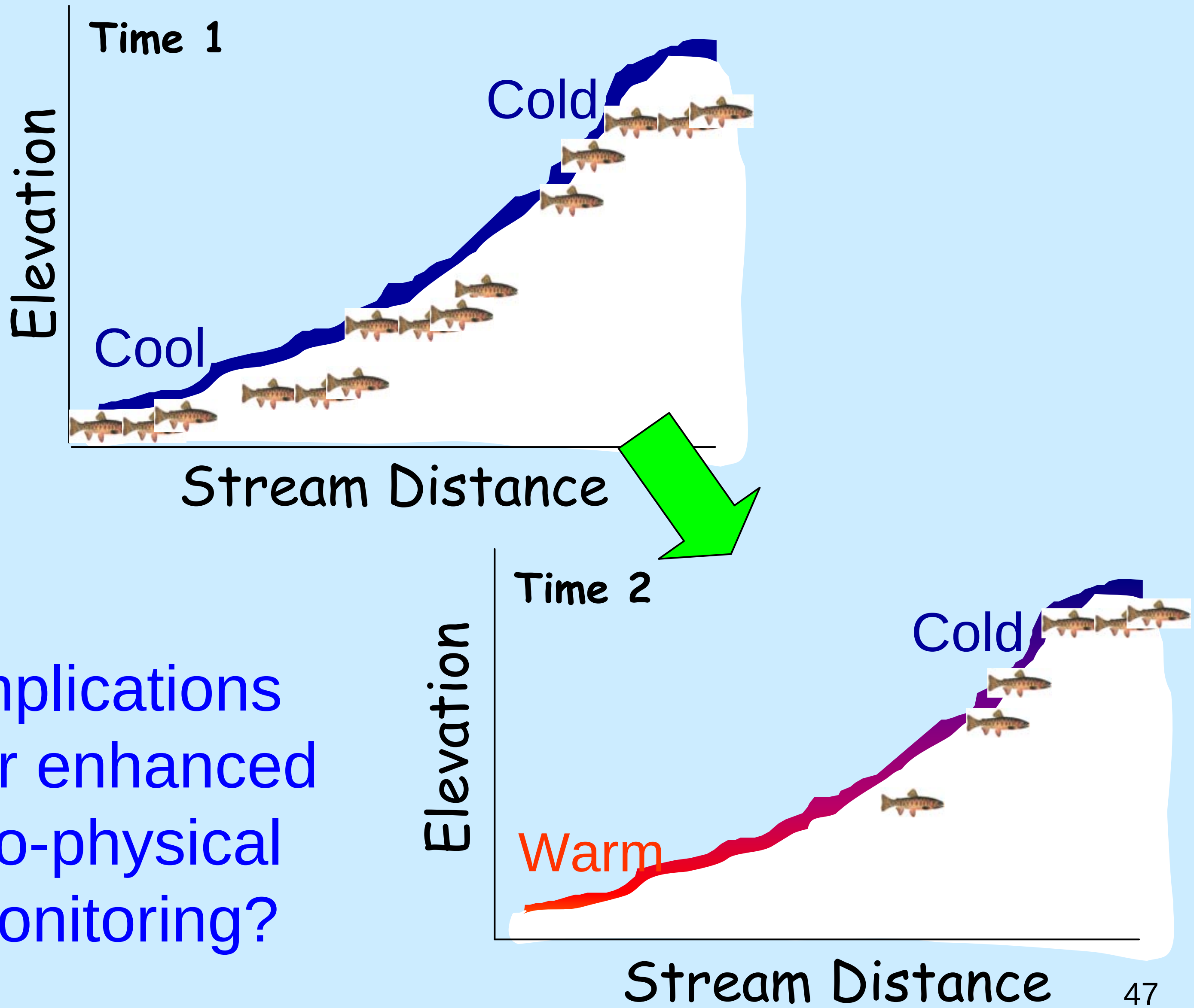
and Extreme Events



Event
(fire & drought)

Courtesy: Dan Isaak, USFS, Boise, ID

Are Cold-Guild Species Distributions Shifting Now?



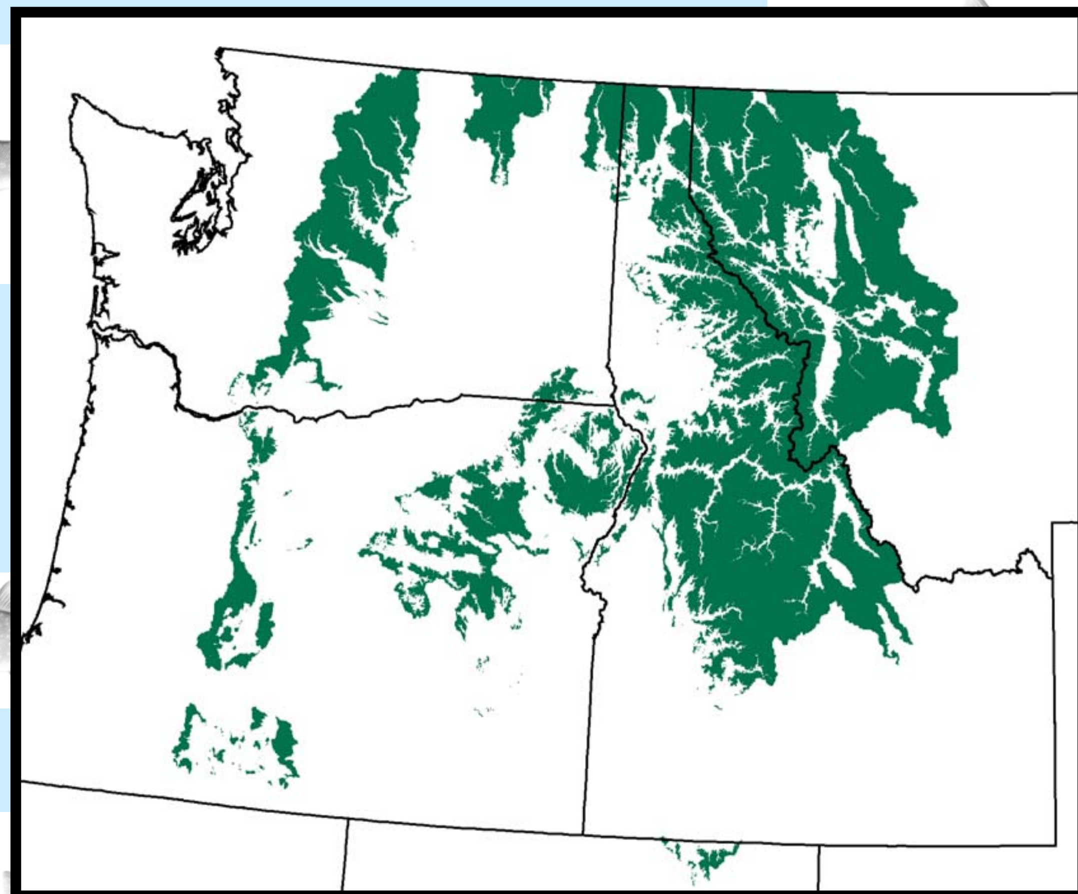
Implications for enhanced bio-physical monitoring?

Courtesy: Dan Isaak, USFS, Boise, ID

Currently Suitable Habitat

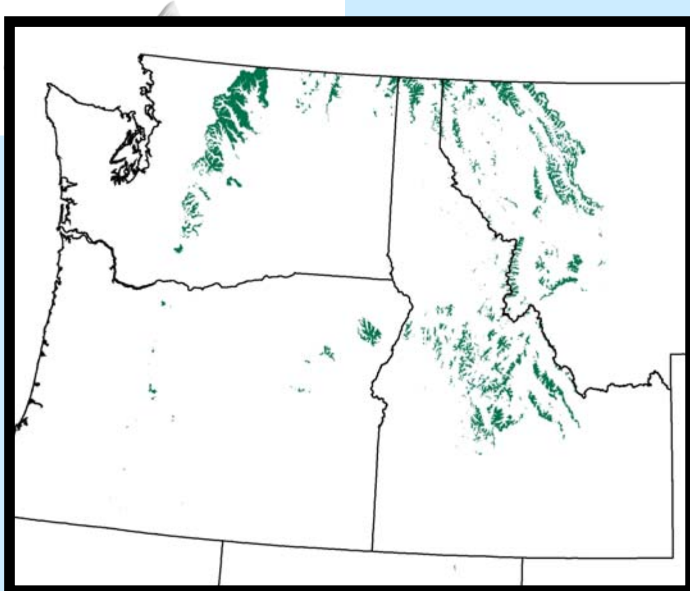
<u>Juvenile Bull Trout Lower Elevation Limit (R^2 = 0.74)</u>

$Y = 18693 - 191(lat) + 73.6(long)$



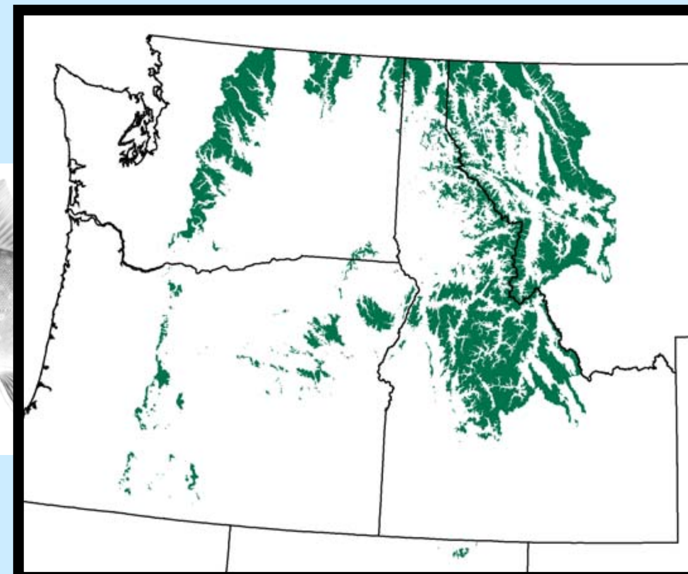
Courtesy: Dan Isaak, USFS, Boise, ID

Future Suitable Habitat?



~ 5.0 °C Increase

Habitat Reduction	Areal Extent	# Patches >5000 ha
Rangewide	-92%	-99%
Idaho	-94%	-100%



~ 1.6 °C Increase

Habitat Reduction	Areal Extent	# Patches >5000 ha
Rangewide	-40%	-60%
Idaho	-37%	-70%

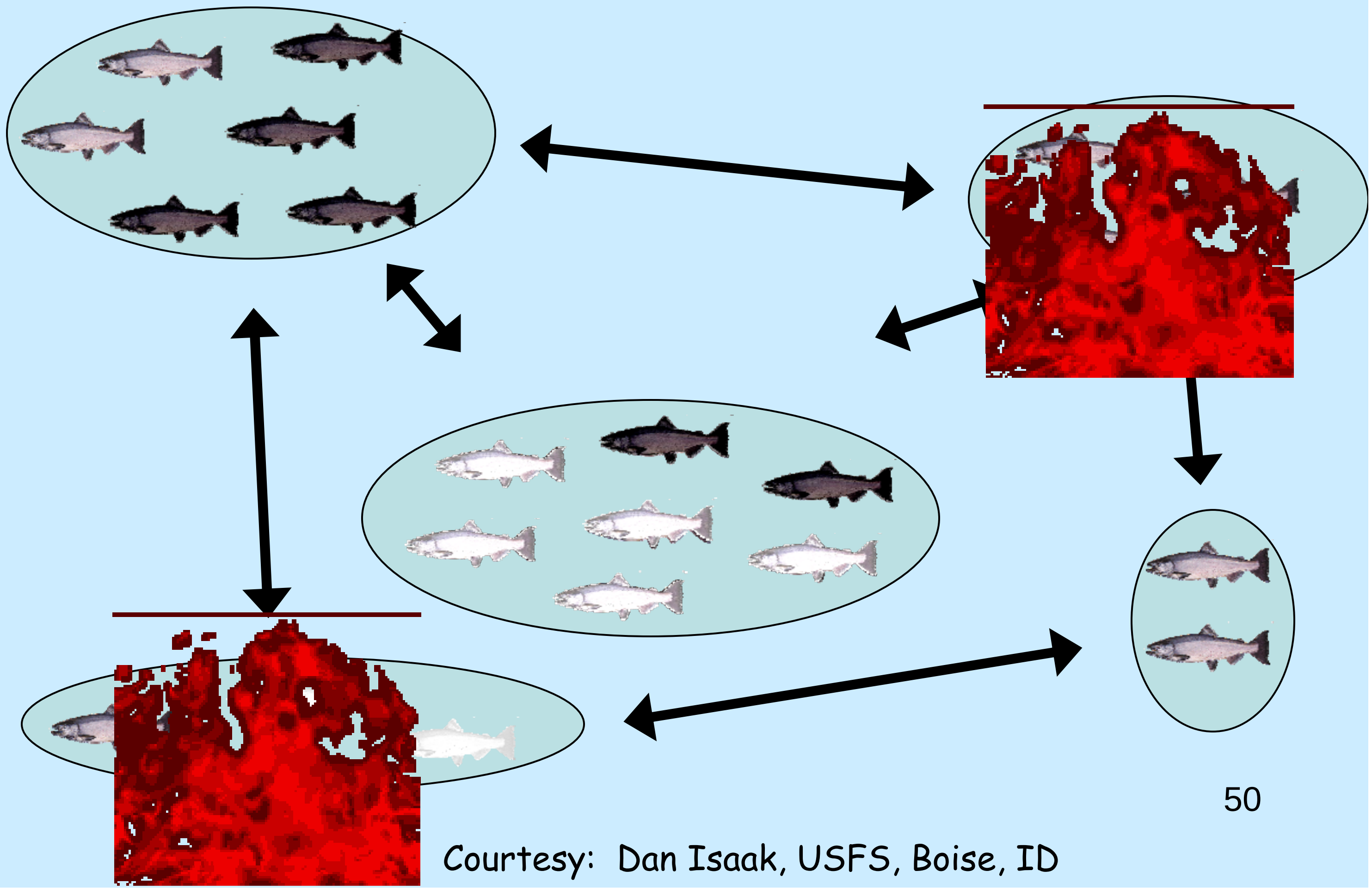
Courtesy: Dan Isaak, USFS, Boise, ID

Management Implications for Resistance & Resiliency

- Maintain productivity & abundance
- Increase spatial structure & redundancy
- Maintain & increase connectivity / corridors

How to achieve this?

- Riparian management options: what, how, & where?



Courtesy: Dan Isaak, USFS, Boise, ID

Overall Management Implications

What can we do? Can we do anything?

1. **Focus on the most effective responses**
2. **Identify watershed vulnerabilities**
3. **Assess current practices / operations**
4. **Define time period of interest** (20, 50 or 100 yrs). *Since different processes respond at different rates, the identified vulnerabilities will change with time period of interest.*
5. **Modify operations/ practices as required.**