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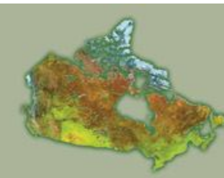
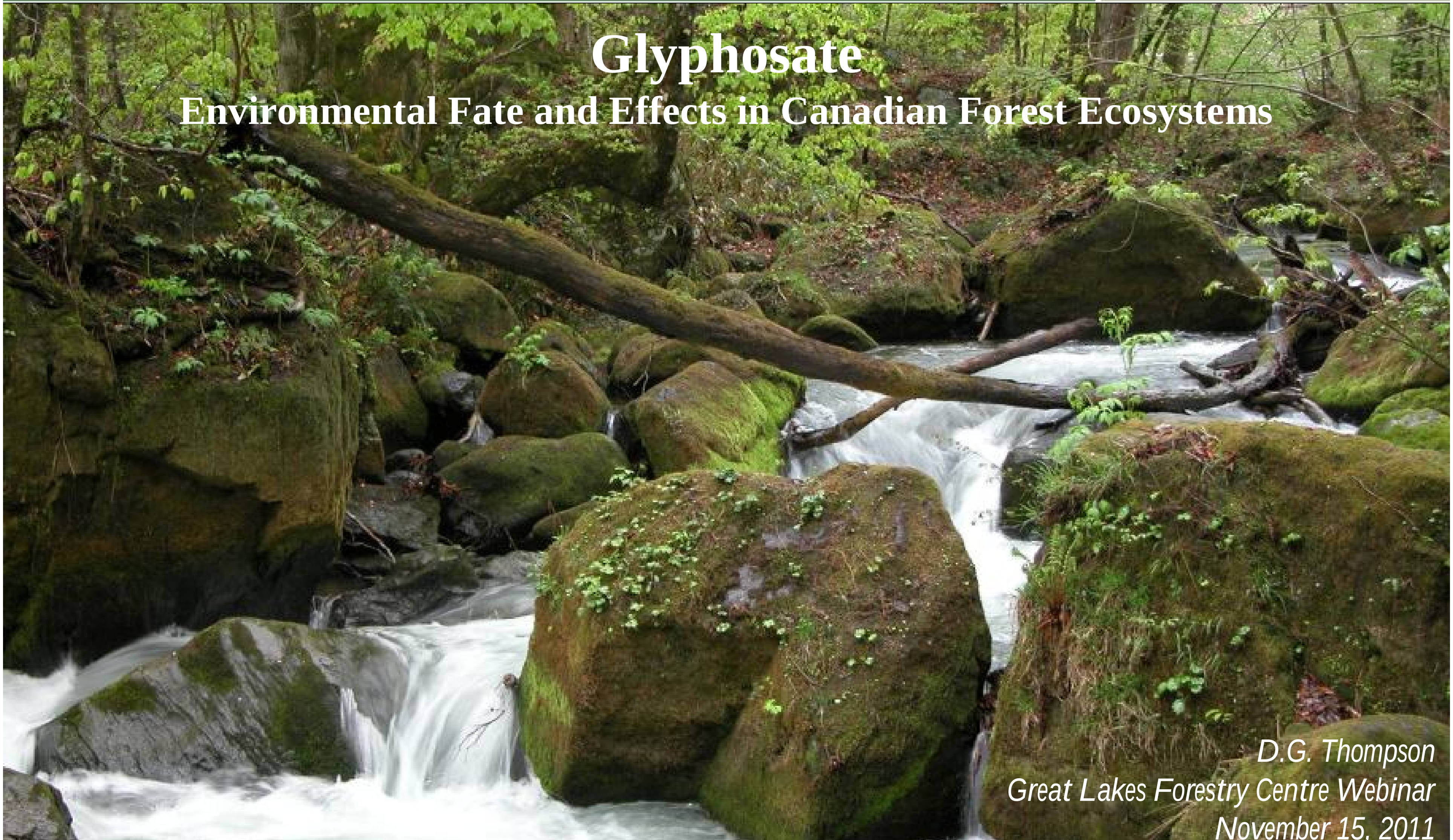


Glyphosate

Environmental Fate and Effects in Canadian Forest Ecosystems



D.G. Thompson
Great Lakes Forestry Centre Webinar
November 15, 2011

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Frontline

Forestry Research Applications

Canadian Forest Service - Sault Ste. Marie

Technical Note No. 112

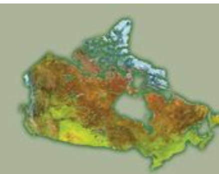
Frequently Asked Questions (FAQs) On the Use of Herbicides in Canadian Forestry

D.G. Thompson, D.G. Pitt

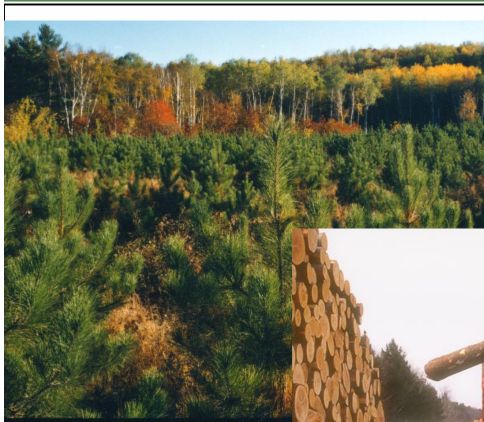
What is the basis of public opposition?

- Part of a much broader general opposition to the use of pesticides
  - Significant historical events (DDT, Agent Orange, Dioxins in phenoxy herbicides) generate fear
- Lack of distinctions historical vs. modern pesticides, classes of pesticides, among individual compounds despite fundamental differences in modes of action, chemistry and toxicology, which are primary determinants of actual risk
- Differential in primary information sources is a key issue
- Public opinion survey *(Wagner et al. 1998)* relating directly to herbicide use in forestry shows
  - support for tree planting; an understanding of the need to control competing vegetation
  - but aerial herbicide use as very risky and unacceptable approach
  - public perspective differs markedly from that of foresters & scientists
- Primary concerns are potential human & environmental health
- Public concerns significantly constrain social license to operate
  - Quebec ban on forest herbicides 2000
  - N. Ont MPs demand investigation 2009
  - Calls to ban glyphosate use in BC & NB in 2011
- Further bans are likely to have significant economic <u>and</u> ecological implications

Why do we need herbicides?



Meeting future demands for wildlife habitat and biodiversity conservation will require that society's growing demand for wood be satisfied on a shrinking forestland base. *Wagner et al. 2004*



> 400,000 jobs

> 22 B $

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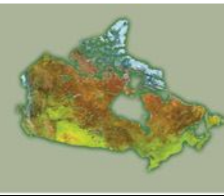
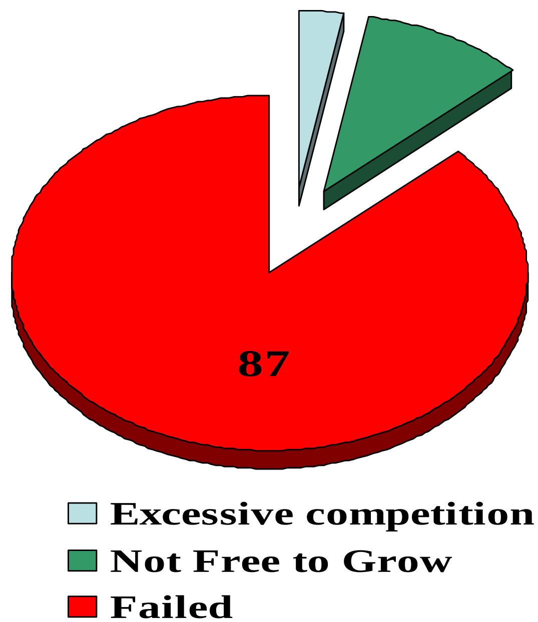
Why not use alternatives?



- Several alternative approaches, no silver bullets; all options carry risks and limitations
  - Natural Regeneration (Do Nothing)
    - 49.5% of harvested area (10 yr avg) *(CFS 2011)*
    - Less control over species competition, extensive land use impacts?
  - Mechanical site prep
    - fossil fuel use, soil compaction, cost
  - Aerial Herbicide
    - Potential indirect effects on wildlife
  - Manual brush saw
    - worker exposure to known carcinogens,
    - Operational feasibility and cost
  - Biological control
    - Potential disease in pruned orchards, limited efficacy, operational feasibility, cost

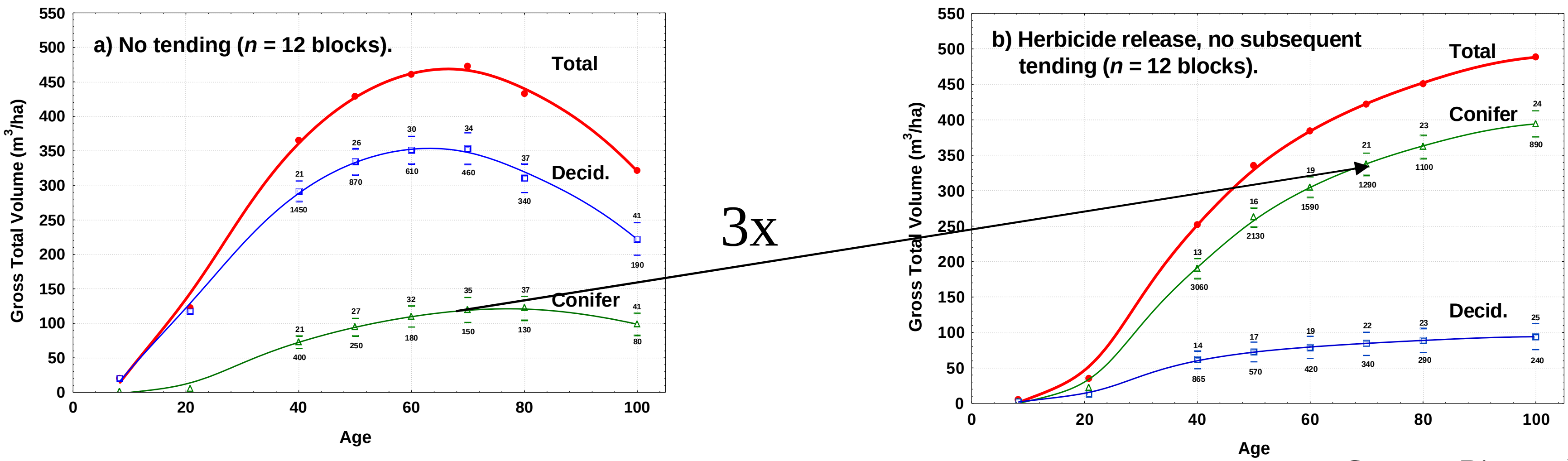
Why not rely on non-chemical alternatives?

- Nova Scotia (Nicholson 2007, NSDNR report)
  - 97 conifer plantations, that were treated with non-herbicide alternatives (i.e. no treatment, manual weeding, large stock) were surveyed 6-8 yrs post establishment
  - 87% outright failures, 10% not free to grow



Are herbicides effective?

- Results of 23 long term (10-30 yr) studies, demonstrate effective control of competing vegetation (primarily with herbicides) yields 30-300% increases in wood volume for major commercial tree species *Wagner et al. 2004*

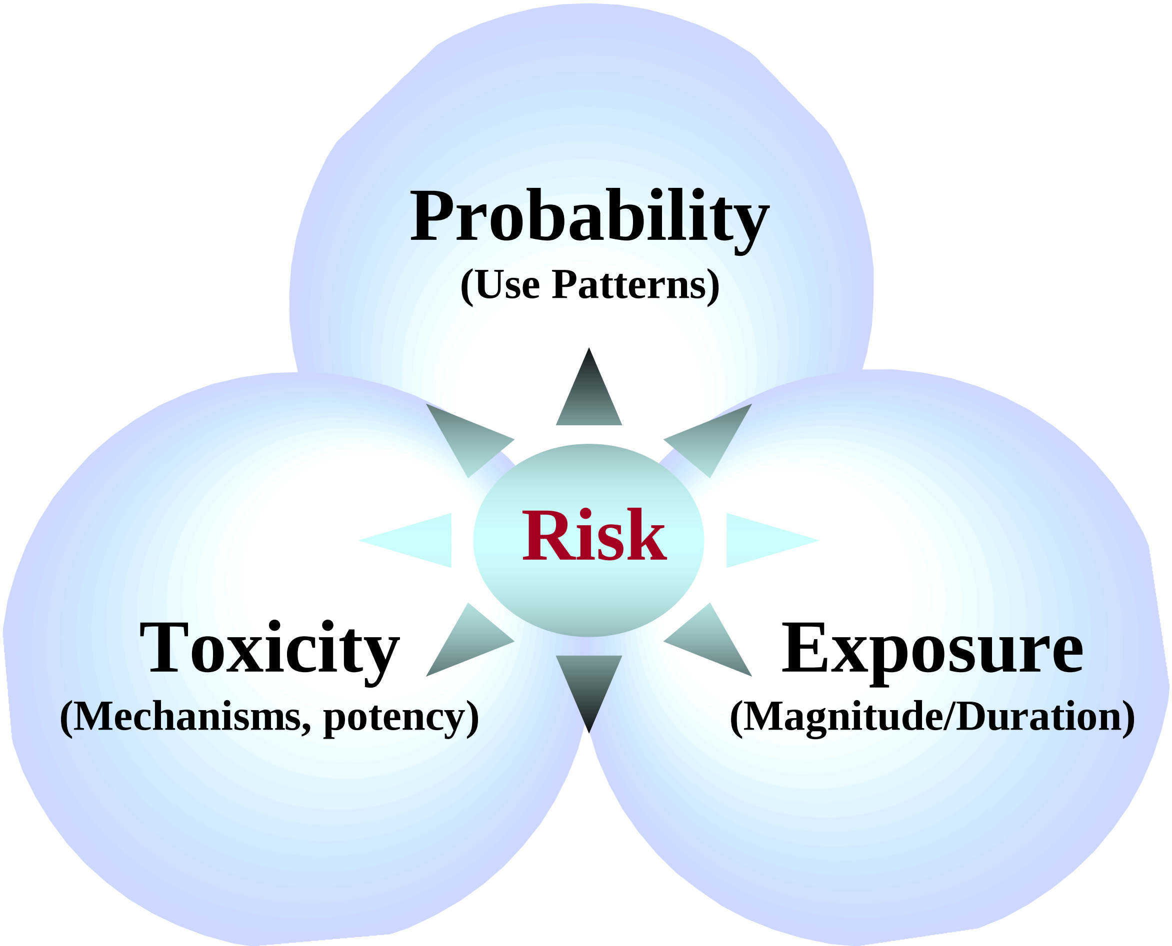


Source: Pitt et al. 2004

- Aerial herbicide treatment is ~ 3x more cost-effective than manual brush saw; Vision (\$12.16 m^{-3}); brushsaw (\$38.38 m^{-3}) *Dampier et al 2006*
- Herbicide treatments are the most cost-effective, reliable and efficient means of releasing conifer from competing vegetation

What are the risks?

- The probability that some specific action will result in an adverse effect or undesirable outcome
- Aerial application of glyphosate-based herbicides
  - direct effects on wildlife?
  - indirect effects on wildlife?



What is Glyphosate?

- Glyphosate is the active ingredient in several formulated products -Vision, VisionMax, Forza, Vantage
- Mechanism of action in plants is on (enolpyruvyl-shikimate-phosphate-synthetase (EPSPS)) enzyme of the shikimic acid pathway
- Biochemical pathway occurs only in plants and some micro-organisms, not in higher animals, thus glyphosate itself is relatively non-toxic to animals *(Devine et al. 1993; Durkin 2003)*
- <u>**BUT**</u> all formulated products contain surfactants to enhance uptake of glyphosate across plant cuticles
- Surfactants (e.g. POEA) are general narcotics and are known to be the primary toxicant in animals, particularly aquatic organisms

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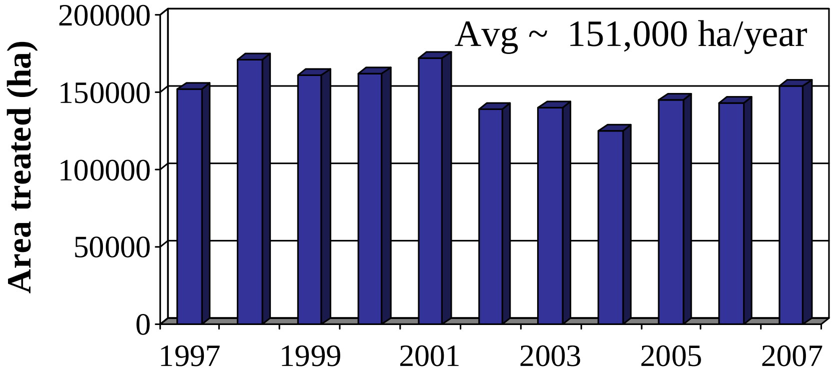
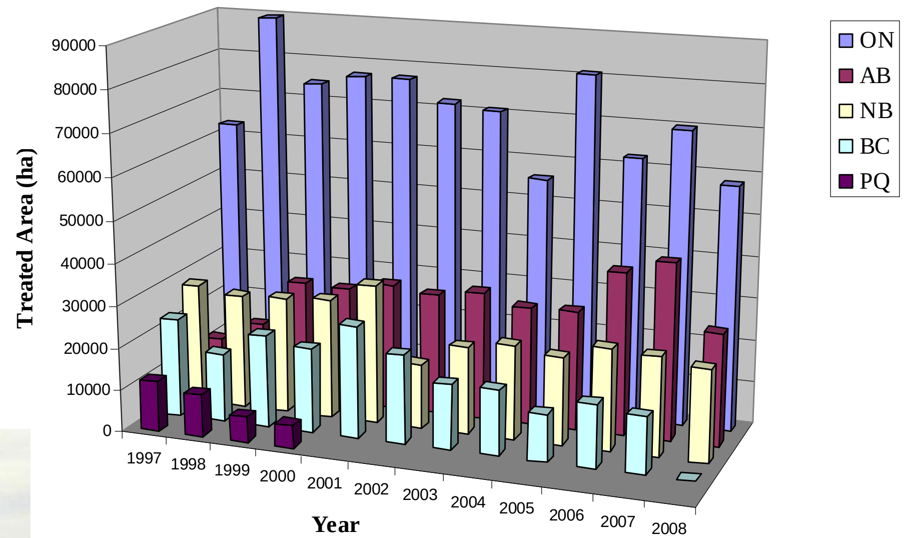
How are glyphosate-based herbicides used in forestry?

National Historic Profile



Trends in Major Use Provinces



Typically via aerial application @ rates ~ 2 kg a.e./ha
Single site treated typically 1x, max 2x per rotation

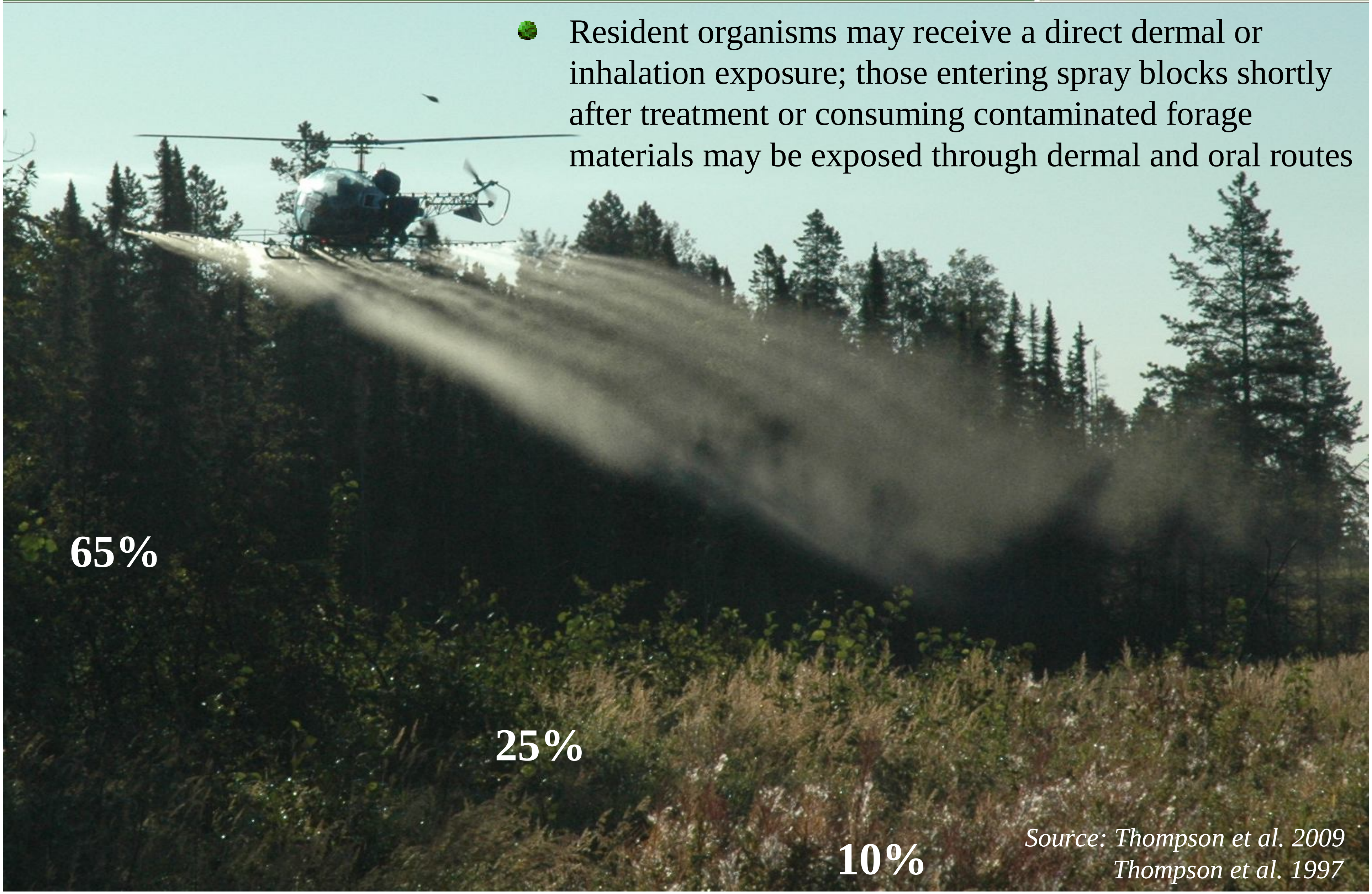
In context (Ontario 2008)
58,038 ha ~ 0.16% of productive forest land

116,076 kg ~ 21% of total 547,397 kg used in agriculture

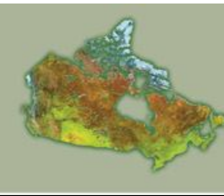
Sources: National Forestry Database Program 2011
OMAFRA 2011
OMNR State of Forest Report 2006

Which organisms are most likely to be affected

- Resident organisms may receive a direct dermal or inhalation exposure; those entering spray blocks shortly after treatment or consuming contaminated forage materials may be exposed through dermal and oral routes

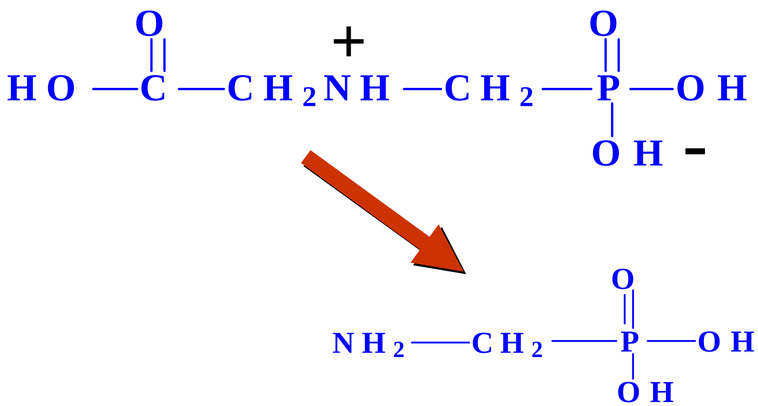


Source: Thompson et al. 2009
Thompson et al. 1997

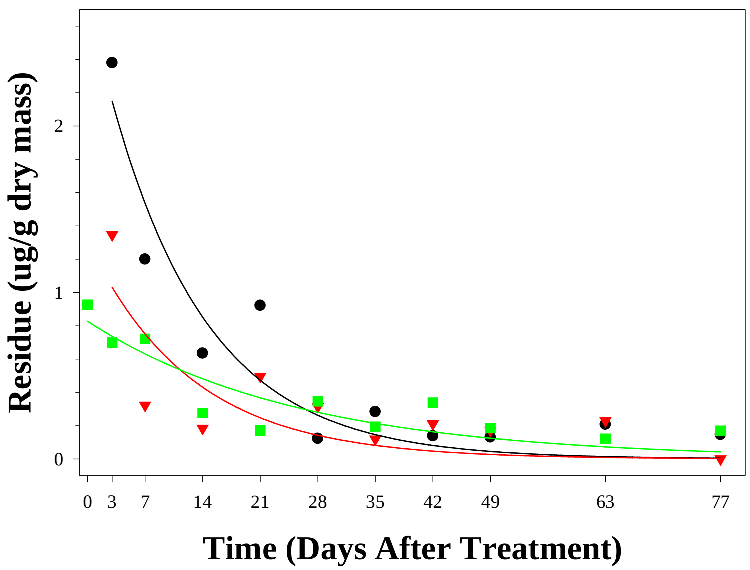


How does glyphosate behave in the environment?

Glyphosate



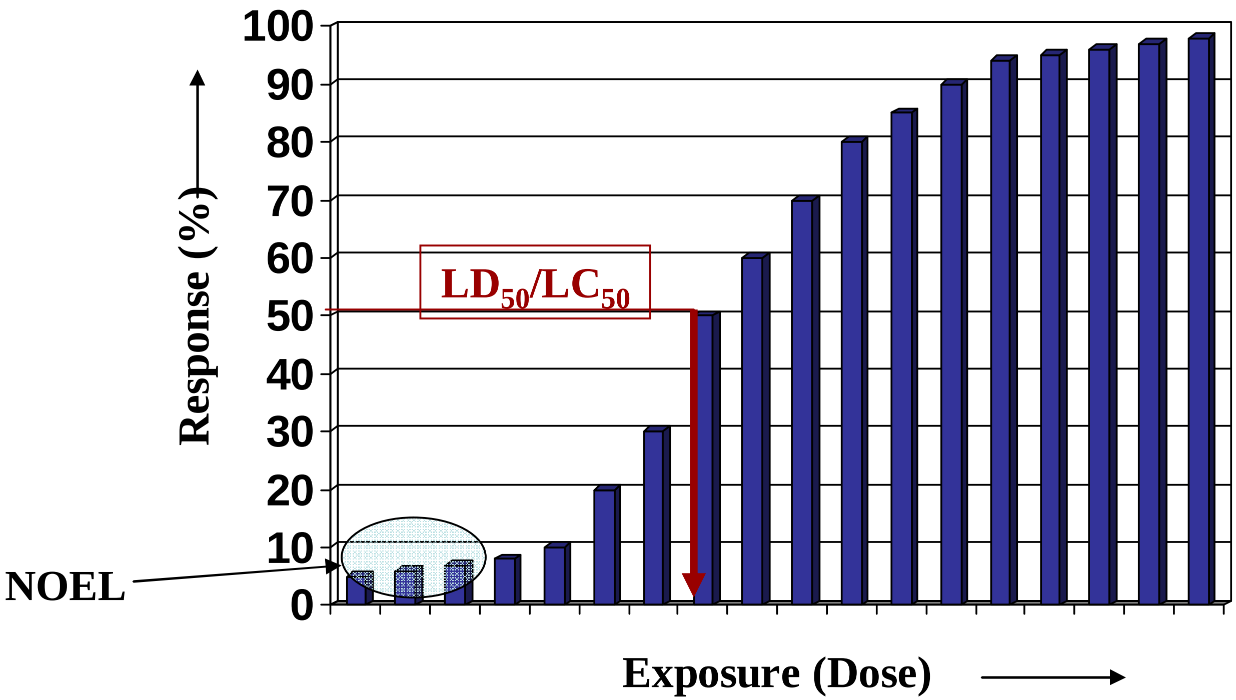
AMPA



- Non-chlorinated, low Kow = no bioconcentration
- Highly water soluble but also zwitterionic
- Binds strongly to organic matter and clay in soils & sediments, not susceptible to leaching
- Glyphosate dissipates rapidly following exponential decline curves in vegetation, soils and water and is non-persistent
- In aquatic systems both glyphosate and POEA are strongly sorbed and rapidly degraded *(Wang et al 2005)*
- Microbial degradation in soils and water, first degradation product is AMPA
- Uptake, translocation and metabolism in plants
- Fate of glyphosate has been examined via field study in most major forest regions of Canada, typical values for DT_{50} (days):

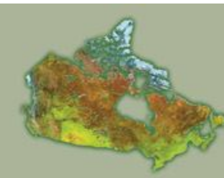
Vegetation 2 (Thompson et al. 1997)
Berries < 20 (Roy et al. 1989; Legris et al. 1989)
Litter 10-12 (Feng & Thompson, 1989; Thompson et al. 2000)
Soils 10- 24 (Thompson et al. 2000, Roy et al. 1989)
Streams < 1 (Feng et al. 1989)
Wetlands 4-26 (Wojtaszek et al. 2004)

Toxicology Fundamentals



- Sigmoidal relationship with exposure or dose
- Increasing exposure (Dose) results in increasing effect
- Best comparative estimator of inherent toxicity is LD_{50} (LC_{50})
- NOEL/NOEC is most important endpoint for assessing direct toxicity

Which wildlife species are at greatest risk?



Tier I Risk Assessment Based on Hazard Quotients (HQ)

- HQ = environmental CONC/NOEC
- HQ ≥ 1 indicate potential risk requiring higher tier testing and evaluation

Group	Conc $_{(Max)}$	NOEC	HQ
Large mammals (Goat)	529	2100	0.25
Small mammals (Mouse)	322	2500	0.13
Birds (*C. virginianus*)	529	5620	0.09
Earthworms (*E. foetida*)	1.4	250	0.01
Soil microorganisms	1.4	16	0.28
Fish (*O. mykiss*)	0.16	0.84	0.19
Zooplankton (*D. magna*)	0.55	1.9	0.28
Amphibians (*L. pipiens)*	*0.55*	0.83*	0.66
Aquatic Plants (*M. sibiricum*)	0.55	0.78	0.71
Phytoplankton (*S. capricornutum*)	0.55	0.73	0.75
Periphyton (Mixed colonies)	0.55	0.89	0.62

Sources:
Conc (mg a.e./L) (max) as cited in Thompson et al. 2011
TRV from Giesy et al. 2000 except
** LC10 L. pipiens from Edginton et al. 2004*

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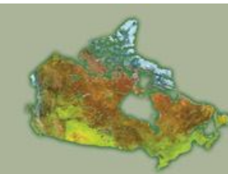
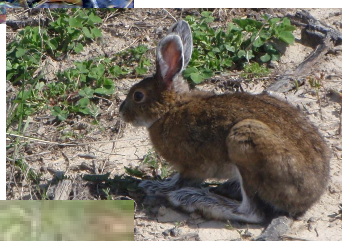
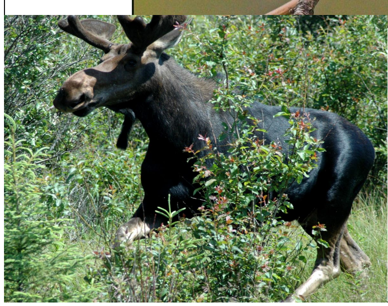
What do others say about direct toxicity risks to wildlife?

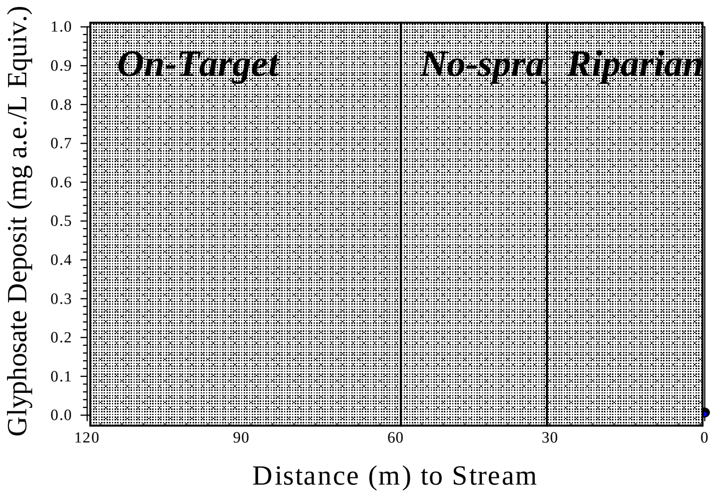


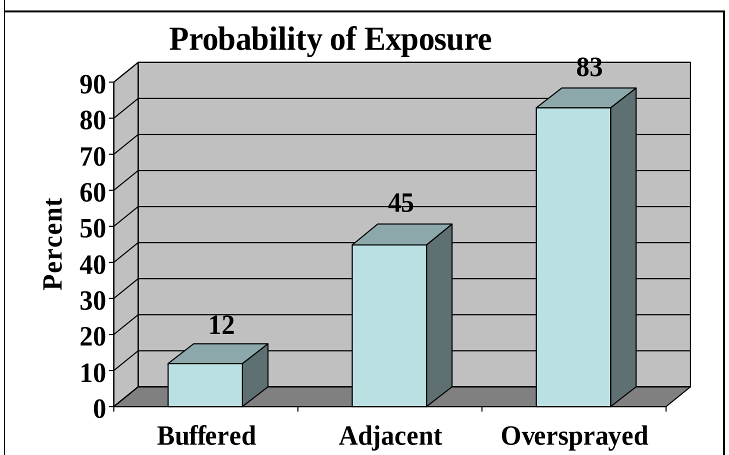




- Based on current data, EPA has determined that the effects of glyphosate on birds, mammals, fish and invertebrates are minimal *(USEPA 1993)*
- Herbicide concentrations in environmental media following forestry applications typically are much lower than concentrations associated with adverse effects on both fish and wildlife. *(Tatum et al. 2004)*
- Foliar concentrations are below acute and chronic toxicity thresholds for herbivores *(USDA-FS 2003)*
- For small mammals, a large margin of safety exists relative to dosages typically acquired under forest use scenarios (*McComb et al. 2008)*
- Several comprehensive have observed birds in forest plots treated with glyphosate-based herbicides, in no case was there evidence of direct toxicity *(Giesy et al. 2000)*
- Typical field rates yield soil concentrations far below levels expected to be acutely toxic to soil organisms; no deleterious effects on litter decomposition or several metrics of soil microbial function at typical use rates/soil concentrations *(Stratton 1990, Houston et al. 1998, Fletcher and Freedman, 1986)*

Potential Direct Effects on Aquatic Species

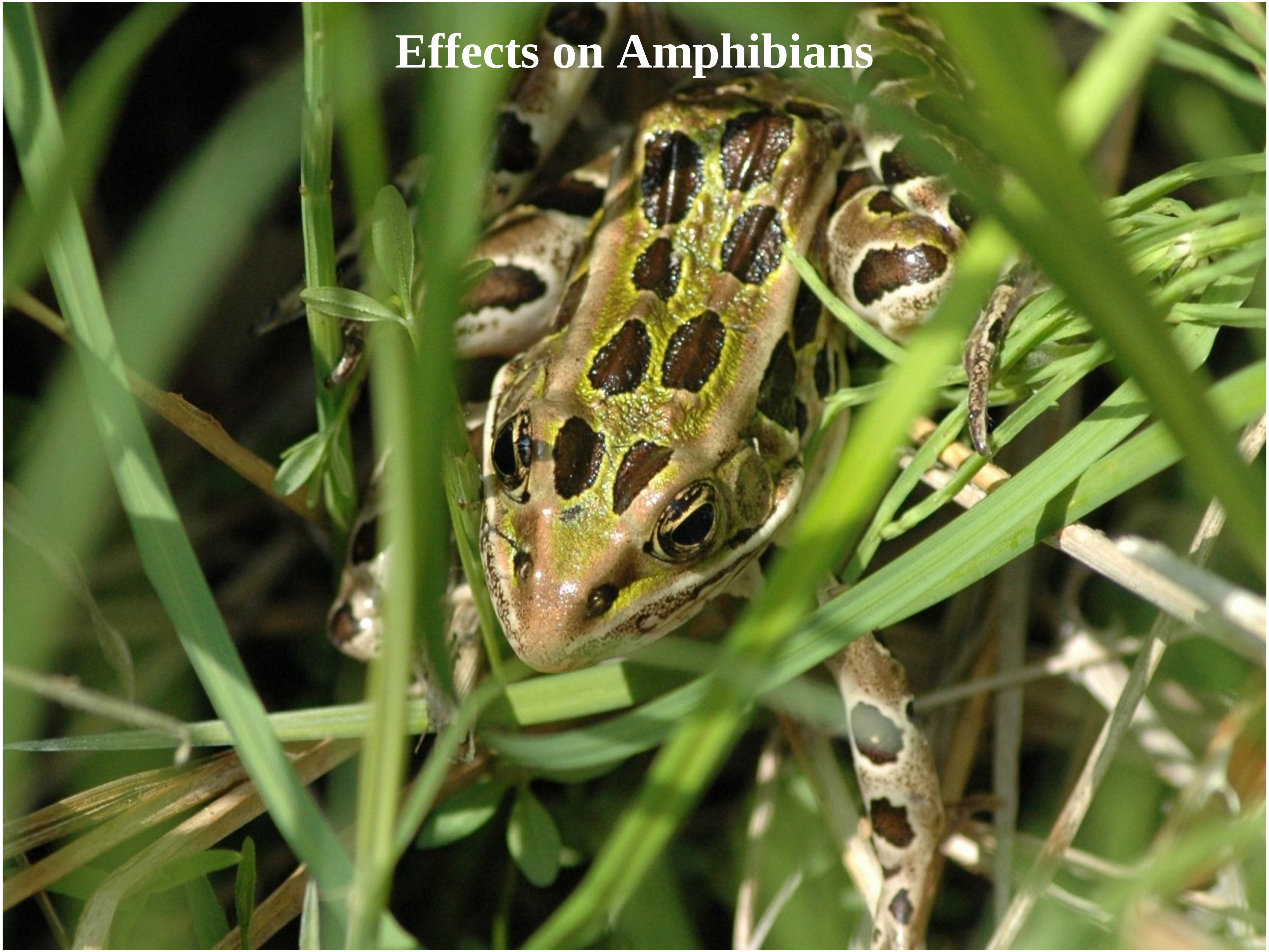




- In combination, electronic guidance, low-drift nozzles and buffers, strongly mitigate against exposure & effects on non-target aquatic organisms in both flowing and non-flowing systems

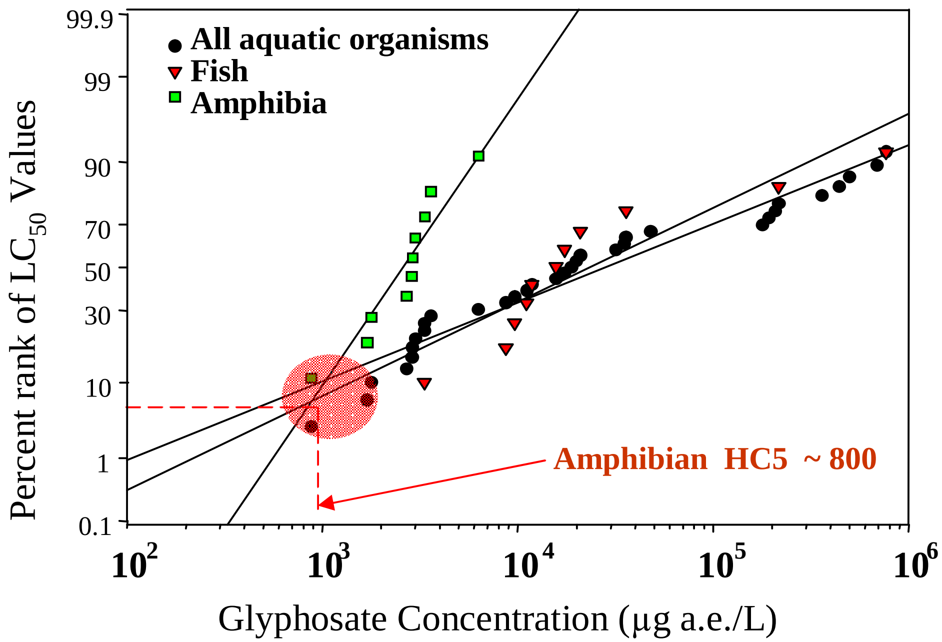
- Stream example: whole watershed study in coastal BC
  - buffered streams conc. < 4 ppb
  - oversprayed stream max conc. of 162 ppb (pulse)
    - coho salmon fingerlings caged in situ 2.6% mortality; catch per unit effort recovered within 3 weeks *(Holtbie & Baillie 1989)*
    - No significant efffect on aquatic invertebrates *(Kreutzweiser et al 1989)*

- Wetland example: results of operational monitoring in 51 different wetlands in N. Ontario
  - wetlands protected by buffers have dramatically lower probability of contamination (any detectable levels of glyphosate) as well as dramatically lower mean aqueous concentrations


Effects on Amphibians

Amphibian SSD

(Roundup® or Vision®)



- Amphibian larvae are highly sensitive to formulated glyphosate products containing surfactants (e.g. POEA)
- Relatively narrow range of sensitivity among various species
  - (LC_{50} ~ 800 to 3500 ppb)
- Study by *Edginton et al. 2004* continues to provide one of the lowest LC50 estimates for native Cdn species (Leopard frog larvae = 880 ppb)
- Recent study by *Relyea and Jones 2009* provides similar estimates of 800 ppb for spring peeper and bullfrog larvae
- Estimates of toxicity thresholds for amphibian larvae (most LC_{10} values, HC5) are similar at ≥ 800 ppb

Source: Solomon and Thompson (In prep)

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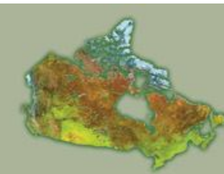
Direct effects on Amphibians?

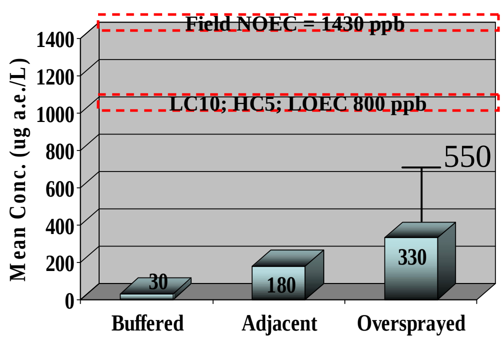


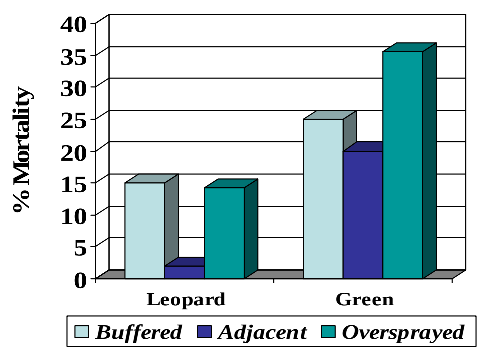
- *Relyea 2005* - concluded "current application rates of Roundup can be highly lethal to many species of amphibians"; **<u>but</u>** formulation (RWGK), rate (12.5 kg a.e./ha) and test concentration (3100 ppb) are all essentially irrelevant with respect to formulations, rates & exposure scenarios typical of forest or agricultural sectors

- *Wojtasek et al 2004* - in situ enclosure studies,
  - caged leopard & green frog larvae in 2 different wetlands
  - exposed to several different concentrations of Vision
  - NS effects on mortality, avoidance response or growth of either spp at concentrations below 1430 ppb

- *Thompson et al 2004* operational monitoring of 51 small wetlands in N. Ont.;
  - 99th centile exposure levels
    < Lab tox thresholds LC10,HC5
    << field derive NOECs

  For 2 species of larvae caged-in situ,
  - NSD in mean mortality
  - NS concentration dependence

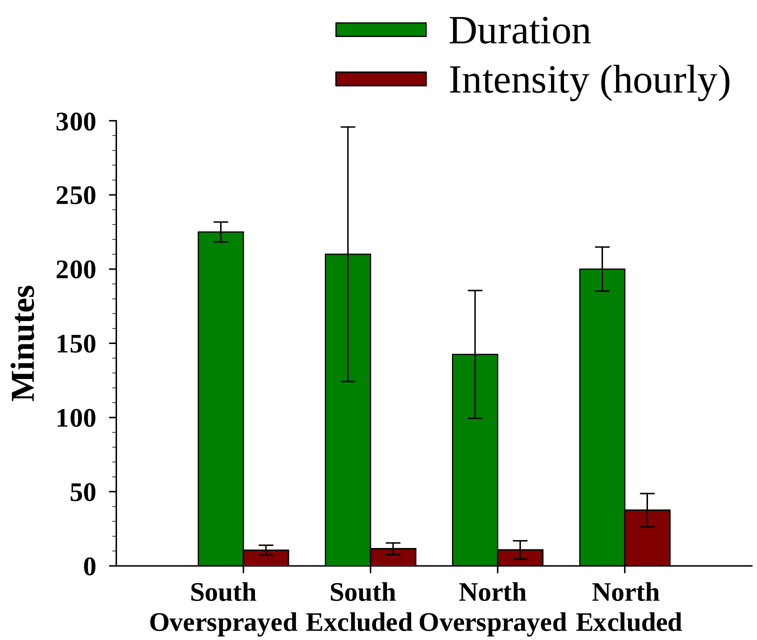


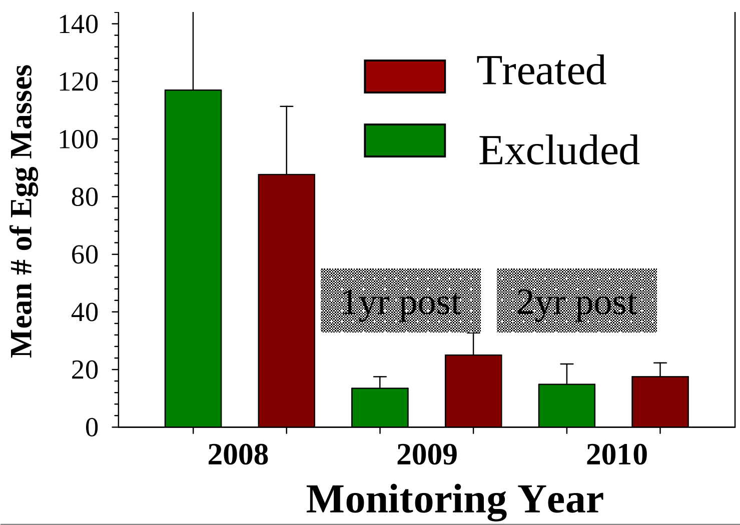


Effects on Breeding Populations of Wood Frogs (*L. sylvatica*) ?

Source: Thompson et al. In prep

Breeding Effort and Success
(Treated vs Untreated Sites)



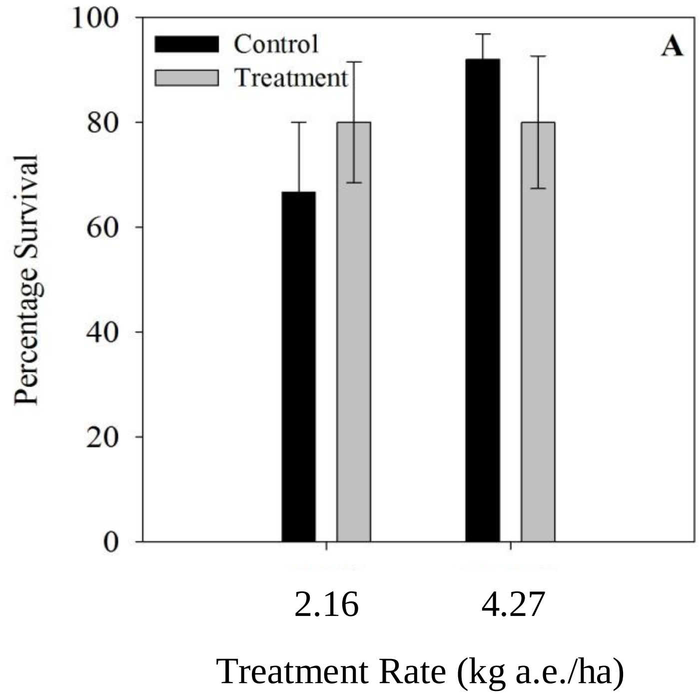


- Paired treated and excluded areas replicated through both space and time
- All sites occupied in all years
- Equiv. calling phenology, duration & intensity
- NSD ($p > 0.05$) in number of egg masses
- NSD ($p > 0.05$) in egg hatch success
- Equivalent abundance of juveniles & adults
- Equivalent size and mass of juveniles & adults

Source: Thompson et al. In prep

Effects on terrestrial life stages?

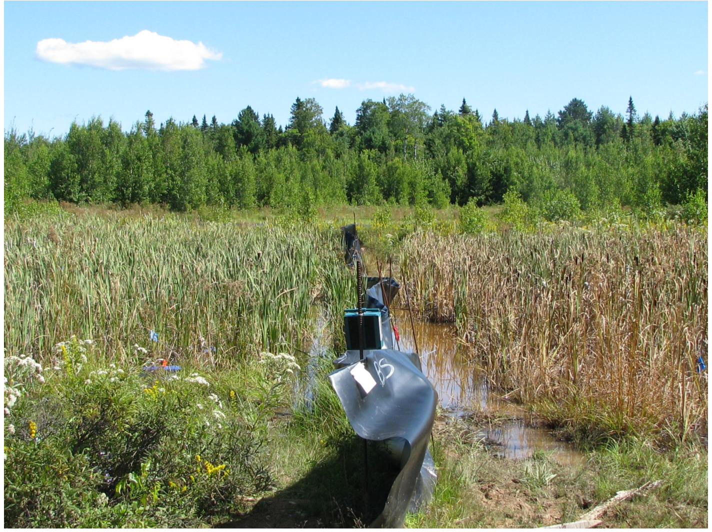
(Juvenile Green Frogs (*L. clamitans*))

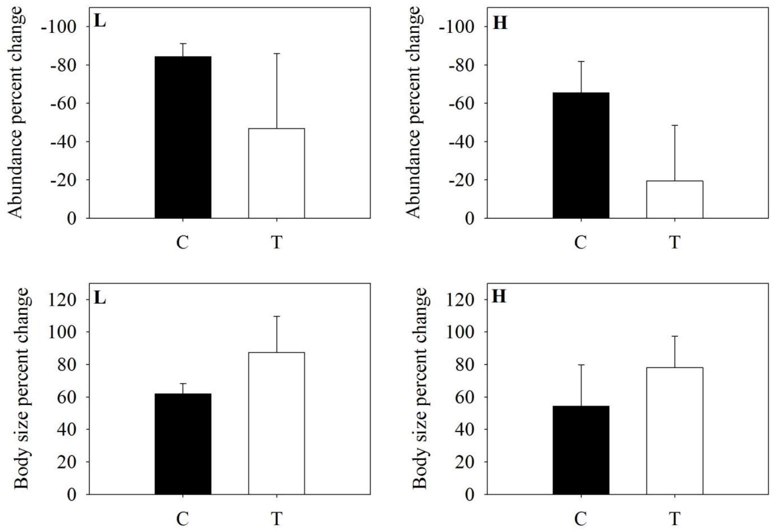


- Direct exposure to VisionMax formulation, in-situ littoral enclosures, 14 days
- NSD on survival, body condition, liver somatic index or Bd (chytrid fungus) infection rates for juvenile green frogs exposed at either typical or 2x treatment rates

Source: Edge et al. 2011

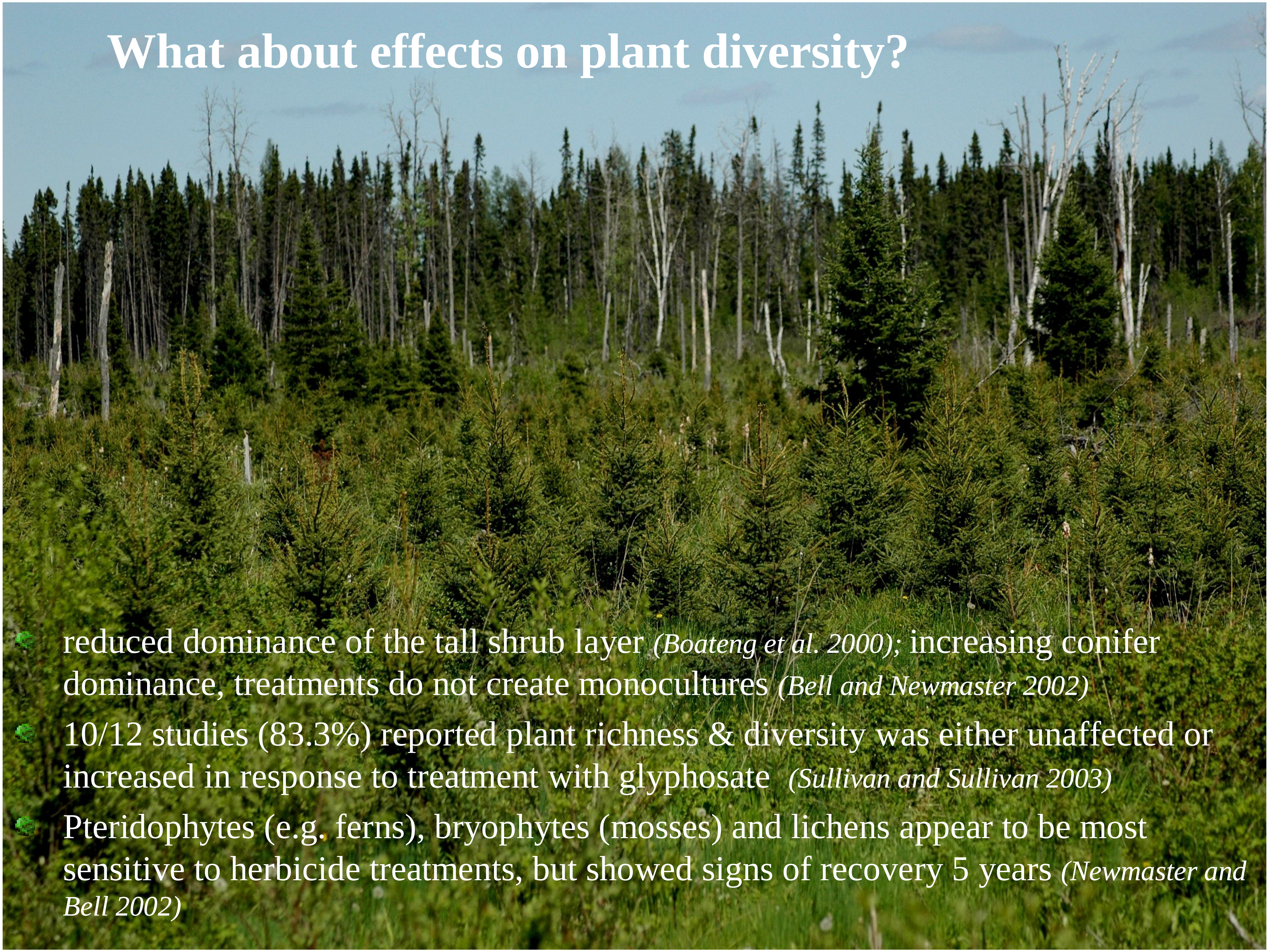
Multiple Stressor Effects In Wetlands ?





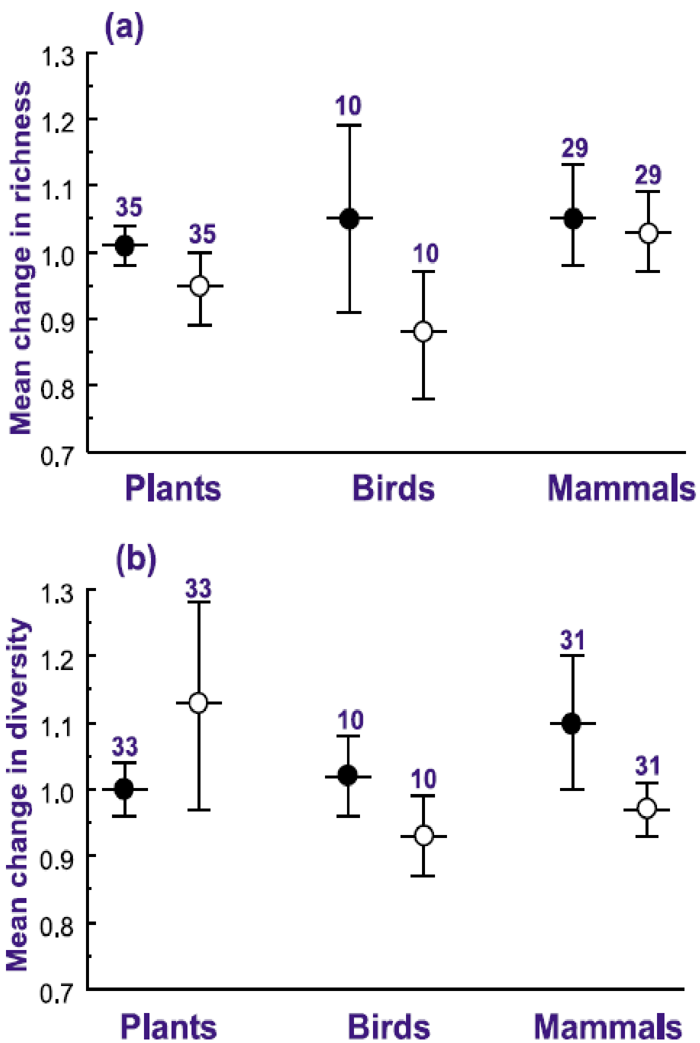
- Replicated split-wetland experimental design under both agricultural and forestry scenarios
  - effects on macrophytes, phytoplankton, zooplankton and amphibians
- Initial results for split-wetland forestry scenario experiments show:
  - Negative trends but NSD in green frog abundance for either H or L treatment levels versus controls
  - Positive trends but NSD in body size for both treatment levels
  - At end of 2 yr larval stage, NSD or deleterious trends at either treatment level

What about effects on plant diversity?



- reduced dominance of the tall shrub layer *(Boateng et al. 2000);* increasing conifer dominance, treatments do not create monocultures *(Bell and Newmaster 2002)*
- 10/12 studies (83.3%) reported plant richness & diversity was either unaffected or increased in response to treatment with glyphosate *(Sullivan and Sullivan 2003)*
- Pteridophytes (e.g. ferns), bryophytes (mosses) and lichens appear to be most sensitive to herbicide treatments, but showed signs of recovery 5 years *(Newmaster and Bell 2002)*

What about indirect effects on terrestrial wildlife?

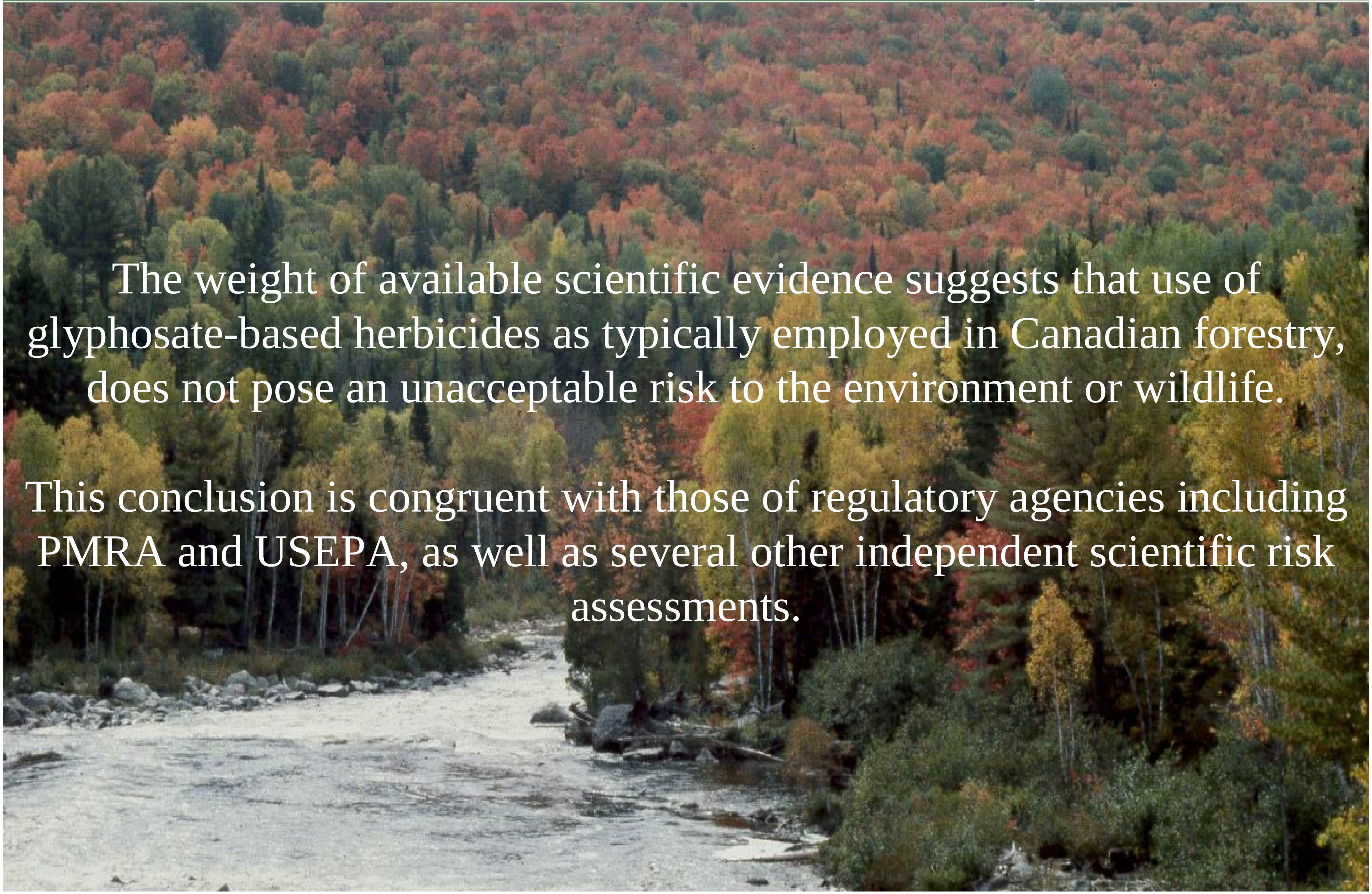


Source: Sullivan & Sullivan 2004

- Analyses based on 60 published studies (*Sullivan & Sullivan 2004)*
  - the magnitude of herbicide induced changes in mean species richness and diversity of vascular plants, birds, and small mammals, were within the range of natural variation
- Large mammals (*Lautenschlager et al. 1999)*
  - Reduced moose activity in treated sites1-5 years post-treatment associated with reduced browse availability; after 7-11 years moose actually favour treated areas, no effect of forage quality
- Indirect effects on wildlife species are highly variable and species specific (*Guynn et al. 2004*)
  - various studies showing negative, nil or positive effects; shifts are not necessarily negative and primarily reflect a different suite of species exploiting the changing habitat structure brought about by herbicide application.

Take-Home Points

- Efficient & effective conifer regeneration is essential to sustainable use and to retaining conifer dominated stands on the landscape
- Aerial application of glyphosate-based herbicides is the most-cost effective & reliable tool for ensuring successful conifer; more intensive management, including herbicide use, on prime sites could reduce the overall ecological footprint associated with extensive forestry
- Tier I HQ risk analysis indicates a very low risk of direct acute toxic effects for wildlife species including large and small mammals, birds, fish, amphibians
- Several field studies demonstrate no significant effects on aquatic larval, terrestrial juvenile or breeding populations of representative species under exposure regimes typical of glyphosate-based herbicides as used in Cdn forestry
- Aerial applications of glyphosate do not result in plant monocultures
- Effects on wildlife populations are largely indirect, resulting from changes in structure & composition of vegetation; wildlife responses (richness & diversity) for birds, small & large mammals) are species-specific, typically transient & within the range of natural variation observed on untreated sites
- Managing for a mosaic of habitats at appropriate scales across the landscape will help to offset potential indirect effects



The weight of available scientific evidence suggests that use of glyphosate-based herbicides as typically employed in Canadian forestry, does not pose an unacceptable risk to the environment or wildlife.

This conclusion is congruent with those of regulatory agencies including PMRA and USEPA, as well as several other independent scientific risk assessments.

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Residues in Game Meat? Liver tumors?

Residues in Meat?

- Chemical characteristics (low Kow & high water solubility) indicate no bioaccumulation potential in animal tissues
- Field studies show only 1/33 samples of game animal flesh (moose, deer, hare) taken from (or near) treated areas *(Legris and Couture 1991);* residue levels in various small mammals are below ambient levels in their food respectively *(Newton et al. 2004)*
- Studies on lab animals (mice, rats, dogs and rabbits) show that glyphosate is poorly absorbed through the gastro-intestinal tract and rapidly excreted in urine or feces

Liver Tumors in Moose?

- The most common effect observed in test animals force fed very high levels of glyphosate for long periods of time (subchronic or chronic tests) is loss of body weight, a few studies do show some changes in liver weight or blood chemistry that might suggest mild liver toxicity or pathology (see *Durkin 2003*); however, risk assessments based on multiple lifetime feeding studies have failed to demonstrate any tumorigenic potential for glyphosate (*Williams et al. 2000*);
- Given the rapid dissipation of residues from treated foliage, that fact the moose browse over very wide areas and not exclusively in treated sites and that detailed reviews of chronic toxicity studies conclude no evidence of tumorigenic potential, it is considered highly unlikely that reported "tumors" in moose liver could be generated by exposure to glyphosate associated with forestry spray operations
- I have discussed this issue with Dr. Scott Fitzgerald (DVM cervid wildlife pathology; MSU) who suggested that natural parasites such as tapeworm (Echinococcus granulosis) and liver flukes often cause large liver nodules that might be confused with tumors, and that these natural parasites are much more likely to be causal factors

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Exposure via Contaminated Berries

- Significant residues (eg. 20 and 8 ppm in raspberry & blueberry) may occur immediately post-spray and dissipate (DT50 < 20 days) with time *(Roy et al. 1989; Legris et al. 1989)*
- Health Canada sets science-based MRLs to ensure the food Canadians eat is safe. The MRLs set for each pesticide-crop combination are set at levels well below the amount that could pose a health concern *(PMRA)*
- Even maximum residues taken immediately after worst case spray scenarios ~ modern MRLs established as safe for routine consumption of barley, canola, soybeans, and sugar beets or their derived food products (10-20 ppm)
- Treatments sites are specifically signed to prohibit consumption of treated berries based on the precautionary principle

Human Toxicology

- Probability of any direct human exposure is very low (remote sites, signage, access restrictions, pre-spray reconnaissance)
- Formulated products (e.g. Rounudp, which includes POEA) are classifed by USEPA in the least toxic category (IV) for acute oral, dermal and inhalation toxicity.
- Individuals directly involved in mixing/loading

  and spraying are most likely to be exposed (exposures mitigated by professional training, licensing, use of PPE, modern loading systems)

- Absorption of glyphosate from the digestive tract is inefficient. Absorption across the skin is also very slow. Between 0.5 and 2% of glyphosate applied to human skin will be absorbed in 24 hours if not washed off. Virtually all glyphosate absorbed into the circulation is excreted unchanged by the kidneys in a few days. Workers applying glyphosate or occupying areas recently treated recently treated have been shown to absorb only small amounts of the herbicide, that have no toxicological significance. (Dost *2003, BCMOF 6)*

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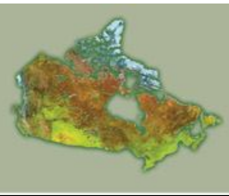
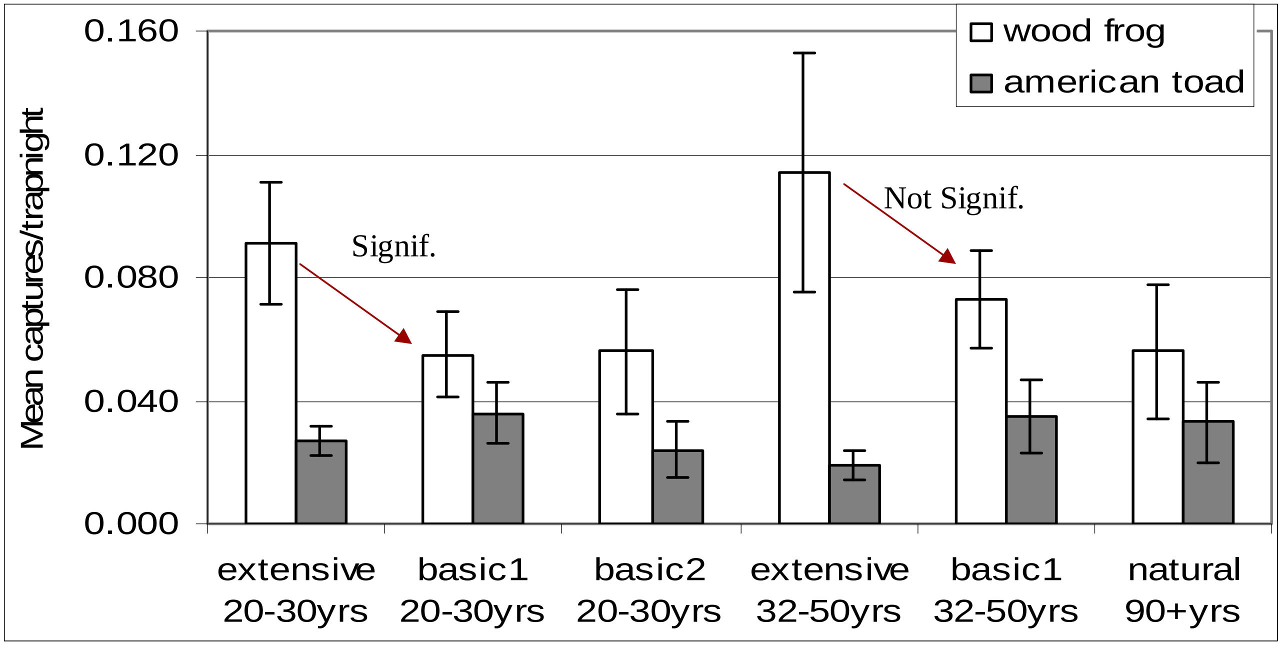
Long term effects on amphibians through habitat change?



American toads unaffected by silvicultural treatments.
Lower relative abundance of wood frogs in treated stands 20 to 30 years old than in all other stands including uncut old forests. However, abundance in treated stands more than 32 years old did not differ from untreated or uncut stands. This effect may have resulted from lower moisture levels in treated young stands. (*Thompson, I. et al. 2008*)



(1) "natural"– stands created following a (circa) 1895 wild fire, (2) "extensive"– stands logged and left for natural regeneration, (3)"basic 1" – stands that were logged, planted, and treated with herbicides (tended), and (4) "basic 2" – stands that were logged, scarified, planted, and treated with herbicide.