Environmental Fate of Forestry Herbicides

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Environmental Fate

- Where does it go?
- How does it get there?
- What happens when it gets there?

Where does it go?

- Offsite
- Onsite

How does it get offsite?

- Spray Drift
- Runoff

Minimizing Spray Drift

- Use of modern spray drift reduction technologies significantly reduces pesticide drift
  - Felsot et al. 2010. Agrochemical spray drift; assessment and mitigation – a review. *Journal of Environmental Science and Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes* 46: 1-23.
- NCASI herbicide use survey asked about use of spray drift reduction techniques
  - NCASI. 2015. Herbicide Use Patterns on Corporate Forest Lands in the United States, 2011 Technical Bulletin No. 1031.

Drift reduction techniques used in forestry

- Use of extremely coarse, very coarse, or coarse spray droplets
- Flow control devices
- Boom/rotor ratios <75%
- Low application heights
- Meteorological limits
- On-board GPS
- Aircraft velocity limits
- Half-boom spraying near streams
- Drift reduction adjuvants
- Straight/level fight paths to reduce shearing
- Parallel flight path near sensitive areas
- Spray buffers

Spray Buffers

- Riparian vegetative buffers effectively mitigate off-site movement via spray drift
  - Thistle et al. 2009. "Deposition of Aerially Applied Spray to a Stream within a Vegetative Barrier" *Transactions of the ASABE* Vol. 52(5):1481-1490.
    - With OFPA-specified buffers, average reduction in stream deposition was 92% with very fine to fine droplets (chosen to maximize drift potential)
- Key component of forestry best management practices (BMPs)

Runoff

- Modern forestry BMPs are highly effective at preventing runoff of herbicides into adjoining water bodies
  - Louch et al. Potential risks to freshwater aquatic organisms following a silvicultural application of herbicides in Oregon's coast range. Integrated Environmental Assessment and Management. DOI:10.1002/ieam.1781.
  - McBroom et al. 2013. Runoff of silvicultural herbicides applied using best management practices. Forest Science 59:197-210.
  - Scarbrough et al. 2015. Herbicide concentrations in first-order streams after routine application for competition control in establishing pine plantations. Forest Science 61: 604-612.
- Implementation rates of forestry BMPs are high
  - Cristan et al. 2016. Effectiveness of forestry best management practices in the United States: Literature review. For. Ecol. Manage. 360:133–151.

If herbicides do get into water, what can happen to them?

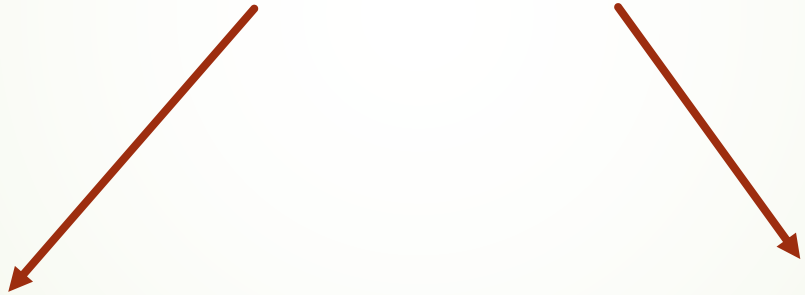
- Diluted and removed by flowing water
- Partition into sediments
- Adsorb to suspended sediment
- Remain dissolved in water
- Volatilize
- Degrade

A lot of this, at first

Then, mostly this

Onsite – Where does it go?

Herbicide Spray

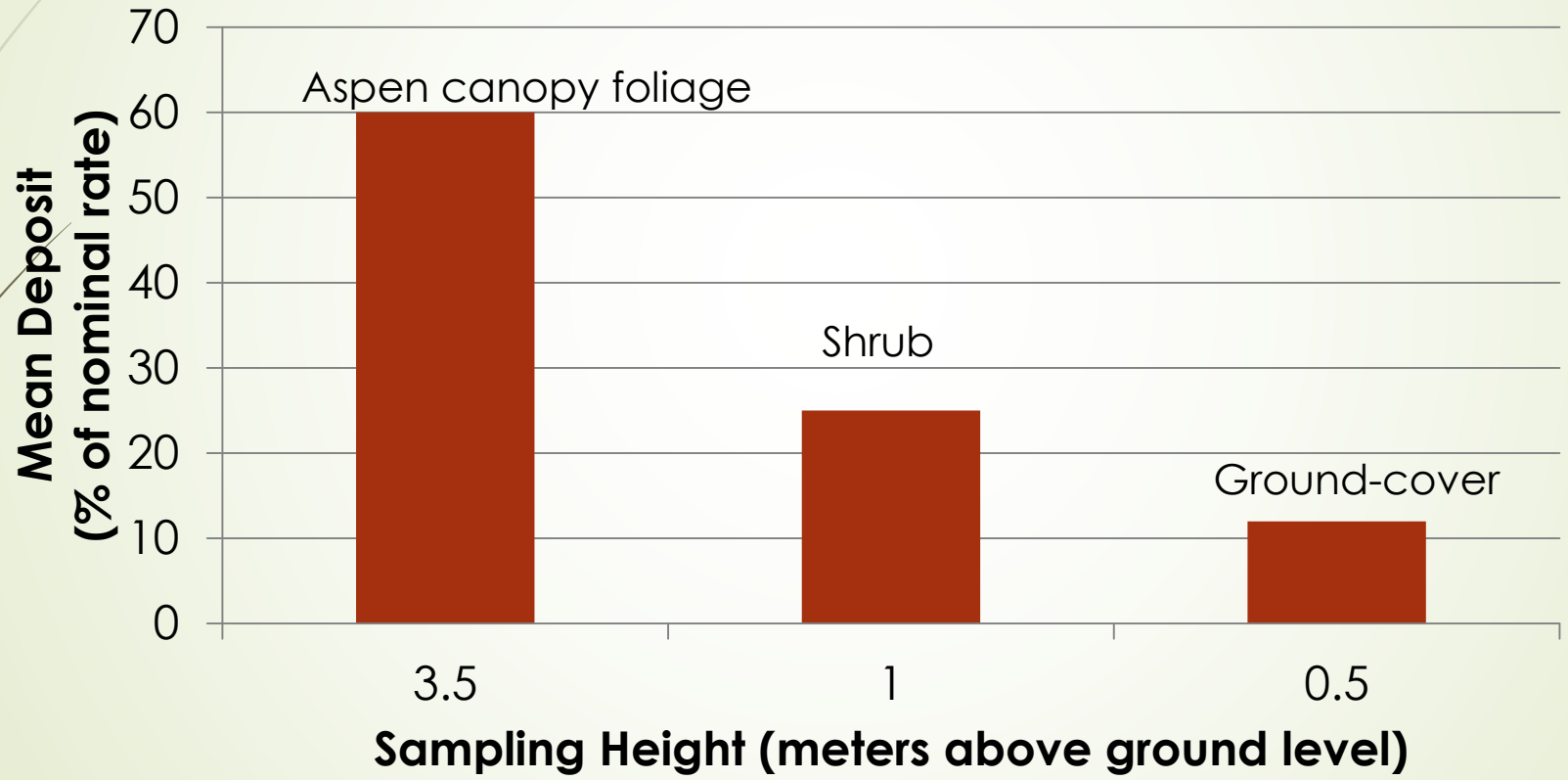


Interception
By vegetation

Falls on soil

Most is intercepted by vegetation

Aerial applications of glyphosate and triclopyr 3-8 yrs post-harvest/replanting of spruce in Ontario aspen-spruce-mixedwood forest



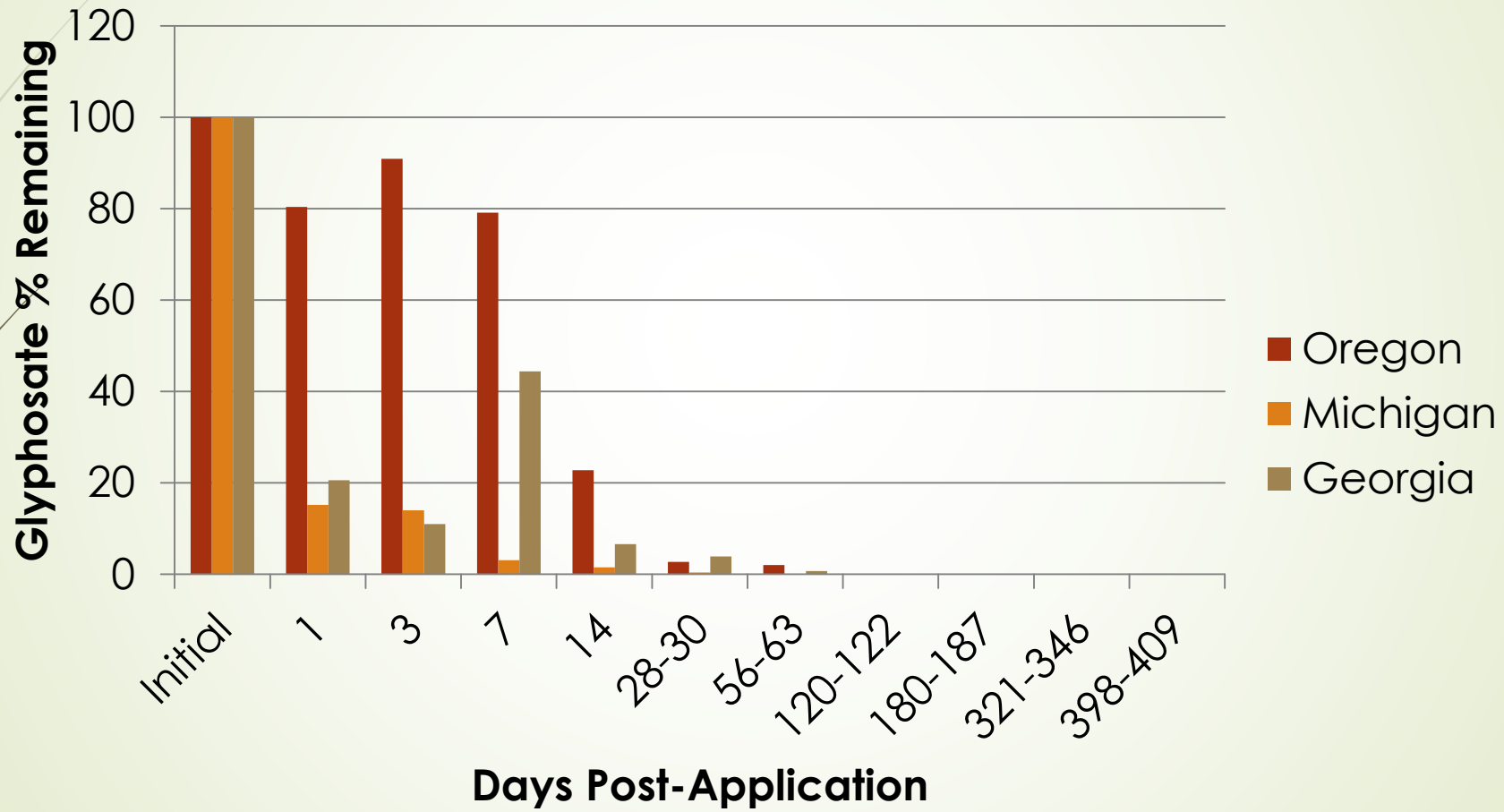
Thompson et al. (1997) On-target deposit and vertical distribution of aerially released herbicides. *Forestry Chronicle* 73:47-59

Fate of Glyphosate in Vegetation

- 3 study sites (Oregon, Michigan, Georgia)
- Aerial application (helicopter) of 4.12 kg (a.e.)/ha of glyphosate, no surfactant
- Residues on vegetation sampled at 8 stations/site

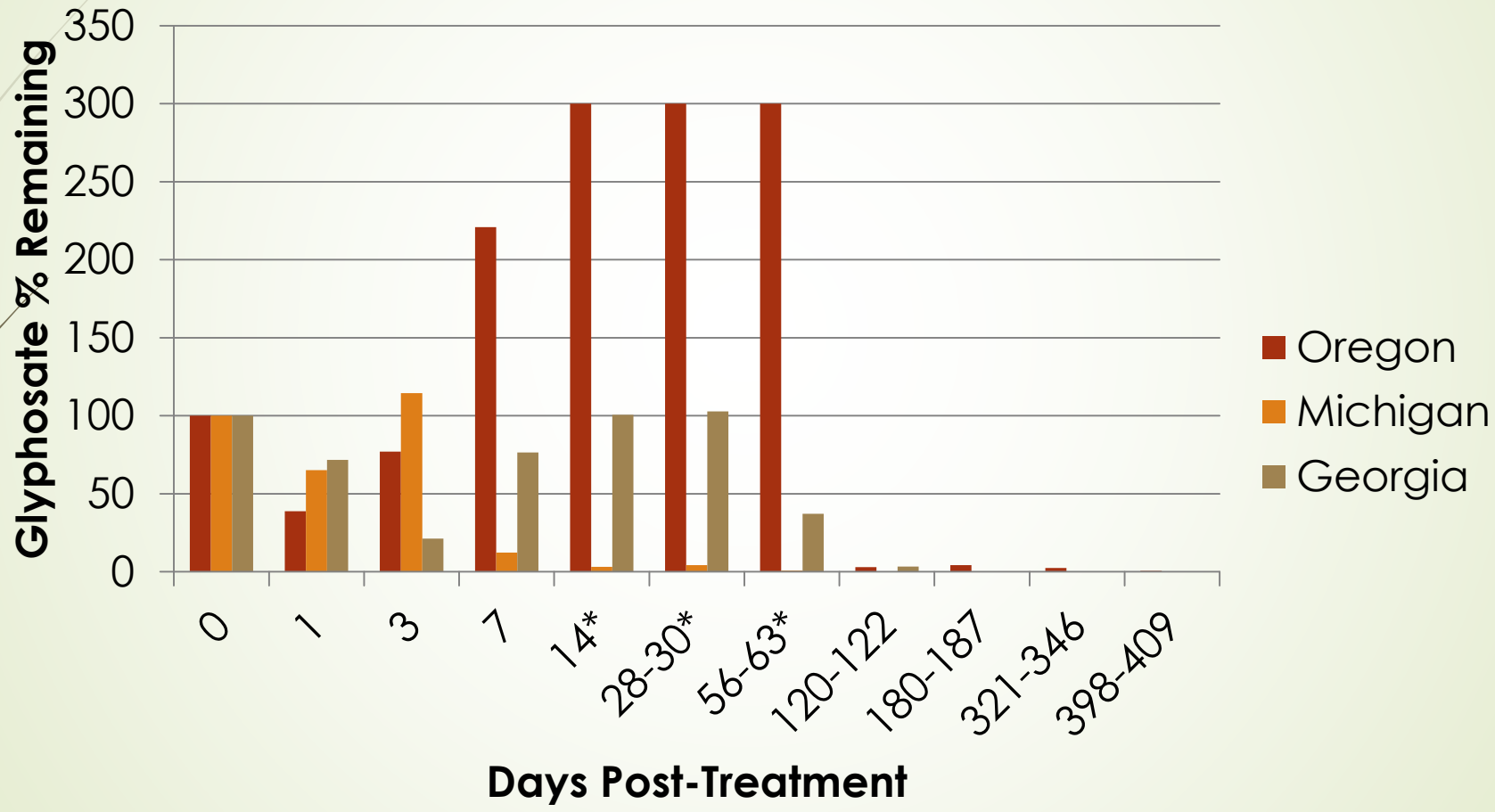
Newton et al. 1994. Dissipation of glyphosate and aminomethylphosphonic acid in North American forests. *J. Agric. Food Chem.* 42:1795-1802

Glyphosate in Upper Foliage



"Missing" data points = no foliage due to defoliation or winter leaf fall

Glyphosate in Surface Litter



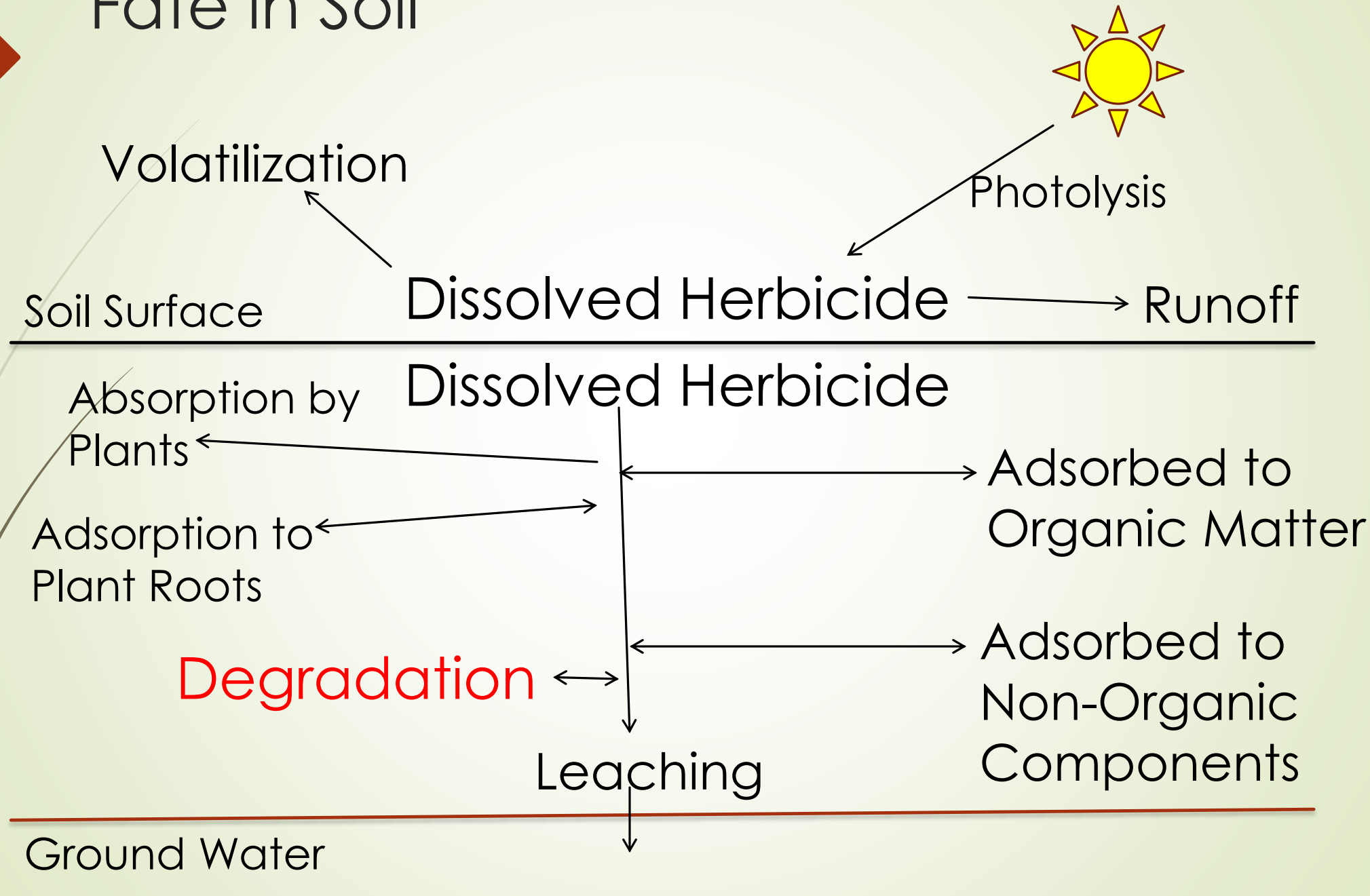
*Oregon data truncated for scale

Once herbicides get on/in soil, what can happen to them?

- Adsorb to soil or components of plants
- Be absorbed by plants
- Remain dissolved in soil water
- Volatilize
- Leach
- Degrade

Mostly this

Fate in Soil


Volatilization
Photolysis
Soil Surface
Dissolved Herbicide
Runoff
Dissolved Herbicide
Absorption by Plants
Adsorbed to Organic Matter
Adsorption to Plant Roots
Degradation
Adsorbed to Non-Organic Components
Leaching
Ground Water

Volatilization

- Evaporation of herbicide
  - From the surface of soil or plants
  - Into air spaces within the soil from herbicides dissolved in soil water and subsequently into the atmosphere
- For commonly used forestry herbicides, the tendency to volatilize in the environment is very low
  - National Council for Air and Stream Improvement, Inc. (NCASI). 2016. *Assessing the risk of forest herbicide volatilization*. Special Report No. 16-01.

Leaching

- A function of:
  - Herbicide solubility
  - Soil characteristics
  - Post-application rainfall frequency and intensity
  - Tendency to adsorb to soil
- Most forest herbicides are not susceptible to leaching to any great extent under actual field conditions
  - Michael, J.L. 2004. Best management practices for silvicultural chemicals and the science behind them. *Water, Air, and Soil Pollution* 4:95-117.

Adsorption

- It's a big deal
  - The relative preference of a herbicide molecule for the aqueous and solid phases of a soil will affect every other aspect of its behavior in soil
    - Degradation
    - Leaching
    - Efficacy
    - Overall persistence
  - The soil water is where most of the action (degradation, transport) happens

Degradation

- Non-biological
  - Photolysis
    - Direct – sunlight disrupts chemical bonds
    - Indirect – sunlight generates reactive substances (e.g. hydroxyl radicals) that degrade herbicide molecules
  - Hydrolysis
    - Herbicide molecule reacts with water
  - Oxidation/Reduction

Degradation

- Biological
  - Microorganisms
    - Most common
    - Microorganisms "digest" herbicide molecules in enzyme-catalyzed reactions
    - Most effective when soil conditions are optimal for microbial activity
  - Fungi, plants, invertebrates
    - May play minor role in some circumstances

All of these factors interact to determine the two indicators that are typically used to describe environmental fate:

- Persistence
- Mobility

Soapbox Moment

- Predictions about persistence and mobility are often made based on indicators of volatility, leaching, adsorption, and degradation that were derived from laboratory studies or in settings that do not resemble forests. There are a multitude of factors present in forests that affect persistence and mobility and are not, or cannot be, adequately replicated in those studies.

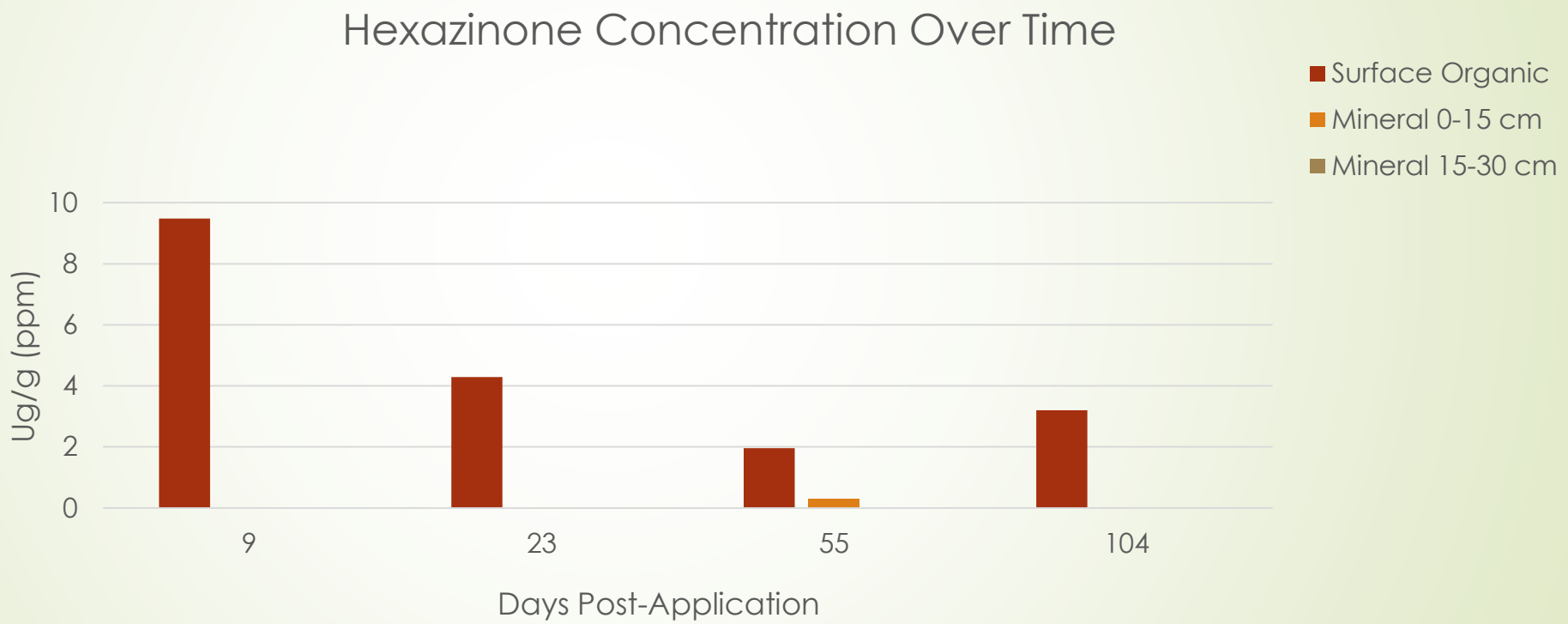
Persistence (Half-Life) in Soils in Forestry Field Studies of 4 Most Commonly Used Herbicides

- Glyphosate
  - 1-197 days, average 32 days
- Imazapyr
  - 35-142 days
- Metsulfuron Methyl
  - 7-42 days
- Sulfometuron Methyl
  - 12-65 days

Mobility in Soils in Forestry Field Studies of the Four Most Commonly Used Herbicides

- Glyphosate
  - Virtually no leaching
- Imazapyr
  - Minimal leaching, generally remains in upper 50 cm of soil. No run-off into streams or lateral movement in soil observed in forest dissipation studies in field studies.
- Metsulfuron Methyl
  - Generally remains in upper 50 cm of soil, but supporting database not strong
- Sulfometuron Methyl
  - Generally remains in upper 8 cm of soil, but supporting database not strong

Fate of Hexazinone at British Columbia Forestry Field Site



Feng, J.C. 1987. Persistence, mobility and degradation of hexazinone in forest silt loam soils. *J Environmental Science and Health* B22:221-233.