Measuring diurnal signals in tree sway period as an indicator of water stress

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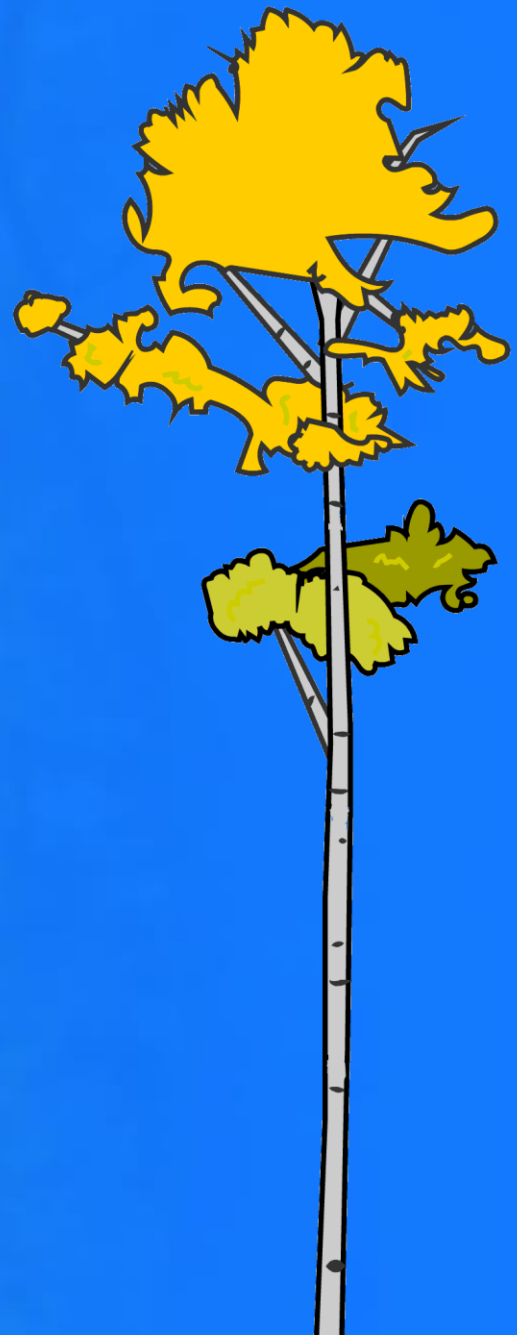


Outline

1. Drought effects and detection tools

1. Tree sway → Measure of water stress

1. 24-hour experiment with accelerometers
   - Diurnal changes in mass, stiffness, sway period

2. Controlling factors for sway period

1. Potential for detecting water stress with accelerometers

Motivation:
Detecting drought effects in trees

Forests & Drought

Instrumentation: Time, $$$

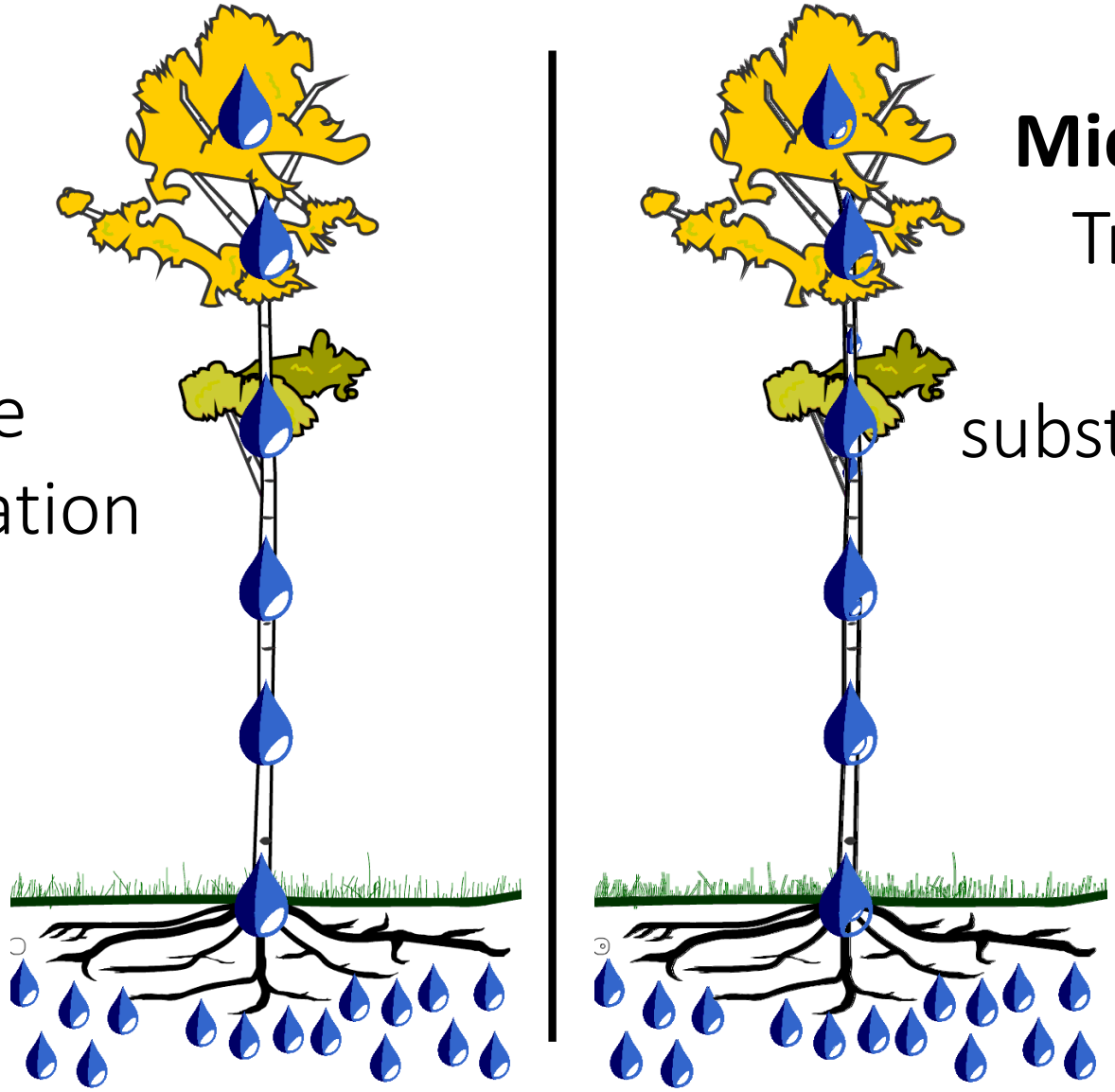
Leaves, water potential: Time intense, costly, point measure

Trunk sap flow: Transpiration, costly, indirect, continuous

Soil moisture: How much available water? Destructive, indirect point measurement

Theory: Water transport within tree (daytime)

Early morning:
Water starts to be used for transpiration



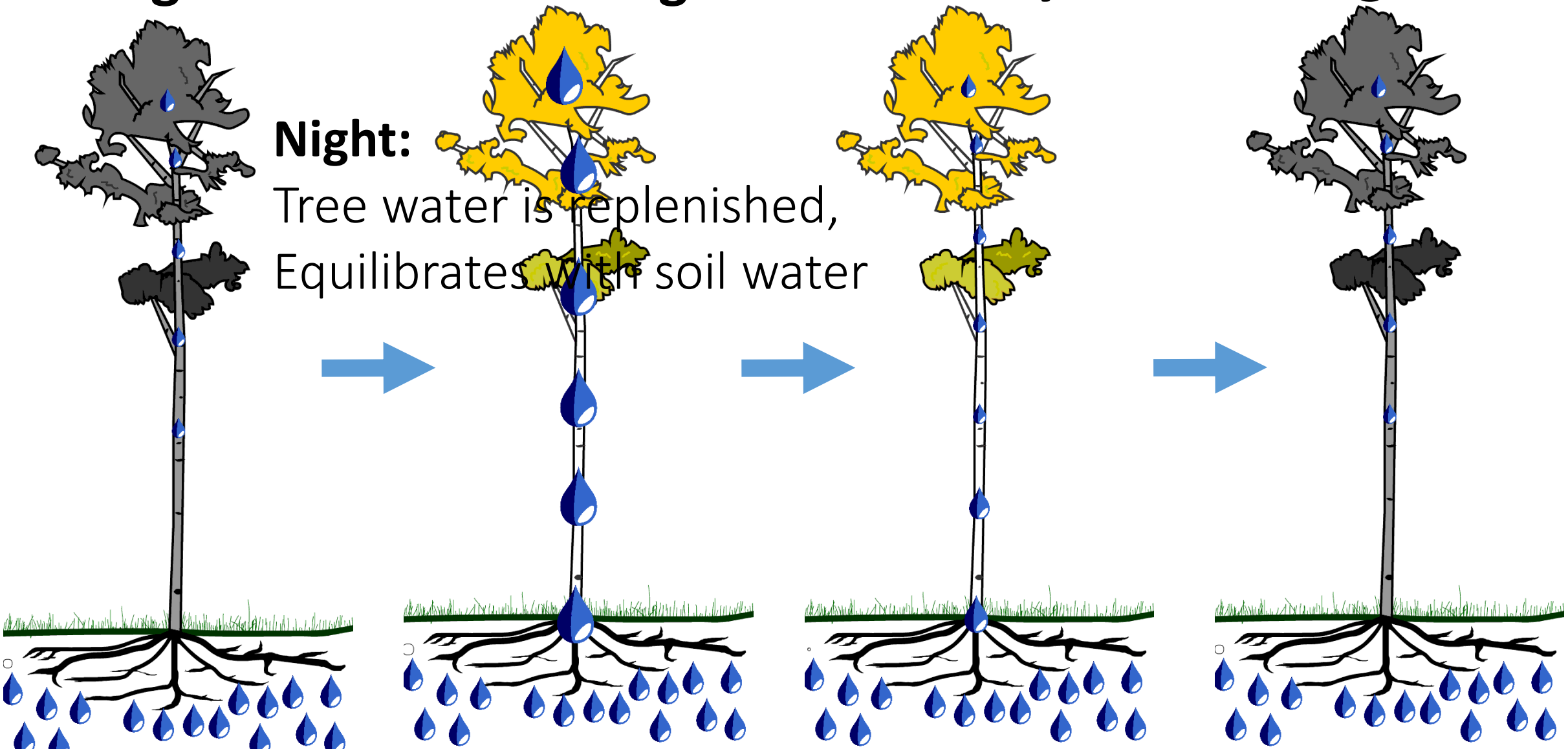
Midday (no stress):
Tree water storage is slightly depleted
No drought, Plenty of water, Low ET demand

Midday (water stress):
Tree water storage is substantially replenished
Drought, Dry conditions, High ET demand

Theory: Water transport within tree

When water stressed

Night **Morning** **Midday** **Night**



Night:
Tree water is replenished,
Equilibrates with soil water

Theory: Diurnal changes in tree traits

midday

Lower water content

Less mass

Lower turgor pressure

Lower stiffness

Lower turgor pressure

Lower stiffness

Higher turgor pressure

Higher stiffness

night

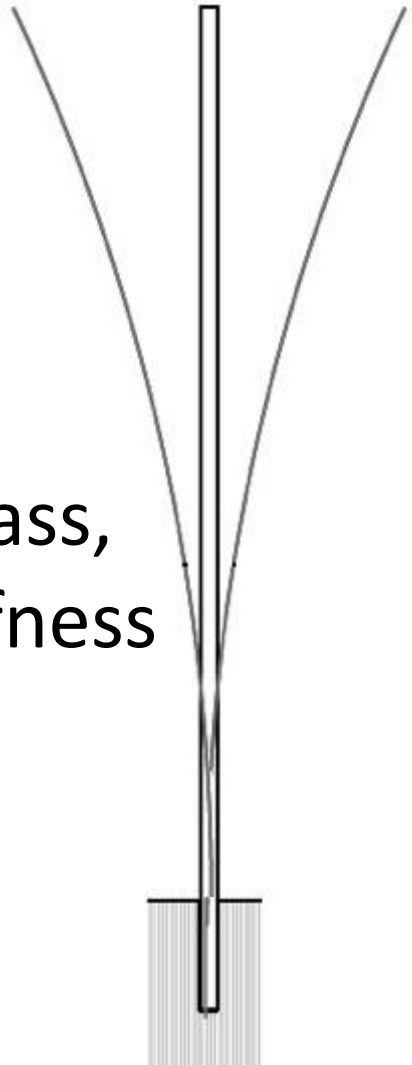
Higher water content

More mass

Higher turgor pressure

Higher stiffness

Theory: Mechanical vibrations



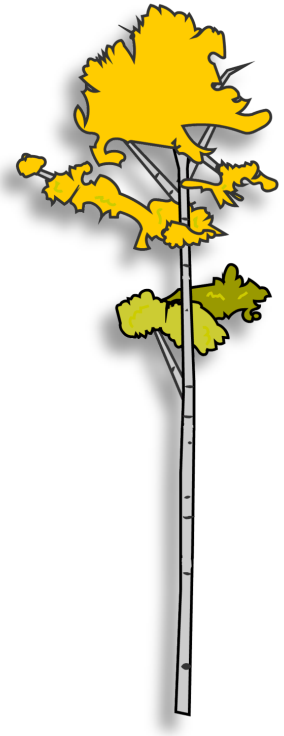
mass, stiffness

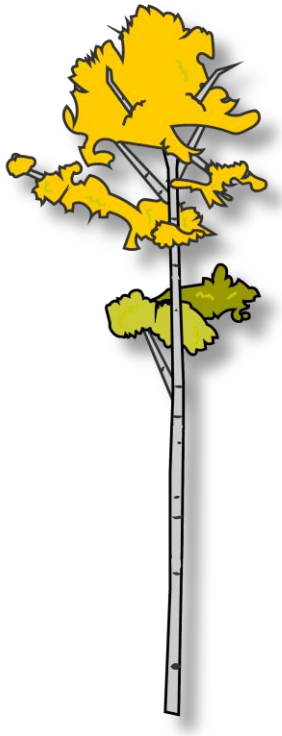
$$\frac{mass}{stiffness} \propto natural\ sway\ period$$

Shorter period

Mass ↓

Stiffness ↑





Longer period

Mass ↑

Stiffness ↓

Theory: Biomechanical vibrations of trees

mass,
stiffness

$$\frac{mass}{stiffness} \propto natural\ sway\ period$$

Midday

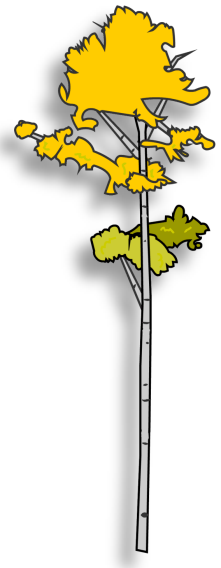
$\downarrow \frac{M}{K}$

Night

$\uparrow \frac{M}{K}$

Theory: Biomechanical vibrations of trees

$$\frac{mass}{stiffness} \propto natural\ sway\ period$$

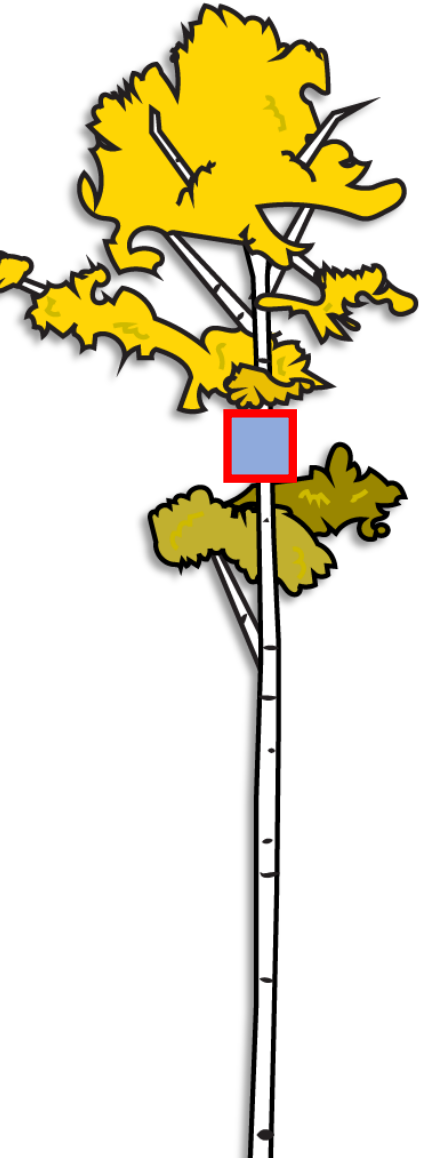


$$\frac{\downarrow\downarrow M}{\downarrow K} \propto T\downarrow$$

$$\frac{\downarrow M}{\downarrow\downarrow K} \propto T\uparrow$$

$$\frac{\downarrow M}{\downarrow K} \propto T$$

Accelerometers to detect drought effects



Inexpensive, continuous measurements of sway period in single tree

- Sub-hourly measurements over weeks, months, seasons

Previous studies hypothesize sway period changes as a function of diurnal changes in mass

- Assume stiffness does not change

We hypothesize that **diurnal changes in stiffness associated with changes in turgor pressure** are also important

Research questions

Are there **detectable changes** in tree **mass**, **stiffness**, and **sway period** of a tree associated with water stress over 24 hours?

What is the dominating tree parameter for evaluating sway period?

- Tree mass, stiffness, or inconclusive?

$$\downarrow\downarrow\frac{M}{\downarrow K} \propto T\downarrow$$

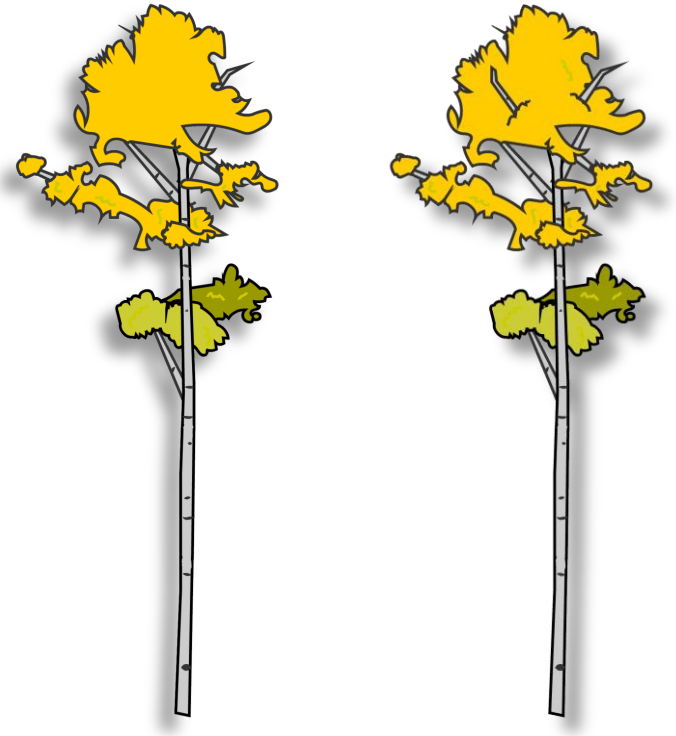
$$\frac{\downarrow M}{\downarrow\downarrow K} \propto T\uparrow$$

$$\frac{\downarrow M}{\downarrow K} \propto T$$

Methods: 24-hour experiment

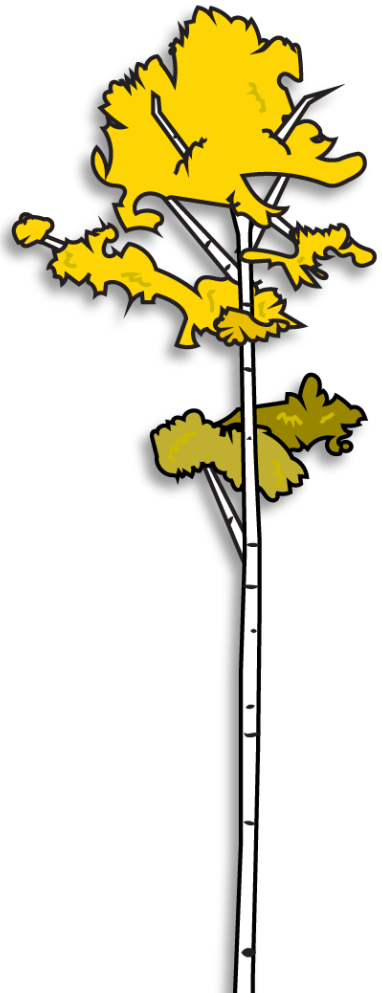
Diurnal changes in **mass**

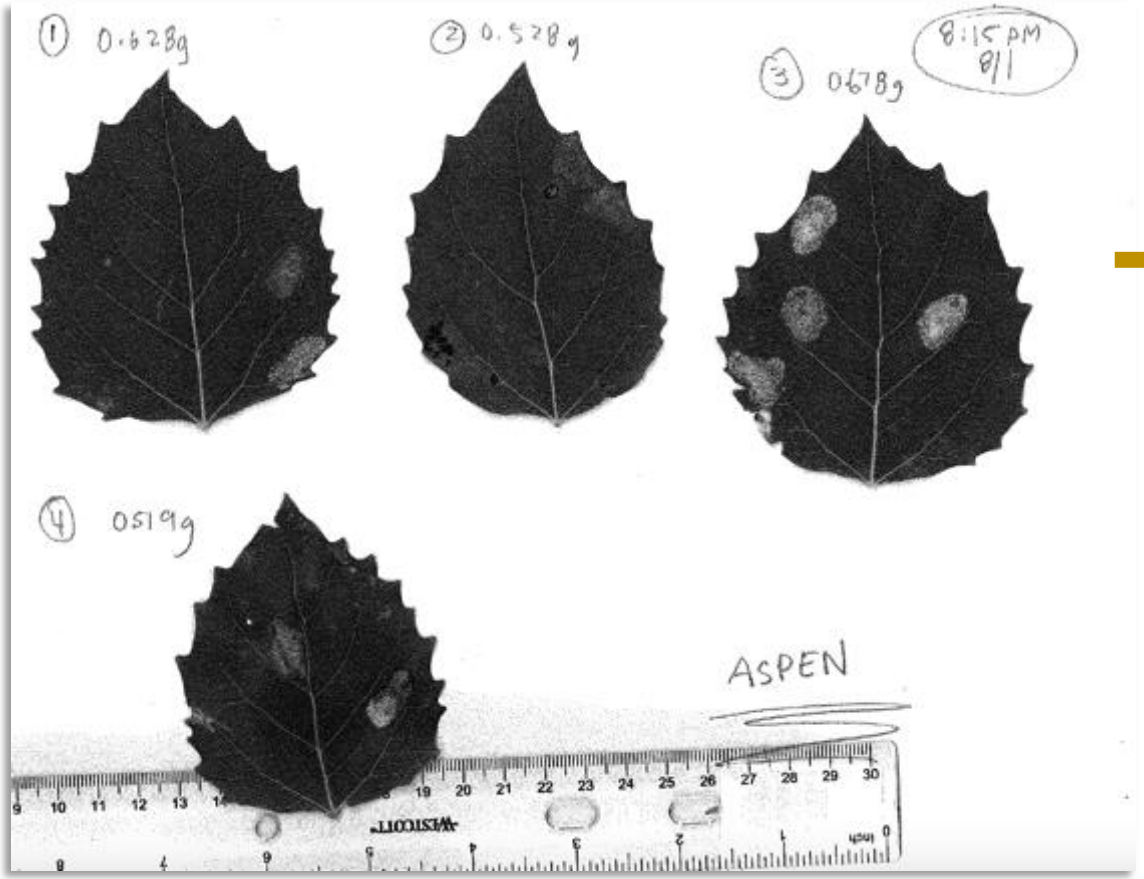
Diurnal changes in **stiffness**



Diurnal changes in **sway period**

Diurnal changes in **mass** (every 4 hours)

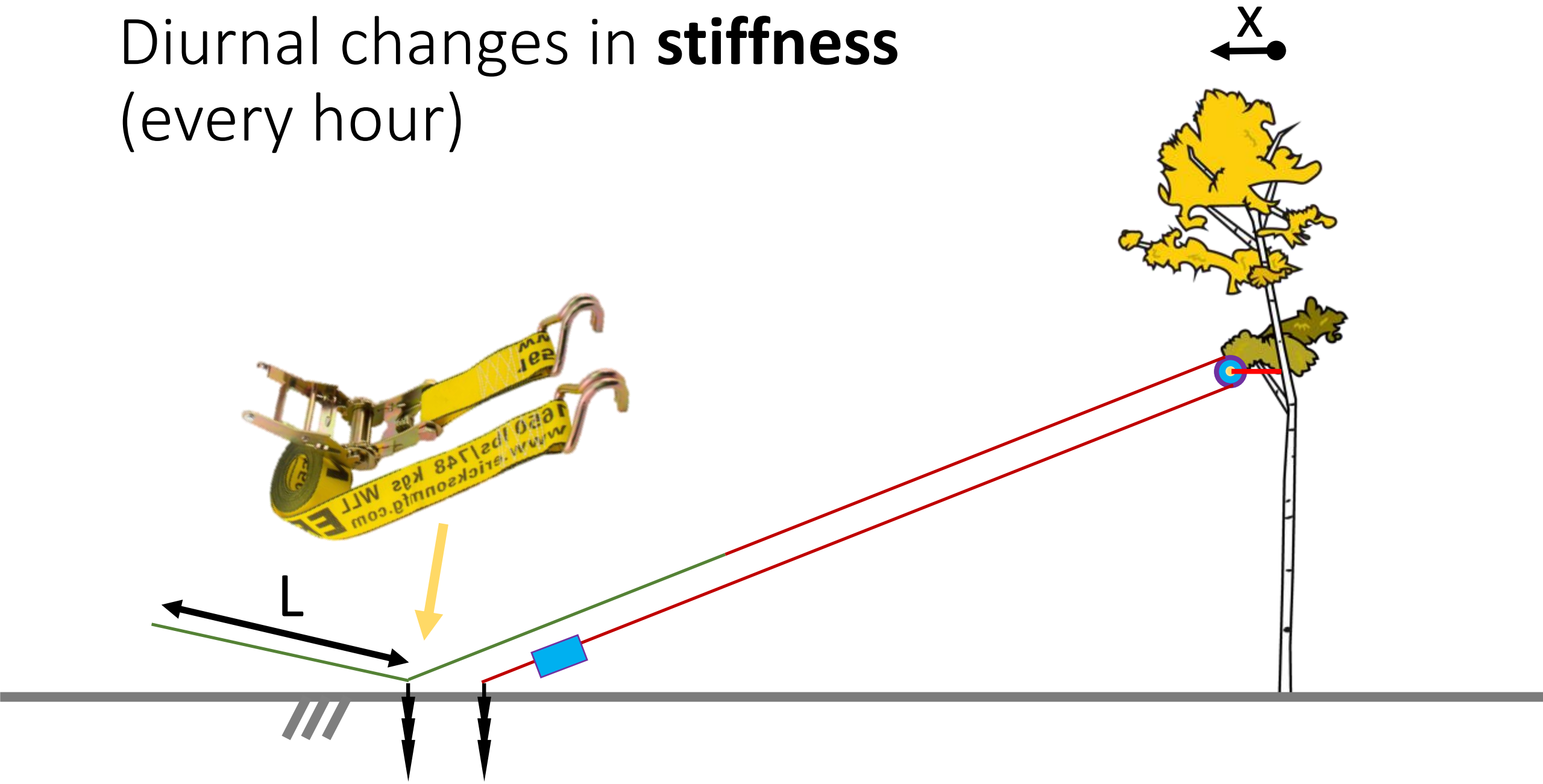




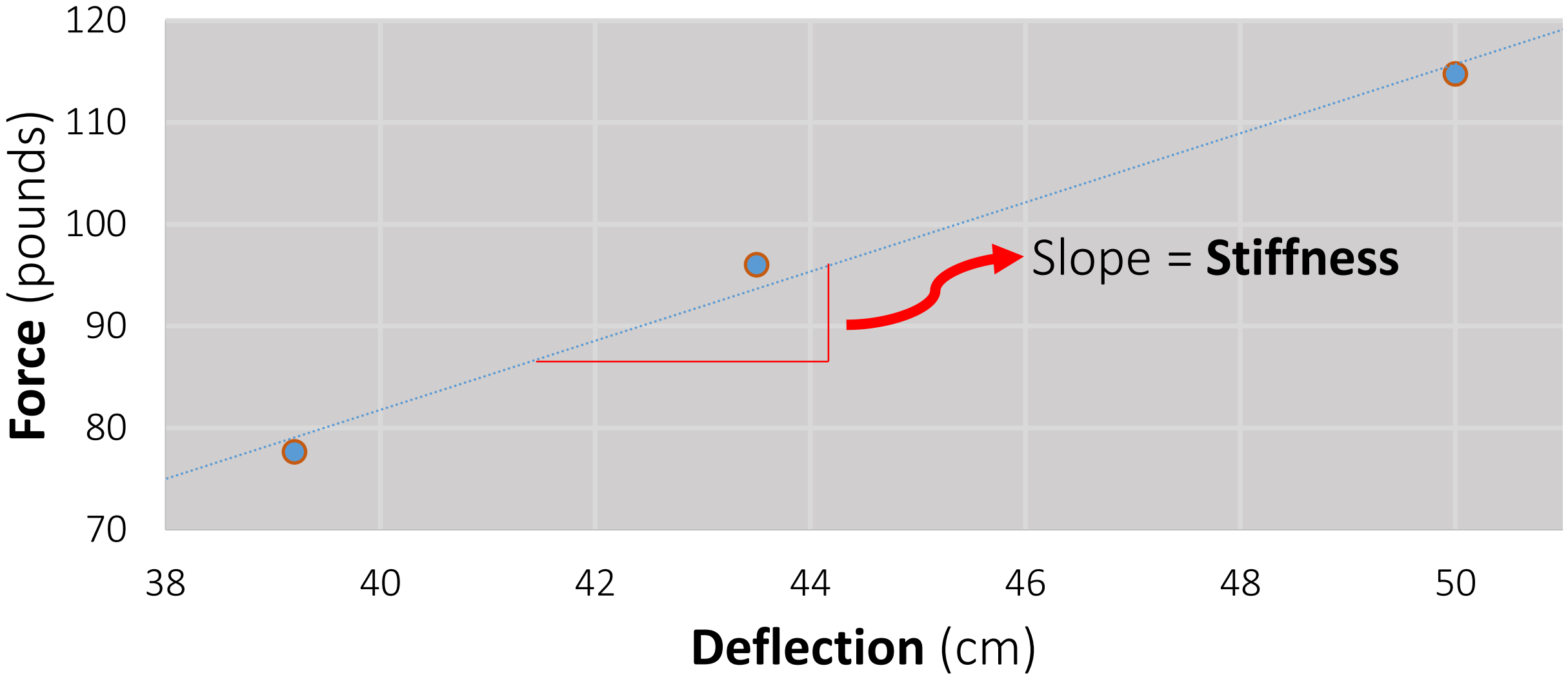
$$\frac{\text{wet leaf mass}}{\text{leaf area}}$$

Diurnal changes in **stiffness** (every hour)

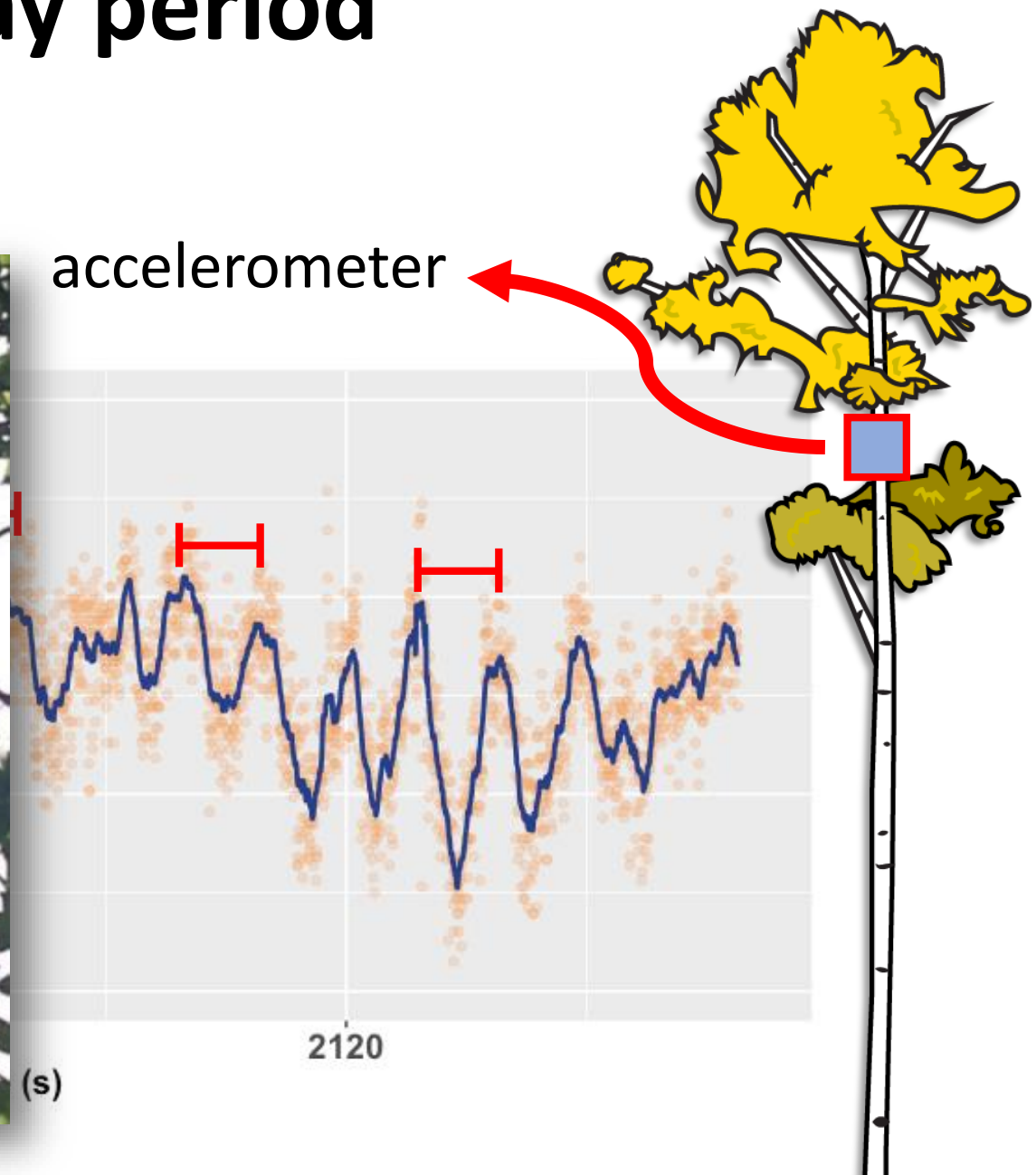
Diurnal changes in **stiffness** (every hour)



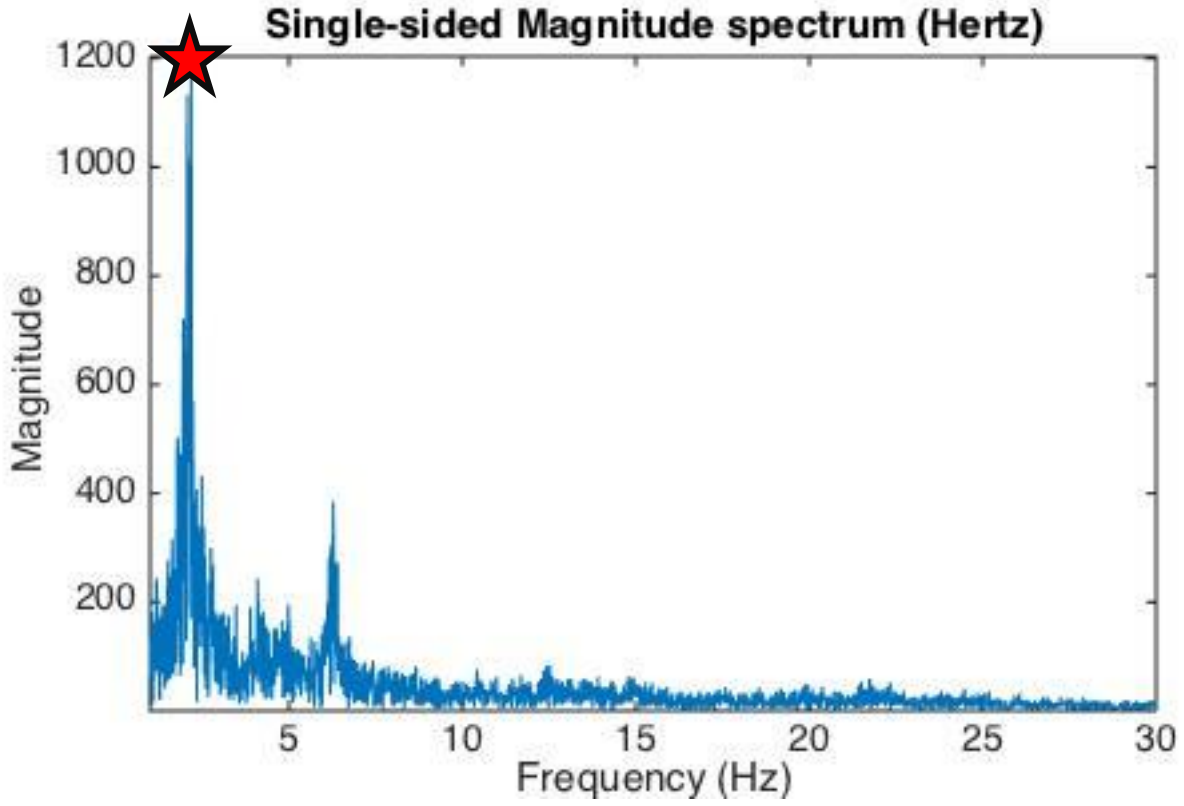
Diurnal changes in **stiffness** (every hour)

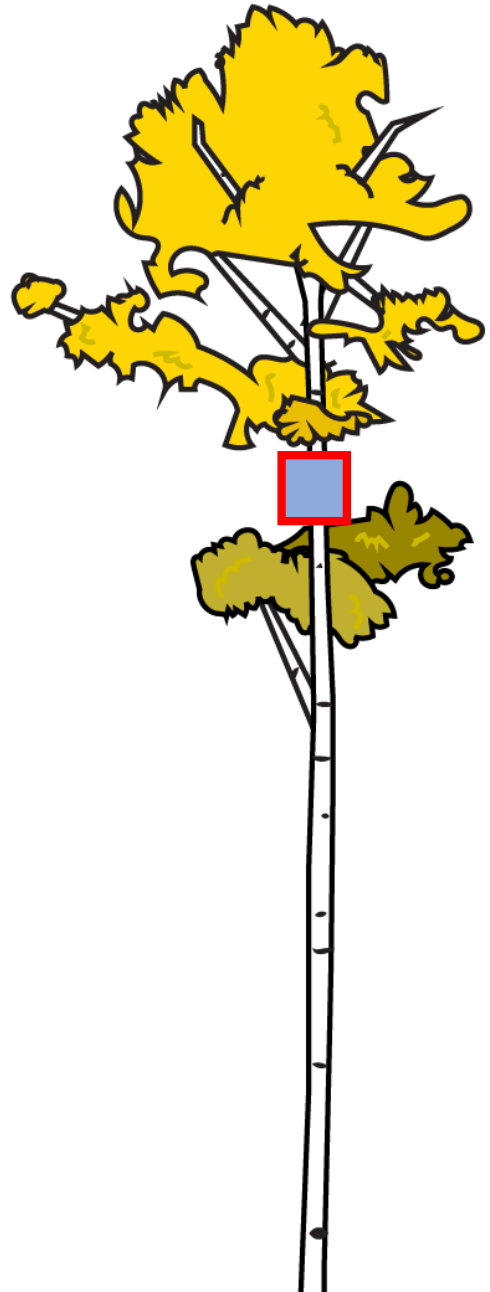


Diurnal changes in **sway period** (every 30 minutes)



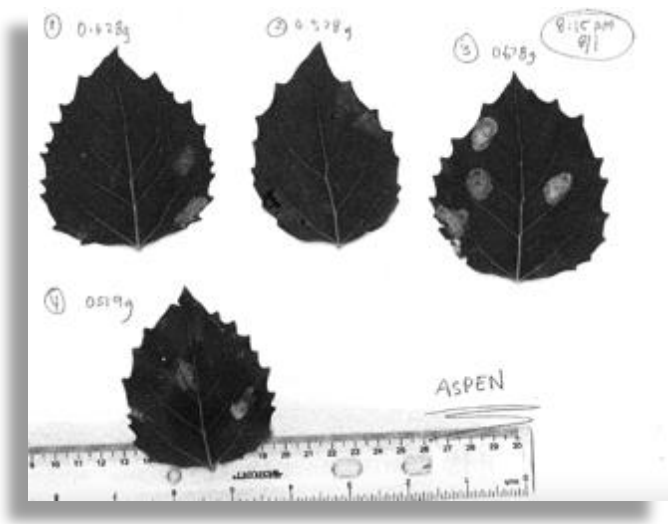
Diurnal changes in **sway period**



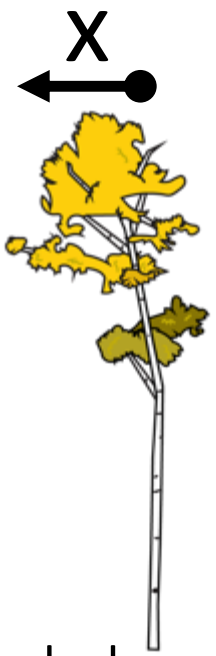


Peak frequency → Sway period ($T = \frac{1}{f}$)

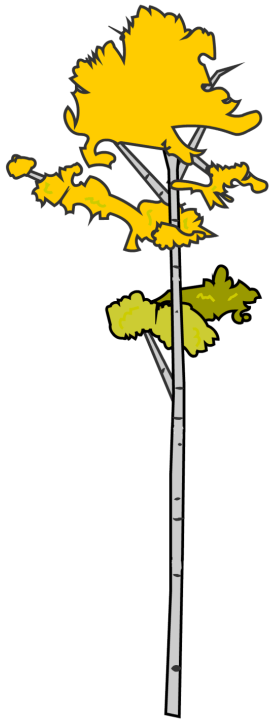
Results of 24-hour experiment



Diurnal changes in
mass

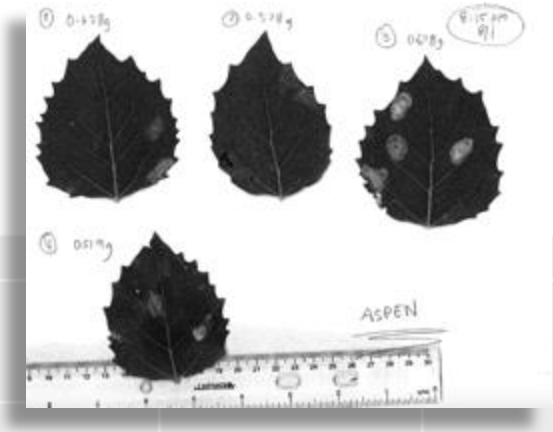


Diurnal changes in
stiffness



Diurnal changes in
sway period

Diurnal changes in **mass**



Oak

Aspen

SLA (grams/cm^2)

0.015

0.014

0.013

0.012

5

10

15

20

25

Hours since midnight

l changes in **stiffness**

Oak

Aspen

MOE (GPa)

1.75

1.50

1.25

0

5

10

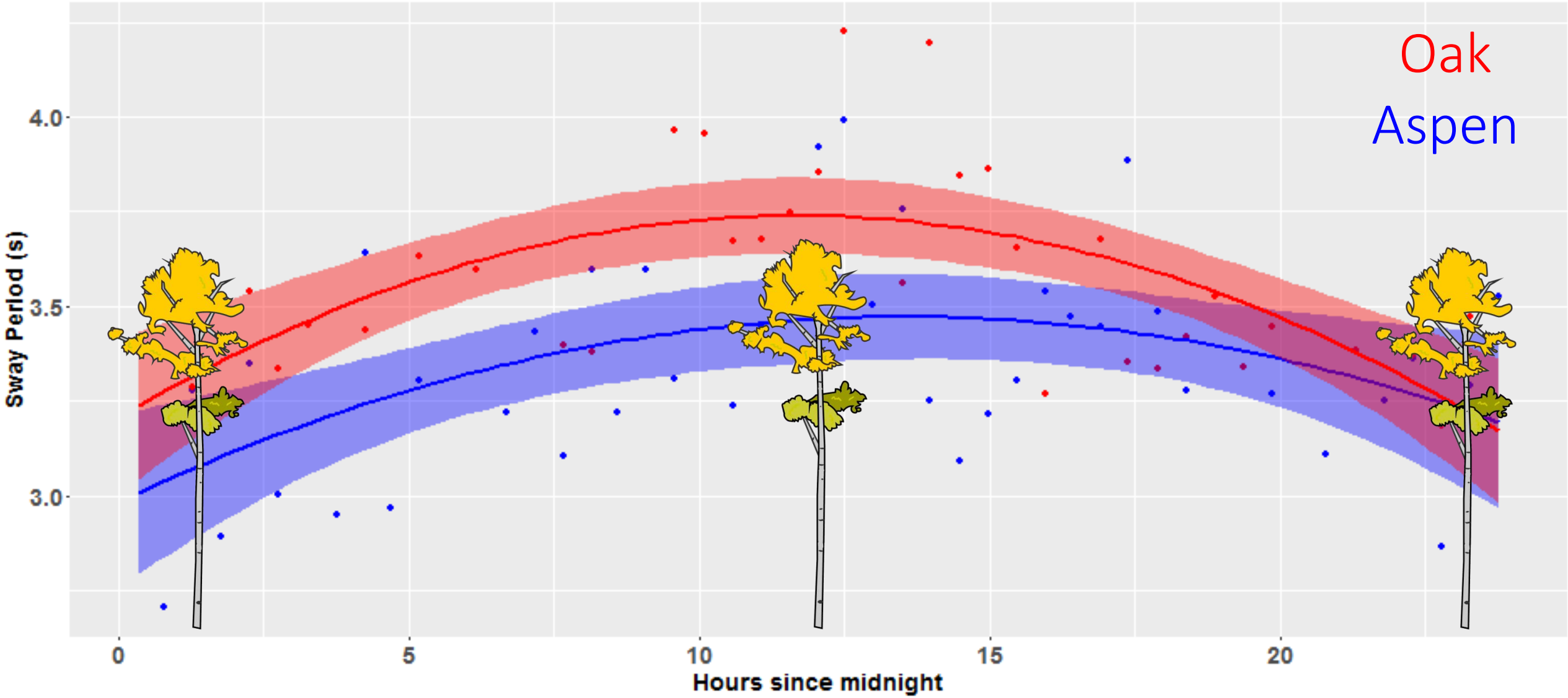
15

20

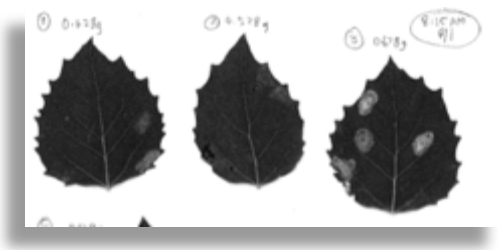
25

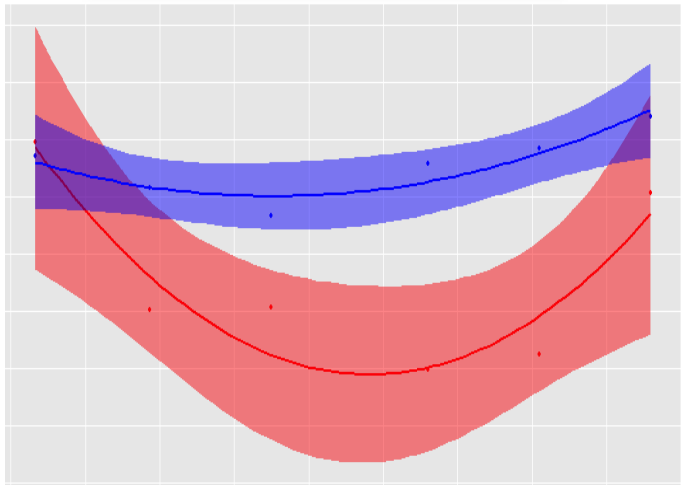
Hours since midnight

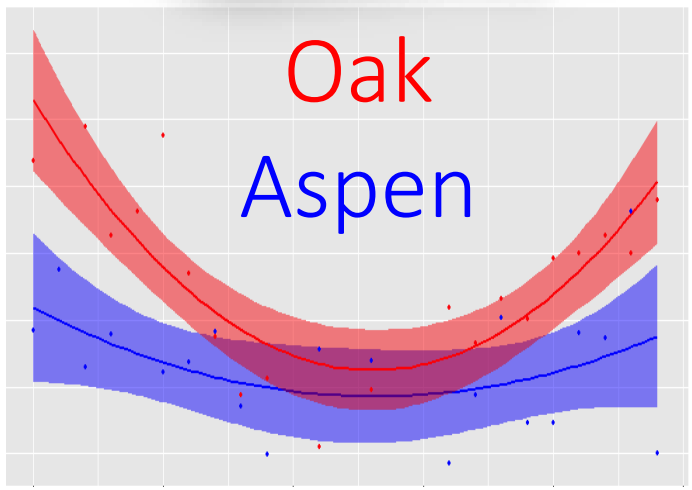
Diurnal changes in **sway period**

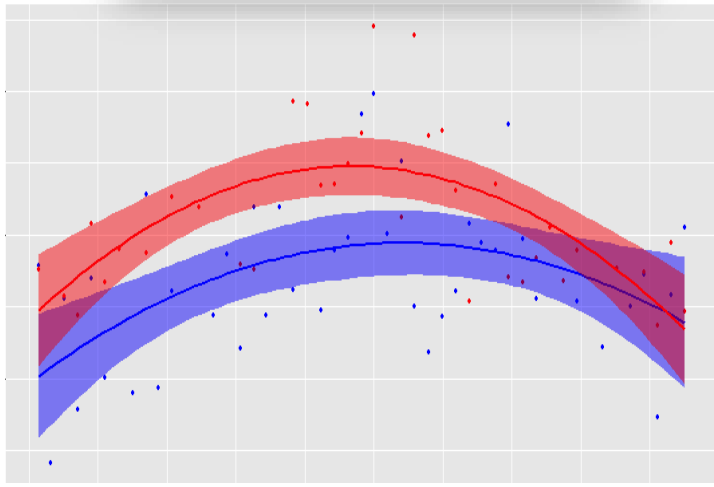


Summary of 24-hour experiment: Midday vs. night









Decrease in mass

Decrease in stiffness

Increase in sway period

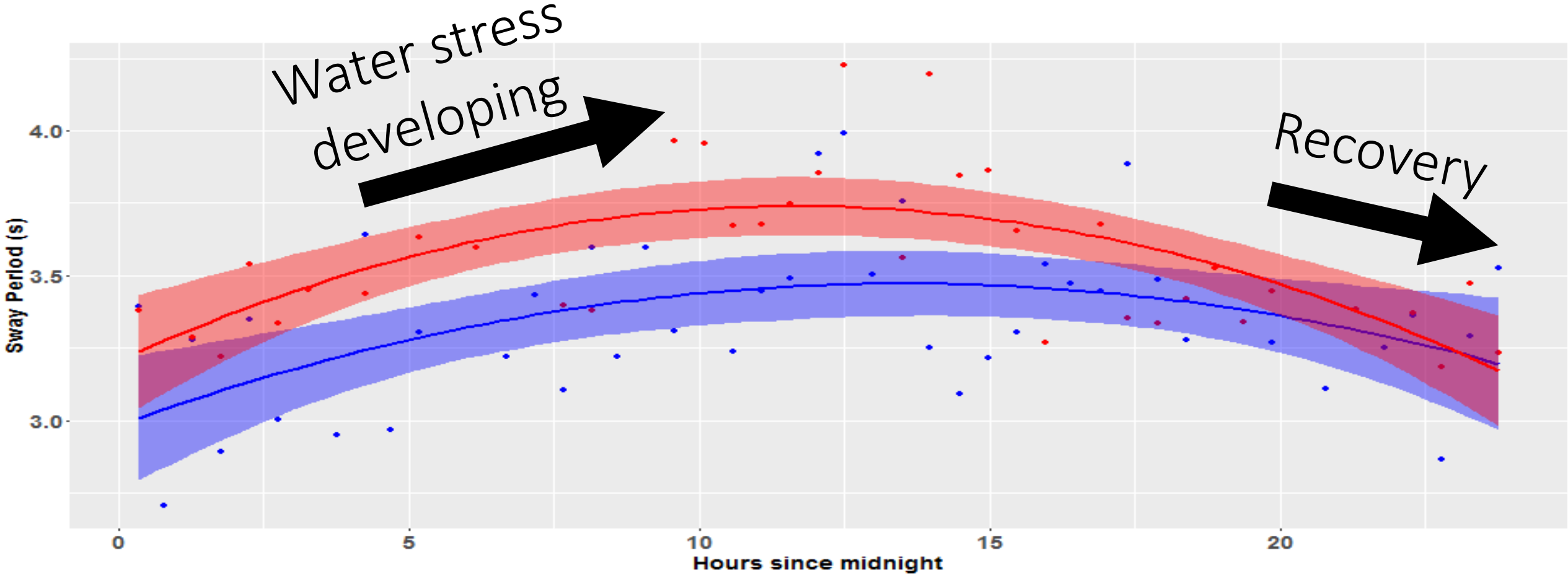
Conclusions

We observe expected midday decreases in mass and stiffness

$$\frac{\downarrow M}{\downarrow\downarrow K} \propto T\uparrow$$

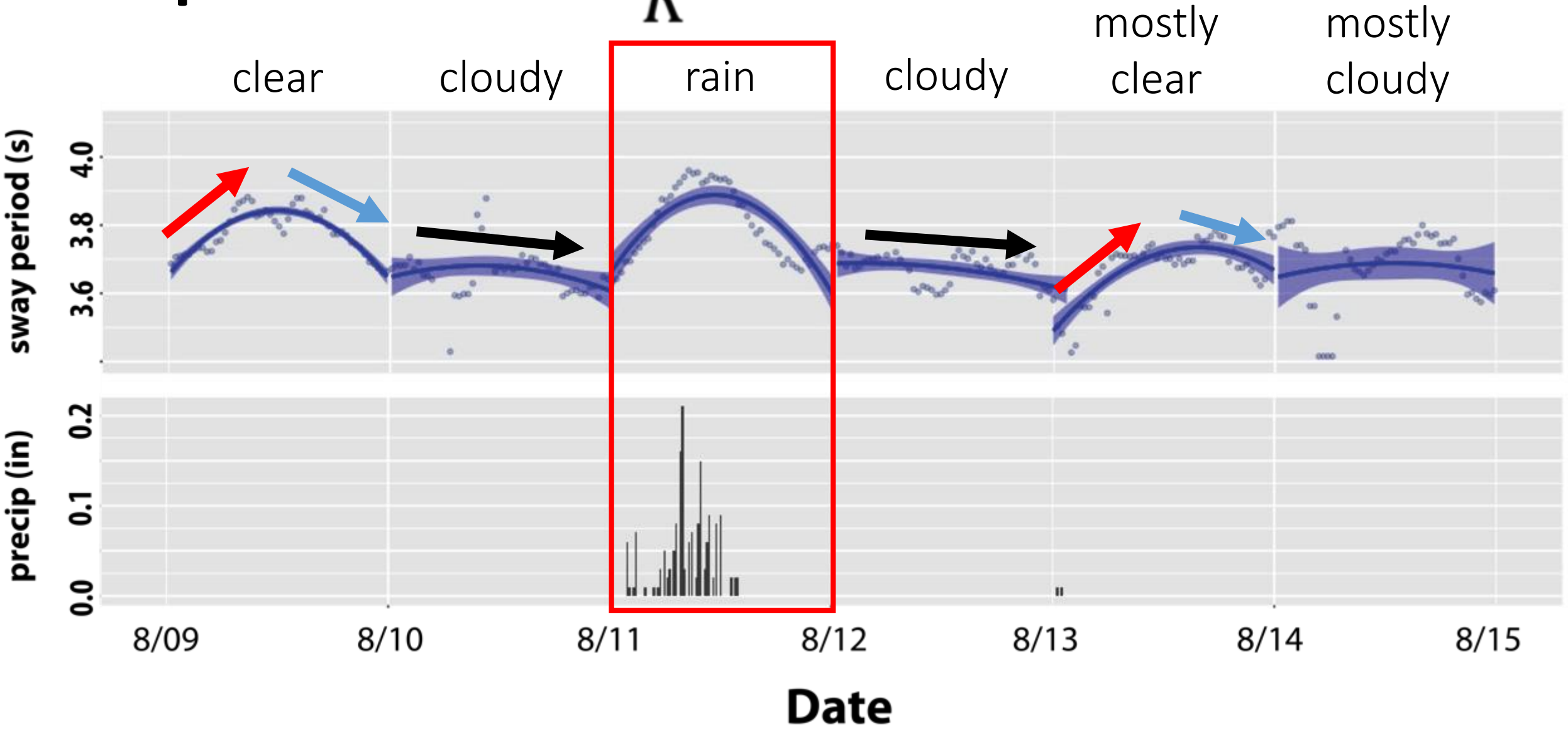
Experiment suggest that the **stiffness** of the tree may be **controlling sway period**

Potential indications of daily water stress, even during the 4th wettest summer in WI



Implications

$$\frac{M}{K} \propto T$$



Acknowledgements

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Thanks for listening!
Questions?