Two path length effects emerging from ontogenetically stable axial xylem design affect the conductance of inner sapwood rings

Giai Petit[1], Maurizio Mencuccini[2], Marco Carrer[1], Angela Luisa Prendin[1], and Teemu Holtta[3]

[1]Università degli Studi di Padova Dept TeSAF Viale dell'Università 16 35020 Legnaro (PD) Italy
[2]CREAF Bellaterra (Cerdanyola del Vallès) E08193 Spain
[3]Institute for Atmospheric and Earth System Research / Forest Sciences Faculty of Agriculture and Forestry University of Helsinki Latokartanonkaari 7 FI 00014 Helsinki Finland

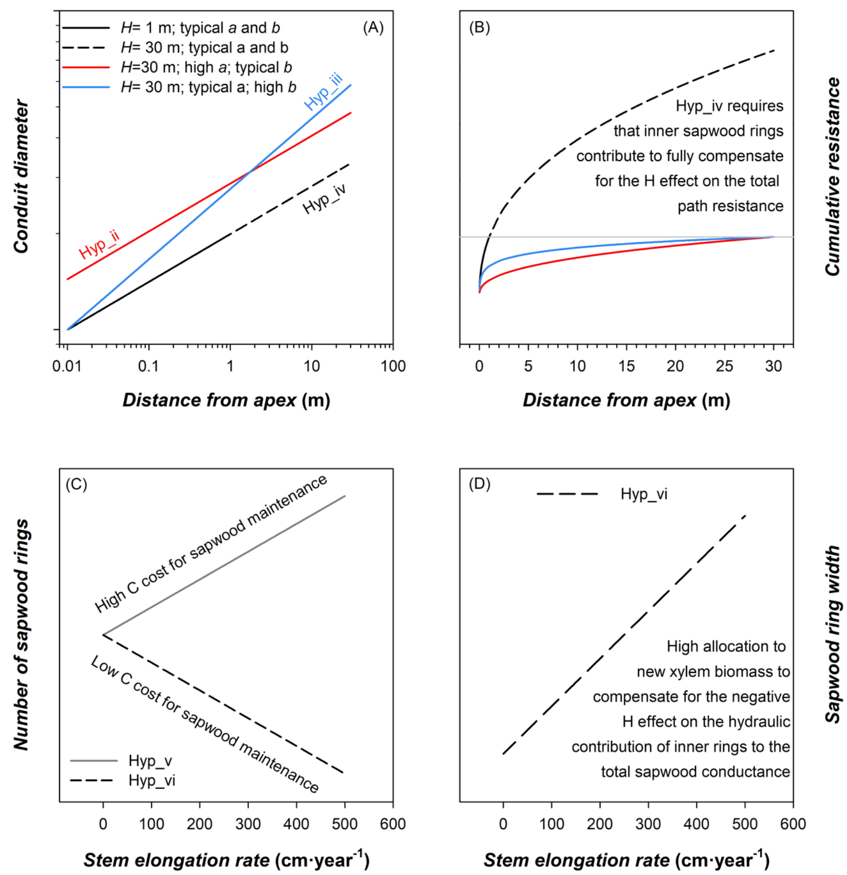
April 12, 2022

Abstract

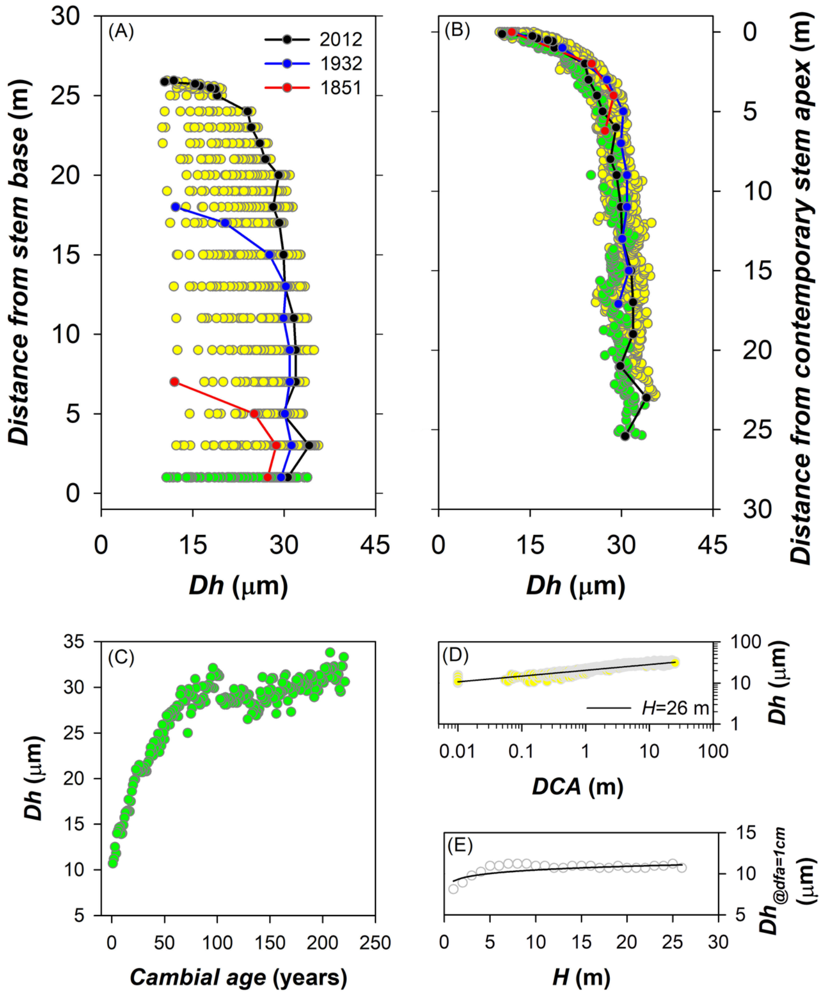
The process of sapwood/heartwood transition in trees is not fully understood. We tested whether the ontogenetically-stable apex-to-base conduit widening generates path length effects limiting the conductance of inner sapwood rings. The axial scaling (b) of conduit hydraulic diameter (Dh) was estimated at annual resolution in a spruce and beech tree. We compiled a global dataset of sapwood ring number ($NSWr$), their average width ($SWrw$), tree height (H) and stem elongation rate (ΔH) in conifer and angiosperm trees. A numerical model simulated the effects of H and ΔH on the conductance of each xylem ring (K_{RING}). b resulted ontogenetically stable. Simulations well predicted the observed patterns of increasing $NSWr$ with H and decreasing $NSWr$ with ΔH, assuming that heartwood forms when the marginal conductance gain of maintaining the functionality of an inner ring becomes negligible. Sapwood/heartwood transition minimizes the C costs associated to allocation to secondary growth and maintenance of living sapwood required to attain a given sapwood conductance. The number of sapwood rings depends on the effects of H and ΔH on the conductance of inner sapwood rings. The width of sapwood rings contributes to compensate for the lower conductance of inner sapwood rings at high ΔH.

Hosted file

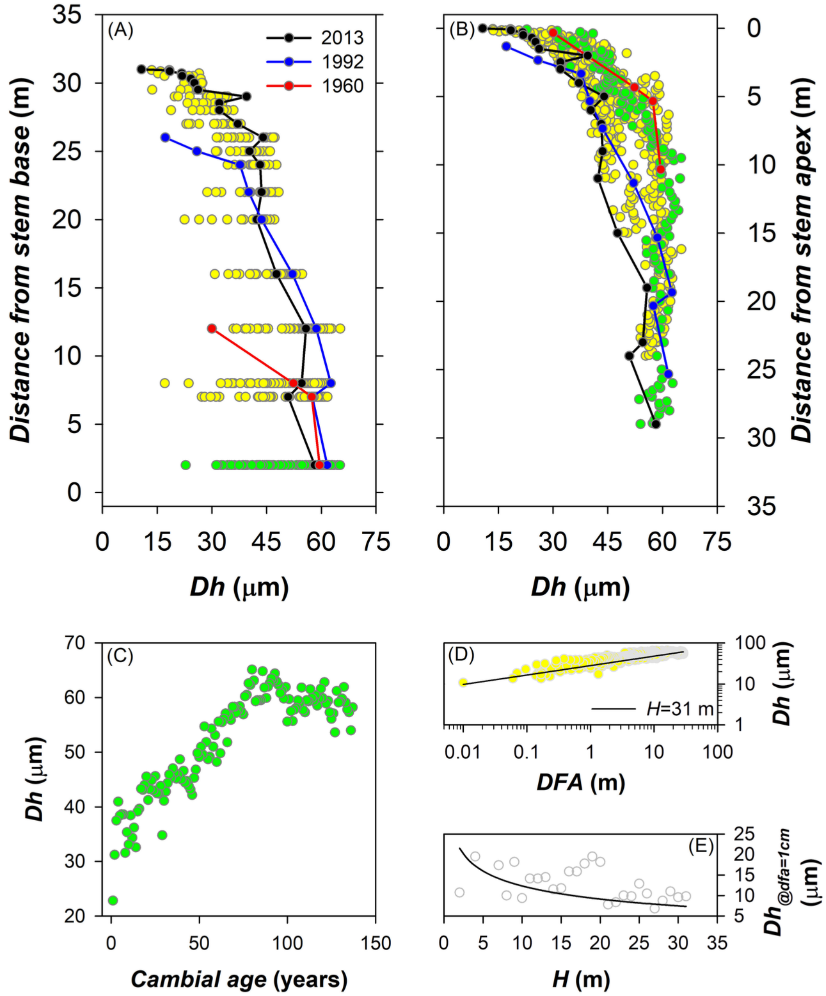
`Petit et al_main body.docx` available at https://authorea.com/users/475656/articles/565007-two-path-length-effects-emerging-from-ontogenetically-stable-axial-xylem-design-affect-the-conductance-of-inner-sapwood-rings

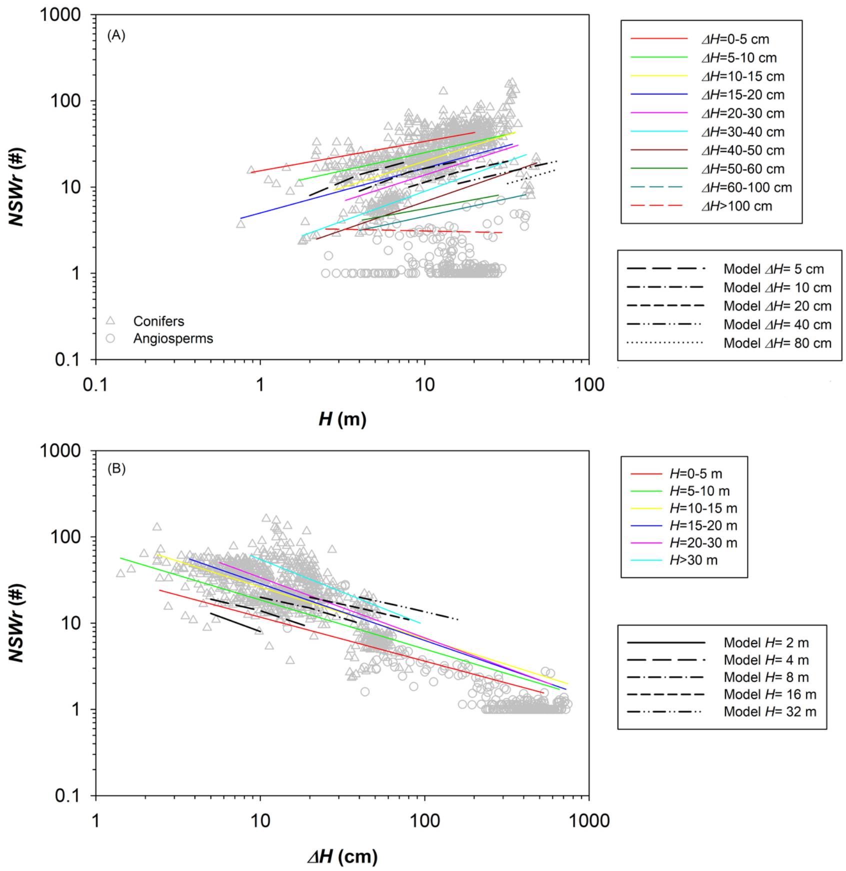


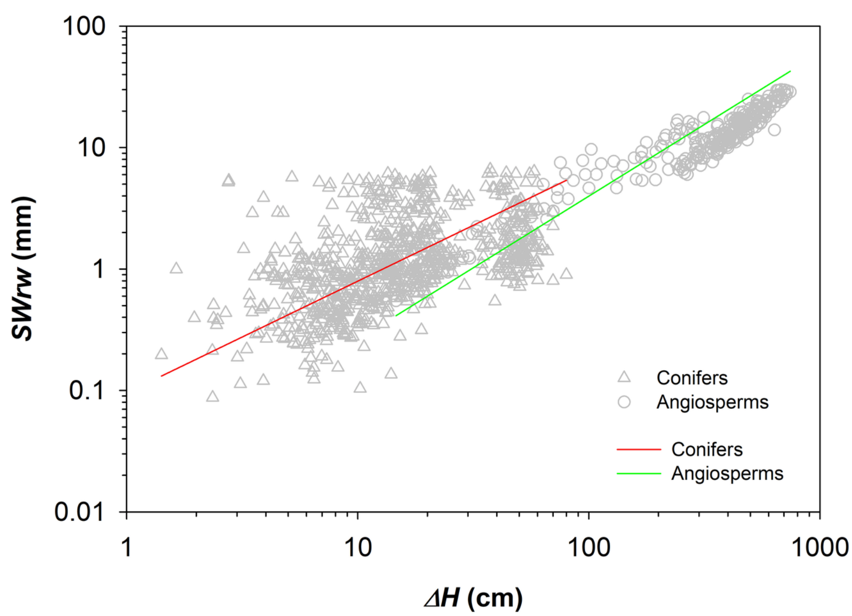
(A)
H= 1 m; typical a and b
H= 30 m; typical a and b
H=30 m; high a; typical b
H= 30 m; typical a; high b
Hyp_ii
Hyp_iii
Hyp_iv
Conduit diameter
0.01
0.1
1
10
100
Distance from apex (m)
(B)
Hyp_iv requires
that inner sapwood rings
contribute to fully compensate
for the H effect on the total
path resistance
Cumulative resistance
0
5
10
15
20
25
30
Distance from apex (m)
(C)
High C cost for sapwood maintenance
Low C cost for sapwood maintenance
Hyp_v
Hyp_vi
Number of sapwood rings
0
100
200
300
400
500
600
Stem elongation rate (cm·year-1)
(D)
Hyp_vi
High allocation to
new xylem biomass to
compensate for the negative
H effect on the hydraulic
contribution of inner rings to the
total sapwood conductance
Sapwood ring width
0
100
200
300
400
500
600
Stem elongation rate (cm·year-1)

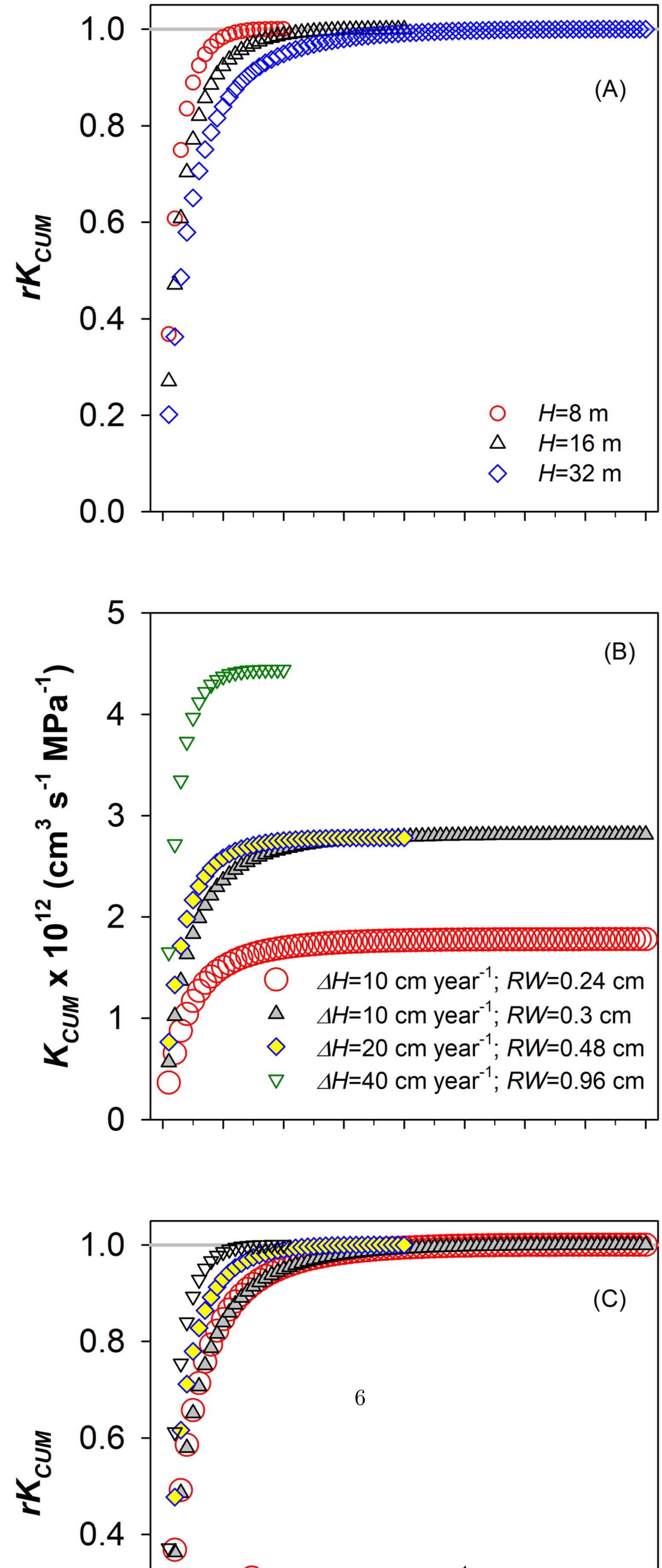


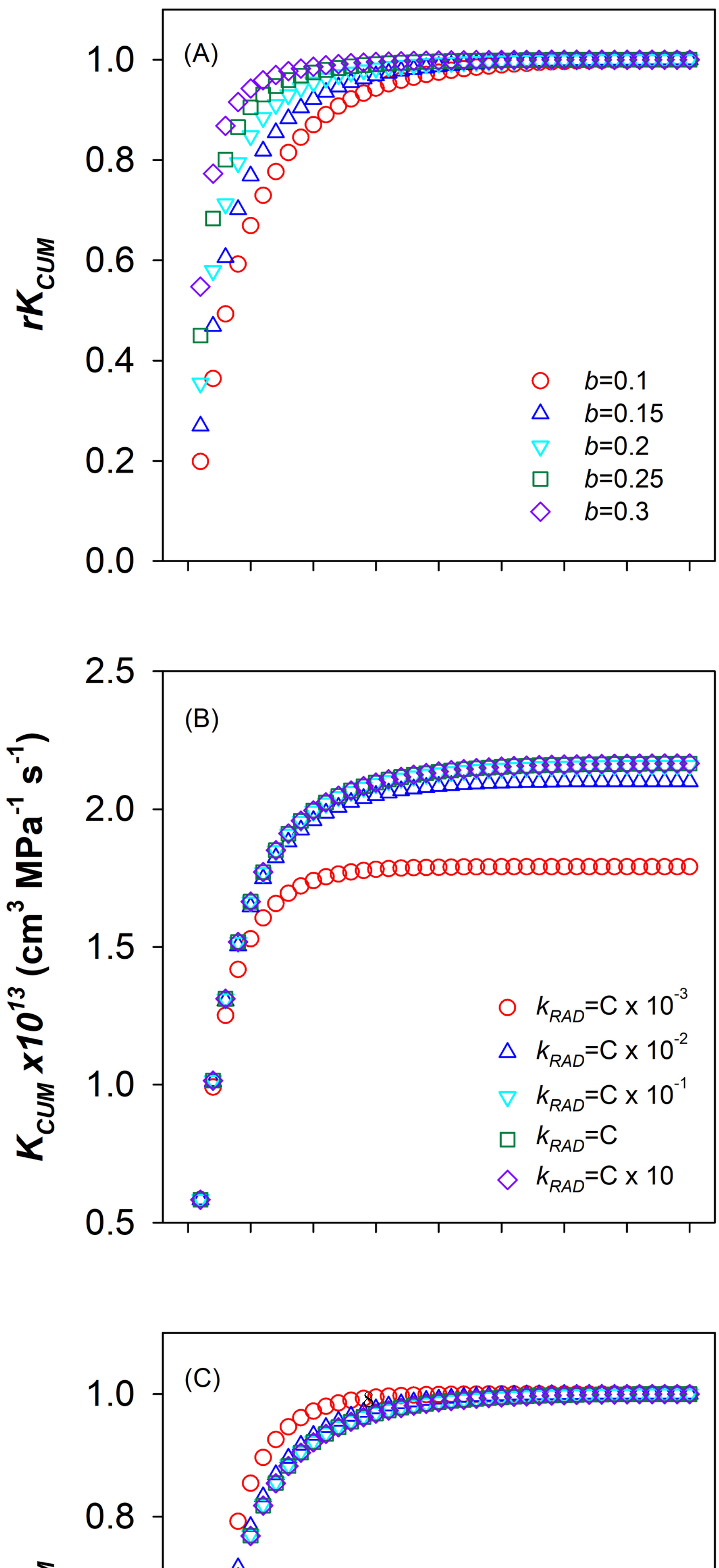
(A)
2012
1932
1851
Distance from stem base (m)
Dh (µm)
(B)
Distance from contemporary stem apex (m)
Dh (µm)
(C)
Dh (µm)
Cambial age (years)
(D)
H=26 m
Dh (µm)
DCA (m)
(E)
Dh@dfa=1cm (µm)
H (m)


(A)
2013
1992
1960
Distance from stem base (m)
Dh (μm)
(B)
Distance from stem apex (m)
Dh (μm)
(C)
Dh (μm)
Cambial age (years)
(D)
H=31 m
Dh (μm)
DFA (m)
(E)
Dh@dfa=1cm (μm)
H (m)


(A)
NSWr (#)
H (m)
ΔH=0-5 cm
ΔH=5-10 cm
ΔH=10-15 cm
ΔH=15-20 cm
ΔH=20-30 cm
ΔH=30-40 cm
ΔH=40-50 cm
ΔH=50-60 cm
ΔH=60-100 cm
ΔH>100 cm
Model ΔH= 5 cm
Model ΔH= 10 cm
Model ΔH= 20 cm
Model ΔH= 40 cm
Model ΔH= 80 cm
Conifers
Angiosperms
(B)
NSWr (#)
ΔH (cm)
H=0-5 m
H=5-10 m
H=10-15 m
H=15-20 m
H=20-30 m
H>30 m
Model H= 2 m
Model H= 4 m
Model H= 8 m
Model H= 16 m
Model H= 32 m


SWrw (mm)
ΔH (cm)
Conifers
Angiosperms
Conifers
Angiosperms


(A)
rK_CUM
1.0
0.8
0.6
0.4
0.2
0.0
H=8 m
H=16 m
H=32 m
(B)
K_CUM x 10^12 (cm^3 s^-1 MPa^-1)
5
4
3
2
1
0
ΔH=10 cm year^-1; RW=0.24 cm
ΔH=10 cm year^-1; RW=0.3 cm
ΔH=20 cm year^-1; RW=0.48 cm
ΔH=40 cm year^-1; RW=0.96 cm
(C)
rK_CUM
1.0
0.8
0.6
0.4


(A)
rKCUM
1.0
0.8
0.6
0.4
0.2
0.0
b=0.1
b=0.15
b=0.2
b=0.25
b=0.3
(B)
KCUM x10^13 (cm^3 MPa^-1 s^-1)
2.5
2.0
1.5
1.0
0.5
kRAD=C x 10^-3
kRAD=C x 10^-2
kRAD=C x 10^-1
kRAD=C
kRAD=C x 10
(C)
1.0
0.8