NON-LINEAR PROCESSES IN SEAGRASS COLONIZATION.

A NEW APPROACH FROM PARTICLE GROWTH MODELS.

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Cabrera

A. antarctica

C. nodosa

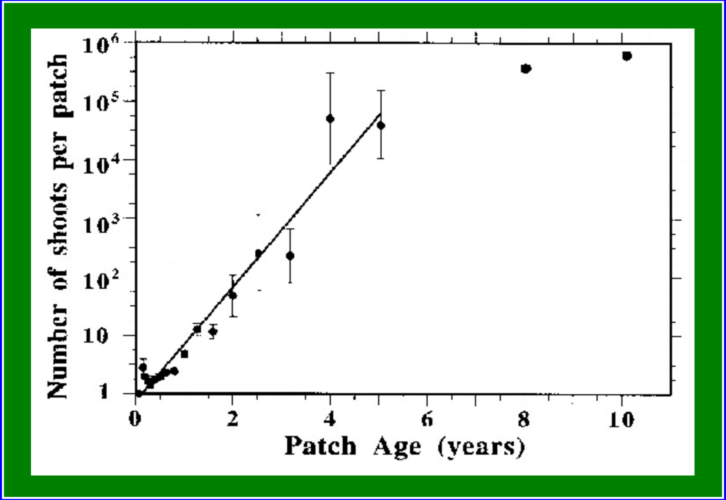
Growth Rules

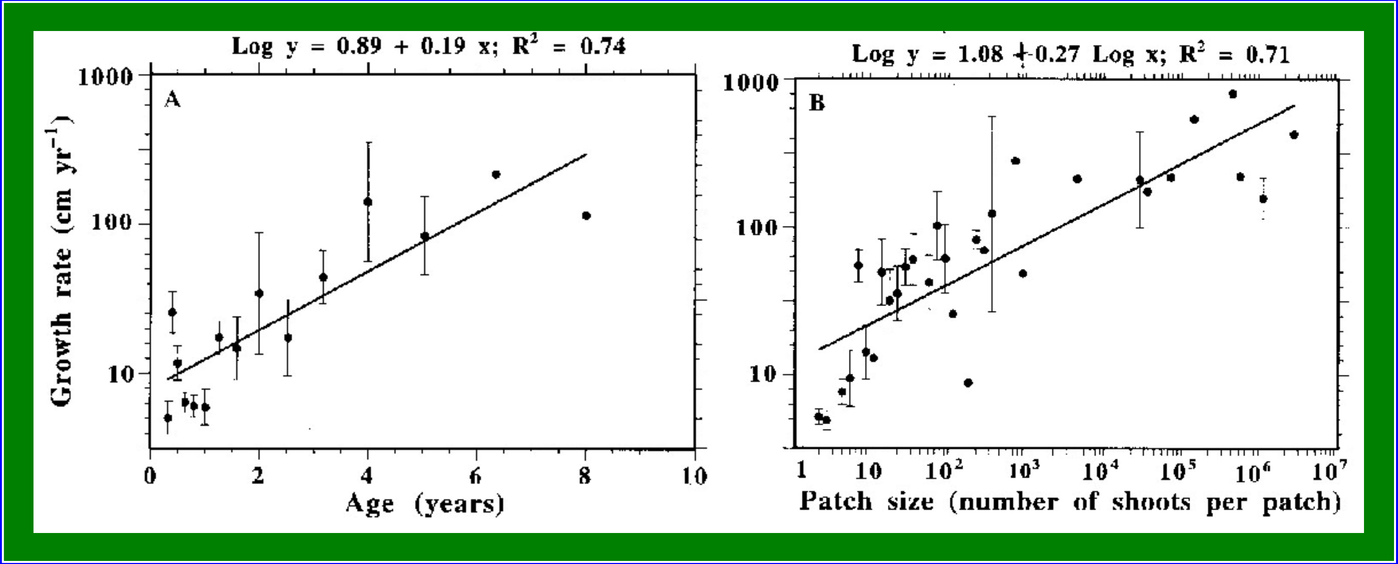
Parameter	Unit
Spacer length (ρ)	Cm
Rhizome elongation rate (v)	cm yr^{-1} rhizome $apex^{-1}$
Branching rate (ν_b)	branches $yr^{-1} apex^{-1}$
Branching angle (ϕ)	Degrees
Shoot mortality rate (μ_r)	units yr^{-1}

OBSERVED SEAGRASS PATCH DYNAMICS (C. Nodosa)

Vidondo et al. 1997

Parameter	Source
ρ=3.7±0.1cm	Terrados et al 1997
v =160±5 cm yr^{-1}	Duarte & Sand-Jensen 1990
ν_b =2.30±0.05 branches yr^{-1} apex^{-1}	unpublished data
ϕ=46±15 degrees	Marbà & Duarte 1998
μ_r =0.92±0.08 units yr^{-1}	Duarte & Sand-Jensen 1990





PARTICLE GROWTH MODELS: EDEN vs. DLA

EDEN

M. Eden (1961)

Applications in
Biology
Colloidal and Material Science

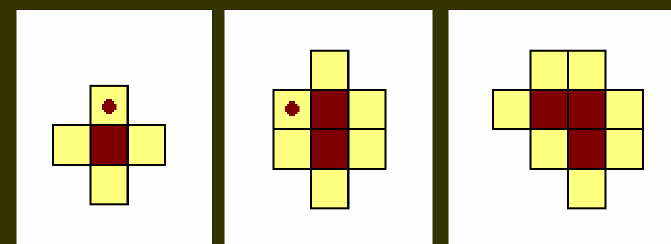
Williams & Bjerkness (1972)
Skin Cancer

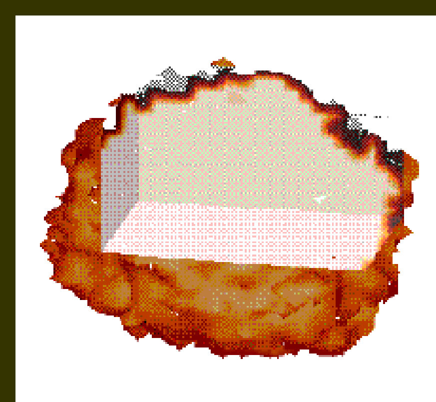
Plischke & Rácz (1984)
Active zone

Botet (1987)
(off-lattice simulations)
$\xi_{\perp} \sim \langle r \rangle^{a}$; $a \cong 0.369$

Growth of rough surfaces:
KPZ (1+1 model) (1986); a=1/3

Model





DLA

Witten & Sander (1981)

Dielectric Breakdown

Niemeyer et al. (1984)

$V_x = f(\nabla_n \Phi_x)$

$\nabla^2 \Phi = 0$

$\Phi = \Phi_0$ (occupied sites)

$\Phi = 0$ (distante surface enclosing the cluster)

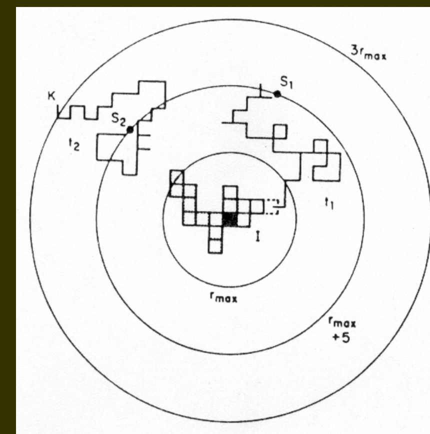
$\Phi(i,j) = \{\Phi(i-1,j) + \Phi(i+1,j) + \Phi(i,j-1) + \Phi(i,j+1)\}/4$

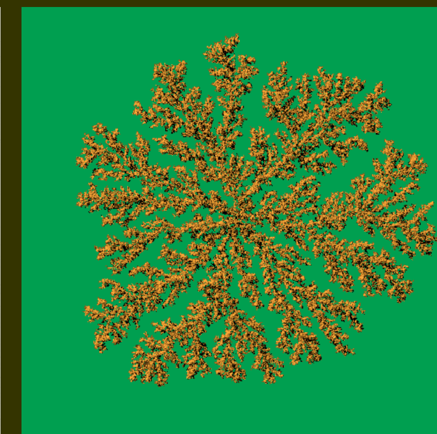
$V_{ij} = f(n, |\Phi_0 - \Phi(i,j)|) = n\,|\Phi_0 - \Phi(i,j)|^{\eta}$

$$P_{ij} = V_{ij} / \sum V_{lk}$$

growth probability depends on the global cluster geometry

Model





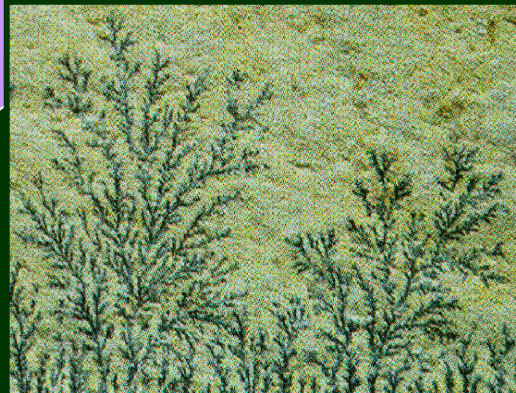
Random walker:

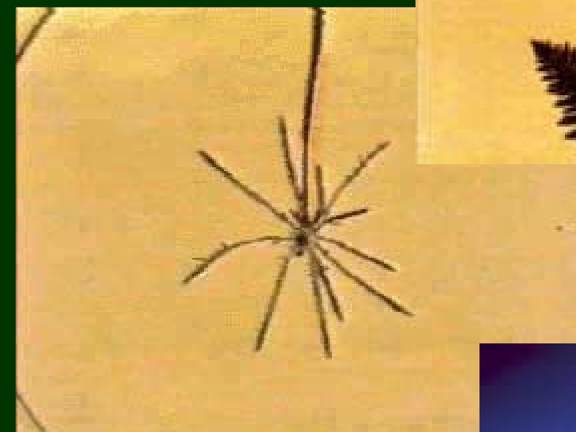
$P(i,j) = \{P(i-1,j) + P(i+1,j) + P(i,j+1) + P(i,j-1)\}/4$

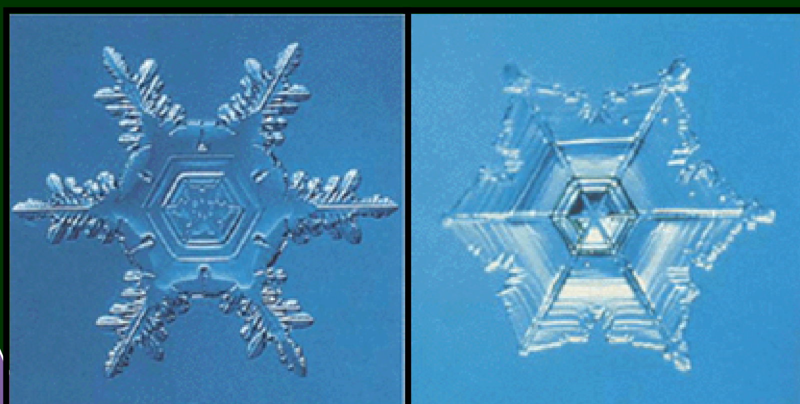
A scalar field Φ that obeys the Laplace eq. can be simulated by a random walk with the same boundary conditions.

$P(i,j) \sim \Phi(i,j)$

DLA in Nature







"Under the microscope, I found that snowflakes were miracles of beauty; and it seemed a shame that this beauty should not be seen and appreciated by others. Every crystal was a masterpiece of design and no one design was ever repeated. When a snowflake melted, that design was forever lost. Just that much beauty was gone, without leaving any record behind." Wilson A. Bentley

Cluster Morphology

Radius of gyration

$$R_g^{\,2}(t) = \frac{1}{N(t)} \sum_{i=1}^{N} \left(r_i(t) - \langle r(t) \rangle \right)^2$$

$$R_g \approx N^{\alpha}$$

EDEN

Compact structure
Rough surface

$$\alpha = \frac{1}{d}$$

$$d = 2, \quad \alpha = 1/2$$

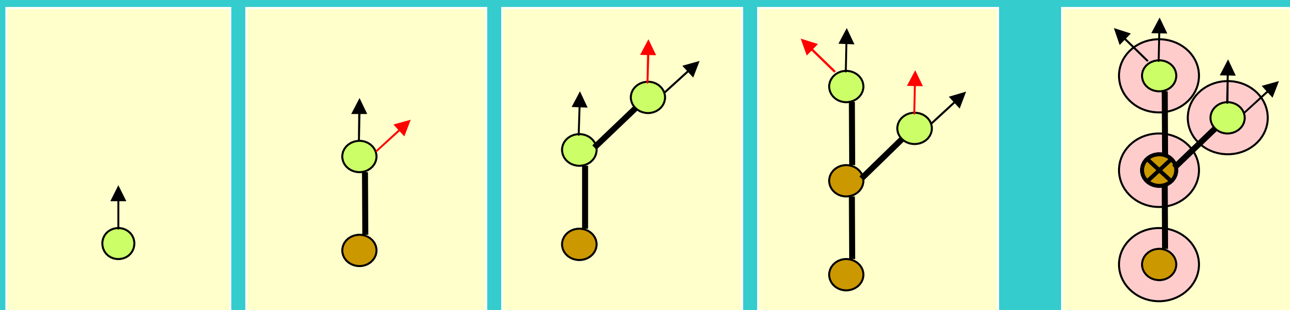
DLA

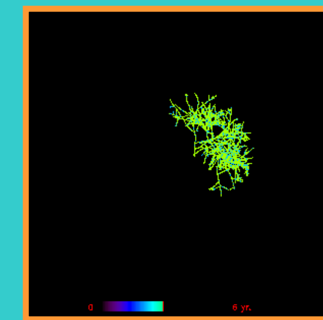
Fractal structure

$$\alpha = \frac{1}{D_f}$$

$$D_f(d{=}2) = 1.7, \ \alpha \cong 0.59$$

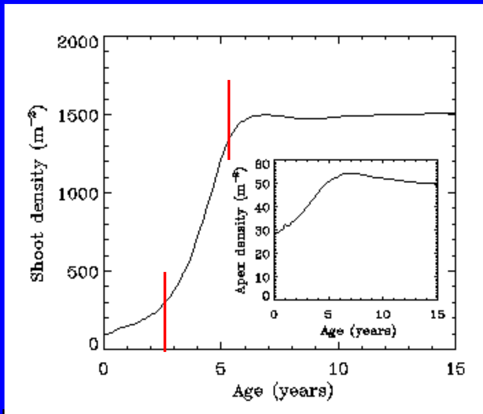
NUMERICAL MODEL

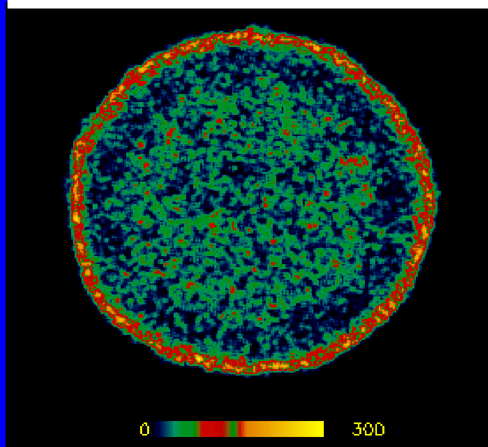


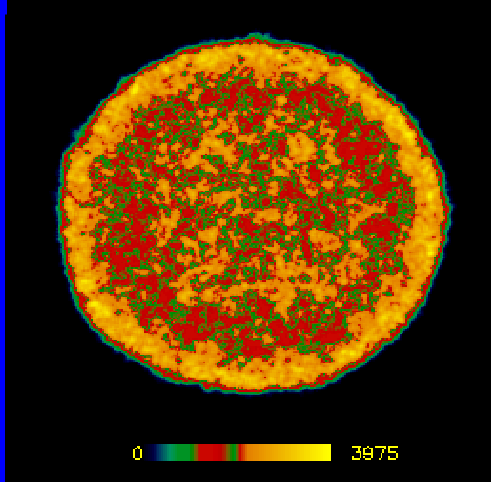


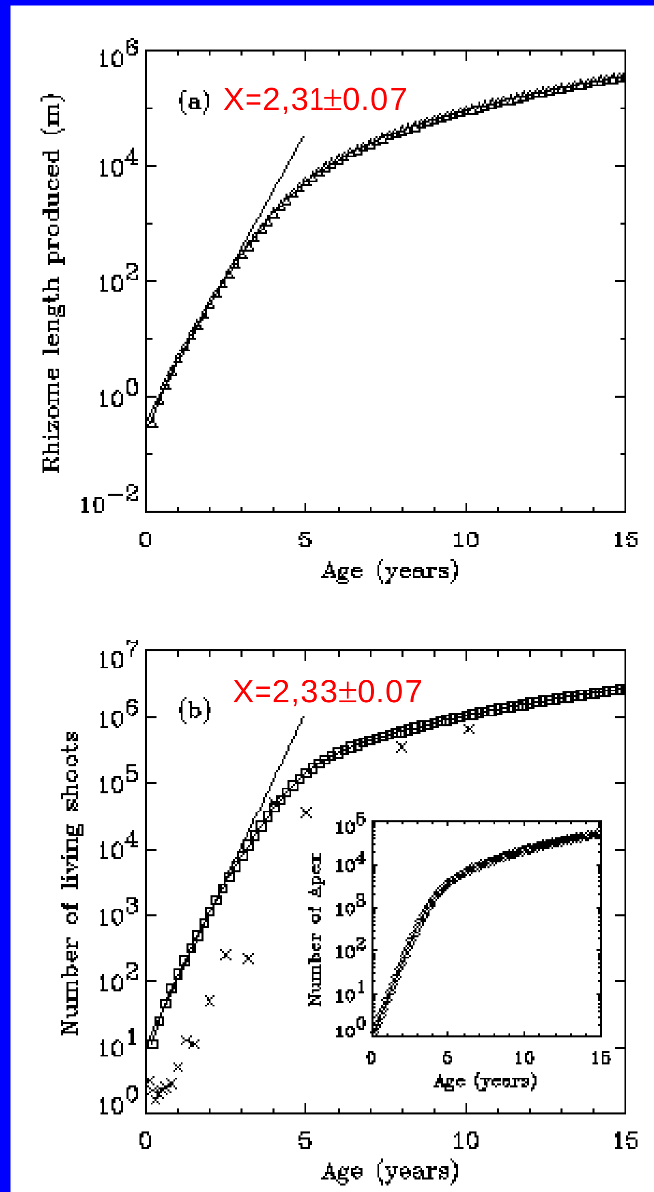
$$\Delta t = \frac{\rho}{v N_a(t)}$$

NUMERICAL RESULTS (C. nodosa)









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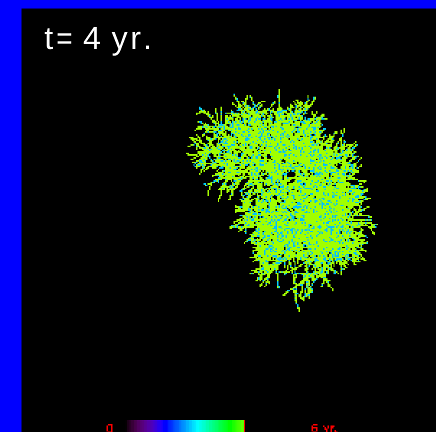
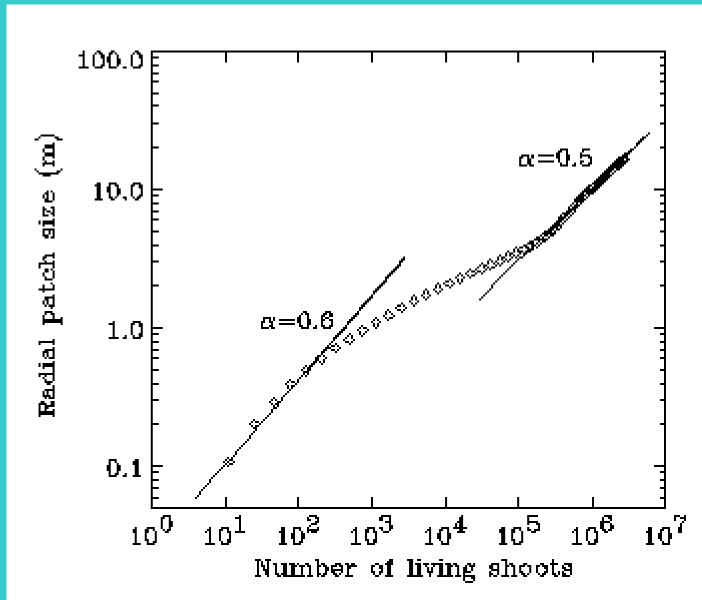


$$\frac{dN_a}{dt} = \nu_b N_a$$

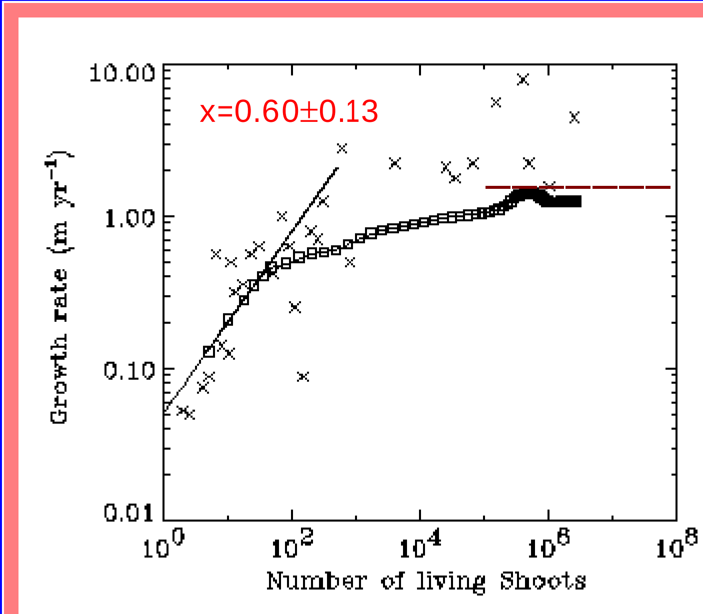
$$\frac{dN_s}{dt} = -\mu_r N_s + N_a$$

$$N_a = e^{\nu_b t}$$

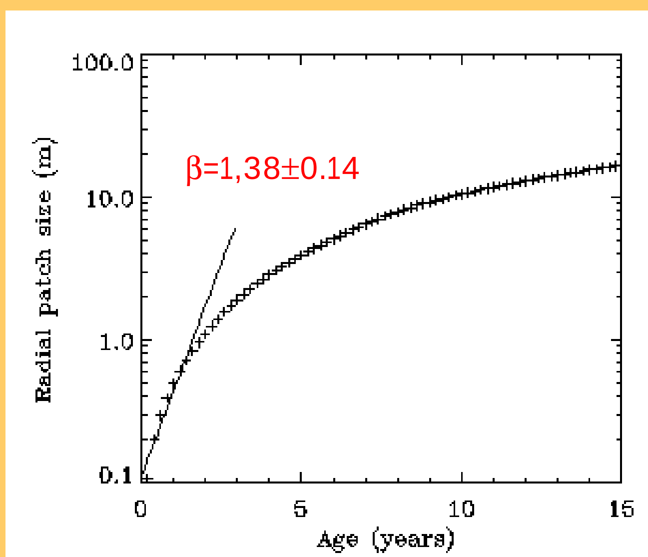
$$N_s = \left(1 - \frac{1}{\mu_r + \nu_b}\right).e^{-\mu_r t} + \frac{1}{\mu_r + \nu_b} e^{\nu_b t}$$



$$R_g \approx N^{\alpha}$$



$$d_t R_g \approx \beta N_s^{\alpha}$$

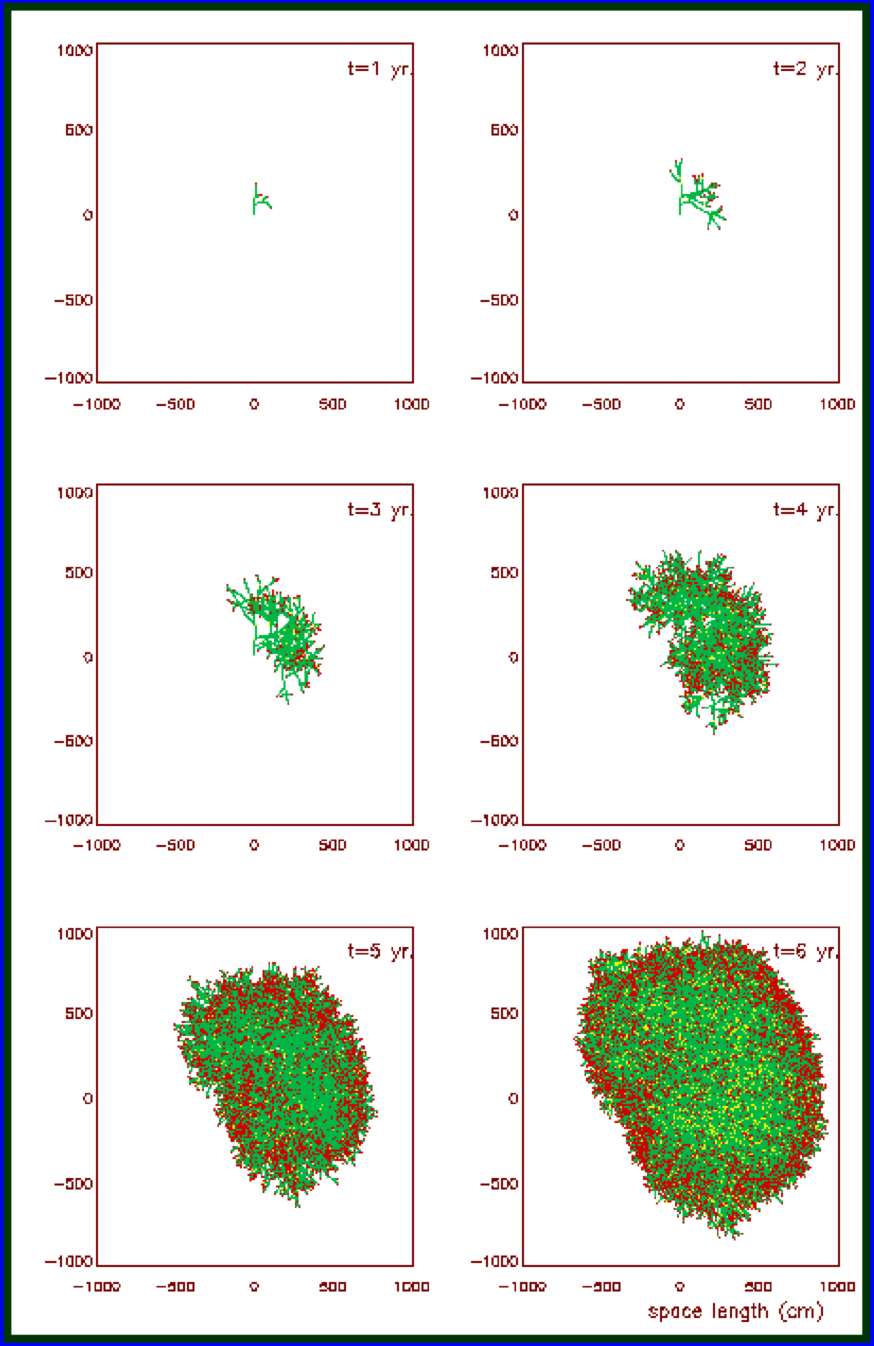


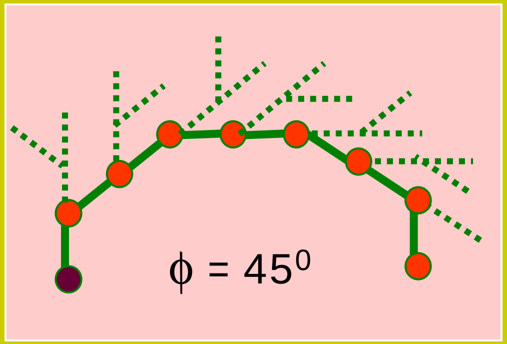
$$R_g \approx N_s^{\alpha}$$

$$N_s \approx \exp(\nu_b t)$$

$$R_g \approx \exp(\beta t)$$

$$\beta = \nu_b \alpha \ (= 1.38)$$





$$\frac{8 \text{ branches/apex}}{2{,}3 \text{ branches/apex/year}} \approx 3.5 \text{ years}$$

Conclusions

T < 3 years

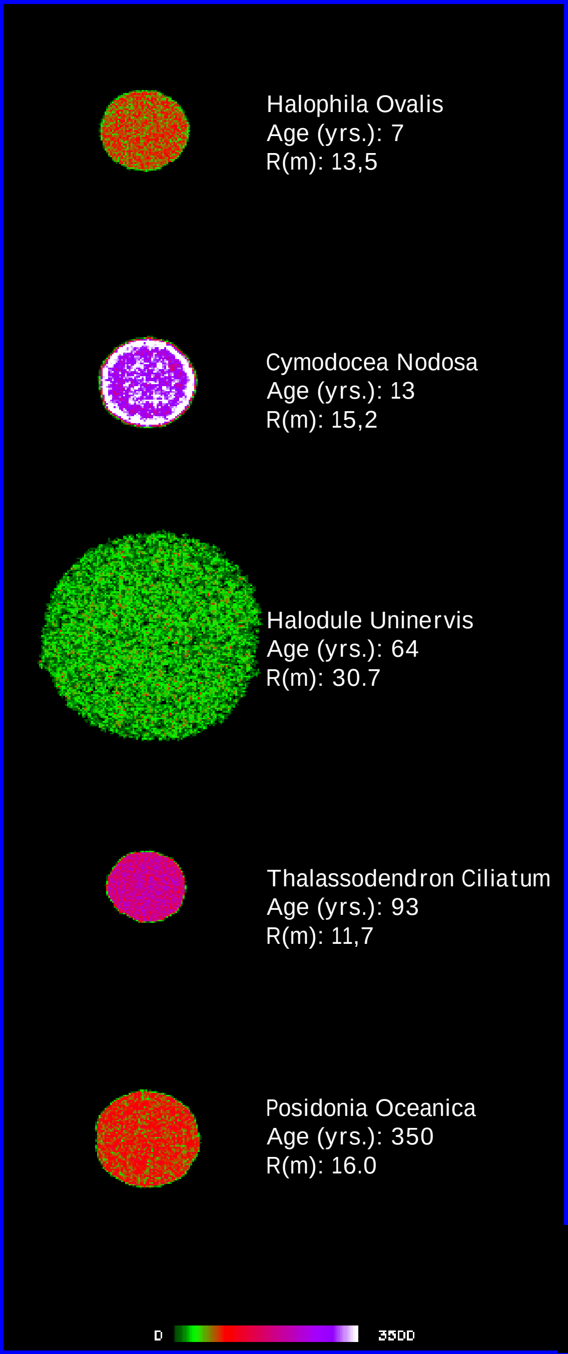
- Low density fractal structures
- $\alpha \approx 0.6$
- Growth dominated by ν_b
- Increase in the space occupation rate (below rizhome elongation rate)

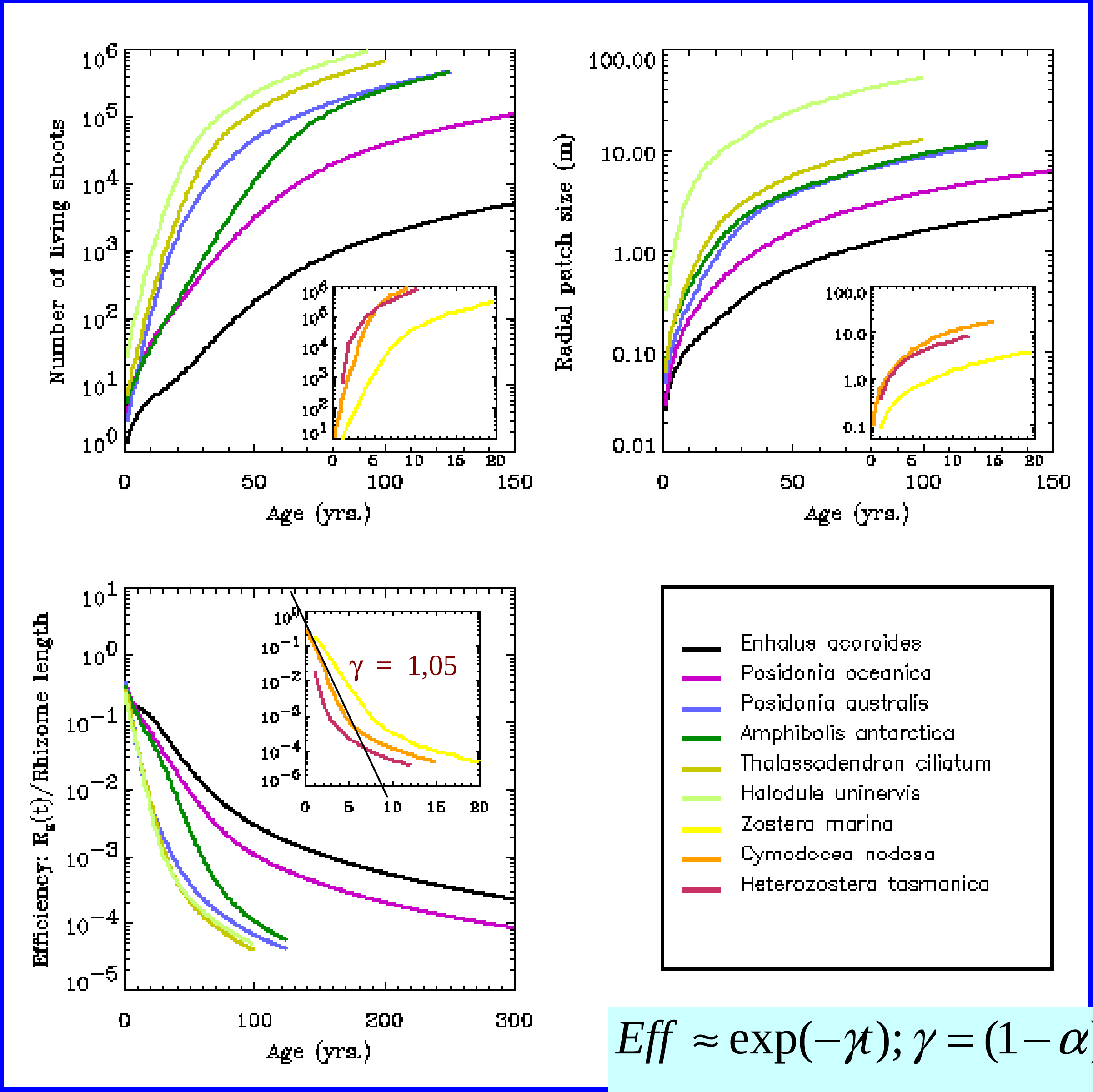
Transition time:

$$\tau = \frac{2\pi / \phi}{\nu_b}$$

T > 5 years (>10^5 shoots)

- Steady state density.
- Compact structure with rough surface.
- $\alpha \approx 0.5$
- Radial (centripetal) growth
- space occupation rate reaches a plateau value (rizhome elongation rate)





$$Eff \approx \exp(-\gamma t);\ \gamma = (1-\alpha)\nu_b$$

$(\gamma_{Cn} \approx 0{,}92)$

Rizhome production: 250 Km

Weight-density relationship: Yoda's Law

Yoda et. al. *J. Biol*, **14**, 107 (1963)

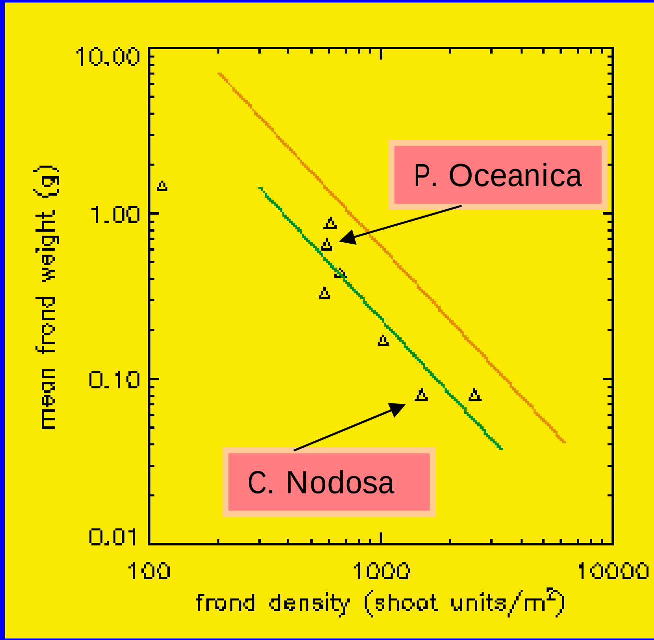
Area ~ L^2
Weight~L^3

Weight ~ $Area^{3/2}$ ~ $density^{-3/2}$
$W=K\ d^{-3/2}$

$\log_{10} w = \log_{10}K - 1.5 \log_{10}d$

Cousens and Hutchings, *Nature*, **301** ,240 (1983)

Limiting value: **$\log_{10}K < 4,3$**



$\log_{10}K=3,91$; Slope=-1,51