Thermal Remote Sensing and the Thermodynamics of Ecosystem Development

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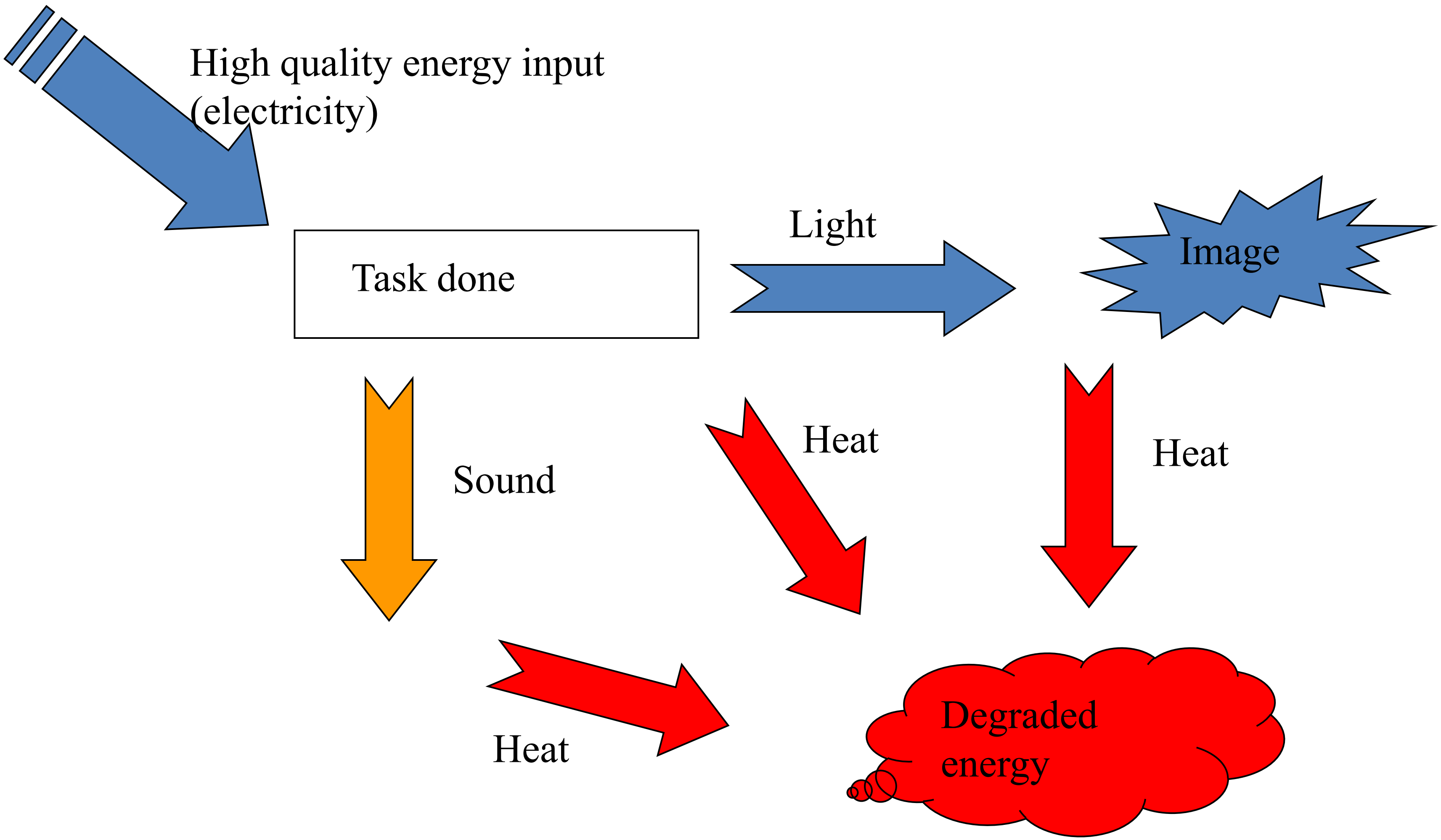
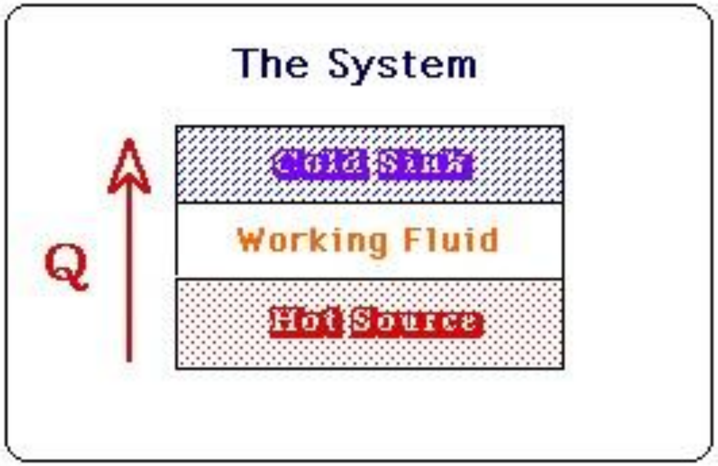
In Memory of James J. Kay 1954-2004

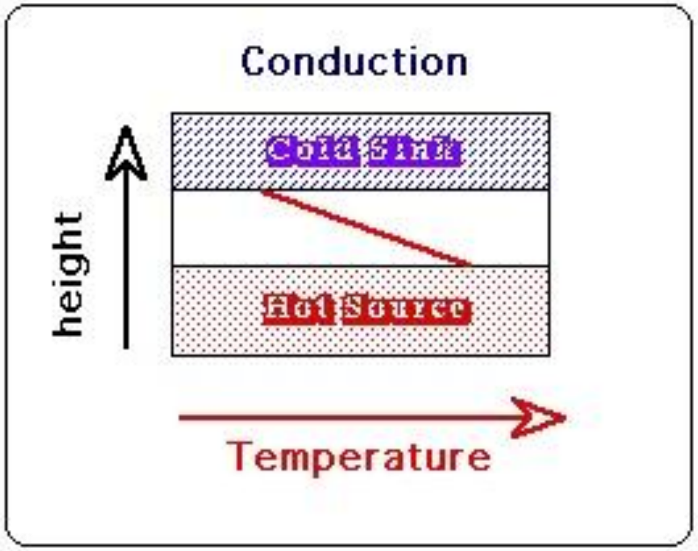
Energy **IN** = Energy **OUT**

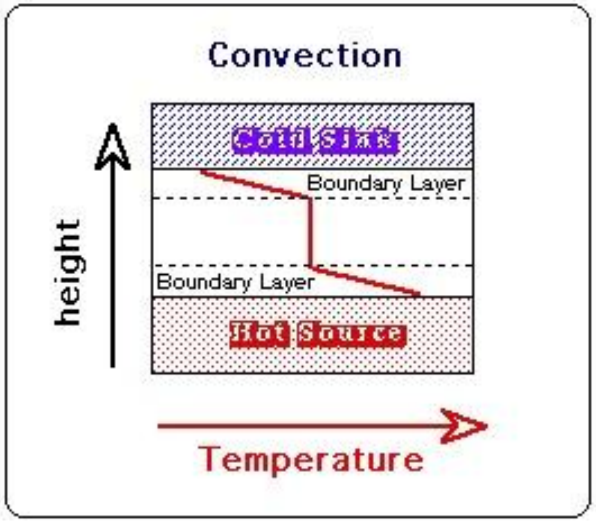
Exergy **IN** »» Exergy **OUT**



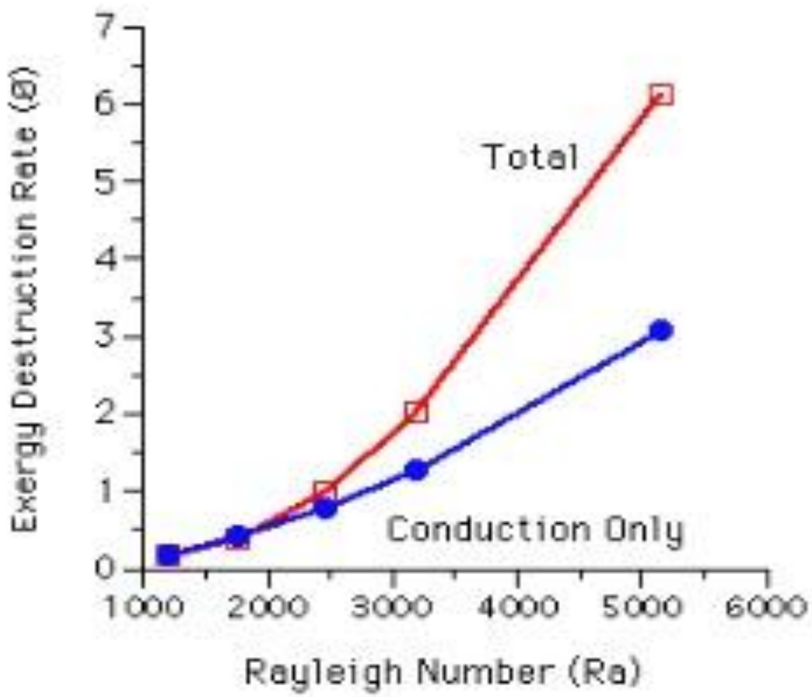
Bénard Cells





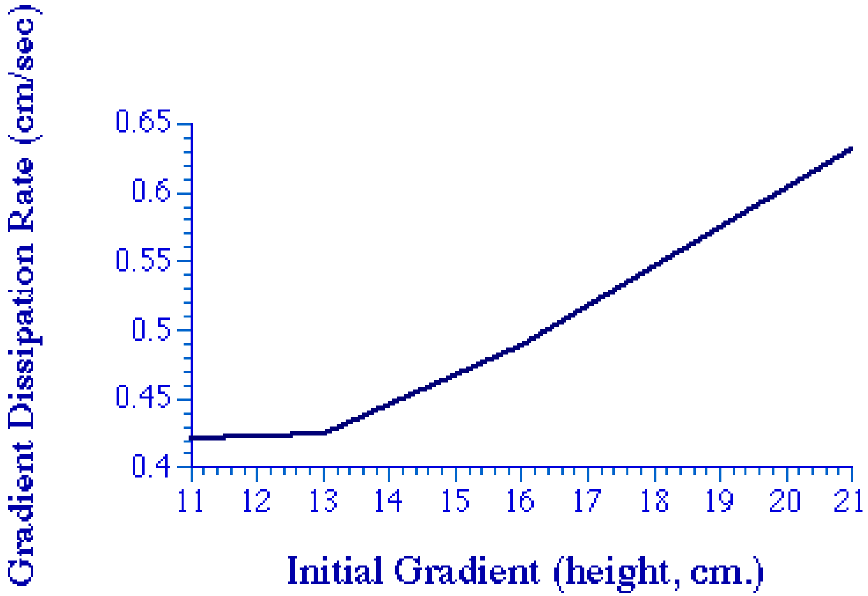


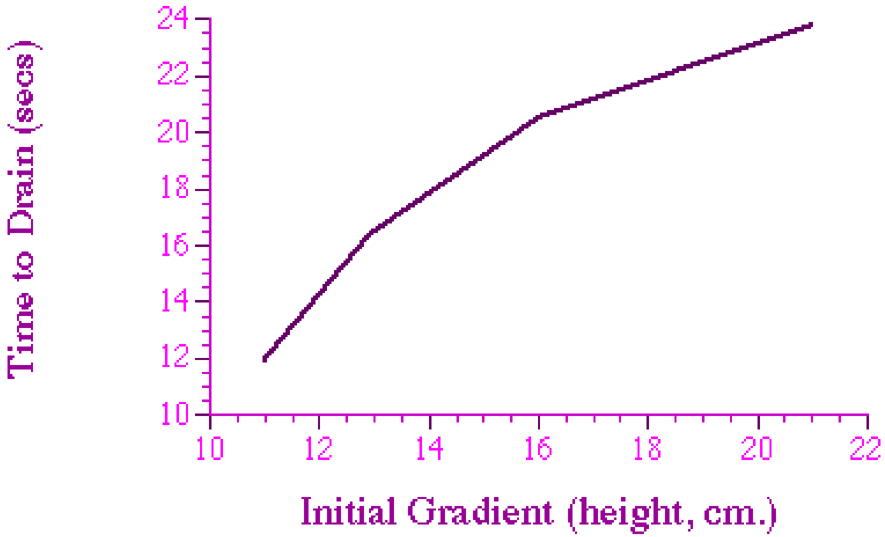
Exergy Destruction Rate (W) vs Gradient (Ra)



© James J. Kay 1992

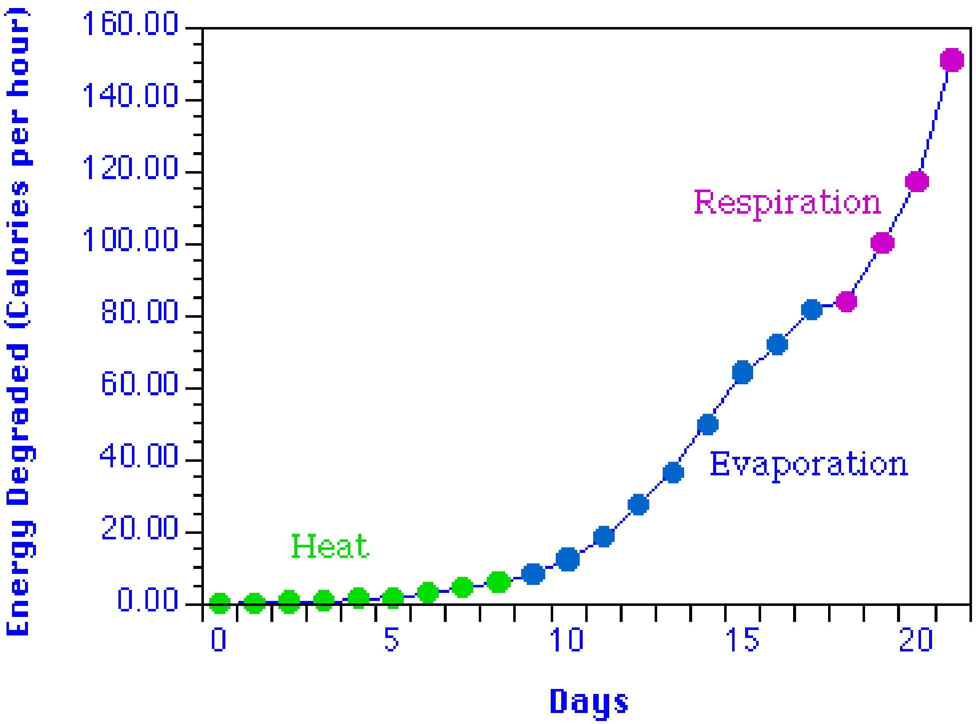
"Tornado in the Bottle"





Dissipation rate for a chicken embryo

(Data from Briedis and Seagrave, 1984)



Second law and ecosystems

What is the thermodynamic game?

Store energy

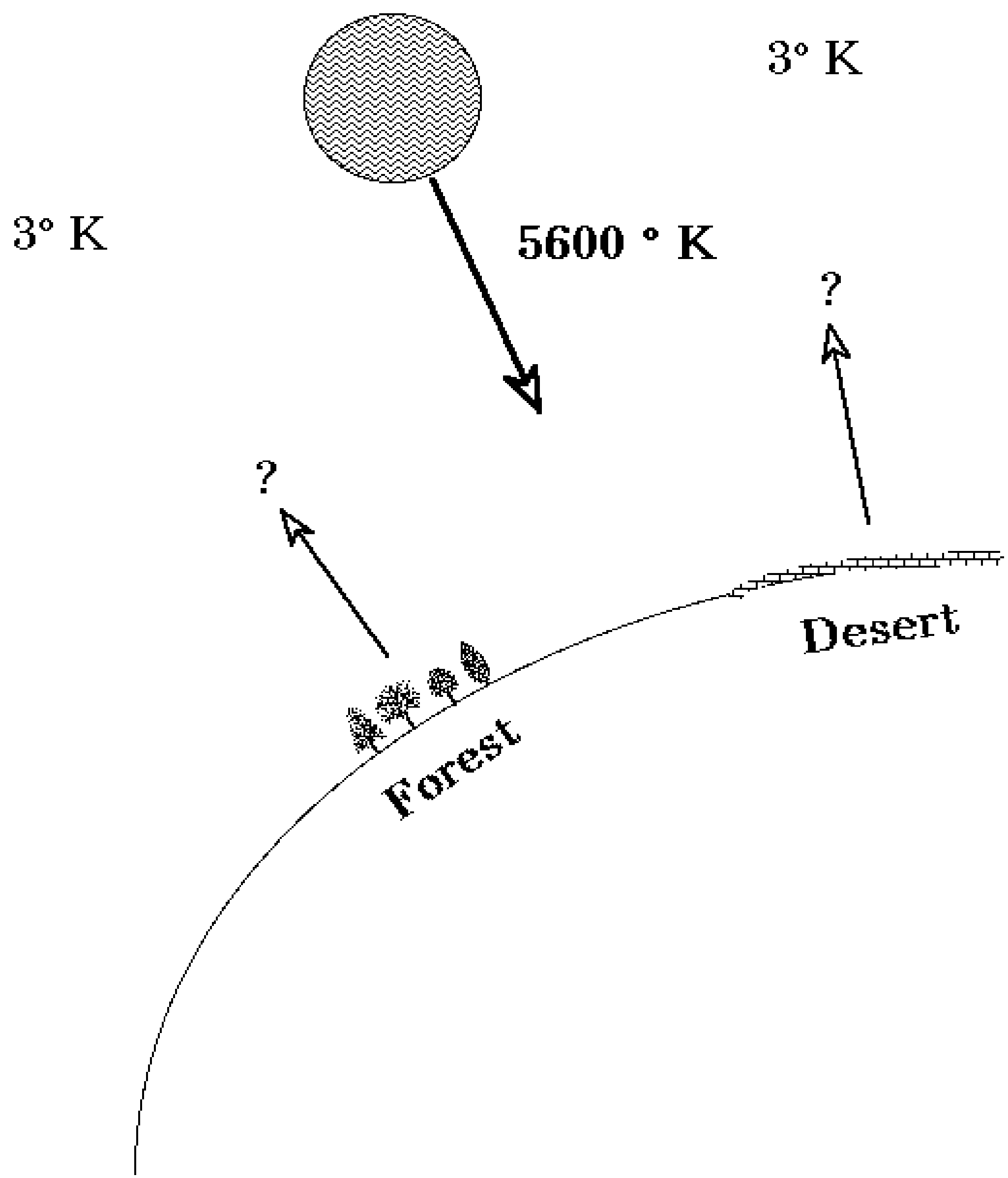
Increase Biomass

Make use of as much of the exergy as possible to perform tasks. Make the most effective use of the energy. Win!

(H.T. Odum was right! If maximum work principle means extract the most available work from the energy source.)

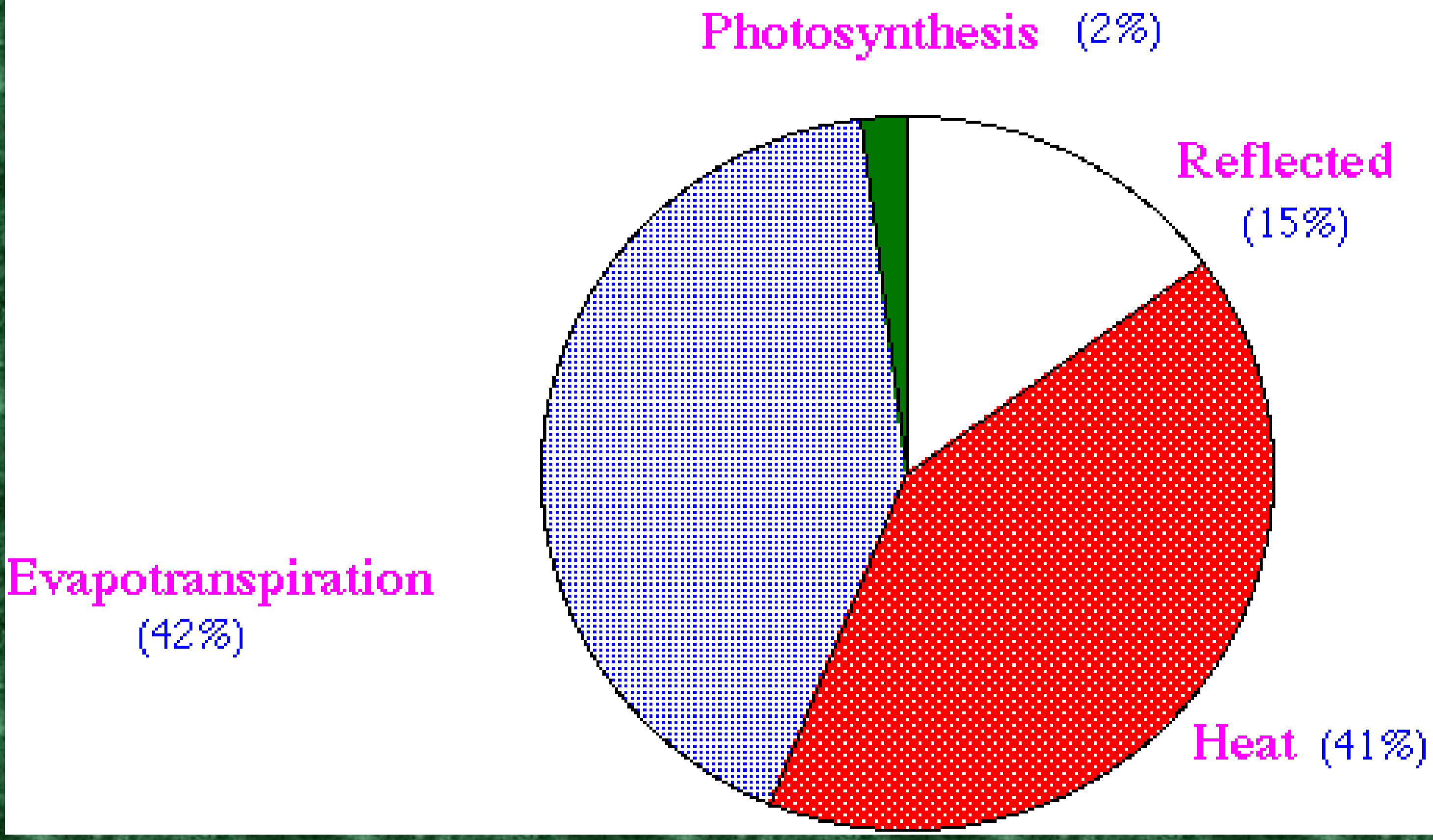
In thermodynamics, the exergy of a system is the maximum work available through any process that brings the system into equilibrium with a heat reservoir (environment). Exergy is the energy available for use.

Which degrades more energy?



The distribution of solar energy during the growing season in the Hubbard Brook Forested Ecosystem

(From Bormann and Likens, 1978)



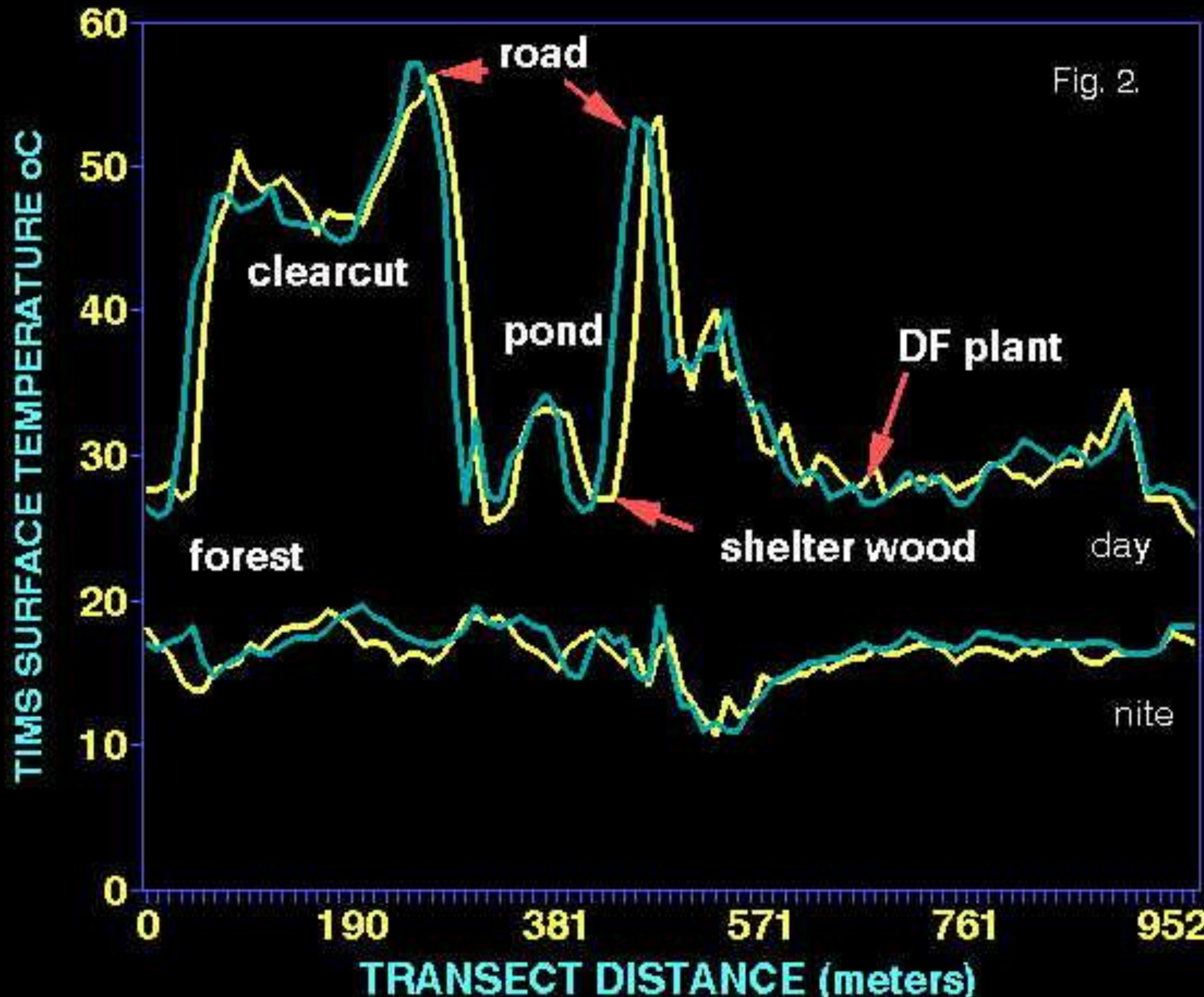
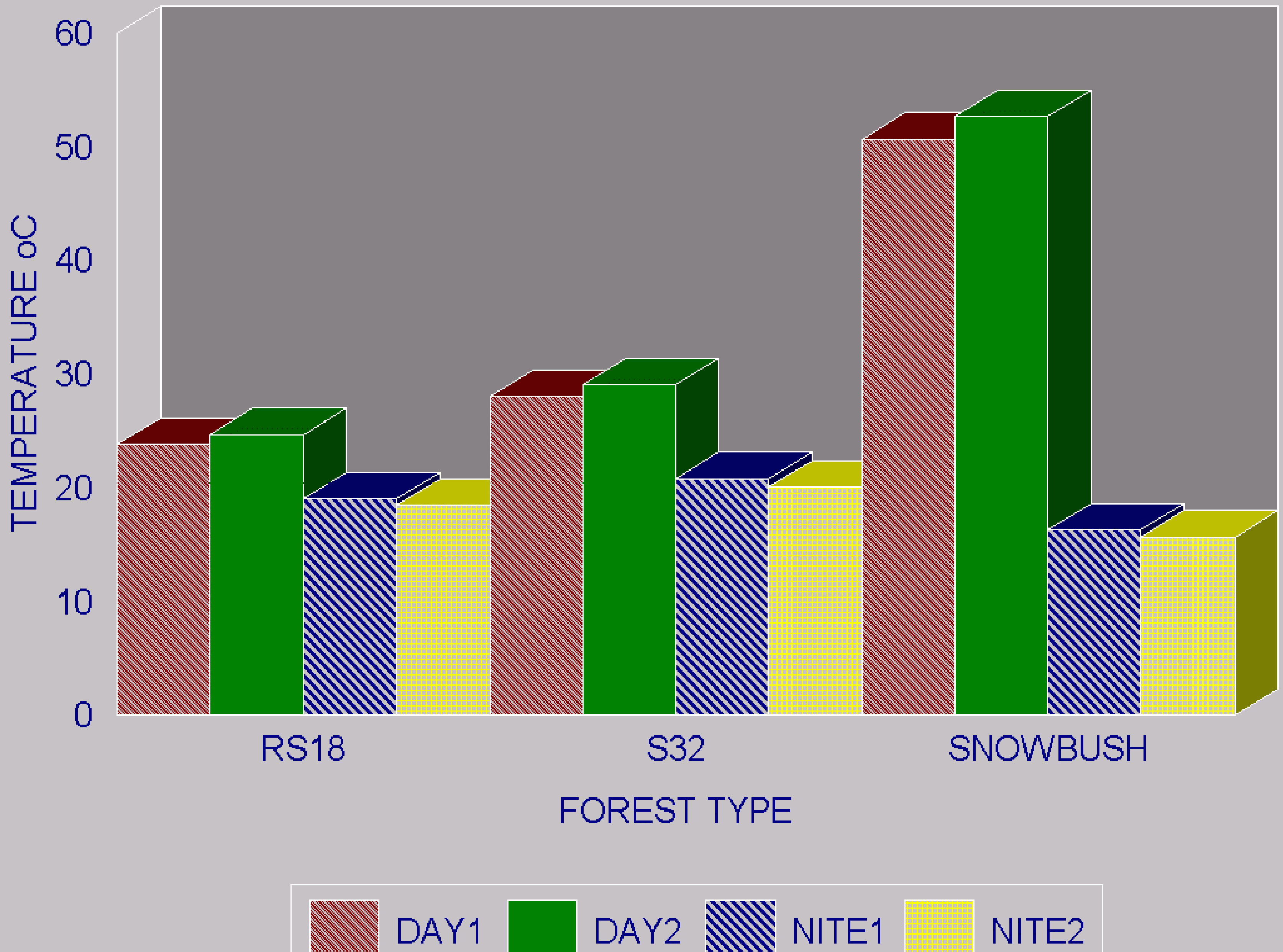
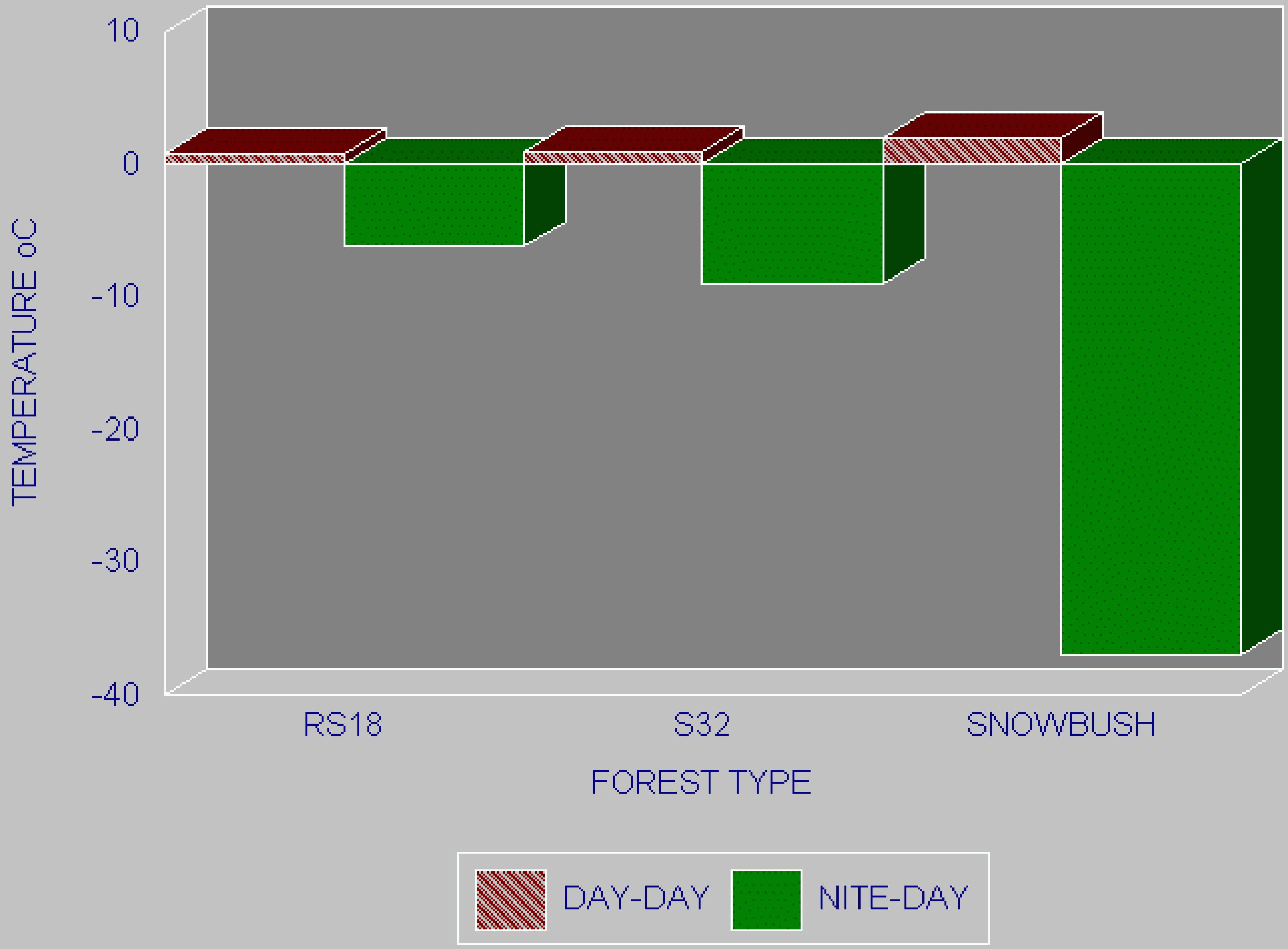


Fig. 2.
road
clearcut
pond
DF plant
shelter wood
forest
day
nite
TIMS SURFACE TEMPERATURE oC
60
50
40
30
20
10
0
0
190
381
571
761
952
TRANSECT DISTANCE (meters)

AVERAGE SURFACE TEMPERATURES



CHANGE IN SURFACE TEMPERATURES



HYPOTHESES

- For more developed ecosystems:
  - The ratio Rn/K^* will be larger.
  - Lower surface temperature.
  - Smaller temperature change in response to a given amount of energy input (net radiation).
  - Spatial variation of surface temperature will be less.

Thermal Response Number

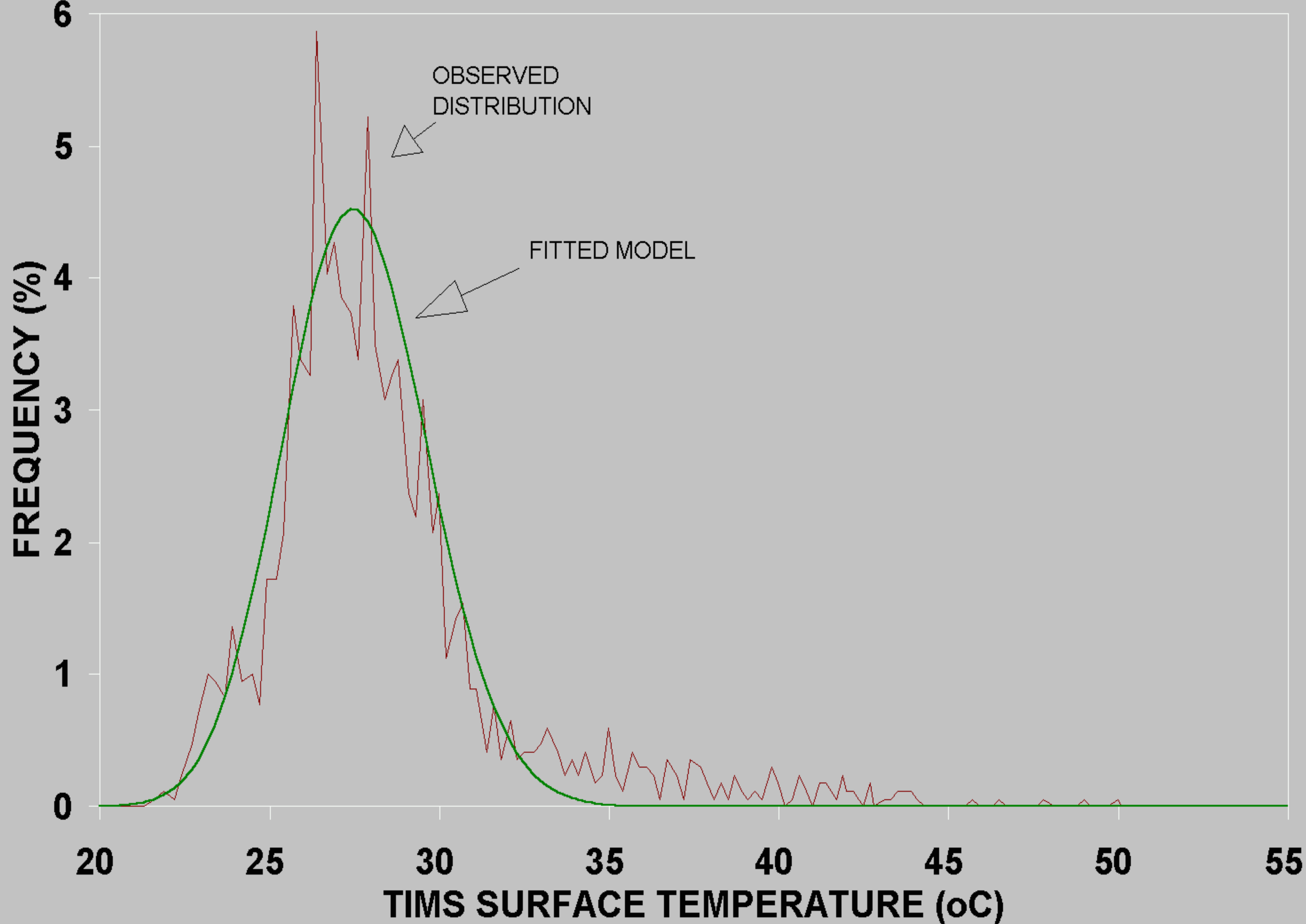
TRN = Q*/delta T

where:

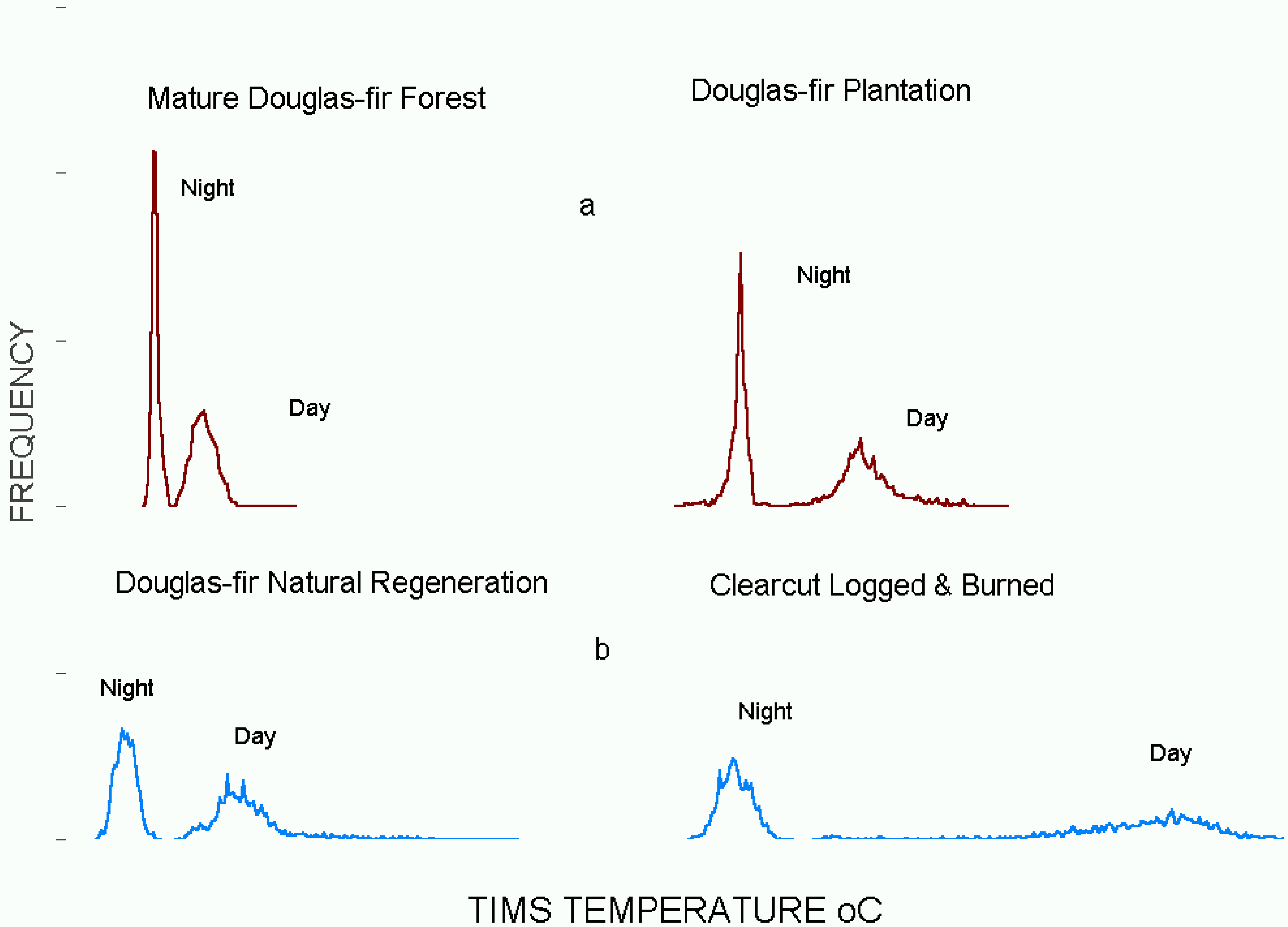
Q* = net radiation

delta T = change in temperature

- Uses the change in surface temperature between 2 measurement times
- Uses surface net radiation as amount of energy available the surface for partitioning
- Produces a quantifiable value (kj m-2 oC -1)
- Allows the classification of land use in terms of energy partitioning



6
5
4
3
2
1
0
FREQUENCY (%)
OBSERVED
DISTRIBUTION
FITTED MODEL
20
25
30
35
40
45
50
55
TIMS SURFACE TEMPERATURE (oC)



Mature Douglas-fir Forest
Night
Day
Douglas-fir Plantation
Night
Day
a
FREQUENCY
Douglas-fir Natural Regeneration
Night
Day
Clearcut Logged & Burned
Night
Day
b
TIMS TEMPERATURE oC

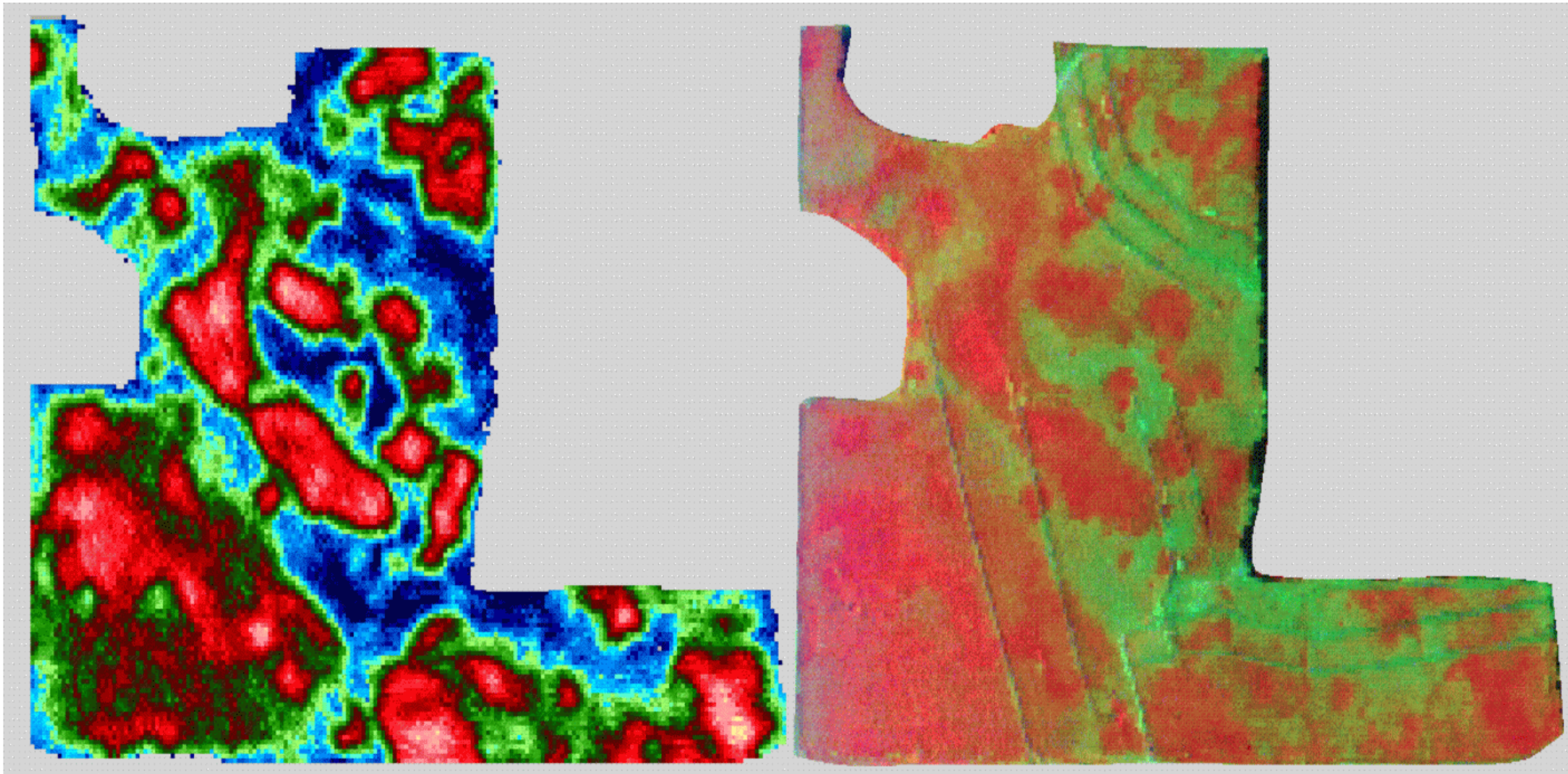
	Quarry	Clearcut	Douglas Fir Plantation	Natural Forest	400 year old Douglas Fir Forest
T (^oC)	50.7	51.8	29.9	29.4	24.7
R_n/K^* (%)	62	65	85	86	90
Beta Index	12.9	6.3	34.4	17.2	130.7
TRN	168	406	1631	788	1549

Beta Index: Spatial variability in the surface temperature

Thermal Response Number (TRN): For a given input of energy over a given time, the change in surface temperature. Temporal variability.

Both are measures of inertia, so bigger means less variability.

1997 Corn Yield vs Remote Sensing



Harvested September, 1998 June 26, 1998

Thermal Band correlation > 0.86

D. Rickman, et al., 1999

Nonequilibrium thermodynamic hypotheses concerning ecosystem development

- Exergy utilization will increase
  - Rn/K* will increase
  - Surface temperature will decrease
- Internal equilibrium will increase
  - Spatial variation in surface temperature will decrease (Beta index increases)
  - Temporal variation in surface temperature will decrease (TRN increases)

Conclusions

- Ecosystems develop structure and function that degrades the quality of the incoming energy more effectively.
- The ecosystem T and Rn/K * and TRN are excellent candidates for indicators of ecological integrity.
- The potential for these methods to be used for remote sensed ecosystem classification and ecosystem health/integrity evaluation is apparent.

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