Botanical Engineering

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Dedicated To

(Source: http://www.manofthetrees.org/HTMLS/worldscope.htm)

Richard St. Barbe Baker

Richard St. Barbe Baker, OBE
Oct 9, 1889– June 9, 1982
'Man of The Trees'

"It is interesting that when most people lapse into inactivity, he really got going. And he did it with nothing. He basically had no money when he was here...his friends sometimes bought him a plane ticket to get rid of him because it was so much work having him around, receiving visitors, planting trees, meeting dignitaries, media and so on."

- British Forester, born in Hampshire, studied forestry in Saskatchewan, Canada and in Cambridge, UK
- Ultimately responsible for the planting of 26 billion trees
- Started as forester in Kenya, founder of the 'men of the trees'
- Actively promoted desert reclamation, founder of Sahara University
- Successfully lobbied for creation of Ministry of Health after WWI

(Sources: `http://www.manofthetrees.org/`, `http://www.westendlhs.hampshire.org.uk/barbe/index.html`)

(Memorial: West End, Southampton, Chapel Road / High Street)

Part I

Practical Engineering with Plants

Thesis: A surprisingly large number of engineering problems can be solved by resorting to plants instead of machinery and structures

Example 1

How to drain soggy ground

Biodrainage

- *Most important question*: Is this really a good idea? Swamps and Wetlands often are rather unique habitats.
- Conventional methods: Pumps, installation of drainage channels.
- Alternative: Use suitable plant species that draw and transpire a lot of water as a biological pump.
- Historic example: Drainage of the malaria-ridden Pontine Marshes (SE of Rome) by Mussolini, planting Eucalypts.
- In some situations, keeping the water table low is of great importance: *surface evaporation can cause highly destructive salination of soils!*
- Successful trials with biodrainage (for salinity control) in Israel, using Red River Gum (*Eucalyptus camaldulensis*). (Gafni, Zohar, 2001; also: FAO on Biodrainage).

Eucalyptus camaldulensis – Red River Gum

Source: `http://www2.mdbc.gov.au/education/encyclopedia/wildlife/flora/redgums.htm`

Water transpiration $\approx$ some 100 liters/day!

Example 2

How to stabilize an erosion gully

Erosion control

"When a small gully opened near their swimming pool, the clients were anxious to halt the erosion [...]. A local landscaper gave an estimate of $1,300 for a typical reinforced concrete retaining wall. I was asked to consult on an alternative. I suggested arranging used tires up the side of the gully [...] and planting willow cuttings from an adjacent grove. [...] Within nine months, they had a thicket of willows, and the tires were concealed. Their erosion problem is permanently solved, the swimming pool intact – for less than 2 percent of the cost of the proposed concrete wall. "

(From: R. Kourik, *Designing and Maintaining Your Edible Landscape Naturally*, p. 84)

Erosion control

Source: `http://www.igsb.uiowa.edu/inforsch/sny/implemen.htm`

Unconventional Ore Mining

Metal Hyperaccumulators

- Organic Gardeners grow and compost 'dynamic accumulator' plants to 'mine' soil nutrients.
- Well-known examples: Nettles (Urtica dioica), Comfrey (Symphytum officinale, S. uplandicum).
- Likewise, plants known as *hyperaccumulators* can extract and incorporate very big amounts of some heavy metals.
- Example: alpine pennycress (Thlaspi caerulescens) can accumulate up to 4% dry-weight mass of zinc.
- Uses: Phytoremediation (Plant-assisted pollution cleanup), 'Exotic ore' for smelting new metal!

Thlaspi caerulescens

Source: http://www.sciencedaily.com/releases/2007/01/070125114121.htm

Creative Solutions
For the U.S. Mortgage Crisis

Growing Houses

Why build a house when you can grow one instead?



Source: `http://www.inhabitat.com/2006/06/12/grow-your-own-treehouse/`

The (old) 'weaving' technique used to construct these living structures is called '*pleaching*'. The branch of architecture that deals with living structures is called '*biotecture*' and was pioneered by the German landscape architect Rudolf Doernach.

Cellulose as a Building Material

. . . But seriously:

Source: `http://www.straw-bale-houses.com`

"A post & beam frame home on a continuous concrete foundation, cellulose insulation, exterior stucco & interior plastered walls."

In other words: A Straw Bale House

Source: `http://www.straw-bale-houses.com`

The modern technique of using straw bales as bricks originated around 1800 in the (timber-poor!) Great Plains in North America.

A Straw bale building in the UK (Hill Holt Wood)

Not So Rapid Prototyping

Growing as a way of production

"Very few things actually get manufactured these days, because in an infinitely large Universe such as, for instance, the one in which we live, most things one could possibly imagine, and a lot of things one would rather not, grow somewhere. A forest was discovered recently in which most of the trees grew ratchet screwdrivers as fruit."

(Douglas Adams, *Life, the Universe, and Everything*)

A Grown Ladder

Source: `http://www.arborsmith.com/treecircus.html`

Grown Furniture

Source: `http://www.grown-furniture.co.uk`

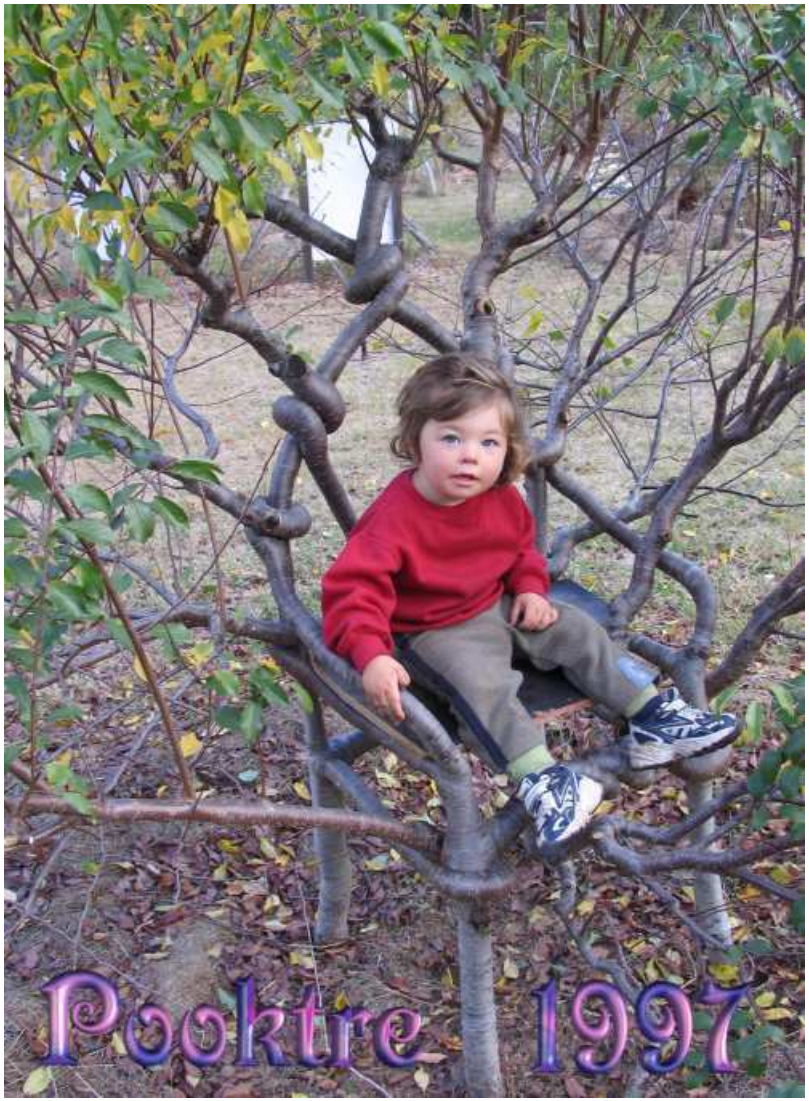
More Grown Furniture

Source: `http://www.pooktre.com`

Growing the mirror

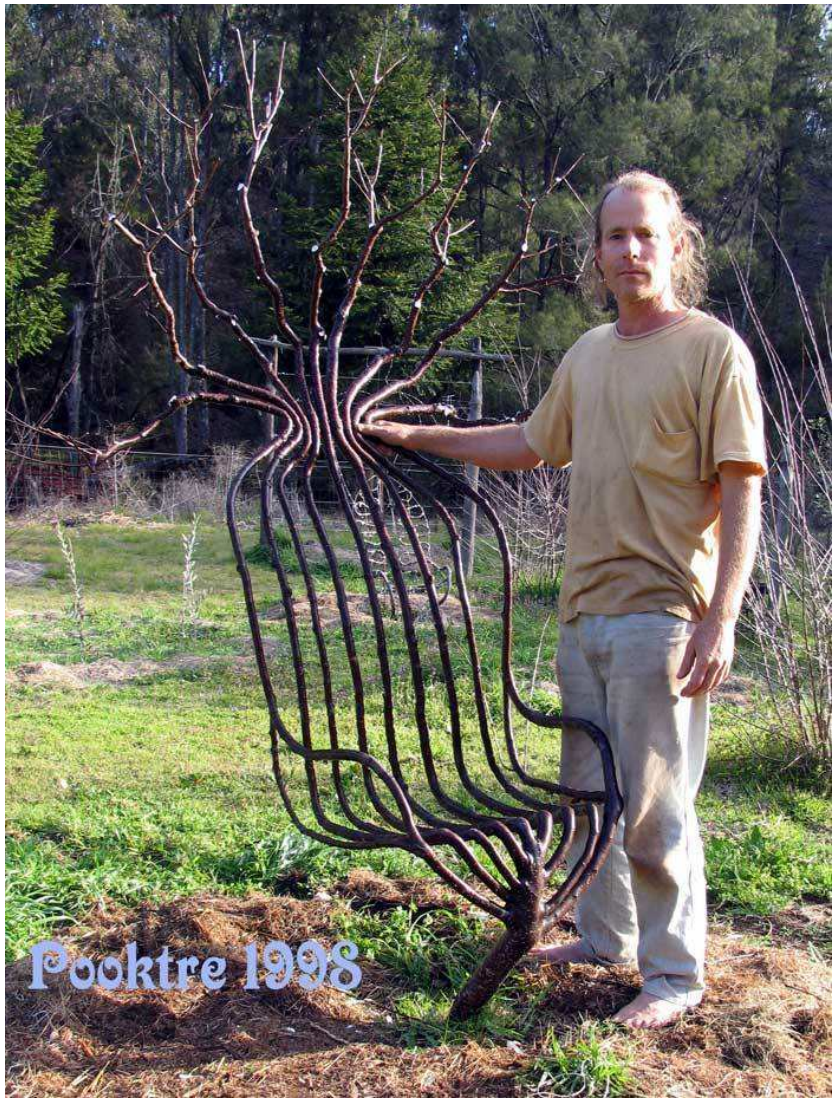
Source: `http://www.pooktre.com`

Growing a chair



Source: `http://www.pooktre.com`

Another chair



Source: `http://www.pooktre.com`

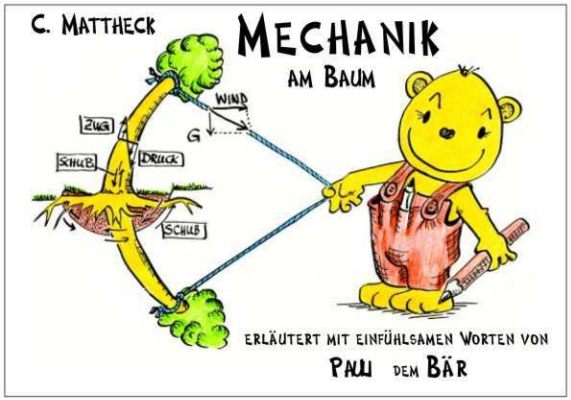
On Grown Structures

Nota bene: Single-growth structures have a number of structural mechanical advantages over structures with artificial joints!

Commercial Break

A rather unusual (but serious) German textbook on structural mechanics:

erhältlich bei
Buchhandlung-MENDE in Karlsruhe, Karlstraße 76
Tel.: 0721-981610, Fax: 0721-815343



Das Buch

- führt ein in eine einfache Mechanik
- vermittelt ein quantitatives Verständnis für den Baum, seine Belastungen, seine Risiken, sein Versagen ...
- enthält neueste Forschungsergebnisse aus dem Forschungszentrum Karlsruhe GmbH - Technik und Umwelt -
- stellt Ihnen einen neuen Freund vor: PAULI DER BÄR!

Er wandert gerne, liebt Großkalibergewehre, Staffordshire-Bullterrier und Bäume, Bäume ...

Der Autor

Claus Mattheck, geb. 1947 in Dresden. Promotion in Theoretischer Physik 1973, Habilitation im Fach Schadenskunde an der Universität Karlsruhe 1985 und Vorlesungen über Biomechanik als apl. Professor. Abteilungsleiter für Biomechanik am Institut für Materialforschung II des Forschungszentrums Karlsruhe, Sachverständiger für Mechanik und Bruchverhalten der Bäume. Wissenschaftspreis der Stiftung Industrieforschung für die Computersimulation biologischen Wachstums 1991, Literaturpreis der Karl Theodor Vogel-Stiftung für Technikpublizisten 1992, Georg-Winter-Preis der europäischen Gesellschaft für Biomaterialien 1993, Ehrenmitglied der ISA England-Irland 1997, Wissenschaftspreis der Berlin-Brandenburgischen Akademie der Wissenschaften 1998 (gest. von der Gottlieb-Daimler und Karl-Benz-Stiftung), Chadwick Preis für Baumpflegeforschung der ISA 1998, Henry Ford European Conservation Award (Umwelttechnologie) und Inge u. Werner Grüter-Preis für Wissenschaftspublizistik 1999.

The 'Plants For A Future' Project

- Today, less than 20 plant species provide more than 90% of our food.
- Known edible plants: $> 20\,000$
- Apart from the most obvious ones (food, timber, medicine), there are many other, sometimes exotic, important uses of plants. (As we have seen!)
- The 'Plants For A Future' Project:
  - Founded by Ken Fern in 1989.
  - Located in Cornwall, U.K.; 28 acres.
  - Grows $1\,500+$ different species on site, some of them highly unusual.
  - Maintains and publishes a database on uses of more than $7\,000$ plants that grow in our (present or future) climate.

The ‘Plants For A Future’ Site

The PFAF site (in the background) is heavily wooded, due to the project’s emphasis on (woody) perennials.

(Source: `http://www.pfaf.org`)

An Example from the P.F.A.F. Database

Althaea officinalis - the 'Marsh Mallow' (German: 'Echter Eibisch')

(Source: `http://de.wikipedia.org`)

Althaea officinalis

- 'Marsh Mallows' originally were made out of the roots of the marsh mallow plant.
- Belongs to the family of *Malvaceae*.
- Genus name *althaea* comes from the greek word 'altho' (healing).
- Types of uses (classified by P.F.A.F. – omitting details)

Adhesive	(Glue can be produced from the root)
Antitussive	(Root relieves coughing)
Demulcent	(Relieving inflammation, forms soothing film over mucus membranes)
Diuretic	(Regulates the flow of urine)
Egg substitute	(from cooked root)
Emollient	(highly; Softens skin, causes warmth, helps with insect stings)
Excipient	(Pharmaceutical binding agent in pill-making; from root)
Fibre	(Paper from stem and root)
Laxative	(slightly; can treat constipation)
Oil	(from seed, for making paints and varnishes)
Tea	(from root)
Toothcare	(Toothbrush from root; also: chewing root eases teething pain)

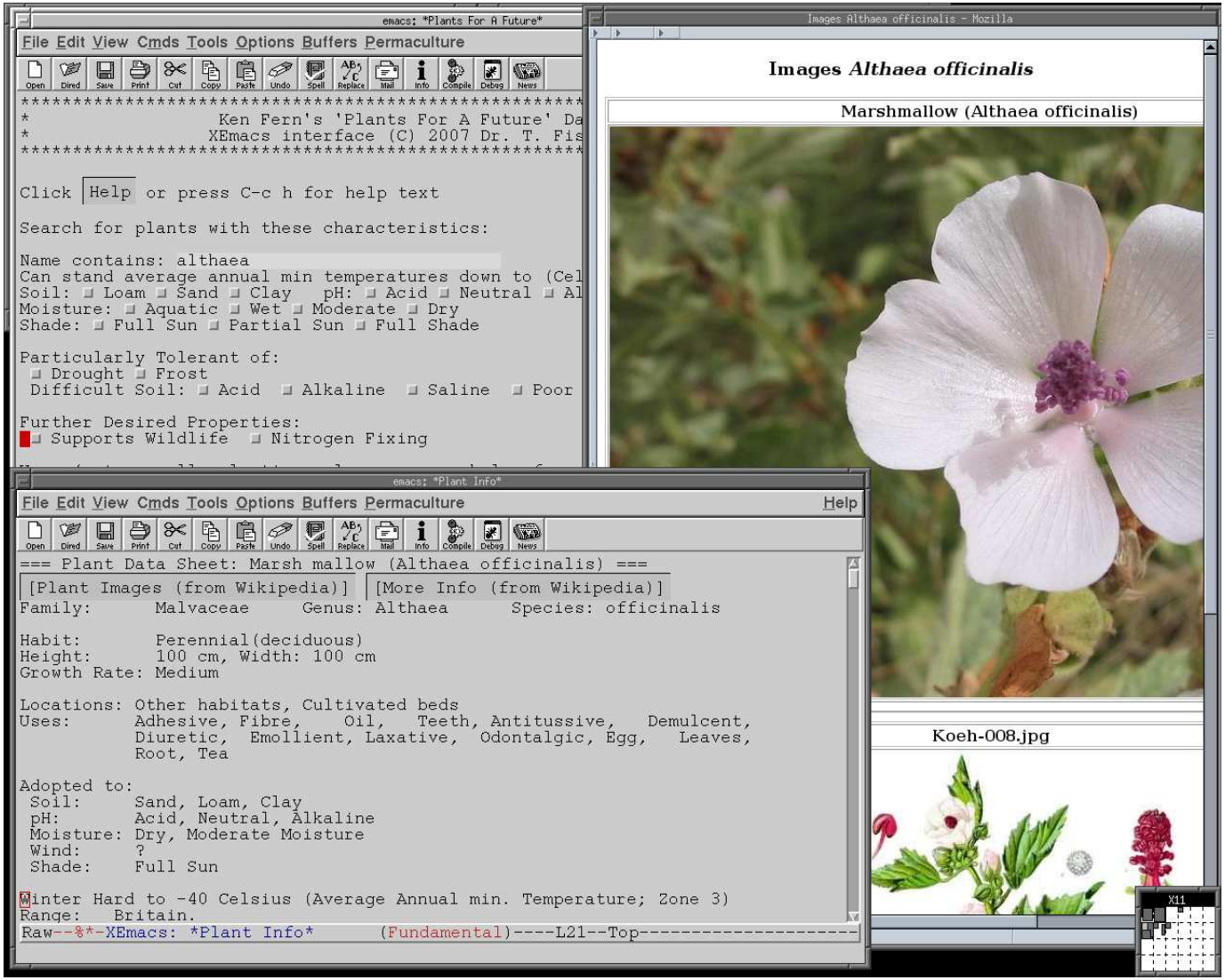
The Beauty of Progress

Marsh Mallows – old and new

(Sources: `http://www.herbalsage.com`, `http://www.candyusa.org`)

The P.F.A.F. Database in Emacs

(A hobby project of mine: An Emacs interface to the PFAF Database)



And now for something completely different...

How to recognize different types of tree from quite a long way away

Number one. The Larch.

Part II

The Physics of Biological Systems

Some Golden Rules for Understanding Ecosystems

Nota bene: These are not about nature itself, but about *how to read nature*!

1. *The Most Important Rule*: A natural system in equilibrium is so complex that we cannot even hope to ever know all the important processes!
2. *The Cooperation Rule*:
   - Life strives to improve the conditions for more life.
   - Nature did do a lot of experiments over many millions of years: systems co-evolved to work in harmony.
   - No Waste: One system's output is another system's input.
3. *The Energy Rule*: Expressing processes in the language of energy flows often allows deep insights.
4. *The Cycling Rule*: Nature optimises nutrient usage through cycling. Hence, we must learn to read these cycles.
5. *Redundancy and Niches*: Important functions are usually provided by more than one species. Every species is adapted to a particular set of circumstances.

Some (selected) Examples

The 'Knowledge' Rule

"To conserve soil moisture during the dry summer months, most trees in California drop [...] leaves. The oaks have a different method – they rely on the oak leaf caterpillar. In spring and summer, [...] caterpillars eat oak foliage, reducing the leaf surface area and the oak's demand for water.
[...]
Tampering with the oak-caterpillar symbiosis can be disastrous. During the famous California drought of 1977-78, some oak trees were killed by the well-meaning eradication of caterpillars. "

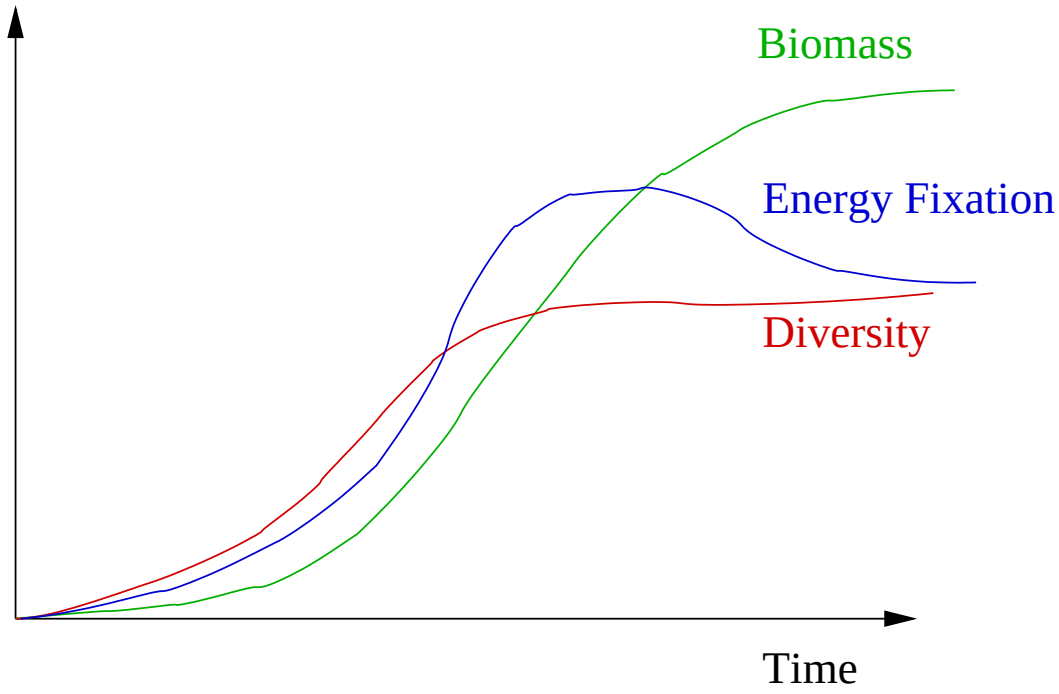
(From: R. Kourik, *Designing and Maintaining Your Edible Landscape Naturally*, p. 84)

The ‘Energy’ Rule I

Evolution optimised photosynthetically driven biosystems over millions of years towards efficient utilisation of sunlight.

Biological succesion and energy flow

(rough sketch)



The 'Energy' Rule II

A slightly over-simplified picture:

- Colonization of new ground through *succession*.
- Beginning: small number of pioneer species start to grow.
- Rather than pioneer growth leveling off in a sigmoid curve, the system increases energy throughput by adding more complexity: more complex species assemblies enter the scene that depend on structure (food, nutrients, microclimate, etc.) provided by pioneers.
- Establishment of a number of different *trophic levels*.
- Eventually, the whole assembly reaches 'maturity' (a *climax state*) where only maintenance processes happen.
- Some parts of the system keep others from reaching individual maturity.
- Agriculture and forest management mimicks this pattern: Coppicing artificially keeps a woodland in a state of vigorous growth.

The 'Energy' Rule III

Energy flows in an American oak forest (g/yr of dry organic matter)

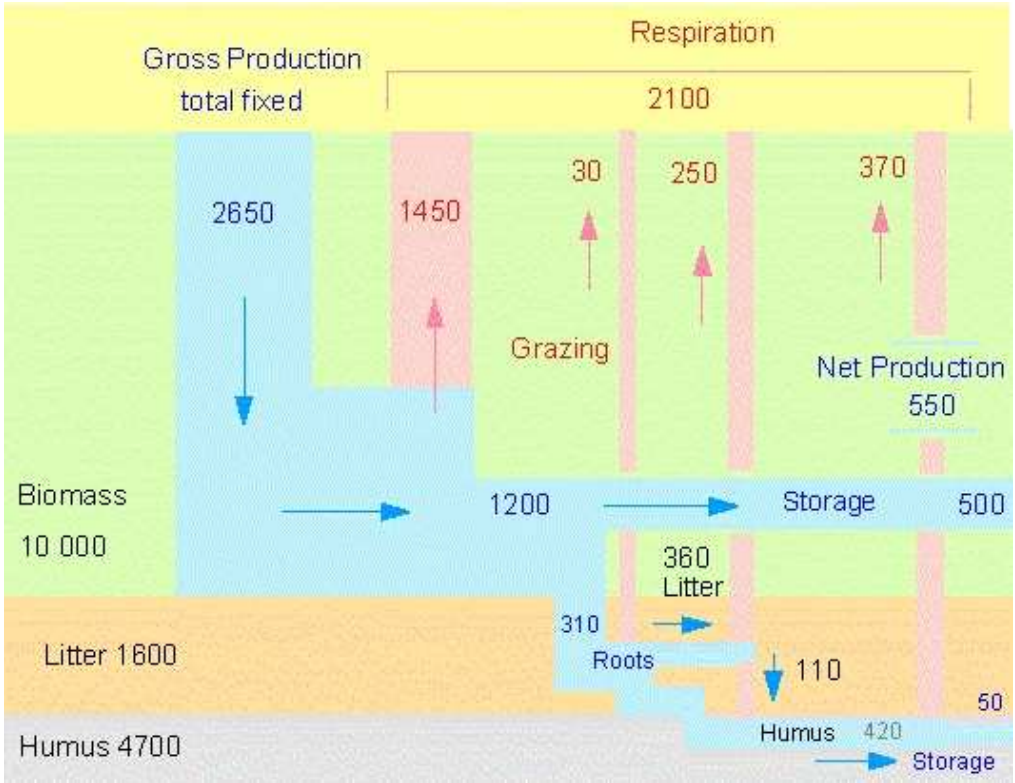


Image source: `http://www.biologie.uni-hamburg.de/b-online/e54/54.htm`

The 'Energy' Rule IV

Typical productivities ($g/m^2/yr$ dry OM) of various ecosystems

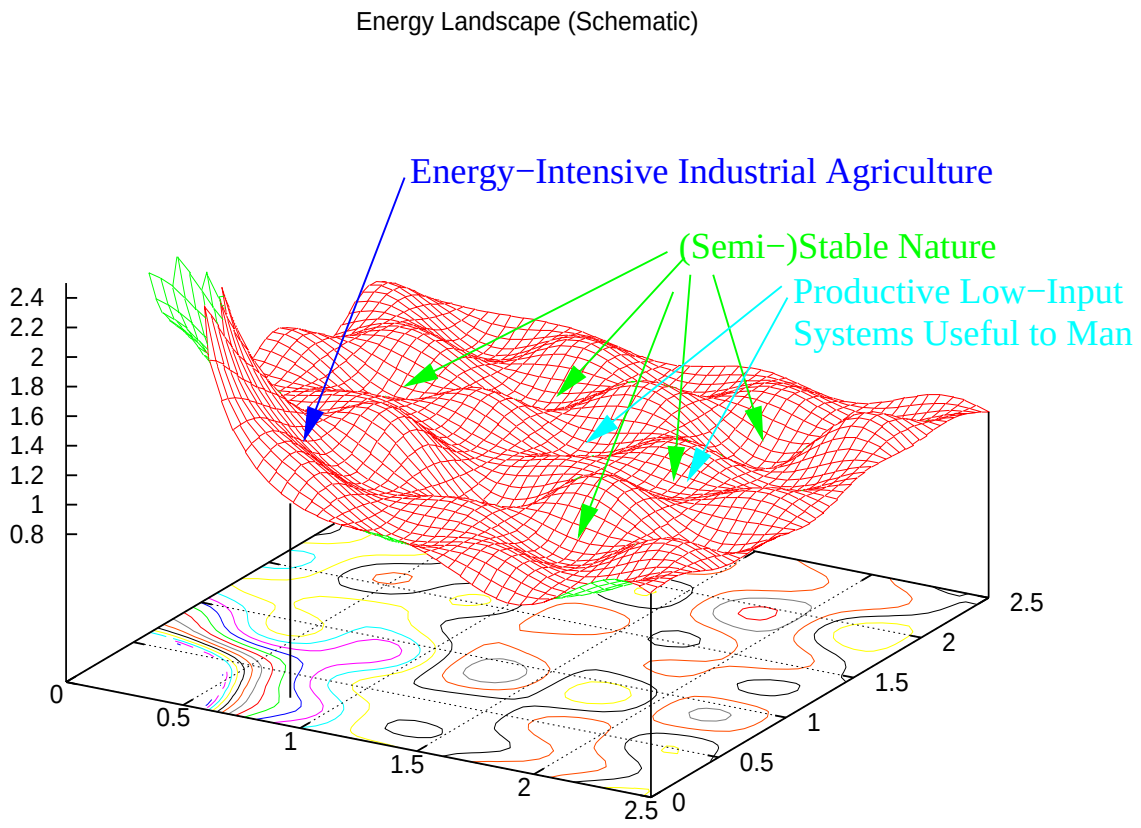
Type	Average	Range
Trop. rainforest	2 200	1 000-3 500
Reefs	2 500	500-4 000
Swamp, marsh	2 000	800-3 500
Estuaries	1 500	200-3 500
Temperate forest	1 200	600-2 500
Agriculture	650	100-3 500

Source: P. Whitefield, *The Earth Care Manual*, p. 26

Note: $100\,\mathrm{g/m^2} = 1\,\mathrm{ton/ha}$

Excursion: Energy and Agriculture

Present-day agriculture expends a lot of energy in stabilising a biological state far away from the natural equilibrium (in our climate: woodland):



Energy Efficiency and Agriculture

Aikido-style agriculture (minimal modification of nature towards a useful self-stabilizing small-scale state) more energy-efficient than Karate-style agriculture (destroying & replacing nature on large scales)

Most energy efficient high yielding method of food production: Gardening!

On Energy and Material Flows

Civilisation from the perspective of Physics:
What are the most prominent civilisation-induced energy and material transport phenomena?

(Source: NASA, Apollo 17)

For example:
What is the biggest (mass-wise) export commodity of the USA?

On Energy and Material Flows

- Total export of economic goods from the U.S.A. in 2005: 0.489 Gton

  (Source: U.S. Dept. of Transportation, Federal Highway Administration)

On Energy and Material Flows

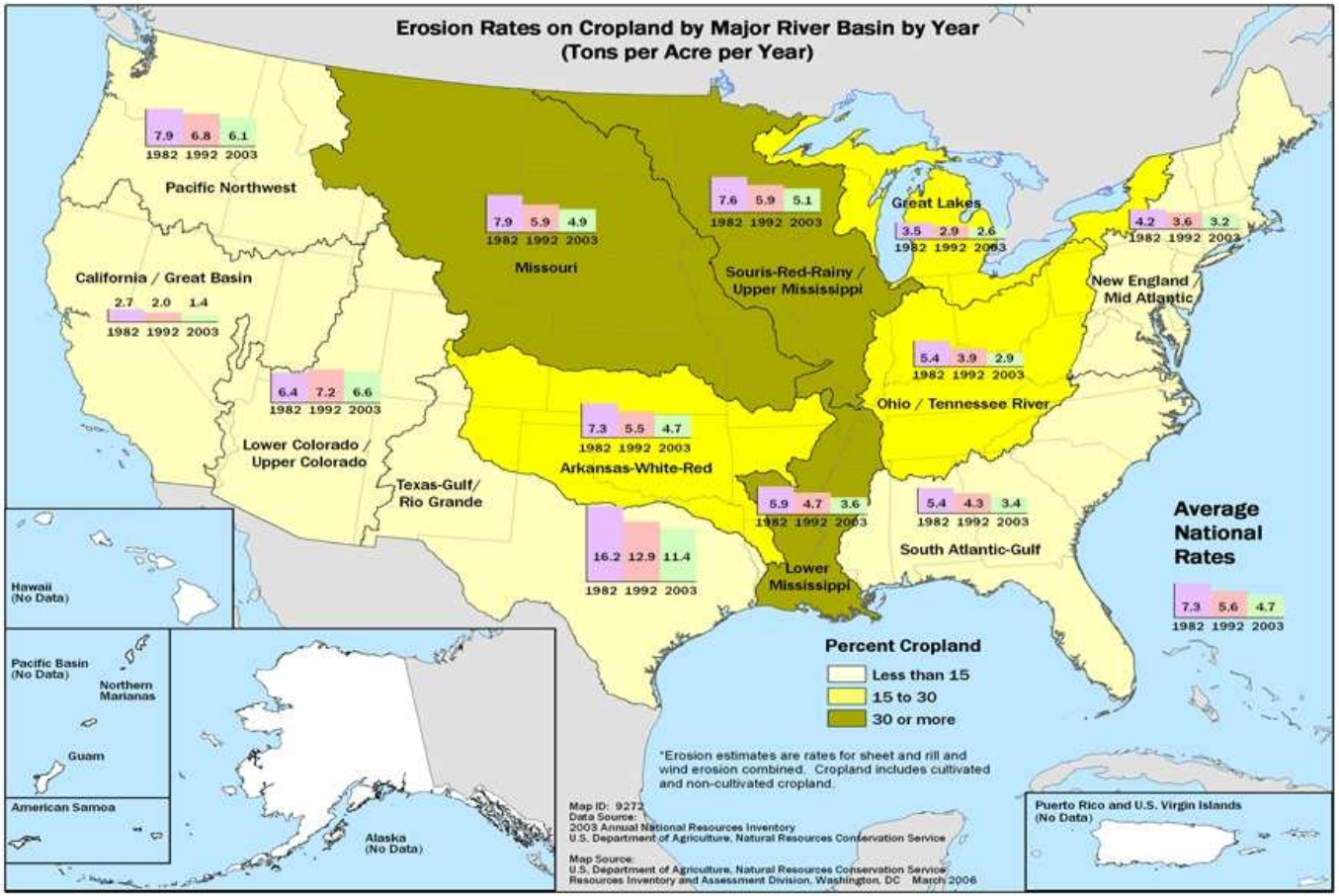
- Total export of economic goods from the U.S.A. in 2005: 0.489 Gton

  (Source: U.S. Dept. of Transportation, Federal Highway Administration)

- Total annual export of *fertile topsoil* at present: 4.0 Gton

  (Source: Brady & Weil's soil science textbook, '*The Nature and Properties of Soils*)

Homo Sapiens: a self-limiting soil disease?



(Source: `http://www.nrcs.usda.gov`)

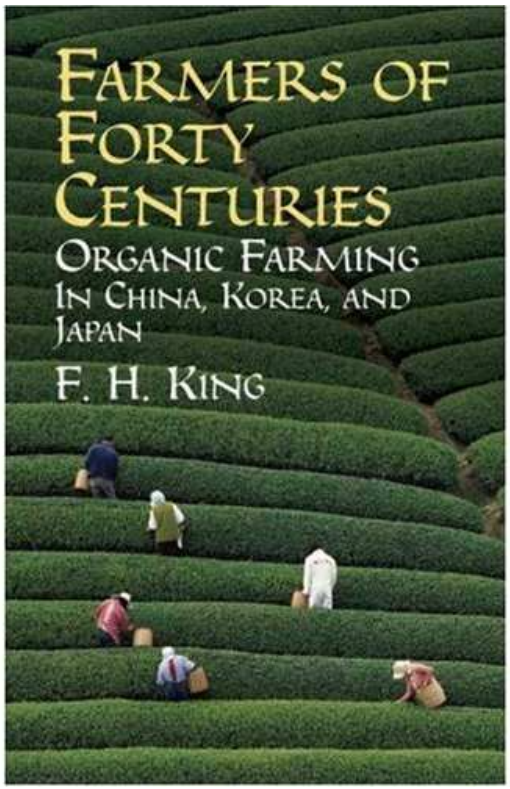
Erosion in the U.K.

There goes our soil

River Avon, near Bath, 02.12.2007

Agriculture without Erosion

Not necessarily so! Asian cultures managed to keep their soils productive over long periods of time using small-scale gardening techniques.



(Source: `http://www.amazon.fr`)

Permaculture Design

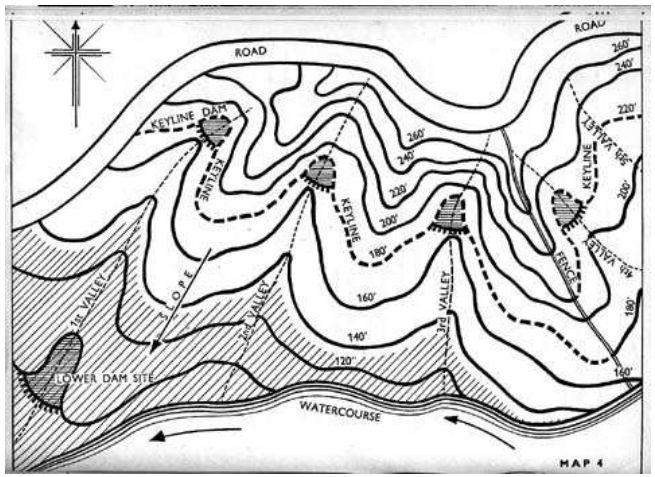
Permaculture is an alternative strategy towards land management that applies basic principles from physics and engineering to design low-input highly productive biological systems (= gardens).

Key Ideas:

- Energy and Material Flow mapping; design with and for the erratic flows of energy in nature (rain, wind, sunlight, ...).
- Entropy-oriented design: Early interception of energy flows, putting as many productive uses beween source and drain as possible.
- Waste avoidance: one system's output is another system's input.
- Using the natural behaviour of biological systems to one's advantage.
- Emphasis on low-maintenance plant species (such as hardy perennials).

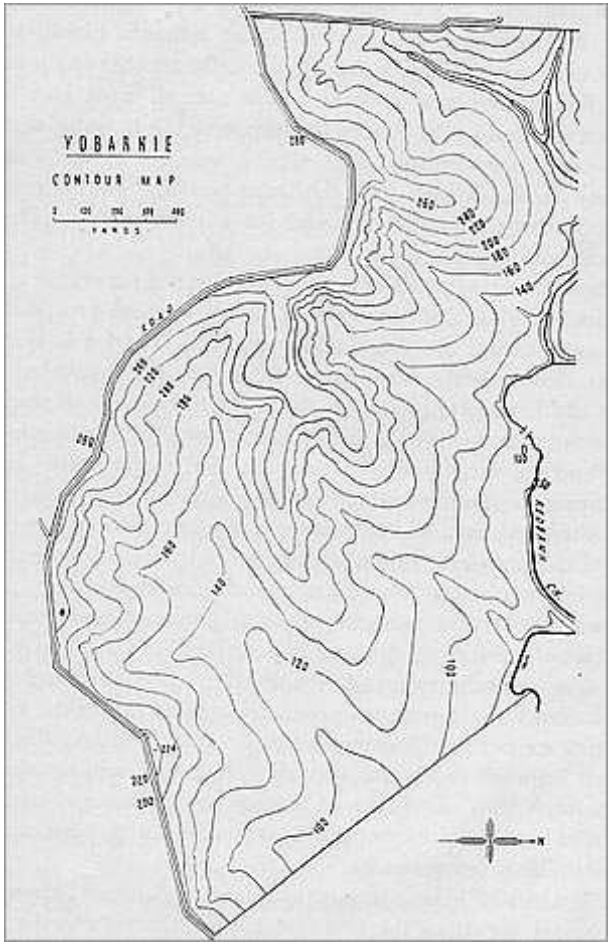
Permaculture Examples

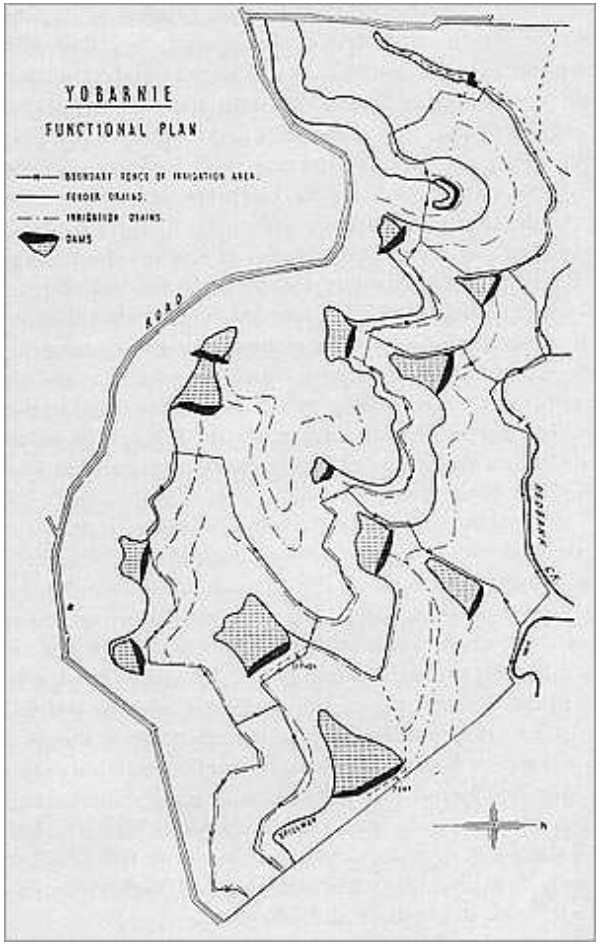
A typical permaculture approach: Catching water as high as possible in a landscape & routing it through a sequence of ponds for aquaculture & irrigation:



Sources: P.A. Yeomans, 'The Keyline Plan' free e-book; `http://www.krameterhof.at`

More Examples





Source: `http://www.yeomansplow.com.au`

Conclusion

There is a number of interesting ideas (and also some rather weird ones) at the interface of engineering and biology that are based on the concept of working with (rather than forcefully imposing our will on) nature.