# The saprotrofic food chain in terrestrial ecosystems : Soil Biota

## What controls the community / food web structure?

Top-down or bottom-up?

(predation or availability of food resources)

- Litter enrichment experiments (food, habitat structure, moisture)

- Predator exclosure experiments

- Mesocosm experiments, e.g. enriching the soil by food sources as glucose to stimulate microbial growth (respiration)

What exactly is the trophic position of a given organism?

- Food preference experiments (choice)
- Analysis of gut content
- Direct observation
- Labelling of potential food with $^{14}C$ (radioactive isotope)

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## Using stable isotopes (C, N) to estimate trophic position

- $^{15}N$ / $^{14}N$ ratio ($\delta\ ^{15}N$)

- Enrichment in $^{15}N$ per trophic level in organisms (on average by 3.4 ‰)

- Range of $^{15}N$ / $^{14}N$ ratios in given community indicates number of trophic levels

- $^{15}N$ / $^{14}N$ increases with soil depth (thus species collonizing deeper soil layers might contain higher $^{15}N$ concentrations despite belonging to lower trophic level)

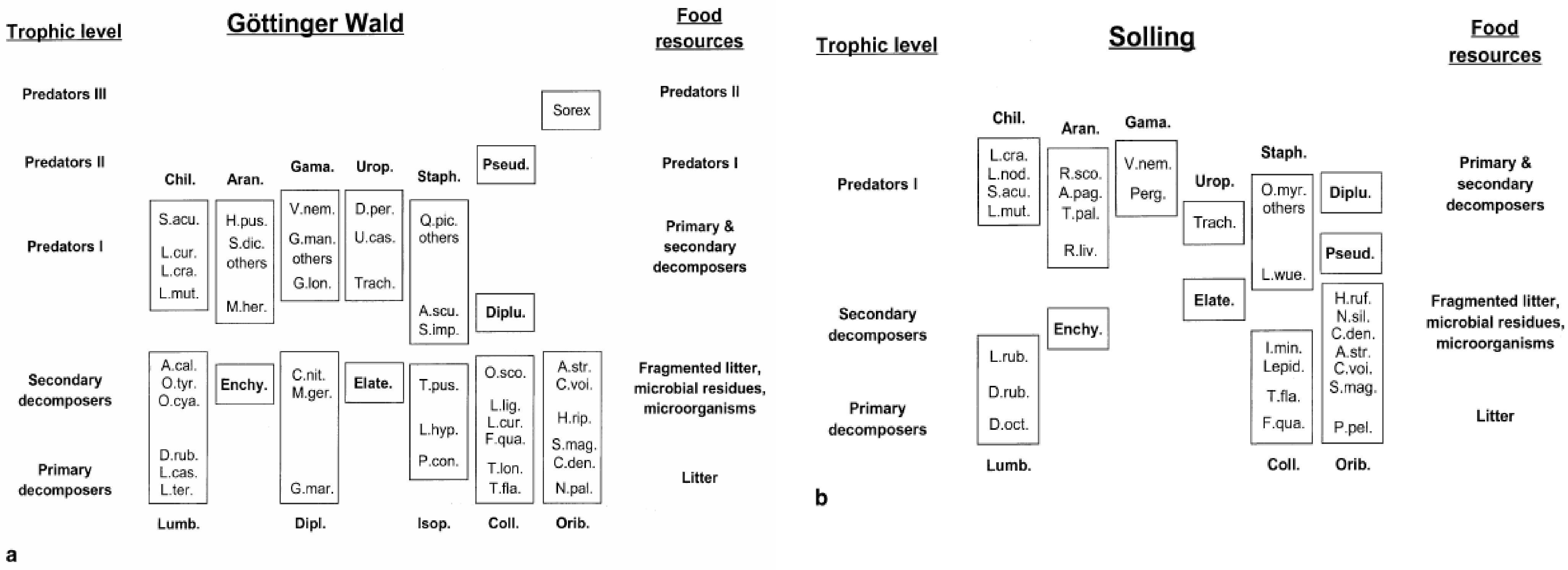
- $^{13}C$ / $^{12}C$ ratio ($\delta\ ^{13}C$)

- Different ratio in C3 (e.g. wheat, rye, rice) and C4 plants (e.g. maize)

- Measurement of incorporation of organic matter from defined food source (e.g. C4 plant litter added to a system based on C3 plant production)

# The saprotrofic food chain in terrestrial ecosystems : Soil Biota

## Using stable isotopes to estimate trophic position




Trophic position and food resources of the soil animal community in two beech forests (Göttinger Wald – on limestone, mull humus, Solling – on acidic sandstone, raw humus)

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

The effect of resource quality on decomposition rate

- Different tissue types have characteristically different decomposition rates

- This applies to plant organs as well as to secondary resources as
  - microbial tissues
  - faeces and corpses of animals (phyto-, zoo-, saprophages)

**Table 4.1.** Turnover of main types of primary resource in forests of differing climates. Wood includes branches (>2 cm diameter) and twigs (<2 cm diameter) but not main stems. Data from Satchell (unpublished) for Meathop Wood, U.K. and Healey & Swift (unpublished) for Barro Colorado Island, Panama.

| | | Temperate Deciduous Forest | | | Tropical Rain Forest | | |
|---|---|---|---|---|---|---|---|
| | | Leaf | Wood | Reproductive | Leaf | Wood | Reproductive |
| Fall | $kg\ ha^{-1}\ yr^{-1}$ | 3240 | 1580 | 600 | 7040 | 3020 | 3280 |
| Standing crops | $kg\ ha^{-1}$ | 2010 | 4810 | 270 | 2760 | 8090 | 340 |
| $k$ | $yr^{-1}$ | 1·61 | 0·33 | 2·22 | 2·55 | 0·37 | 9·65 |

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

- For the same type of tissue there are species-specific differences in the rate of decomposition. A tenfold difference between lowest and highest rates was found in field experiments .

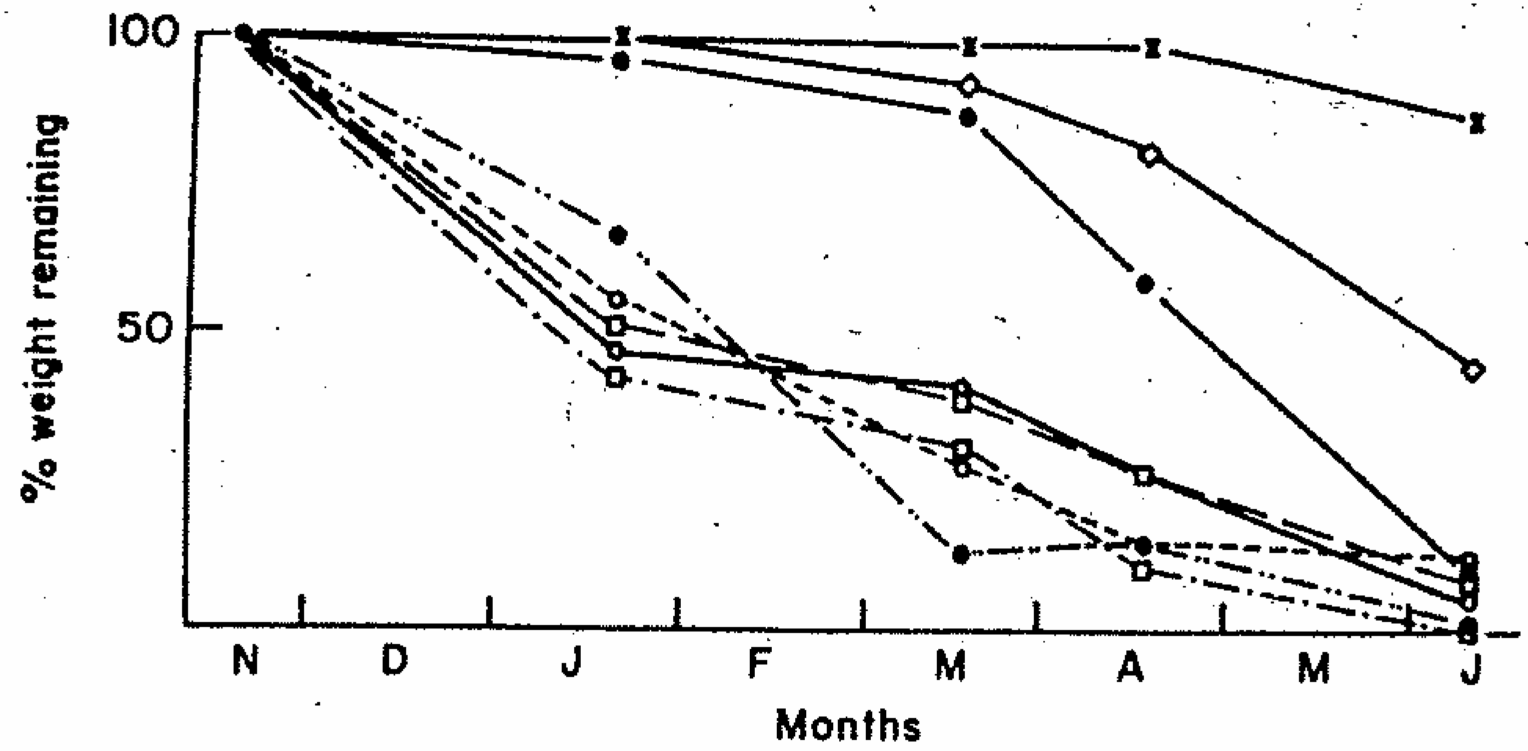



FIG. 4.1. Variation in decomposition of deciduous tree leaf litters in a woodland site on calcareous soil in Belgium. The species are □——□ *Carpinus betulus*, ○——○ *Acer pseudoplatanus*, ●——● *Acer campestre*, ●—·—● *Prunus avium*, ○------○ *Fraxinus excelsior*, □—·—□ *Tilia platyphyllos*, ◇——◇ *Quercus robur*, *——* *Fagus sylvatica* (from Mommaerts-Billiet 1971).

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

- In a laboratory experiment a threefold range in decomposition was found with mosses at the low and deciduous tree litter at the high end of the range.

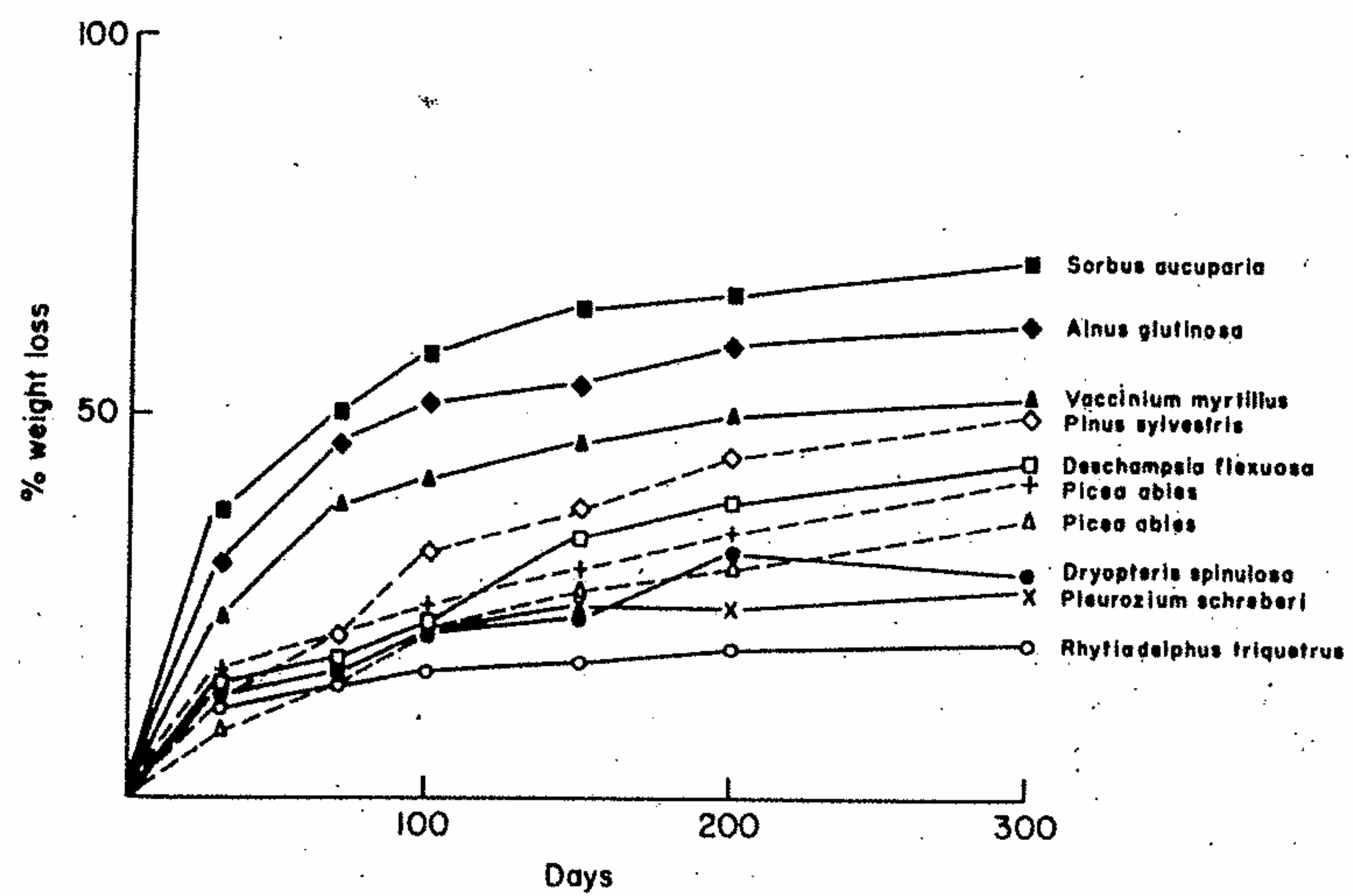



FIG. 4.2. Decomposition of litter of various deciduous and coniferous tree leaves, grasses, dwarf shrubs and cryptogams under laboratory conditions (from Mikola 1955).

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

Decomposition measured as weight loss includes losses due to

- catabolism,
- leaching,
- removal or export following comminution.

When assessed saparately resource-specif rates are still apparent (see results of litter bag experiment below) .

**Table 4.2.** Differences between resources in rate of catabolism and total weight loss. Respiration rate at 10°C and field weight loss after one year for four types of litter on blanket bog (from Heal, Latter & Howson 1978).

| Litter type | Respiration $\mu l\ O_2\ g^{-1}\ hr^{-1}$ | % loss in weight |
|---|---|---|
| *Rubus chamaemorus* leaves | 66 ± 4·3 | 38 ± 1·6 |
| *Eriophorum vaginatum* leaves | 50 ± 4·2 | 26 ± 2·1 |
| *Calluna vulgaris* shoots | 33 ± 4.0 | 15 ± 1·4 |
| *Calluna vulgaris* stems | 11 ± 2·2 | 8 ± 0·6 |

## The saprotrofic food chain in terrestrial ecosystems: Decomposition

- Differences in patterns of loss due to leaching probably reflect structural differences in the substrates (below: leaves). For instance grinding of spruce litter increased the leaching loss in the first day by ca 10 times (simulation of comminution by soil animals).

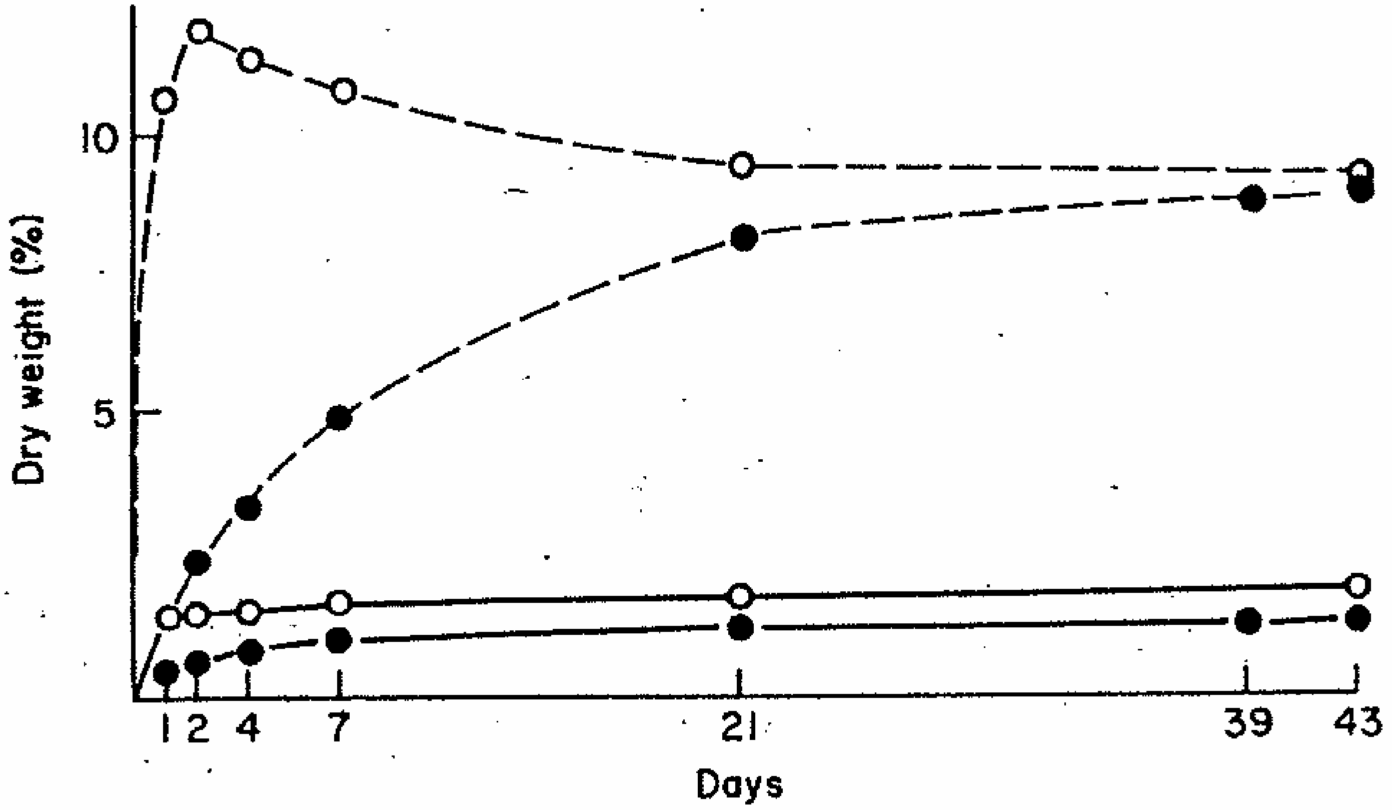



FIG. 4.3. Losses of water soluble organic (---) and inorganic (——) material from *Betula* (○) and *Picea* (●) leaf litter during leaching under anaerobic conditions at 25°C. Results are the dry weight of leachate expressed as a percentage of litter dry weight, each point being a mean of three samples (from Nykvist 1961a).

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

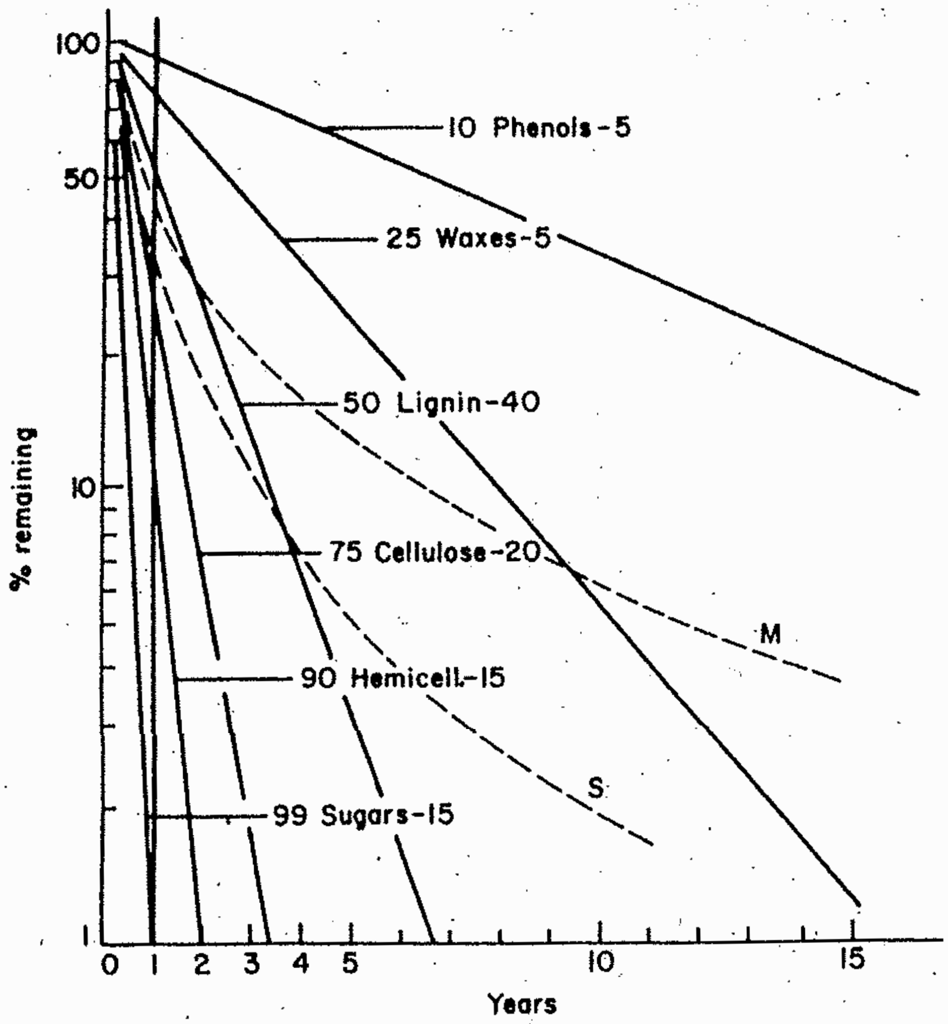



FIG. 4.4. The decomposition curves of the various groups of constituents, if their decomposition could be represented by a logarithmic function (the straight lines from the point 100%). The number in front of the name of the constituent indicates the loss after one year. The number after the constituent represents its percentage in weight of the original litter (these values are rough averages and they do not represent a specific analysis). The line *S* shows the summation curve obtained by annual summation of the residual values of the separate components. The line *M* gives an approximation, based on some analyses, of the probable course of the decomposition of similar resources in the mor-type at Hackfort (from Minderman 1968).

- In a natural complex resource, the total weight loss reflects the summation of the decay curves of the individual substrate fractions (theoretical curve S in the chart).

- The interaction between the components (and possibly the production of new ones) result in greater resistance to decomposition than predicted by considering the components individually (as indicated by curve M in the chart).

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

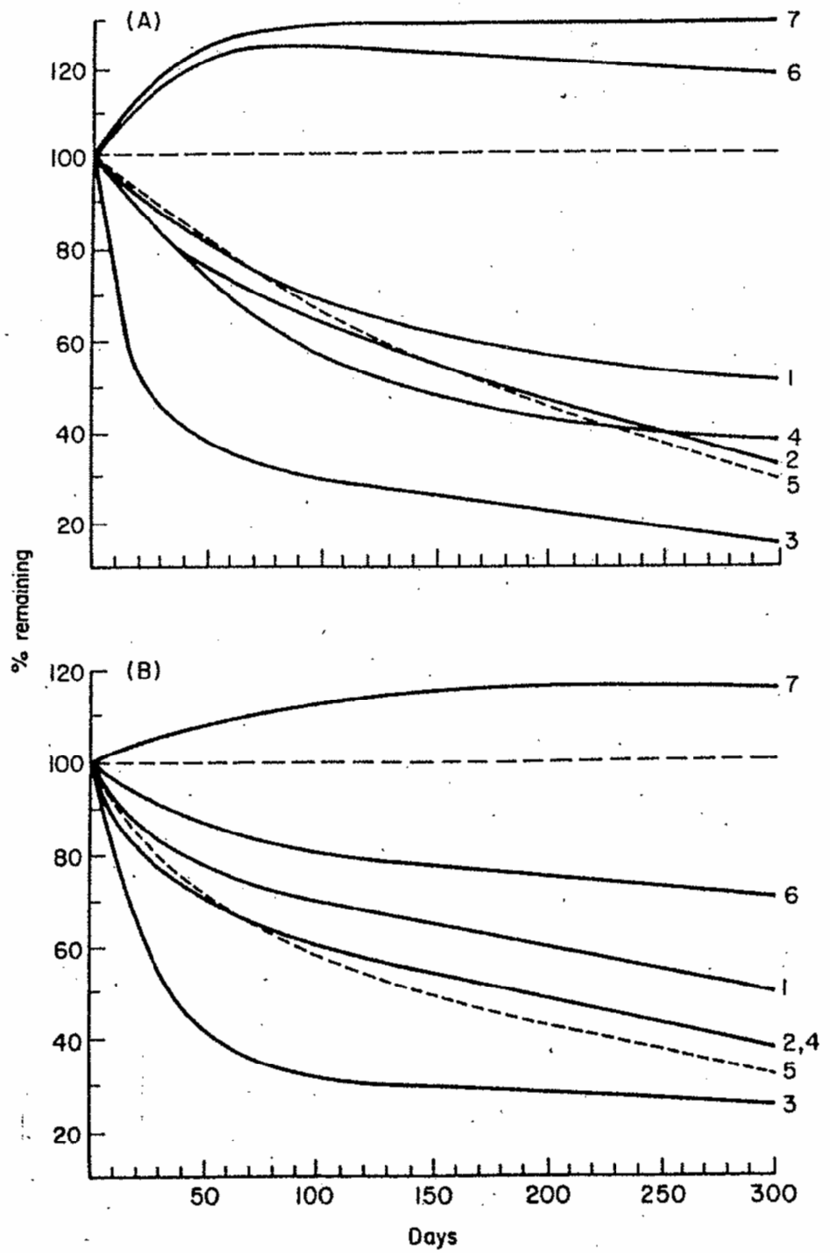



**Fig. 4.5.** Decomposition of the component substrates of leaf litters of (A) *Pinus* and (B) *Betula* under laboratory conditions (Mikola 1955). (1) Total weight; (2) Ether and alcohol soluble; (3) Water soluble; (4) Hemicelluloses; (5) Cellulose; (6) Lignin; (7) Crude protein.

- The weight loss of the total litter and most of its components approximates to a negative exponential function.

- Increase in crude protein and lignin: Growth of micro-organisms, N-fixation, in case of lignin possibly alteration of extraction efficiency due to changes in structure of decomposing substance or due to synthesis of lignin-like compounds by micro-organisms (extracted in lignin-fraction).

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

**Carbon and energy sources – requirements of decomposers**

- Largest quantitative demand: energy released from organic substances and carbon for tissue synthesis.

- Plant tissues – high content of polysaccharides
  vs Animal tissues – high protein and lipid contents

- Microorganisms: composition of tissues adapt to high degree to composition of food source!

- High demand for N: can lead to N-immobilization in microflora when food-source has high C/N ratio.

- Nevertheless, new research confirm that for instance earthworms are limited by C content of food source.

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

**Table 4.6.** Major organic components (carbon and energy substrates) of decomposer resources.

| | Deciduous leaf —young *Quercus* sp. (1) | Deciduous leaf —old *Quercus* sp. (1) | Conifer needle —old *Pinus* sp. (1) | Grass leaf *Deschampsia flexuosa* (2) | Grass stem *Zea mais* (1) | Deciduous wood Range (3) |
|---|---|---|---|---|---|---|
| Lipid, ether soluble | 8 | 4 | 24 | 2 | 2 | 2–6 |
| Storage/metabolic carbohydrate, water soluble (cold and hot) | 22 | 15 | 7 | 13 | 15 | 1–2 |
| Cell wall polysaccharide, hemicellulose (alkali soluble) | 13 | 16 | 19 | 24 | 18 | 19–24 |
| Cellulose (strong acid) | 16 | 18 | 16 | 33 | 30 | 45–48 |
| Lignin, residue | 21 | 30 | 23 | 14 | 11 | 17–26 |
| Protein, N × 6·25 | 9 | 3 | 2 | 2 | 1 | — |
| Ash, incineration | 6 | 5 | 2 | — | 8 | 0·3–1·1 |

| | Conifer wood Range (3) | Faeces invertebrate *Glomeris marginata* (4) | Faeces vertebrate Horse (1) | Bacteria Range (5) | Fungi Range (7) | Earthworm *Lumbricus terrestris* (7) | Arthropods Various | Vertebrate carcass Steer (11) |
|---|---|---|---|---|---|---|---|---|
| Lipid, ether soluble | 3–10 | — | 2 | 10–35 | 1–42 | 2–17 | 13–26(8) (glycogen) | 50 |
| Storage/metabolic carbohydrate, water soluble (cold and hot) | 2–8 | 2 | 5 | 5–30 | 8–60 (chitin) | 11–17 | 14–31(8) (chitin)(9) | ? |
| Cell wall polysaccharide, hemicellulose (alkali soluble) | 13–17 | | 24 | 4–32 | 2–15 | — | 5–9(8) | 0 |
| Cellulose (strong acid) | 48–55 | 38 | 28 | | | | | |
| Lignin, residue | 23–30 | ? | 14 | 0 | 0 | 0 | 0 | 0 |
| Protein, N × 6·25 | — | 11 | 7 | 50–60 | 14–52 | 54–72 | 38–50(10) | 39 |
| Ash, incineration | 0·2–0·5 | 8 | 9 | 5–15 | 5–12 | 9–23 | ? | 11 |

Sources: (1) Waksman (1952); (2) Mikola (1955); (3) Browning (1963); (4) Nicholson *et al.* (1966); (5) Luria (1960)—from laboratory cultures; (6) Compiled from Cochrane (1958) and Hawker (1950)—from laboratory cultures; (7) Laverack (1963); (8) Spector (1956) *Gasterophilus intestinalis* larva; (9) Jeuniaux (1971) suggests chitin contents in adult arthropods may exceed 50%; (10) Calculated from range of N contents in final four rows of Table 4.10; (11) Giese (1962).

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

In absolute numbers the weight loss of polysacharides is high, total decomposition will be determined by cell wall saccharides decomposition.

**Table 4.7.** The fraction of individual organic components lost during decomposition, and the contribution of each component to the total weight loss (from Swift 1976 after Tenney & Waksman 1929).

| | Corn stalk[1] | | | Oak leaf[2] | | |
|---|---|---|---|---|---|---|
| | Fraction lost | Actual weight lost (g) | Fraction of total loss | Fraction lost | Actual weight lost (g) | Fraction of total loss |
| Dry matter | 0·36 | 74·0 | 1·00 | 0·22 | 50·0 | 1·00 |
| Ether soluble | 0·30 | 1·1 | 0·02 | 0·26 | 2·1 | 0·04 |
| Cold water soluble | 0·80 | 17·1 | 0·23 | 0·81 | 15·0 | 0·30 |
| Hot water soluble | 0·55 | 4·0 | 0·05 | 0·46 | 5·8 | 0·12 |
| Cellulose | 0·44 | 26·2 | 0·35 | 0·34 | 10·4 | 0·21 |
| Hemicellulose | 0·41 | 14·7 | 0·20 | 0·27 | 7·9 | 0·16 |
| Lignin | 0·00 | 0·0 | 0·00 | 0·00 | 0·0 | 0·00 |

[1] Loss after 27 days; original weight 203 g.
[2] Loss after 66 days; original weight 223 g.

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

- The presence of lignin retards the decomposition of cellulose.

**Table 4.8.** The effect of lignin content on the ability of bacteria to decompose cellulose associated with it. Decomposition over a 21-day period of cellulose complexed with differing amounts of lignin prepared by extraction of lignin from jute by monoethanolamine treatment for varying times; the test organism was *Pseudomonas ephemerocyanea*. (Fuller & Norman 1943).

| Cellulose content (%) | Lignin content (%) | % of cellulose decomposed |
|---|---|---|
| 99·2 | 0·0 | 100·0 |
| 95·5 | 3·3 | 95·6 |
| 89·2 | 5·3 | 83·1 |
| 82·7 | 11·9 | 37·9 |
| 75·6 | 12·6 | 17·7 |

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

**Table 4.10.** Nutrient element composition of primary resources and decomposers (% dry weight). All leaf material after litter fall; root and wood from living plants. Sources: (1) Daubenmire & Prusso (1963); (2) Heal, Latter & Howson (1978); (3) Allen *et al.* (1974); (4) Frankland *et al.* (1978); (5) Cromack *et al.* (1975); (6) Swift (1977b); (7) Stark (1973); (8) Luria (1960); (9) Ausmus & Witkamp (1973) quoted by (10) McBrayer *et al.* (1974).

| Primary resource | Species | Source | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|
| Deciduous leaf | *Populus tremuloides* | (1) | 0·56 | 0·15 | 0·60 | 2·35 | |
| | *Betula papyrifera* | (1) | 0·58 | 0·32 | 0·78 | 1·71 | |
| Conifer leaf | *Abies casiocarpa* | (1) | 0·69 | 0·09 | 0·30 | 1·18 | |
| | *Pinus contorta* | (1) | 0·51 | 0.04 | 0·15 | 0·55 | |
| Sedge leaf | *Eriophorum vaginatum* | (2) | 0·97 | 0.04 | 0·09 | 0·20 | 0·08 |
| | *Nardus stricta* | (2) | 0·53 | 0·03 | 0·10 | 0·08 | 0·08 |
| Herb leaf | *Rubus chamaemorus* | (2) | 1·31 | 0·07 | 0·09 | 0·85 | 0·53 |
| Shrub shoot | *Calluna vulgaris* | (2) | 1·38 | 0·07 | 0·09 | 0·34 | 0·06 |
| Tree root large | *Quercus petraea* | (3) | 0·5 | 0·06 | 0·2 | 0·4 | 0·08 |
| Tree root small | *Q. petraea* | (3) | 0·9 | 0·10 | 0·4 | 0·4 | 0·11 |
| Sedge root | *E. vaginatum* | (2) | 0·50 | 0·06 | 0·21 | 0·11 | 0·08 |
| Outer bark | *Q. petraea* | (3) | 0·5 | 0.17 | 0·08 | 0·5 | 0·03 |
| Cambium | *Q. petraea* | (3) | 0·9 | 0·08 | 0·4 | 1·3 | 0·15 |
| Sapwood | *Q. petraea* | (3) | 0·16 | 0·02 | 0·14 | 0·05 | 0·01 |
| Inner heartwood | *Q. petraea* | (3) | 0·10 | 0·01 | 0·06 | 0·06 | 0·01 |
| Decomposers | | | | | | | |
| Fungus mycelium (on leaf) | *Mycena galopus* | (4) | 3·60 | 0·24 | 0·57 | — | — |
| Fungus fruit bodies (on leaf) | Mixed | (5) | — | 0·68 | 2·90 | 0·07 | 0·07 |
| Fungi (on leaf) | Mixed | (9) | 2·80 | 0·24 | 0·12 | 3·30 | 0·19 |
| Fungus mycelium (on wood) | *Stereum hirsutum* | (6) | 1·34 | 0·09 | 0·41 | 0·79 | 0·10 |
| Fungus fruit bodies (on wood) | | (7) | 1·87 | 0·33 | 0·88 | 0·07 | 0·12 |
| Bacteria—culture | Range | (8) | 8–15 | 2–6 | 1–2 | 1 | 1 |
| Bacteria—leaves | Mixed | (9) | 4·0 | 0·91 | 1·50 | 0·95 | 0·15 |
| Oligochaeta | — | (3) | 10·5 | 1·1 | 0·5 | 0·3 | 0·2 |
| Diplopoda | — | (3) | 5·8 | 1·9 | 0·5 | 14·0 | 0·2 |
| Insecta | — | (3) | 8·5 | 6·9 | 0·7 | 0·3 | 0·2 |
| Detritivores | | (10) | 7·74 | 0·80 | 0·13 | 10·30 | 0·27 |
| Fungivores | | (10) | 7·74 | 1·39 | 0·40 | 3·95 | 0·46 |

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

**Table 4.13.** Egg production and moulting frequency of *Folsomia candida* on a diet of *Coriolus versicolor* grown at varying N levels (Booth & Anderson 1979).

| | No Food | Levels of nitrogen | | | |
|---|---|---|---|---|---|
| | | 2 ppm | 20 ppm | 200 ppm | 2000 ppm |
| Egg laying rate eggs $ind^{-1}$ $wk^{-1}$ | 1·6 | 9·9 | 14·3 | 28·4 | 6·5 |
| Moulting rate exuviae $ind^{-1}$ $wk^{-1}$ | 0·41 | 0·61 | 0·69 | 0·83 | 0·79 |

**Table 4.14.** Micronutrient element composition of decomposers compared with the resources on which they are growing ($\mu g\ g^{-1}$). (1) Cromack *et al.* (1975); (2) McBrayer *et al.* (1974); (3) Stark (1973).

| | Na | Cu | Zn | Mn | Fe |
|---|---|---|---|---|---|
| Leaf litter (1) | 3·6 | 17·3 | 67 | 858 | 17·3 |
| Basidiocarps (1) | 824 | 44 | 108 | 157 | 44 |
| Insecta (2) | 0·3 | 50 | 150 | 30 | 200 |
| Isopoda (2) | 0·3 | 50 | 130 | 40 | — |
| Pine needles (3) | 265 | 4·5 | 19·3 | 88 | 38 |
| Rhizomorphs (3) | 219–2400 | 244–34·2 | 39·2–213·0 | 88–193 | 669–6815 |

# The saprotrofic food chain in terrestrial ecosystems: Decomposition

**Table 4.15.** Palatability of tree litters to earthworms in relation to their tannin content (Satchell & Lowe 1967).

| Litter | Unweathered: Leaf discs eaten as % of controls | Unweathered: Tannins % dry wt Condensed | Unweathered: Tannins % dry wt Hydrolysable | Unweathered: Total | Weathered: Leaf discs eaten as % of controls | Weathered: Tannins % dry wt Condensed | Weathered: Tannins % dry wt Hydrolysable | Weathered: Total |
|---|---|---|---|---|---|---|---|---|
| Elm | 362 | 0 | 0 | 0 | 358 | 0 | 0 | 0 |
| Alder | 324 | 0 | 0 | 0 | 336 | 0 | 0 | 0 |
| Sycamore | 298 | 0 | 0 | 0 | 386 | 0 | 0 | 0 |
| Birch | 281 | 0·22 | 0·11 | 0·33 | 342 | 0 | 0 | 0 |
| Spindle | 275 | 0 | 0·10 | 0·10 | 338 | 0 | 0 | 0 |
| Ash | 260 | 0 | 1·22 | 1·22 | 279 | 0 | 0 | 0 |
| Lime | 247 | 0·40 | 0·05 | 0·45 | 331 | 0 | 0 | 0 |
| Hazel | 169 | 0·20 | 0·32 | 0·52 | 182 | 0 | 0 | 0 |
| Gean | 143 | 0·63 | 0 | 0·63 | 234 | 0·02 | 0 | 0·02 |
| Beech | 84 | 1·96 | 0·40 | 2·36 | 184 | 0·10 | 0 | 0·10 |
| Pine | 44 | 1·81 | 1·38 | 3·19 | 74 | 0 | 0 | 0 |
| Larch | 38 | 1·27 | 3·95 | 5·22 | 84 | 0 | 0 | 0 |
| Oak | 21 | 0·88 | 0·45 | 1·33 | 173 | 0·05 | 0 | 0·05 |