AQUATIC ECOLOGY SUBJECT INDEX

(by Diana L. Walstad)

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***Note: Authors in bold lettering represent papers particularly dedicated to the subject. And a 'W' or 'WW' represents Wetzel's textbook edition and page number in the book. An 'N' represents Nester's textbook and page number (See 'Abbreviations')***

Al (Aluminum)-

alum is an aluminum potassium phosphate cpd used in wastewater tx (N787) flocculating and acidifying reagent (Boyd 95; Fort 95; **Hall 91**); will precipitate DOC (Thurman 85);

chelation with humus (Russel 73; Urban 90) and citrate (Lacroix 93) reduces its toxicity (Wild 88; Lacroix 93)

hydroxides of Al bind micronutrients (Donahue 83; Ponnamperuma 81); reduce Al toxicity to animals (Nieboer 80) and plants (Wild 88); and bind Cu in water reducing Cu toxicity (Pagenkopf 86)

levels in lake waters (Bowen 97; Fraser 82; Lacroix 93; Urban 90); sediments (Bowen 79); and terrestrial plants (Davies 97)

major component of soils (Bowen 79; Kawaguchi 77; Kyuma 89; Wild 88) and plant tissue (Lucas 93); enters the soil solution in acidic tropical soils (Davies 97)

release into acidified lakes- Fraser 82; Lacroix 93; Urban 90

resistance to Al toxicity by calcifuge plants (Foy 78; Rorison 60a, 60b, 84; Russel 73; Vickery 84; Wild 88) and those that release malate from their root tips (Huang 96); tolerance common in tropical terrestrial plants (Davies 97; Foy 78)

soil Al responsible for exchange acidity and base unsaturation (Boyd 95); replaces the base cations of tropical soils (Vickery 84)

solubility increases in soils below ~pH 5 (Ag. Ext.; Davies 97; Ponnamperuma 81; Ross 89; Russel 73; Wild 88) and in lakes with pH below 5 (Lacroix 93; Urban 90); insolubility decreases its toxicity to animals (Nieboer 80); 1,000 X more soluble at pH 5 than pH 6 (Boyd 95)

stimulation of growth (Foy 78) in a calcifuge plant fed ammonium (**Rorison 85**)

symptoms of toxicity in plants (Foy 78; Grise 86; Rorison 85) and on the gills of fish (Gundersen 94; Lacroix 93)

toxicity to plants (Bowen 79: Donahue 83; Glass 89; Grise 86; Foy 78; Rorison 60a,b; Smits 92; W316; Wild 88); bacteria (Tsai 86); animals (Nieboer 80), and fish (Fort 95; Hall 91; Gundersen 94; **Lacroix 93**; Winner 92; **Witters 90**); a common problem in the tropics (Davies 97); nitrates enhance uptake and toxicity (**Rorison 85**)

uptake by aquatic plants (Grise 86; Titus 90)

Algae-

air exposure of marine intertidal algae can increase PS (**Johnson 74;** Reiskind 89)

algal blooms: Red Tides (**Anderson 94**); possible bacterial effects on (Azam 98); control by viruses (N326) algicides- **Aliotta 90**; Frank T4(6); **Greca 90, 92**; Keating 77; Smart 85

allelopathy in (Dor 78; Gopal 93; Hay 88; **Juttner 81**; **Keating 77, 78, 87**; Proctor 59; **Rice 84**; Rizvi 92; van Vierssen 85; W367; Wolfe 79); phytoplankton more vulnerable to allelochemicals than epiphytic algae (Hilt 08) *See also* 'Algae: toxins of' *and* 'Allelopathy'

ammonium preferred over nitrates- Guerrero 81; Kuenzler 86; Serra 90) phytoplankton preference and better growth with ammonium (**Trommer 20**

aquarium, typical algal flora- Fitzgerald 69

attachment preferred by 90% of algae (W561); holdfast of marine macroalgae (Cuny 95; Mann 73); holdfast of Chara absorbs P well (Forsberg 90)

bacteria stimulate attachment of algal spores onto their biofilm (Joint 02); bacteria consume algae (Geesey 78); algal extracts stimulate bacterial growth (**Marsollier 04**); bacteria feed on diatom mucus (Azam 98)

balls of algae are *Cladaphora* species- Kasselmann 03

barley straw controls algae (Barrett 99) but not in USA (PC Tom Barr 09)

bicarbonate use common (Bowes 93; Holbrook 88; King 72; Prins 89; Raven 93; W529), unlike plants, 3 algal species had 38X better affinity for bicarb and 1.7X greater affinity for CO2 than 5 bicarbonate-using species of aquatic plants (**Allen 81**)

binding to sand grains- **Meadows 66**

bioassay- Brand 83; **Fitzgerald 72**; Goldman 72; Kuenzler 86; **Linton 98**; Martin 91; Sakaguchi 81

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blue-green algae

adaptability of- Carmichael 94; King 72; W343

chelator, synthesis of own- Eichenberger 86; W313; Anderson 82 *See also* "Algae:siderophores…."

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Na requirements- King 72; Wetzel 1972, W193; Wurtzbaugh 88

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nutrient requirments- Bowen 79

Prochlorococcus: ancestor of plant chloroplasts- Ash 02

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tolerance of high temps and low CO2- King 72 toxins of (N276), kill predators (zooplankton, etc)- Carmichael 94; **Gross 98**

C content- W151

Ca uptake as a nutrient (Gerloff 75; Otsuki 74; W188) and in calcification (Reiskind 89)

carboxysome, cell body for storing high concentrations of RUBISCO- Bowes 93

CH storage by marine macroalgae- Mann 73

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chromatic adaptation (**Bennet 73**; Boston 89; Kirk 94; Lee 89; Rich 90; Richardson 83); some algae use green light for PS (Resikind 89); production of protective UV-absorbing pigments (e.g., mycosporine-like amino acids) is widespread in planktonic algae (Kaiser 97)

circadian rhythm of PS in Euglena- Lonergan 90

Co, beneficial element (Wild 88) that stimulates algal PS (Allen72; Goldman 72), but is not required by plants

CO2 uptake (Allen 81; Dodds 91; King 72; Morton 72; Otsuki 74; Sand-Jensen 91a); many marine species have very effective CCM (Bowes 93; Reiskind 89a); Rhodophyta can only use CO2 (Bowes 93; Reiskind 89); CO2 compensation points for 16 algal species (**Birmingham 79**)

communication between bacteria and algae via chemicals produced by bacteria- Joint 02

composition of algae: elemental (Fabregas 86; Tarifeno); DOC, proteins, etc (Marsollier 04); fatty acids (Proctor 59)

control in lab (Barko 81a, 86; Grise 86; Huebert 83; Smart 85; Titus 90); aquarium (Fitzgerald 69); ponds (Burton 78; Barrett 99); and in hydrophonic cultures (Kane 90)

critical concentration of nutrients- Gerloff 75

digestibility, 96% is biodegradable- Marsollier 04

ephiphytic (Moeller 88; Sand-Jensen 91; W571)-- attachment to SAMS and filamentous algae (Fitzgerald 69; Hough 75; Simpson 87; Underwood 91; W567); high productivity of (Adey 91; Borun 87; W555,580+); symbiosis with SAMS (Allen 71; Sand-Jensen 89; W534); P uptake from host SAM (**Moeller 88;** Wetzel 90)

extracellular enzymes secreted by- Kim 93; Gross 96; Wetzel 93

Fe uptake by- **Anderson 82**; **Rich 90**

fishfood, algae as component of- Fabregas 86

gluteraldehyde, toxicity to green alga, invertebrates and fish- **Sano 05**

heterotrophic augmentation- Mann 73

inhibition of SAMS (Balls 89; Borun 87; **Ozimek 91**; Roeloffs 84; **Sand-Jensen 91**; Simpson 86; **Szabo 98**); by ephiphytic algae (**Cuny 85; deVillele 95**; Gopal 93)

light: light saturation of algae PS at low levels (Reiskind 89, 89b; **Richardson 83**; Riemer 84; Thompson 89; W355; Wild 88); low compensation points (Sand-Jensen 91b); algal turfs are 'sun plants' (Adey 87, 91; **Carpenter 85**); inhibition by UV (**Culotta 94; Richardson 83**); can lower the R/FR ratio by absorbing R light and trigger a shade signal to plants (**Mommer 06)**

lignin, none in algae (Fries 74; Grisebach 81; Monties 89); digestibility, 96% is biodegradable- (Marsollier 04)

marine macroalgae, including kelp forests, much more productive than phytoplankton (Boston 89; **Mann 72, 73)**; readily available C allows them to do as well as terrestrials (Lee 89); parasitism of seagrasses (Cuny 95)

marine phytoplankton, species of (Richardson 83); they account for 1/3 of global primary productivity (Bowes 93); rhodopsin photosynthetic pigments are common in marine phytoplankton (N226, 763)

metal toxicity in- Borgmann 83; Eichenberger 86; Nieboer 80; Sposito 86; Winner 91

motility (W396, 562) affected by allelochemicals- Stom 81

N uptake by pond algae- Adey 98

nutrient excretion- Brezonik 72; Mann 73; Sand-Jensen 91; W265,392+,407,503

nutrient uptake (Falkowski 83; Gerloff 75; Kuenzler 86; Moeller 88; Nakajima 81; Prins 89; Tarifeno 82) within seconds (King 72); rate varies with species (Fabregas 86)

nutritional requirements of marine algae have adapted to environment- Brand 83

parasitism and grazing of (Mann 73; Saunders 72; Shapiro 90: Underwood 91; W376+); consumption by Daphnia (**Saunders 72**; **Shapiro 90**) and bacteria (Geesey 78); UV light may stilmulate algae by kil +lling off grazers (Kaiser 97)

periphytic algae use sediment as a nutrient source- **Hansson 91;** W567

pH, lake acidification to pH 5 has no effect on growth- Kelly 84

phytoplankton, low productivity of- Adey 87; Mann 73; W582+

PS and C uptake- Bowes 93; W390

respiration higher than SAMs, because there's more PS machinery to maintain- Sand-Jensen 91b

seasonal succession of species- Keating 77, 78; King 72; W373+

siderophores in blue-green algae as iron chelators (**Wilhelm 94**; Anderson 82); responsible for solubilizing iron in sediments (Ash 02)

size (Anderson 82), surface area and uptake of nutrients (King 72; Kuenzler 86; W150, W401+); cell volume of (Thompson 89)

spores persist for years (Anderson 94; Ash 02); attach preferentially to bacterial biofilms (Joint 02)

temperature optimum varies with species (W376); seaweed growth even at 0° C (Mann 73)

terrestrial soils, algae live on or just below the surface- Vickery 84

translocation of nutrients by marine macroalgae- Mann 73

toxins of-- cyanobacteria (Saito 89; **Carmichael 94**), marine algae (**Hallegraeff 93**; Harvell 99); **'**Red Tide' algae (**Anderson 94**), *Caulerepa* (deVillele 95), dinoflagellates (Barker 97); toxins inhibit gram positive bacteria (Rheinheimer 85);

turf algae, high productivity- **Adey 87**; Carpenter 85 ultrastructure- Pollio 93

UV inhibits bacteria more than algae because of protective pigments and larger size (Kaiser 97)

viruses and bacteria pathogeneic to algae (**Adolph 71**; Fitzgerald 69; Freeman 77; Geesey 78; **Proctor 90; Safferman 63; Suttle 90**; W376); phage keep bacteria and algae in check (N326)

vitamin requirements- W363

wastewater tx- Adey 91; Tarifeno 82

water movement, growth- Adey 87; **Ghosh 94**; Mann 73; Proctor 59

zooxanthellae of corals- **Adey 91**

Algal advantages over SAMS-

can concentrate CO2- Bowes 93

can drive pH up to 11 where SAMs can no longer PS- **Allen 81**; Gopal 93

CO2 diffusion across boundary layer much quicker- Prins 89; Sand-Jensen 91; W528

ecology of- **Sand-Jensen 91**

heterotrophic augmentation- Allen 71; Mann 73; Sand-Jensen 91; W217; 366

light use efficiency (Berry 82) greater for phytoplankton than SAMS (Sand-Jensen 91b); a PS pigment for every wavelength (Reiskind 89)

nutrient uptake faster- Barko 86; Gerloff 75

review- Gopal 93; Sand-Jensen 91

smaller size- Kuenzler 86; W362

tolerance of high pH, high oxygen, and low CO2 (Allen 81; **Simpson 86**) and low light (**Sand-Jensen 91b**)

Allelopathy-

aquatic plants, allelopathy in (**Elakovich 95)**

alga allelochemicals not like those of SAMS (Anderson 94; Carmichael 94; Hallegraeff 93; Hay 88) designed to inhibit zooplankton (Keating 87)

algae v. algae (**Juttner 81**; **Keating 77, 78, 87**; **Rice 84**)-- fatty acid inhibitor (**Proctor 59**) or heat labile agent (Keating 77, 78; **Wolfe 79**); related to water N (Fitzgerald 69) and water P (Forsberg 90); algal inhibition of red tide algae (Moon 85)

algae v. bacteria (Hay 88; Fujimoto 95; Juttner 81; **Nielsen 55**); dialyzable inhibitor (Dor 78)

algae v. fish- Anderson 94; Carmichaeal 94; **Hallegraeff 93; Hay 88**; Lee 89; **Paul 93;** Rheinheimer 85; Saito 89

algae v. plants (Gopal 93); allelochemical inhibition of brackish water SAMs (van Viersen 85), duckweed (**Szabo 98**) and water hyacinth (Sharma 85) algal blooms, succession of species due to allelochemicals- **Keating 77,78;87**; release of toxins by Blue Green Algae- Lee 89

algal production of phenols and tannins limited (Boyd 69; Hay 88; Lodge 91)

alkaloids common in lilies but not in SAMS (Elakovich 91; Hutchinson 75; McClure 69; Newman 91; Su 73); none in marine algae (Hay 88; Paul 93); some in SAMs (**Ostrofsky 86**), but no correlation with herbivory (Lodge 91); toxicity of nicotine and other alkaloids to duckweed (Wink 92); waterlily alkaloid (**Elakovich 96**)

allelochemical concentration of aquatic plants: tannin content is 5 to 6% (**Boyd 68**); phenol content is 7% (Planas 81); release of phenols is 0.003% of content in 10 days (Saito 89)

allelochemicals released by live aquatic plants into water (McClure 70; Pennak 73; Saito 89; van Aller 85; WW571); type of natural phenols in water related to plant category (Buikema 79) and are toxic to algae at 10 mg/l (Kim 93; Planas 81; Serrano 90); effect of phenols on extracellular enzymes (**Wetzel 93**); review and meta-analysis of field studies (**Hilt 08**); inhibit phytoplankton more than epiphytic algae (Hilt 08)

aquarium- Fitzgerald 69

autoinhibition (Barko 88; **Chou 87**; Gopal 93; **McNaughton 68**; Patrick 64; Putnam 86; Rice 84; Szczepanski 77; Whittaker 71)

bacteria, effect of allelochemicals on (Gopal 93; Elakovich 87; Jobidon 92; Leather 86; Planas 81; Putnam 86; Rice 74, 84; Wetzel 93); production of allelochemicals by (**Fujimoto 95**); allelopathy is part of bacterial competition (Leclerc 03)

bioassay using duckweed (Einhellig 85; Elakovich 89; Gopal 93; **Leather 85;** Rowe 82); continuous root exudate trapping system (**Tang 86**); or algae (Greca 92; van Aller 85)

charcoal removal of allelochemicals- Keating 87; Maida 93; Rice 84

chemical nature of allelochemicals (Ashton 85; Harborne 89; Newman 91; Seigler 81; Stevens 81; Tang 86; Whittaker 71); activity of allelochemicals depends on specific compound structure (**Greca 92**; Hay 88; Stenlid 70)

chlorosis from allelopathy- Elakovich 89; Frank 80; Leather 86; Steven 81

corals and sponges, allelopathy in- Berenbaum 95; Maida 93

cost to producing plant is considerable (Coley 85; Hay 88; Stafford 90); 25% of plant genes devoted to secondary metabolites (Szathmary 01)

cyanogenic allelochemicals (Bell 81; Whittaker 71), in watercress (Newman 92), and Myriophyllum (Hutchinson 75)

decaying SAM leaves release allelochemicals (**Harrison 80**) and become less toxic (Kerfoot 89; Newman 92); DOC release by dead SAMS is 40% of PS (Otsuki 74)

decomposition of allelochemicals (Wetzel 93) by bacteria (Buikema 79; Gunnison 89; Keating 78; Romheld 83); water hydrolysis of allelochemicals (Aliotta 92; Center 91); internal detoxification (Harborne 88) by plant enzymes (Pridham 64), vacuolar storage and protection by cell walls (Pollio 93) defensins (**Ganz 94**); of humans (Diamond 93) and plants, etc (**Broekaert 95; Terras 95; Thevissen 96**) *See* ‘phytoalexins’ below

detoxification of phenols by sulphation and glycosylation (Harborne 75; Marchand 87; Whittaker 71) or the animal synthesis of large amounts of proline-rich proteins (Stafford 90)

distribution of allelochemicals among all non-motilie, non-parasitic organisms (**Berenbaum 95**)

DOC toxicity in soils (Donahue 83), straw mulches (Jobidon 92), sediments (Barko 82, 83a, 86; Dooris 82; Wetzel 93), and lake water can be phytotoxic (Wetzel 93); majority of DOC in lake water is probably humic acids (Hama 80; Wetzel 93); 10 mg/l is toxic to algae (Kim 93; Planas 81; Saito 89)

emergent plant allelochemicals v. algae (**Aliotta 90;** Saito 89); emergent plants contain more algicides, phenols and alkaloids than submerged plants (Boyd 69; Gross 96; Kerfoot 89; Les 90); DOC release from (Mann 96)

evolution of allelochemicals in aquatic plants- Les 90; **McClure 70**; Newman 91

extracellular enzymes inhibited by phenols- **Kim 93; Wetzel 93**

extraction of plants by different solvents yields different results- Alliota 91; Saito 89; Vergeer 97

FAM allelochemicals v. algae- Aliotta 91

flavonoids are common in higher plants (Harborne 89; Jacobs 88) and some can be allelopathic (Dreyer 81; Jacobs 88; Nicholson 87; Rice 84, 74; Saito 89; **Stafford 90**; Stenlid 70); proanthocyanins are condensed tannins (Stafford 90); sulphation of flavonoids (Harborne 75); synthesis induced by stress (Stafford 92)

genetics of, heterogenous nature of plant defensins and thionins (Florack 94; Terras 95); 25% of plant genes devoted to secondary metabolites (Szathmary 01)

glycosylation of phenols (Harborne 88; McClure 69; Pridham 64; Wallace 69) and flavonoids (Hosel 81; Marchand 87; McClure 70; Stafford 90; Wallace 69) makes them less toxic (Stenlid 70); and more water soluble (Stafford 90)

hardwater, toxicity of phenols is less in- Wetzel 93

herbivores: growth stunted by unpalatable (Dreyer 81) allelochemicals (Center 91); reaction with digestive proteins of insects (Haslam 89; Haukioja 00)

herbivory of aquatic plants (Hay 88; Newman 91; Paul 93) releated to leaf age (Center 91), tannin content (Boyd 69); phenols (Lodge 91) but not to alkaloids (Lodge 91); decaying SAMs, after allelochemicals have leached out, are prefered (Newman 91, 92); herbivory a trade-off between plant nutrient and allelochemical levels (Boyd 68; Center 91; Hay 88; McKey 78; Newman 91)

humic acids are allelopathic phenols (Wetzel 93) that are toxic to algae at 10 mg/l (**Kim 93**; Planas 81; **Serrano 90**); formed from tannins and other polyphenols (Haslam 89)

insecticides produced by terrestrial plants- Grossman 94; Haslam 89

interconversion of related allelochemicals- McClure 70; Wallace 69 invertebrates and insects, effect of SAMs on (Center 91; Dhillon 82; Gopal 93; Newman 92; Pennak 73); effect of Java moss, Hornwort and Cabomba on Neocaridina shrimp (**Vazquez 22**); insects avoid Elodea and Vallisneria (Newman 92)

leaf v. root production- Elakovich 87; Muller 72

leaf exudation- Muller 72; Serrano 92

light, effect on phenol content and disease resistance (Vergeer 95)

lignin, none in algae (Grisebach 81; Monties 89) and reduced in aquatic plants (Sculthorpe 67) as they evolved (Kerfoot 89; McClure 69; Monties 89; Ostrofsky 86); 20-30% of terrestrial plants is lignin (Westerman 93)

luteolin, a flavenoid, found in *Spirodela*, duckweed (McClure 70; Wallace 69), spikerush (Stevens 81), and Potamogeton sp. (Les 90)

mechanism of action of allelochemicals (**Rice 84**); phenols on algae ultrastructure (**Pollio 93**; Harrison 80), extracellular enzymes (Kim 93; Wetzel 93), ATP formation (**Stenlid 70**), hormone transport (Jacobs 88), -SH groups, peroxidases, cation fluxes and DOC leakage **(Baziramakenga 95**); complexation with proteins (Gross 99; Haslam 89)

metabolic blockers of phenol synthesis (Kerfoot 89); decrease disease resistance (Carver 94)

metabolism and turnover of allelochemicals in the producing plant is dynamic- Barz 81; McClure 70; Nakai 99; Wallace 69

Myriophyllum species and allelopathy (**Gross 96, 99**): water extracts of *M. spicatum* and *M. aquaticum* are toxic to duckweed and lettuce seedlings (Elakovich 89); benzene/methanol extracts of *M. spicatum* are toxic to mosquitos (Dhillon 82); HCl/methanol extracts of *M. spicatum* contain phenols that are toxic to algae, enzymes, and nitrifying bacteria (Gross 96,99; Planas 81); *M. verticillatum* contains carotenoids, polyprenols, sterols, hydroxy fatty acids, phenylpropanoid glucosides that are toxic to algae (Aliotta 92); cyanogenic compounds in *M. proserpinacoides* (McClure 70) and *M. aquaticum* (Hutchinson 75); water leachates of *Myrioplyllum* sp. repel daphnia (Pennak 73; W555); *M. brasiliense* extracts toxic to cyanobacteria (Saito 89); *M. spicatum* continuously releases allelochemicals against blue-green algae (Nakai 99)

N_2 fixation inhibited by allelochemicals- Rice 92

new growth most toxic- Center 91; Hay 88; Paul 93

nitrification inhibited by allelochemicals (Jobidon 92; Planas 81; Rice 74, 84); inhibition specific to nitrification and increases with species succession (Rice 92)

PAL, stimulation by light- Vergeer 95

pH, effect on phenol toxicity- Rice 84; Wetzel 93

phenol cells, disease resistance (Carver 94; Center 91; **Martyn 83a,b;** Nicholson 87); in seagrasses (Cuny 95; de Villele 95)

phenol chemistry- phenols are derived from shikimic acid and the phenylpropane metabolic pathway (Whittaker 71) and form lignins, flavonoids, tannins, stilbenes (Grisebach 81; Harborne 89; Haslam 81; Ibrahim 81); phenols bind to proteins (Mole 87; Wetzel 93) and clay (Muller 72), and chelate iron (Hopkins 95; Romheld 83); phenols are water soluble (Harrison 80; Muller 72; Zapata 79) and can be oxidized to quinones (Vergeer 95)

phenol occurence in: aquatic plants (Aliotta 91, 92; Boyd 68; **Cuny 95**; de Villele 95; Lodge 91; Kerfoot 89; McClure 70; Planas 81; Steven 81; Su 73; **Vergeer 97**); sediment humus (Buikeima 79; Hoagland 85), and DOC of lake water (Hama 80; Serrano 90; W678; Wetzel 93); is only about 5-25 ug/l (Thurman 85)

phenols are toxic to plants, algae, yeast, terrestrial and aquatic plants (Aliotta 91, 92; DeDonder 71; Greca 89, 92; Ibrahim 89; Kim 93; McKey 78; McNaughton 68; McPherson 71; Muller 72; Planas 81; **Pollio 93**; Rice 74; Rowe 82; Saito 89; Serrano 90; Smith 90; **Stom 81; Sutton 86;** van Sumere 72; Vergeer 97; Whittaker 71); phenols more toxic to cyanobacteria than algae (Aliotta 92; Kim 93; Planas 81) not too toxic to aquatic plants (Rowe 82; Smith 90; Stom 81; Sutton 86)

phytoalexins and disease resistance (Jacobs 88; Ebel 86; Nicholson 87**; Vergeer 95, 97**); phytoalexins are mainly isoflavonoids and are induced by stress (Nicholson 92; Stafford 90); phenols induced in aquatic plants by disease (Cuny 95; de Villele 95; **Vergeer 95,97**) or bacterial LPS (Fujimoto 95); thionins and defensins against fungus are induced in terrestrial plants (Broekaert 95; Florack 94; Ganz 94; **Terras 95; Thevissen 96**); are similar to mammalian defensins (Diamond 93) *See also* stimulation of allelochemical production

quantitation of allelochemicals (Center 91; Paul 91) and phenols (Buikema 79; Greenberg 92; Harborne 89; Mole 87; Serrano 92); fluorescence of phenols (Carver 94)

release of allelochemicals by live plants (Gross 96,99; Romheld 83; Tang 86,95) is continuous (**Nakai 99**); intercellular transfer by algae (Gross 99)

review, allelopathy (Bell 81; Elakovich 89; Fuerst 83; Newman 91; Rice 84; Rizvi 92; Szczepanski 77; Whittaker); in aquatic plants (Gopal 93; van Vierssen 85)

SAMS v. algae (Balls 89; Elakovich 87; Greca 89; Gopal 93; **Harrison 80; Hasler 49;** Kim 93; **Planas 81; Serrano 90**), particularly blue-green algae (Aliotta 92; Elakovich 87; Kim 93; Planas 81; Saito 89; van Aller 85); water-soluble inhibitory compounds identified (**Aliotta 92**; Ashton 85; **Greca 89**; Gross 96; Planas 81; Saito 89; van Aller 85; Wium-Andersen 82, **83**); anionic nature of Hydrilla inhibitor (Dooris 82); bacterial-mediated allelopathy (Fitzgerald 69); marine macroalgae (**Cuny 95**); continuous low-level release controls algae (**Nakai 99**)

SAMs v. bacteria (Elakovich 87; Harrison 80; Hutchinson 75), nitrifying bacteria (Planas 81; **Rice 74, 84**), and cyanobacteria (Aliotta 92; Elakovich 87; Greca 89; Kim 93; Planas 81; Saito 89; van Aller 85)

SAMs v. fish- **Newman 91**

SAMs v. insects- Center 91; Dhillon 82; Gopal 93; Newman 92; Pennak 73

SAMS v. SAMS (**Agami 90;** Barko 81a; Gerloff 75; Gopal 93; Kulshreshtha 83; McCreary 83; Smith 90; **Sutton 86a; Titus 83**)-- water-mediated inhibitors (Agami 85; Elakovich 89; **Kulshreshtha 83**) or soil-mediated inhibitors (Ashton 85; **Frank 80; Stevens 81;** Sutton 86a; **Szczepanska 71**, 77; Tang 86); in the aquarium [**Krombholz** T5(4)]

SAMs v. slime-moulds- **Vergeer 95,97**

SAMSs v. snails- **Barlocher 94**; Newman 91,92

SAMS v. terrestrial plants (Elakovich 89; El-Ghazal 86) including rice (Gopal 93)sediment organic matter (from trees), inhibition of Hydrilla but stimulation of algae (Dooris 80, 82)

seasonal production of different allelochemicals thwart insects (**Haukioja 00**)

soil, most persistent allelochemicals in are caffeic, ferulic, p-coumaric, and p-OH benzoic acids (Rice 84); allelochemicals bind to clay & humus (Chou 87; Fisher 87)

stimulation of allelochemical production (Hay 88; Newman 92; Whittaker 71) by wounding and infection (Cuny 95; de Villele 95; Hanson 81; Jacobs 88; Newman 91; Nicholson 87; Santamaria 94; Stafford 90; **Vergeer 95,97**), bacterial exudates (Raskin 99), light (Hanson 81; Hay 88; McClure 69; Santamaria 94; Stafford 90); UV light (Grossman 94; Tang 95); fungal penetration (Carver 94); and nutrient deficiency (**Tang 95**); increased DOC release by SAMs with epiphytic algae (Hough 75)   *See also* phytoalexins and disease resistance

stimulation of growth by low concentrations of allelochemicals- DeDonder 71; **Fries 74**; Gopal 90,93; van Sumere 72

storage of allelochemicals (Hay 88; Martyn 83a,b; Pollio 93; Whittaker 71) as glycosides (Aliotta 92; Hosel 81; Les 90; McClure 70; Newman 91; Stafford 90; Wallace 69) in the cell wall (**Marchand 87**)

substrate type, effect on allelopathy- McKey 78; McPherson 71; Szczepanska 71

sulphation (Stafford 90) detoxifies phenols (Harborne 75)

synergistic activity of phenols; yes (Aliotta 92; Einhellig 83; Muller 72; **Rice 84**); no (Stevens 81)

tannins (Gross 96; Haslam 81; Hay 88; Saito 89); none in algae as compared to aquatic plants (Boyd 68; Haslam 81); correlation with palatability (Boyd 68; Haukioja 00; McKey 78; Stafford 90); confounds of Folin assay for (Center 91; Harborne 89; Hay 88); condensed tannins are proanthocyanin flavonoids and are found in the vacuoles (Martyn 83a; Stafford 90); origin of Tellimagrandin II (Gross 99; Haslam 89)

terrestrial plants, allelopathy in- Donahue 83; McPherson 71; Muller 72; Nicholson 87; Putnam 86; Tang 86; Whittaker 71

theories: production of multiple allelochemicals most effective herbivory deterrent (Paul 93); terrestrial herbivorous insects are specialists, aquatic ones are generalists (Hay 88; Newman 91); quantitative (phenols) versus qualitative (alkaloids) defense (Center 91; Coley 85; Hay 88; McKey 78; Newman 91); and allelochemical production higher in depleted environments (Coley 85; Gross 99; Janzen 74; McKey 78); mature, climax systems are tight with little leakage of nutrients (Rice 92); overview of theories (Berenbaum 95); paradox of autoinhibition (Chou 87); complexity of aquatic systems (Keating 87)

thionins (Florack 94) and fungal inhibition by (Thivessen 96) universality, allelochemicals are common to all organisms (Whittaker 71), but are less common in animals and parasitic organisms (**Berenbaum 95**) and have general toxicity (Elakovich 87; Greca 91; Harrison 80; Kim 93; Newman 92; Wetzel 93)

water lily extracts are highly toxic (Elakovich 91); plants have high phenol (Kerfoot 89) and alkaloid content (Hutchinson 75; McClure 70); used for tanning (Sculthorpe 67)

Ammonia/Ammonium-

acidity produced by ammonium uptake (**Brix 02**)

algae- phytoplankton preference and better growth with ammonium (**Trommer 20)**

amino acids formed directly from ammonia via glutamate- Boussiba 90; Givan 79; Hageman 80; Lewis 86; **N162**

ammonia is the toxic component of ammonium solutions (Dendene 93; **Vines 60**) and what crosses cell membrane (**Barr 74;** Kleiner 81; Russo 85; Spotte 79); cell entry depends on cell pH (**Milne 58; Stabenau 59**) and increases pH of cell (Kleiner 81; Twitchen 94; Warren 62)

ammonium cellular transport mechanisms (**Boussiba 90; Jayakumar 85; Kleiner 81**); uptake by plants requires energy (Koch 90; Trought 81; Yamasaki 92) or not (Nelson 80); no evidence for ammonium transport in higher plants (**Kleiner 81)**, but probably K+ exchange or co-transport with Cl- (Paradiso 94-PC); crystal structure of ammonia transporter (**Khademi 04**); excretion by fish gills often coupled with Na+ uptake (Bond 96, p 404; **Morris 21**)

anammox is anaerobic ammonia oxidation by bacteria (**Jetten 99; Pynert 03; Strous 99**); slow doubling time of 29 days v. 1.2 days for nitrifiers (**Jetten 99**) *See also* “Bacteria:anammox”

AOA v. AOB in aquarium filters- **Sauder 11**

bacterial production of: from nitrates via ‘DAP’, from ‘ammonification’ of OM (*See under* ‘Bacteria’)

C skeletons are required for plant uptake- Givan 79; Hageman 80; Koch 90; Lewis 86; Santamaria 94

competition with K uptake in calcicoles but not calcifuges- Roelofs 86

detoxification, biochemical mechanisms of plant- **Givans 79** *See also* ‘Ammonia/Ammonium: Anammox’ *and* ‘Nitrification’

enzyme for ammonia oxidation is ammonia monooxygenase (*amoA*) is used for detecting ammonia-oxidizing bacteria, both AOB and AOA- **Sauder 11**

exchange for KCl in sediment- Nichols 76; Ross 89

fish excretion of N: most N is excreted as ammonia from the gills, while the kidneys excrete some urea while rest is urea (kidneys) (Bond 96, p404; Hinshaw 92; Kleiner 81; Spotte 79); gill excretion of NH_3 is coupled to Na+ uptake (via several membrane transporters and enzymes) (**Morris 21**), but not in cardinal tetras (**Cremazy 16**)

hypolimnion accumulation- W241

inhibition of nitrate uptake *See under* ‘Nitrates’

invertebrate susceptibility and tolerance for ammonia- **Chen 89**

K release, antagonism (Barko 88; **Barr 74**; Beck 91; Roelofs 84; Ross 89; Schuurkes 86); but only in calcicoles (Roelofs 86; Rorison 86); NH4+ leakage in K+ channels, but no K+ leakage in NH4+ channels (Khademi 04)

leaf uptake preferred- Iizumi 82; **Pedersen 97**; Schuurkes 86; **Thursby 82**

oxidation by bacteria See "Nitrification"

pH: ratio of ammonium to ammonia (**WW 214**); toxicity and uptake (**Warren 62)**; ammonia more toxic at lower pH (Russo 85); pH on ammonia toxicity to fish (**Frank 91**)

rapid penetration of cell membranes (Barr 74; Bennet 71; Boussiba 90: Kleiner 81; Milne 58; Warren 62), but NH3 channels may increase the supply (Khademi 04)

root uptake of ammonium, most translocated to leaves- Caffrey 92

sediment acidity- Kirk 95

sediment anoxia reduces root uptake- Koch 90; Yamasaki 92

sediment association (Kirk 95; **Jones 82**; W248); levels of 80 ppm in pore water not toxic (Painter 88)

sediment levels of (Santamaria 94); no need for it in the water (Huebert 83)

storage in vacuoles as NH_4^+- Barr 74

temperature: effect on toxicity to fish **(Frank 91**)

terrestrial leaf uptake- Cowling 81; **Hutchinson 72**; **Sommer 91**; **Whitehead 87**

toxicity: mechanisms of toxicity (**Crofts 67**: Santamaria 94); toxicity to bacteria (Anthonisen 76; Burrell 01); to aquarium fish (**Frank 91**); to fish **(Ackerman 06; Russo 85**; Spotte 79; **Twitchen 94**) at concentrations greater than 0.1 mg/l (Sauder 11), recommended levels for aquaculture ponds are 0.2-0.3 ppm (**Gross 03**), effect on fish immune system and disease susceptibilitiy (**Ackerman 06**); to plants (Abrol 90; Best 80; Hageman 80; Holtz 79; Lewis 86; McGrath 82; **Vines 60**; W233; Wild 88), root symptoms of (**Bennet 71**); to aquatic plants (**Dendene 93**; Painter 88; Roelofs 84; Santamaria 94), toxic levels to aquatic plants are 1.8 to 9 mg/l (Jampeetong 09); to brine shrimp nauplii (**Chen 89**) and shrimp on contaminated sediments (**Lee 07**)

uptake by live plants only- Porath 82

uptake similar day and night (Nelson 80; Toetz 71) affected by N limitation (**Dodds 91**; Fitzgerald 69); causes acidification of nutrient media (Edwards 56; Cary 83)

volatilization from water (Dendene 93; Edmond 93; Reddy 87) and soils (Wild 88, p. 670)

water movement required for effective ammonia uptake by duckweed- Porath 82

Ammonium versus nitrate-

Al either stimulatory or non-toxic when given to calcifuge plants fed NH_4^+ (Foy 78; Rorison 85)

algae- Brezonik 72; **Broussiba 84**; **Dortch 90,91**; Doucette 91a,b; **Falkowski 83**; **Guerrero 81**; Kuenzler 86; Martin 91; McKee 62; **Ohmori 77**; **Serra 90**; **Thompson 89**; W226,234

emergents (Reddy 83a, Yamasaki 92, Zhang 09); cattails prefer NH_4^+ (Brix 02); reeds grow better with NH_4^+ (Tylova 05)

energetics of- Hageman 80; Lewis 86; McKee 62; Nelson 80; Thompson 89

FAMS- **Beck 91; Cary 83**; **Fang 07**; **Ferguson 69;** Gaudet 73; Gopal 87; **Holst 79**; **Ingemarsson 84, 86**; **Jampeeton 09**; **Nelson 80;** Orebamjo 75; **Porath 82; Reddy** 83a, **83b**; **Tucker 81**

growth: aquatic plants grow better with NH4+ (**Best 80; Brix 02; Cary 83**; Edwards 56; **Jampeetong 09**)

light (Dodds 91; Dortch 90; Kuenzler 86; Thompson 89; Toetz 71; Ullrich 84) required for assimilation of nitrates (**Canvin 74**; Hageman 80; Notton 83), and stimulation of nitrate reductase (Lewis 86; Schwoerbel 74); effect on N uptake rates (**Miyazaki 85; Nelson 80; Toetz 71**)

Mo requirements- Howarth 85; Notton 83; Raven 88

liverworts prefer ammonium- Katoh 80; **Miyazaki 85**

mosses- **Jauhiainen 98**; Paffen 91

metal toxicity and calcium inhibition of growth enhanced by nitrates in calcifuge species- **McGrath 82; Rorison 84,85**

negative charge of cell interior favors ammonium over nitrate uptake- Ullrich 84

nitrate inhibits growth, chlorophyll, etc (**Boedeltje 05; Jampeetong 09**) due to metabolic disturbance (Boedeltje 05)

pH changes resulting from NH_4^+ uptake (Beck 91; Cary 83; Wild 88); plants acidify lab media when they take up NH_4^+ (Cary 83); effect on uptake by calcicoles and calcifuges (**Gigon 72**); pH affects uptake differently (Brix 02)

reduction of water levels *in situ* (Brezonik 72; Kuenzler 86; Reddy 87; Short 84; Toetz 71; W243) and in a duckweed pond (Porath 82)

SAMS-- (**Best 80**; **Edwards 56**; Holst 79; **Iizumi 82**; Nichols 76; Ozimek 90; **Reddy 87; Roelofs 84, 94**; **Schuurkes 86**; **Schwoerbel 72, 74**; **Short 84**,87; **Toetz 71**; Underwood 91; WW548); isoetids prefer nitrates (Roelofs 94; Schuurkes 86); *Potamogeton alpinus* (Boedeltje 05)

seagrasses preferring ammonia- Lee 99; Paling 94; Terrados 97; Touchette 00; Vonk 08

terrestrials (**Abrol 90**; Cowling 81; Donahue 83; **Hageman 80**; Hutchinson 72; **Lewis 86**; McKee 62; Porath 82; Rice 84; Ross 89; Tinker 79; Whitehead 87; Wild 88); ammonium preference of climax terrestrials (Rice 92) and ammonium-adapted conifers (Krajina 78); calcicoles prefer nitrates (Foy 78; Gigon 72; McGrath 82; Rorison 85)

theory for NH_4^+ preference: NH_4^+ in sediments 10X > than NO_3^- making NH_4^+ the natural N source (Boedeltje 05); situation reversed in terrestrial soils where NO_3^- predominates (Brix 02)

translocation- Beck 91; **Iizumi 82**; Toetz 74

turnover times of N in *Pistia stratiotes*- Nelson 80 uptake rates of NH_4^+ in roots and leaves of seagrasses shows higher NH_4^+ uptake for than NO_3^- in the two species compared (**Touchette 00**); uptake rates in *Salvinia molesta* (**Jampeetong 09**)

Aquatic plants-

aerenchyma (lacunae), gas transport from plant tops to roots, X-section photos of FAM roots (**Jedicke 89**); formation in plants, protective diaphrams, etc for transport of all gases including methane, review (**Vroom 22**); lacunae act as source of CO2 for recycling respiratory CO2 (Wetzel 90)

algae v. SAMS, competitive pressure for light and nutrients (Balls 89; Fitzgerald 69; Gerloff 75; Hasler 49; Jones 90; **Ozimek 91**; Roelofs 84; **Sand-Jensen 91**; **Simpson 86**; Smart 85; W553); survey of 319 Florida lakes (**Bachmann 02**)

alkaloid content low- McClure 70; Ostrofsky 86; Su 73

allelopathy in- **Elakovich** 95 *See also under* Allelopathy

aquarium plants (de Wit 64; **Kasselmann 03**)

Azolla (**Chakraborty 86**; Reddy 84; Riemer 84; Wild 88) harbors bacteria that fix N_2 (N275, 774)

bacteria biofilma on (**Marsollier 04**)

benefits to fish (Sand-Jensen 89) are removal of CO2 more than O2 generation (Atz 52)

boom and bust growth of *Myriophyllum in situ* (Trebitz 93) due to insect predation (Painter 88)

boundary layer of SAM leaves (WW541); thickness can be greater than 0.1 mm (**Madsen 93**) or several mm (WW541);

brackish water (van Vierssen 85), poor adaptation to (W198); species that grow in (Gopal 90); salt tolerance of *B. monnieri* (**Ali 97**)

buoyancy in water; Hornwort protects itself from strong water movement by becoming less buoyant (Kasselmann 03); ethylene used for buoyancy (Blotnick 80)

C uptake strategies in aquatic plants (**Bowes 87**): survey of 30 plants (**Yin 17**) *See also* 'CO2 Uptake Strategies'

Ca channels in (**Felle 91)**; Ca and Mg widely interchangeable as nutrient (WW01, p. 182) *See also under* Calcium

C:N is 17:1 (Gaudet 73; Hill 79) much lower than terrestrial plants (Misra 38) and the 6.6 of marine algae (Riesbesell 07)

cell interior always has a negative charge (duckweed Em is about 240 mV), which attracts cations such as K^+ and NH_4^+ (Ullrich 84), and is necessary for RUBISCO (Pokorny 85)

classification (W520, 524) as possessing C3 photosynthesis (Bowes 91; W533)

clonal variants of *Vallisneria* species- (**Biernacki 97**) and *P. pectinatus* from different longitudes **(Pilon 02)**

competition and allelopathy (**Gopal 90,93**); competition between FAMS- Agami 90; Gopal 93 competitive advantages of certain aquatic plants from canopy formation (Barko 91b); tubers v. turions (**Spencer 89**); shoot elongation (Barko 81a); carbohydrate storage (Barko 81a; Brinson 76; **Titus 79**); low light PS of Hydrilla (Van 76)

Cryptocoryne, habitat and water parameters for (**Mansor 94)**; lighting changes can induce Crypt meltdown (Kasselmann 03)

Cu requirement lower than terrestrials- Gerloff 75

cytoplasmic streaming- Stom 81

disease resistance in terrestrial plants from phenols (Nicholson 92); thionins (Florack 94) and defensins (Terras 95; Thevissen 96)

diseases (Vergeer 95) and herbivory general, not specialized like in terrestrial systems (Newman 91); slime-mold of *Z. marina* (**Vergeer 95,97**); fungal pathogens of *M. spicatum* (Smith 93); bioform formation on plants by *Mycobacterium ulcerans* (Marsollier 04); ultrastructure of leaf cells being invaded by bacteria (Rogers 83)

DOC release from SAMs, both living (**Hough 75**; **Wetzel 72, 69**) and dead (Harrison 80; **Otsuki 74**); from emergents (**Mann 96**)

drawings- de Witt 64; Fassett 57; Godfrey 79; Hellquist 80; Hotchkiss 67; Kansas 67; Mason 57; Muenscher 44; Preston 97; Subramanyam 62; van Vierssen 82; Watson 81

electrical neutrality maintained within plant by ion excretion- Amundsen 82; Hageman 80; Lewis 86; W532; Wild 88

element composition of: 5 different SAMS from multiple sources (**Zimba 93**); water hyacinth (**Gopal 87**)

emergent v. submerged form of same plant; purchased aquarium plants, which are usually grown emersed, need to shed emersed leaves and grow new submersed leaves (**Kasselmann 03**); morphological adaptations to submergence (W525, 533); emergent forms characterized by lacunae, stem/petiole rigidity and hairy leaves **(Kasselmann 03**); keeping photoperiod at 12 hr discourages emergent growth and reproduction in water lilies (Kasselmann 03); leaf gas films on emergent plants facillitate gas exchange and prevent algal growth (**Pedersen 10**) *See also* ‘Aquatic Plants:submergence’, ‘Heterophylly…’ *and* ‘CO2, Strategies: ’aerial growth’

ethylene used for water buoyancy (Blotnick 80) and petiole extension (W526)

evolution of aquatic plants and algae (Brown 99; Les 90; Madsen 91; McClure 70; Monties 89; Newman 91; Riemer 84; W520) and their chemicals (Les 90; McClure 70; Monties 89)

FAMs (Boston 89; Huebert 91; W527); aqueous CO2 use (Boston 89; Gopal 86; W528); N and P uptake in wastewater treatment (DeBusk 89; **Reddy 83b**); oxygen depletion of water (Aliotta 91; **Reddy 81**, 83a, 84; Riemer 84; W554); all FAMs are C3 and can benefit from CO2 fertilization (Bowes 93); FAMs transpire, so the upper side of their leaves needs to be above water (Kasselmann 03); evapotransmission so have active root pressure kinetics making translocation more efficient (WW546)

flowering- *See under* ‘Reproduction’ *and* ‘Light, biological effects’ general- **Barko 86b; Gopal 93; Sculthorpe 67**

growth- takes 8 days for new growth to actually contribute to the plant (Madsen 93)

hardwater v. softwater plants, habitat of- **Seddon 72**; Smits 92

herbicides (Spencer 89); fluridone treatment of Hydrilla (**MacDonald 08**)

Hydrocharitaceae (Val, Elodea, Hydrilla, Hornwort, , etc) are true aquatic plants, are often dioecious and don't have lacunae (Kasselmann 03); Hydrilla and Egeria densa can use CAM and bicarbonates simultaneously (**Hussner 16**); *Ottelia alismoides* can use CAM, C4, and bicarbonates (**Han 20**)

isoetid communities (**Roelefs 83**); isoetids v. eloetids (Sand-Jensen 79)

lacunae *See* 'aerenchyma'

leaf senescence and decomposition part of the normal life cycle for submerged aquatic plants; more with a short (8 hr) photoperiod- **Sultana 2010a**

light effects on plants: photoperiod, flowering, photorespiration, etc *See under* 'Light, biological effects'

lignin and cellulose content lower than terrestrials and emergents (Barko 91a; McClure 70; Monties 89; W543); lignin content of terrestrials is 20-30% (Westerman 93)

low productivity of submerged plants (**Boston 89**; Bowes 89; Mann 72; Reddy 87; W544+) and low PS due to water boundary layers (Bowes 87; Madsen 91; Prins 89); inefficient carboxylation (Salvucci 82; Van 76); and overcapacity (Madsen 91a)

macroalgae (Chara and Nitella) have no lacunae (W538); have similar allelochemicals (Forbsberg 90; Wium-Andersen 82); holdfast absorbs P (Forsberg 90)

marine v. freshwater-- marine plants have PS efficiency (Madsen 91), higher productivity (Boston 89; Mann 73); and greater resistance to H_2S (Koch 90)

membrane potential is –260 mV in Riccia but only –90 mV in mammalian cells- Fells 91

methane (CH4) transport in SAMs, FAMs, and wetland plants from roots to atm (**Vroom 22**)

morphology- Val has a basal meristem with biomass concentrated near the base, while Myriophyllum has an apical meristem with biomass concentrated near the surface (Madsen 01); hydrathodes (stomata-like organ) control internal water flow (Pedersen 93, 97); hydropotes on the bottom of waterlily pads absorb nutrients and water (Kasselmann 03); pneumatophores (aerial roots) are adaptation to anaerobic substrates (Kasselmann 03); leaf gas films form on water-repellent leaves (**Pedersen 10**)

mosses use DIC only (Bowes 87; **Paffen 91**; W529) and have no lacunae (Jaynes 86; W538); Sphagnum (Roelofs 84) is a cation exchanger (W209) associated with the filling in of swamps (W736, 743)

mycorrhizal fungi associated with aquatic plant roots- Christensen 98; Raven 88b; **Sharma 98**

N and P requirements lower than in algae- Sand-Jensen 91; inhibition of *P. wrightii* growth with an excess of N and P (**Sultana 2010b**)

pH, optima for plants (Gopal 93; Pokorny 85); pH polarity of leaves (Adamec 93; Prins 89) phenols are phenylpropanes while terrestrials have vanillin and syringyl- Buikema 79; McClure 70

photorespiration (**Lloyd 77; Salvucci 82)** takes up O2 and releases CO2 (Raven 92); reduces net productivity (Bowes 91) by as much as 50% and it is affected by temperature, O2 conc. and light intensity, assoc. with C_3 type PS (WW540); may be counteracted by refixation of CO2 (Salvucci 82)

polluted waters, associated with a decline in SAMs (e.g., seagrasses), excess N and P inhibited growth of *Potamogeton wrightii*- **Sultana 2010b**

Potamogeton and Zostera evolved from seagrasses- Iida 06

protein source for animals- Boyd 68; Porath 82

pruning can kill or harm plants (Gopal 90); leaf removal from *Myriophyllum* shows huge release of ^{32}P (DeMarte 74)

PS inefficiency (W533), plasticity, and overcapacity (Bowes 87; Madsen 91a) due to inefficient carboxylative enzymes (Van 76)

PS system mostly C3 (>90% of plants) (Bowes 93; Lloyd 77; Madsen 91a; W532), but the more efficient C4 (CAM) can be induced for 'weed' species during the summer (Boston 89); CAM (malic acid storage of C) is used by unproductive isoetids (Boston 89)

red and brown color in, is stimulated by intense light (Kasselmann 07)   *See also* ‘Pigments:anthocyanins’ *and* ‘Pigments:carotenoids’

release of nutrients and DOC into water- Brinson 76; Christiansen 85; DeMarte 77; Gopal 87; Kufel 91; Mayes 77; McRoy 72

reproduction (Attridge 90; Blotnick 80; Grise 86; Huang 94; Jacobsen 76; Kane 88b; Smart 85; Spence 81; Spencer 89; Sutton 85; Titus 83; W527) in aquarium plants (**Kasselmann 03**); reproduction mostly vegetative, not sexual (Rao 81); sexual reproduction rare, so there is less species diversity (McClure 70); plant propagation by tissue culture yields bushier plants; cultivating *Echinodorus* from adventitious plants (Kasselmann 03)   *See also* ‘Reproduction’ *and* ‘Light;biological effects’

resistance to herbivory (**Lodge 91; Newman 91)** and disease (W543)

respiration (Barko 81a; Madsen 91; Rich 78; Salvucci 82; Sand-Jensen 91b; Steward 84; W530; Wild 88); stored O2 from daytime PS is used for respiration at night such that plants do not draw on O2 from the surrounding water (**WW538**); dark respiration measured in 10 species shows consumption of 1 mg O2/g dry wt/hr, whereas O2 provided by PS is ~1 mg at with low CO2 and 10-15 at high CO2 (**Hussner 16**); respiration in SAMs does not use water O2 (**Sorrell 89;** WW538)

resting period necessary for some species (Aiken 80)

root O2 release: *See under* ‘Root Oxygen Release (ROL)’

salinity, effect on plants: 0.1% salinity = 1,000 ppm = 1 ppt; most SAMs inhibited at 0.1% salinity (Gopal 90); salinity via NaCl involves ion toxicity as well as osmotic stress, plants show immediate osmotic stress in 40 mM NaCl (0.23% salinity) (Iida 06); survival of 12 marine, brackish water, and freshwater species when tested in 0, 5, 10, and 15 ppt salinity*; P. stratiotes* and *Lemna minor* most tolerant plant (**Izzati 15**); *Potamogeton wrightii* and *P. perfoliatus* were undamaged by 1 wk in 1/6 saltwater (0.58% salinity), needed acclimation to reach 1.2% salinity (**Iida 06**); 4-16 week effect of 0.5, 1, 1.5, and 2% salt (NaCl) on *Bacopa monniera* showed flattened morphology but continuous growth by 0.5% (**Ali 97**); salt-tolerant plants *Potamogeton pectinatus* found in brackish water with up to 2.2% salinity, *B. monnieri* could be grown in 0.5-3.0% salt (NaCl) and *Salvinia molesta* grew at a reduced rate in 0.75% salinity (Gopal 90) and is known to grow at 0.7% salinity (via seawater) (Jampeeton 09a); growth of *Salvinia natans*, considered a salt-sensitive species, was not inhibited by 0.29% salt but morphology stunted; salt inhibits K+ uptake, which probably causes the injury; smaller FAMs more vulnerable than larger FAMs (**Jampeetong 09a**); diluting 33 ppt seawater to 0, 5, 10, 20 inhibits the PS of the seagrass *Zostera marina* (**Hellblom 99**); interaction of light and salinity in *Vallisneria americana*, which is not found in nature above 5 ppt, requires 50% more light at 5 ppt salinity than 0 ppt salinity (**French 03**); salinity injured plants become chlorotic, P. stratiotes most tolerant; *Elodea* sp the least (Iida 06); *Najas gramenia* grows luxuriantly in 2% seawater salinity (**Rout 01**); involvement of anti-oxidative enzymes SOD (superoxide dismutase), catalase in salt tolerance (**Rout 01**) *See also* 'Water Chemistry: salinity, seawater, etc.

seagrasses, high productivity of (Adey 91; **Duarte 99**); carbon uptake in (**Hellblom 99**)

seasonal growth: bimodal growth of *M. heterophyllum*, increased biomass in May and August; bimodal flowering of *M. spicatum* (Blotnick 80); seasonal rates of temperate plant *M. spicatum* growth (**Huebert 83**); tropical plants grow same year around (WW47)

spaghnum (peat) mosses inhibit aquatic plants (**Kazda 20**)

spores of water ferns (Isoetes, Marsilea and Salvinia)- Raven 92, p.352 and 335

submerged duckweed (*Lemna trisulca*)- Gopal 93; Huebert 91

submergence, adaptation to counteract the 10,000 lower diffusion rate of CO2, which lowers PS and plant's ability to keep its roots safely oxygenated: in a semi-aquatic plant (*Rumex palustris*), gas diffusion resistance is 40 times lower in aquatic leaves v. terrestrial leaves when underwater, but 25 X greater when in air (**Mommer 06**); shoots elongate to contact air, roots develop gas-tight barriers to prevent O2 loss, develop thinner, more filamentous leaves, reduced cuticle thickness, greater surface area, chloroplasts move from deeper layers in the plant to epidermal surface, closer to the CO2 source (Mommer 06) *See also* 'Heterophylly'

surface area (SA) increased exponentially by plants (Wetzel 90; WW588); 500 to 1,000 cm^2 SA per g plant dry wt. (**Sher-Kaul 95**)

taxonomy of plants, new cladistic system- Brown 99

temperature requirements, species variation (**Gopal 90; Kasselmann 03);** effect on emergent and submerged leaf morphology of *Ranunculus flabellaris* (**WW532**)

transpiration rates of FAMs > terrestrials (Reddy 83b, 84; W522); non-transpiration in SAMS not the reason for their lower productivity (Pedersen 97) transport of nutrients within SAMs driven by osmotic pressure not transpiration (Hostrup 91; Pedersen 97,93)

tropical plants, must have efficient P uptake?- Raven 92, p. 240

Utricularia (**Rutishauser 93**); culturing of (**Kasselmann 03; Pringsheim 62**)

Vallisneria, preference for alkaline water (Grise 86; Overath 91; Titus 90); clones of (Biernacki 97); taxonomy (Lowden 82)

water lilies, small ones for the aquarium- **Kasselmann 07**

water chemistry and species variation:

acidic, temperate waters (**Arts 90; Catling 86; Roelofs 83**); plants tolerant of acidic pH (**Arts 90**)

alkalinity and Ca: in Japan (**Kadono 82**); in Himalayan lake (**Singh 81**); in The Netherlands (**Roelofs 83**)

alkalinity: in Minnesota lakes (**Moyle 45**); Potamogeton distribution in New England (**Hellquist 80**); in central Canada (**Pip 84**); in Ontario (**Fraser 86**)

brackish water – Ali 97; Ferguson 89; Gopal 96

hardwater and bicarbonate uptake- **Sand-Jensen 83**

Lake Tanganyika, plants in- Coulter 91; Kasselmann 03

Myriophyllum veticillatum cannot use HCO_3 as C source and is not found in Swedish waters with a pH above 7.3 (Hutchinson 75)

salt and polluted waters, tolerance to (Ali 97; **Gopal 90**)

softwater and hardwater sites of North and South Carolina- **McMillan 97**

soil Ca in Indian pond (Nasar 74), The Netherlands (Roelofs 83)

species correlate with alkalinity and hardness, not N&P- **Linton 98**, **Vitt 90**

swamps and aquatic mosses- **Vitt 90**

tropical softwater of the Amazon basin (**Junk 80; Kalliola 91; Kasselmann 03; Marlier 67**)

water content high (Boyd 68; Bowes 87; McClure 70); dry wt of Hydrilla is 8.8% in contrast to 22% for a soybean leaf (Van 76)

water lily *N. peltata* needs hardwater; *N. lutea* and *N. alba* do not- Smits 92

Artificial propagation-

aeration used to provide air CO2 during growth studies (**Nielsen 91**)

axenic culturing (Ashton 85; Durako 87; Edwards 56; Elakovich 89; Gaudet 73; Kane 88a,b; Kasselmann 03; **Linsmailer 65**; Porath 82; Smith 90) of Cryptocoryne (**Kane 99,T6(5)**); and Anubia (**Huang 94**); Utricularia (Pringsheim 62)

bulbs from *Barclaya longifolia*- Schaeffer T6(4)

cold treatment and ethanol on germination- Kasselmann 03; Smits 95

DIC for general culture media is 0.85 ppm alkalinity (HCO3 conc) provided by 58.4 mg/l of NaHCO3 and 15.4 mg/l of KHCO3 for final pH of 7.9 and conductivity of 280 uS/cm, N = 16 ppm, K = 6 ppm (**Smart 85**); for DIC of 0.85 mM, use 0.5 mM NaHCO3 (10 ppm Na) plus 0.5 mM KHCO3 (20 ppm K) (**Yin 17**)

embryos- **Kane 88b**

emersed plants- Kane 90; Kutty T5(2); Speirs T5(2)

general- **Smart 85**

gravel-nutrient solution cultivation of emergent plants- Kasselmann 03; Steinberg 94

growing conditions for Salvinia (**Gaudet 73**), water hyacinth (**Gopal 87**), and Marsilea (Edwards 56); cultivation of submerged plants for measuring growth rates (**Dulger 17; Nielsen 91**)

growing season (Florida) is March through November (**Barko 86**)

hormones used in- Hartman 83; Kane 88b, 90; Smits 95

hydroponic cultures of aquatic plants don't grow as well as those in sediment- Pedersen 97

nutrient media for plants (Barko 83a; Bertani 87; Bowen 79; Bristow 71; Gaudet 73; Gerloff 75; Gopal 87; Huebert 91; Kane 90; Linsmailer 65; Moorhead 88; **Nichols 65**; Roelofs 84; Rorison 60b; Schat 84; **Smart 85**; **Sutcliffe 81**; Tucker 81) and bacteria (Bowen 79); effect of bicarbonates in (**Smith 93**); KHCO3 worked ~40% better than NaHCO3 for PS in *P. pectinatus* (**Sand-Jensen 83**);); used 1 mM bicarbonate (0.5 mM K and 0.5 mM Na) in expt media (**Yin 17**)

root rhizome- **Kane 88b**, 90; **Rao 81**

sand culturing of Hydrilla with slow-release fertilizers- Sutton 96

seeds from Crypt. and Aponogeton [Clark T4(1); **Jacobsen 76**; Speirs T4(2); Stevenson T4(3)] and water lilies **(Smits 95);** *Aponogeton* mainly propogated by seeds (Kasselmann 03)

shoot tips from Crypt. (**Kane 90,99**) and Anubia (**Huang 94)**

soil for (Andreasen T4(2); Hartman 83; Kane 90; Smart 85; Sutton 85) for Cryptocorynes (Clark T4(1); **Jacobsen T5(5)**)

stem internodes- **Kane** 87, **88a**

water movement and aeration: water movement greater than 15 mm/sec can inhibit PS (WW 541); in measuring growth rates, water was constantly stirred and aerated with atm air by a submersible pump to avoid O2 buildup and thick boundary layers (**Dulger 17; Nielsen 91**); high flow rates inhibit PS (**Ghosh 94; Madsen 83**); can get growth of Hydrilla and M. spicatum with air CO2, but must include bicarbonates; aeration should be provided to enhance air/water exchange of CO2 (**Smart 85**); aquatic plants (8 species) exposed to 8.6 cm/sec showed reduced photosynthesis, but when their shoots and leaves were adjusted so that they did not flutter in the current, they were fine (**Madsen 01**)

B (Boron)-

available from leachings of borosilicate glass- **Hutner 72**

borax contains 11% B- Sauchelli 69

deficiency symptoms (Krombholz T6(5); Sauchelli 69; Wild 88)

essential for higher plants, but not algae or bacteria (Bowen 79) or animals (Wild 88)

general- W195

necessary for developmental tissue- Glass 89; Wild 88

ocean is the source- Bowen 79

pollen germination requires- Brewbaker 63

Bacteria and Microbes-

acetate, as exclusive energy source for Geobacteria (Methe 03); acetate oxidation yields 8 electrons (Bond 03); most of energy (98%) from acetate goes to methane, while only 2% goes to synthesizing new bacteria cell mass (McKinney 04)

actin recruitment by intracellular pathogens- **Stamm 04**

Actinobacteria *See* 'mycolata'

Actinomycetes are filamentous bacteria related to fungi- McKinney 04

aerosolized bacteria in tiny water droplets travel long distances (McKinney 04; hydrophobic bacteria (e.g., the mycolata), which accumulate in surface scum, are the most likely candidates for aerosolization *See* 'MB…: aerosolized *M. avium*…'

aggregation and clumping of bacteria: polysaccharidases (cellulase, hyaluronidase, etc) used to declump bacteria during isolation (Thorel 04) *See also* 'Biofilms: floc…'

air contains 600 bacteria per liter- Angenent 03

algae-bacteria interaction (Joint 02); bacteria produce Vit Bs that black beard algae can use (**McDowell 17**)

allelochemicals of bacteria that inhibit algae and stimulate phytoalexins in plants (Fujimoto 95); plant allelochemicals altered by bacteria (Gunnison 89; Keating 78) *See also* 'bacteriocins'

ammonification (N770); decomposition of OM (proteins, amino acids, urea, etc) (WW 214), release from anoxic sediments (Edmond 93; Kemp 90; Westerman 93); the ammonia generated is used by wetland plants (**Neori 17**)

amoeba encystment of pathogenic bacteria *See under* 'MB…'

anaerobic bacteria raise pH in water and sediment (Kelly 84) and dominate when organic matter is plentiful (**Pfeiffer 01**); maximize conversion of organic matter to methane instead of bacteria cell mass (McKinney 04)

anammox (N770): bacteria responsible for anaerobic conversion of ammonia plus nitrite to N_2 gas are autotrophic, slow-growing, but efficient N processors. Metabolic pathways, energy transformations, characteristics of the bacteria (**Jetten 99**) *See also* "Bacteria:Planctomycetes"

antibiotics (Abs): types of antibiotics and mode of action (**N495, 500**); multi-drug resistance (**D'Costa 06**) kill good bacteria allowing surviving pathogens to grow more rapidly (Moriarty 98); antibiotic resistance transfer between bacteria (Hong 05) on R plasmids (N209, N214) that can be lost with passage (N69); chloramphenicol stops RNA synthesis and preserves RNA samples (**Keith 05**); antibiotic resistance of normal soil bacteria (**D'Costa 06**), may have a competitive cost (**Gagneux 06**); genetic transfer between bacteria via conjugation, transformation, transduction, and transposons (**N204**); abrupt bacterial lysis releases antigens and causes problems (N655); penicillin discovered serendipitously in 1928 and streptomycin in 1943; *Streptomyces* produces half of all ABs (D'Costa 06)

aquariums, initial colonization can be by almost any bacteria- **Verschuere 97);** natural bacteria micoroflora within fish mostly *Aeromonas* and *Pseudomonas* (**del Rio-Rodriguez 99)**

Archaea domain- ammonia oxidizing archaea (AOA) role in aquarium biofilters (**Sauder 11**); paddy soils (**Wang 05)**; and rhizosphere of SAMs (**Huang 16**) *See also* methane producers

arsenic as a respiratory electron acceptor for some bacteria and as an energy source for other bacteria (**Oremland 03**)

Artemia-associated bacteria- **Austin 81; Verschuere 97**

assimilatory reduction is when bacteria and plants reduce inorganic cpds (e.g., nitrates) in order for an element (e.g., N of NH_4^+) to be used as a nutrient, while dissimiliatory reduction is bacteria using inorganic cpds as e- acceptors (Zindev 78)

Bacillus spores for disease control- **Hong 05; Moriarty 98** *See also* 'probiotics'

bacteriocins: antibacterial substrances released by bacteria (**Hong 05**) tested against *Vibrio* infections in trout (**Spanggaard 01**)

binding of bacteria to solid and air surfaces (Mills 96) driven by nutrient depletion (Marshall 76); binding to detritus by acidic polysaccharides (**Floodgate 72)** and sand grains (Duarte 88; **Meadows 66**; Wild 88); the finer the sediment the more bacteria (Adey 91); interaction with soils (Mills 96); binding to transparent organic colloids (**Azam 98**) *See also* 'Biofilms'

biofilms and polysaccharides of- *See* 'Biofilms'

chemosynthetic bacteria (Rheinheimer 85; W328; 310+); also called 'lithotropic' bacteria (IT); species that use arsenic III as an energy source (Oremland 03); CO2 fixation by (**Dodds 91**; W328, 515+, 682, 687); nitrifying bacteria use RUBISCO to fix CO2 (Schramm 98); most bacteria are heterotrophic not chemototrophic (Rheinheimer 85) *See also* 'Nitrification:bacteria'

colony of bacteria becomes visible when it has 10^6 cells (N90)

competition with SAM roots for nutrients (Ross 89; Russel 73; van Wijck 92; Wild 88) and oxygen (Drew 80); competion between bacteria in fish diseases (**Spanggaard 01**) and in mineral water (Leclerc 03); competition between phage and bacteria (**N326**)

counting bacteria- **N103**

cyanobacteria *See* 'Algae:Blue-green algae'

DAP (dissimilatory ammonium production) (Gilbert 97) [also called 'DNRA' (dissimilatory nitrate reduction to ammonium) (Christensen 00); 'nitrate ammonification' (Kemp 90; Rheinheimer 85; Rysgaard 96); 'ammonia fermentation' (Takaya 02)]; assoc. with sulfate-reducing bacteria (Daalsgaard 94; Rysgaard 96), fungi (**Takaya 02**), performed by fermentative bacteria *Vibrio*, *Citrobacter*, *Clostridium*, and Enterobacteriaceae (**MacFarland 82; Phillips 02**; **Smith 82**); competes directly with denitrification for nitrates and has a nitrite intermediate, equations for (**Phillips 02**); metabolic pathway of DAP (**Takaya 02**); DAP rates 7X more than denitrification underneathe trout sea cages; DAP generally dominates in anaerobic C-rich environments (**Christensen 00**) or those with high C/N ratio (**Gilbert 97; MacFarlane 82**); DAP rates about 10% of denitrification rates in shrimp ponds; neither process great enough to prevent ammonia accumulation (**Burford 01**); with shellfish aquaculture, 98% of nitrate goes to NH_4^+ and only 2% to N_2O (**Gilbert 97**); DAP rates equal those of denitrification rates in coastal sediments (**Rysgaard 96**); high ammonia due to ammonification not DAP (Boon 86a; Burford 01); 13% to 28% of NO_3^- recovered as NH_4^+ in seagrass sediments (Boon 86a); DAP a fermentative process that yields energy, while denitrification is a respiratory, cytochrome-linked process (Boon 86a); DAP requires NADH (MacFarlane 82; Tayaka 02); denitrification occurs at +75 to –225 Redox, whereas DAP keeps increasing to ≥ -275 in coastal marine sediment (Sorensen 78); rate measurements using $^{15}N\text{-}NO_3$ conversion to $^{15}N\text{-} NH_4^+$ (Boon 86a; Gilbert 97; Sorensens 78); bacteria that produce NH_4^+ from $NO2^-$ are more numerous than those that denitrify it (Smith 82); DAP becomes more important than nitrification/denitrification with increasing eutrophication (Kemp 90); DAP increases with greater water depth and reducing conditions in a freshwater lake (**Jones 81**, 82); DAP accounts for 70% of nitrate dissimilated in wastewater sludge (Jones 82); nitrate and nitrite reductase enzymes are different for assimilation, denitrification, and DAP (MacFarland 82; **Takaya 02**); when you add more glucose, *Vibrio* produces nitrite instead of ammonia (**MacFarland 82**)

defense mechanisms of bacteria are: biofilm formation, clumping, production of cytotoxins, and survival in macrophages/amoeba (Mura 06)

detoxification of substrate- Gunnison 89

digestion of DOC and POC by pelagic bacteria- **Azam 98**

disease control by bacterial competition *See* ‘probiotics’ and ‘bacteriocins’

disinfectants (**N123**), household bleach, which is 5.25% NaHypochlorite, diluted 1:100 gives 500 ppm Chlorine (N124) *See also under* ‘MB (mycobacteriosis) and ‘WasteWater Treatment’

DNA, 100 fg = 20 mycobacteria cells (Puttinaowarat 02); DNA repair mechanisms that are stimulated by light (**Kaiser 97**)

DOC stimulation of population growth (LeChevallier 04); DOC released by humus photo-oxidation stimulates growth (Kaiser 97; Williamson 95)

dormant, enzymatically inactive state of *Nitosospira* in biofilm interior (Schramm 99); nitrifiers in anaerobic Anammox biofilm (Jetten 99); EMin amoeba cysts (**Adekambi 06; Mura 06**)

doubling time of 20 min for most bacteria, but much longer for mycobacteria (N87; Wolinsky 73); growth rates faster in biofilms than in planktonic cultures (**Hall-Stoodley 98**; Marsollier 04); rich culture conditions select for fast-growers (**Verschuere 97**); fungi doubles every 2h (McKinney

04); fast doubling time provides major competitive advantage (N761) *See also* 'MB…: doubling time…'

electricity generated by bacteria- Bond 02

enzymes (mucinase, protease, lipase, DNase and RNase) activities analyzed in mycobacateria (**Chen 97**); extracellular used to hydrolyze DOC & POC (Azam 98)

epiphytic, symbiosis with plants and algae- Underwood 91; W571; Wetzel 90

essential for plant growth- **Durako 87**

evolution of bacteria, effect of host immune system on genetic changes over time (Musser 00); antibiotic resistance not due to selection pressure but to innate, underlying genetic diversity of bacteria (**D'Costa 06**); bacteria lose genetic material as their pathogenicity increases (**Ochman 06**)

extracellular products of bacteria (**Chen 97**); specific proteins released by *M. tuberculosis* **(Musser 00**); organic polymeres in oceans (Azam 98); EPS produced by bacteria degrade slowly (McKinney 04)

Fe cycling: oxidation by root-associated bacteria (Ash 02; **Emerson 99**); Fe reduction and solubilization by *Geobacter* (Ash 02); Fe reduction by bacteria not that relevant, review of (**Lovley 91**; WW304); clay Fe reduced by bacteria (Kostka 02) *See also* 'siderophores'

feces contain 10^{11} bacteria/g and bacteria make up 1/3 fecal wt (N612)

fermentation (N152) by facultative aerobes even under aerobic conditions (Pfeiffer 01); competition between fermenters and respirators (**Pfeiffer 01**); an extracellular process involving extracellular enzymes in conversion of large bio-molecules into small organic acids, ethanol, etc; which are then used by separate microbes for methanogenisis (WW640)

filamentous bacteria (Actinomycetes) differ from fungi (pics)- McKinney 04

filter (wastewater treatment) bacteria in two tx plants identified as α- (34%), β- (20%), γ- (6%) Proteobacteria, CF (4-20%), and mycolata (1%) (**Keith 05**); β-Proteobacteria common in filters and include ammonia oxidizers (**Gieseke 01**) and PAO bacteria (Crocetti 00); hospital pool bacteria are mostly α- (30%), γ- (30%) Proteobacteria, *Sphingomonadaceae* (30%) (**Angenent 05**); ammonia oxidizers are mainly β-Proteobacteria (**Burrell 01**)

FISH studies of bacteria- Burrell 01; Crocetti 00; Gieseke 01; N236; Pynaert 03; Schramm 98,99; Strous 99

fish- bacteria species (and quantities of) found in the internal organs, whole fish and shipping water (**del Rio-Rodriguez 99**)

fungi, characteristics and chemical composition of; competition with bacteria in wastewater treatment (**McKinney 04)**; one species *Fusarium oxysporum* can do DAP and denitrify, so its an anaerobe **(Takaya 02)**

gases produced by- Ash 02 *See also* 'Sediment:gases'

general- Kerr 72; **Rheinheimer 85**; Spotte 79; Tenny 72; **Westerman 93**

Geobacter, charactericteristics (**Methe 03**); Fe clay reduction by (Kostka 02); electricity generated by (Bond 02)

geochemical processes, bacterial involvement in- **Ash 02;** Oremland 03;Warren 03

gram stain (N50, 61); gram-negative, gram-positive, and mycobacteria differ in cell wall lipid content (20%, 1-4%, and 60%, respectively (Wolinsky 73); gram-negatives contain the pathogens (Moriarty 98) and sequester more carbon as organic matter than gram-positives (Verrschuere 00b)

growth rates *See* ‘doubling time’

identification of bacterial species: biolog assay monitors metabolism of 95 different carbon sources (Verschuere 97); DNA/PCR v. FISH techniques (Schramm 98) *See* ‘FISH studies’ *and* ‘MB...’: Genetic detection’ *and* ‘MB…’: ‘identification…’

intestinal microbiota essential for fish in stimulating epithelial cell proliferation and metabolizing xenobiotics; without bacteria, fish die at 20 days post-fertilization **(Rawl 04**); intestine colonized by strict anaerobes with ≤0.1% facultative bacteria; different individuals have different bacteria (**Eckburg 05**); potential pathogens kept in check by immune cells in gut epithelium (**Ismail 09**; Rawls 04) *Artemia’*s gut bacteria (Verschuere 97) *See also* ‘Fish: bacteria that colonize…’

lipid content of cell walls varies from 1-60% *See* ‘gram-negative….’

lysis releases endotoxins (N686; N714) and harmful antigens (N655)

metabolism by (**N131**), types of (Tenny 72); about 1/3 of organic matter food used for energy and the other 2/3 used to synthesize new bacterial cell mass (McKinney 04)

metal dissolution by bacteria (Ash 02; **Methe 03**; Oremland 03)

metal toxicity (Bisson 92; Borgmann 83; Nieboer 80; N124; Sposito 86; **Tsai 88**) metals, which react with the bacteria’s SH groups, used as disinfectants (N124); resistance to metals carried on the R plasmid (N209)

methane paradox- as greenhouse gas, CH4 makes up 20% of total radiative force with natural freshwaters contributing 70% of natural methane to the atm (Grossart 11) methane production much higher in freshwater than seawater but both contribute equal amounts to atm because seawater covers more of planet (Tang 16); in situ study in oligotrophic lake shows methanogenesis in oxygenated water, Archaea methanogens assoc. with micro-algae, using their H2 and acetate (**Grossart 11**); methanogen production same in presence of 4 different types (green, diatoms, chryptophyte, BGA), methane accumulation at night due to photoinhibition of methane oxidizers during the day (**Tang 16**); methanogenisis in oxic soils (wetlands, emergent plants, and open water) due to an archaea species (Methanothrix) with O2-detoxification gene *mcrA* is found in 97% of soil samples, could be due to biofilms (**Angle 17**); methane production by all wetland plants (trees to SAMs) (**Vroom 22**)

methane producers (i.e., Archaea Kingdom) (Ash 02; Carpenter 77; **N270**; Le Mer 02; Ohle 78; Rheinheimer 85; Russel 73; Westerman 93; W170, 599+); derive energy from H_2 and CO2 with

bacteria doing nitrate respiration than denitrification to N_2 (Jones 81); *Vibrio* bacteria that do nitrate respiration shift to DAP with higher C/N ratio (**MacFarland 82**)

normal flora protects animal from pathogens by decreasing attachment sites and nutrients and producing acid and inhibitors (**N368**); dynamic nature of and changes in population with environmental factors (**N453**); bacteria accumulate on non-shedding surface like teeth (N613); Lactobacillus release H_2O2 and acid, which inhibits other bacteria (N651); bacteria invading the intestine must be able to attach (N623); menaquinone synthesis by intestinal bacterial provides Vitamin K (N151); intestinal bacteria synthesize vitamins that body can use (N614); specific examples of inter-bacterial competition; face skin (N524), genital tract (N651, 656), *Clostridium difficile* infections (N453), and botulism (N692); species associated with healthy fish are *Bacillus, Achromobacter, Pseudomonas, Aeromonas, Streptococcus* (**Walters 80**); gut bacteria kept in check by gut immune cells (**Ismail 09**; Rawls 04) *See also* 'probiotics'

Nocardia in wastewater tx (de los Reyes 97; McKinney 04) don't compete well with ordinary bacteria (McKinney 04)

nutrient uptake, advantage over algae- Kerr 72; W217, 498

nutrient immobilization (Boon 87a,b; Durako 87; Elwood 88; Kistritiz 78; Lewis 86; Nichols 76; Reddy 77; Rheinheimer 85; Russel 73; Thimann 63; Wild 88); 2/3 of organic matter decomposition used for synthesizing new cell mass (McKinney 04)

oxygen requirements are fairly fixed for bacterial species (Ash 02; **N95**); example with nitrifying species (Gieseke 01); fungi are aerobic (McKinney 04)

oxygen toxicity: *mcr/A* gene (codes for catalase) for O2 tolerance by methanogenes (**Angle 17**; Grossart 11)

pasteurization (72C for 15 sec), quick heat kills many pathogens (N115)

pathogens, attentuated by passage in culture (N416); meningococcal strains from patient infections more virulent than those in normal flora (N687); to algae (Freeman 77); opportunistic fish pathogens found in normal fish microflora (**del Rio-Rodriguez 99**); pathogens shed their genomic material as they evolved from free-living bacteria- **Ochman 06**

pelagic bacteria (**WW489**) feed on transparent organic colloids (**Azam 98**); planktonic bacteria in ocean is 105-107 (N326)

pH, effect on activity (Connell 68; Kelly 84; Ross 89); adaptation to low pH (Ash 02)

phage (**N319**), phage-typing (N218); phage conc. in natural waters high (2.5×10^8) and probably controls bacteria populations (**N326**); phage reduced *Aeromonas* disease in trout (**Ellis 07**); viruses in wetland sediments (**Neori 17**)

phosphate accumulation by PAO bacteria in wastewater tx (Crocetti 00; Gieseke 01; McKinney 04); P storage as volutin granules by *Spirillum* species useful for wastewater tx (N71, 286)

photosynthetic bacteria (Raymond 02) include the purple and green anaerobic bacteria (**N273, 159)**; **WW317**) in addition to the aerobic cyanobacteria (**N274**) pigments of *Psuedomonas aeruginosa*- N556); rhodopsin for photosynthesis and energy accumulation in marine bacteria (N763)

Planctomycetes responsible for anammox- Pynaert 03; **Strous 99,**

plant-associated bacteria in soils is specific (N767) *Agrobacterium tumefaciens* and the Ti plasmid (**N212, 281**); plant hormone production (Donahue 83; Gunnison 89; Russel 73; Wild 88) *See also* mycorrhizae

population distribution (Duarte 88; Kistritz 78; Mann 72; Spotte 79); Westerman 93; Wild 88); sediment top layer (oxidized microzone) has 1,000 X more than overlying water (WW636); distribution of a microbial species is worldwide due to small size (Ash 02); numbers in marine sediments/mulm/water (Ash 02); population turnover is 67-375 per year (WW661); 0.5 X 10^6 to 4 X 10^6 bacteria/ml of natural waters (WW493, 495, 651)

probiotics: review of products and their efficacy in treating animals (**Hong 05**): Bacillus spores help control *Vibrio* disease in prawns (**Moriarty 98**); in *Artemia* culture (Verschuere 97) and aquaculture (**Verschuere 00b**); use in treating fish diseases (**Hong 05; Spanggaard 01**); bacteria from fish's normal flora protected frish from Vibrio pathogen (**Spanggard 01**)

prokaryotes include Bacteria and Archaea- N10

protozoa feed preferentially on bacteria (rich food source)- McKinney 04

Pseudomonads dominate aquatic environment (Leclerc 03; Spanggaard 01); their numbers increase in well-fed *Artemia* cultures (Gorospe 96); all Pseudomonads produce siderophores (Spanggaard 01) such they can be used to control disease (**Spanggard 01**) by removing the Fe required by pathogenic bacteria (Verschuere 00a,b); do well in nutrient-poor environments (e.g., distilled water) (N489)

purple and green bacteria- **N273, 763**

quorum sensing by bacteria of their population density based on lactone synthesis (N186)

radiation resistance of: *Deinococcus radiodurans* can survive 1,000 X the lethal dose (to humans) of gamma radiation (N279).

respiration of (N156): electron acceptor flexibility (Daalsgaard 94; **Methe 03**; Oremland 03); e.g., the same bacteria can switch from Fe^{+3} to sulfur reduction (Methe 03); Warren 03); competition between fermenters and respirators (**Pfeiffer 01**)

rhizosphere ecology in sediments and wetland plants (**Barko 1991a; Neori 17**); viruses and bacteriophages (**Neori 17)**

S oxidation and reduction (**Connell 68**; Jones 81; **Joshi 77**; Kemp 72; **N156**; Pulich 82; **WW315**; Westerman 93; **Zinder 78**); SRB also can reduce nitrate to ammonia (Daalsgaard 94) and remove Zn from wastewater (**Labrenz 00**); SRB (Connell 68; Ross 89; W324) grow best with a reducing agent (Daalsgard 94); sulfide oxidation combined with nitrate reduction (N268; Schulze-R 92)

salt tolerance and requirements: halophiles require 9% NaCl and can tolerate 32% NaCl (N289); tolerance of various *Mycobacterium* species (Astrofsky 00)

saprophytic bacteria defined as those that grow on culture media rich in labile organics- WW493 sediment- bacteria of freshwater and saltwater sediments (review) (**Nealson 97**); Barko 91; Blotnick 80; Bristow 74; Duarte 88; Gunnison 89; Laabroek 90; Spotte 79; W593; **Westerman 93)**; gram positive bacteria comprise 20% of sediment bacteria (Moriarty 98)

Shewanella bacteria, compared to Geobacteria (Methe 03); several species inhabit Zebrafish gut (Rawl 04)

siderophores produced to chelate Fe (**Tsai 88**) help dissolve Fe in sediments (Ash 02); all *Pseudomonas* produce siderophores (Spanggaard 01)

size of a bacterium is 0.2 to 3.0 um (N10,14; WW519); sediment bacteria are 0.18 um, planktonic are 0.04 um (Duarte 88); volume is 0.03 um^3 (Geesey 78); length about 1 um (Costerton 87); of *P. aeruginosa* (Marshall 76); weight of a bacterium is 2 X 10^{-13} g (Kistritz 78); size of mycobacteria rods are 1- 4 uM X 0.2- 0.6 uM (Decostere 04); largest bacteria are 200 um (N15)

snails, interactions with bacteria (Mann 73); as reservoir for mycobacteria (Decostere 04; **Marsollier 04**a)

species distribution is worldwide due to small size (Ash 02); in *Artemia* cultures, both environment and the starting inocculum determine the species composition of the bacterial microflora (**Verschuere 97**); 4,000 species/g soil (N256)

spore formation (**N71**), development, and survival in animal gut- Hong 05

storage cpds of bacteria are mainly glycogen and poly-β-hydroxylbutyric acid polymer (McKinney 04); also, phosphate in volutin chambers (N70)

surface area necessary for most bacteria involved in decomposition- Wetzel 92

surface scum bacteria identified- **de los Reyes 97** *See also* ‘Biofilms’: ‘surface scum’

symbiosis with plants (Barko 91; Blotnick 80; Boon 86a,b; Capone 82; DeBusk 89; **Duarte 88**; **Durako 87**; Gersberg 76; **Gunnison 89**; Pulich 82; Reed 88; Russel 73; Sand-Jensen 91; Underwood 91; Wetzel 85) and algae (Allen 72; King 72; Tenny 72; W226, 504)

taxonomy: ‘tree of life’, 3 domains—based on ribosomal RNA sequence analysis--are archaea, bacteria, and eukaryotes; bacteria and archaea are prokaryotes, comparison to old classification with 5 kingdoms (**Nealson 97**); classification of bacteria according to medical, environmental, and metabolic characteristics (**N266**), phyla/class grouping (**N249**), evolutionary relatedness (**N260**); bacteria of human intestinal bacteria (**Eckburg 05**); families of aquatic bacteria that decompose proteins (WW513); 70% similarity in DNA hybridization means same species (N261); higher temperature increases release of extracellular products (**Chen 97**); heat disinfection and pasteurization (**N116**); hyperthermophiles grow at >100C (N290)

terrestrial bacteria are aquatic (Fair 94; Marshal 76; Mills 96); terrestrial soil bacteria used to study aquatic processes such as nitrification (Cox 80: Powell 92; Stephens 98); no evidence that dentrifying bacteria found in soils and sediments are different species (Gamble 77)

toxins: endotoxins of gram-negatives and exotoxins of gram-positives (**N467**); enterotoxins of *Bacillus cereus* cause food poisoning and diarrhae (Hong 05); toxin of *Mycobacterium ulcerans* (Marsollier 04) uranium ppt by bacteria- Methe 03

UV light kills bacteria (**Hijnen 06**; LeChevallier 04; N120) more than planktonic algae, because of smaller size and absence of protective pigments (Kaiser 97)

Vibrio assoc. with sea phytoplankton (N624); infections in prawns (**Moriarty 98**), *Artemia* (Verschuere 97), and salmon (Maule 80) can tolerate the high salinity of the *Artemia* environment (Gorospe 96)

viruses *See* ‘Bacteria/Phage’

Vitamin B production by (**McDowell 17**)

wastewater tx bacteria identified- **de los Reyes 97; Keith 05**

Zn ppt as ZnS by SRB- Ash 02; **Labrenz 00**

Bicarbonate-

acclimation required for bicarbonate use in aquatic plants that can use bicarbs, must be induced (**Hussner 16**); *H. difformis* doesn’t need to change leaf morphology following submergence (**Horiguchi 19**)

algae, unlike SAMs, has no preference for CO2 over bicarbonates (Allen 81); many algae use bicarbonates (Prins 89)

alkaline habitat of *N. peltata* is due to its need for Ca, not bicarbonates- **Smits 92**

amphibious plant species (H. difformis, etc) that develop use of bicarbonates in their submerged leaves following adaptation to submergence (**Horuguchi 19; Nielsen**)

aquarium plant depletion of bicarbonates within 4 wks, uptake is increased by intense light (**Horst 86 p79**)

benefits to plants in nutrient media: added to saturate PS for *P. pectinatus* (Pilon 02);

bicarbonate-using plants don’t do as well as *non-users* (obligate CO2 users) with increased natural CO2 levels (**Titus 17**); DIC enrichment comparison for 21 species (bicarb, sediment and non-bicarb users), but at the pH 6 used, it provides all plants with more CO2 as well as bicarbonates (**Pagano 07**)

biogenic decalcification: (Adamec 93; Allen 81; Horst 86; King 72; Prins 89; Reiskind 89; **WW202)**; reaction for (Elderfield 02; WW203); crusts on upper surface of leaves (Frost 95; Kirk 94; Prins 89) or intercellular space of marine macroalgae (Reiskind 89); marl encrustations derive C from the plant (Hough 75); polar v. non-polar uptake (**Prins 82**);); summer decrease in lake water due to ppt of CaCO3 (**WW178**); polarized upper leaf with alkaline pH may impede epiphytic algae (Sand-Jensen 83); lower side of leaf has pH of 4-7, while uppper side can be 10-11 (Prins 89); removal from the water (KH decreases) within 4 weeks by 8 different aquarium plant species (**Horst 1986, p. 79**)

buffering action- W203

C source in laboratory culture of plants (Smart 85; Smith 93); CO2 a much better source even for hardwater SAMs (Sand-Jensen 82)

Ca increases bicarbonate uptake (Barko 83a) but it is not essential (Adamec 93)

carbonic anhydrase converts bicarbonates to CO2 (Kirk 94; Prins 89; Reiskind 89) within the extracellular space of aquatic plants (van Veen 21); extracellular action in seagrasses (**Beer 97**); effect of enzyme inhibitor on bicarbonate uptake in seagrasses (Hellblom 99); 3 types o

global warming/acid rain: incr CO2 will not change species composition, because bicarb conc. so great, but incr bicarb due to human acticity will incr the proportion of bicar users (**Iversen 19**)

growth and PS rates: growth of *V. americana* and *E. canadensis* was 4 and 13 X better in bicarb-containing media (4.4 mM) than Gerloff media (no bicarbs) (**Smith 93**); for *Ranunculus aquatilis* at air CO2 levels, growth increased 13-fold with increasing bicarb conc. (0.2 to 1.5 mM), saturated at 1.5 mM (**Madsen 93**); for *Elodea* at air CO2 got a 50% increase when bicarb increased (0.2 to 1 mM) while for *Elodea canadensis* at 1 mM bicarb, got a 6 -fold increase with CO2 increase (20- 600 uM) (Madsen 93); for *Potamogeton pectinatus*, PS two-fold better with 5 mM in media than 1.7 mM DIC at pH 7.5 when ~5% of DIC would be CO2 (**Sand-Jensen 87**); 4.6 mM DIC was high enough to saturate PS in *P. pectinatus* (Pilon 02); PS growth and PS of *E. canadensis* increased linearly with HCO3 increase from 0.1 to 1-2 mM, plants did poorly in soft water (**Madsen 87**); growth of 10 bicarbonate-using species in media with bicarbonates or CO2, growth rates correlate with PS (**Hussner 16**); in 21 species from Adirondacks, growth rate stimulation by CO2 fertilization correlates with bicarb use (**Pagano 07**)

hardwater SAMs need some in the water (Huebert 83; **Smith 93**) or not (Smits 92);

$KHCO_3$ worked about 30% better (PS rate) than $NaHCO_3$ added to tapwate r (Sand-Jensen 83)

levels in freshwater at pH 8.4 in equilibrium with air are 1 mM, while CO2 is only 10 uM (Prins 82); in normal hardwater lakes, 60% of anions are bicarb, bicarb con. > 100 ppm HCO3-, pH > 8 (WW 188); and seawater (W203) are 2- 2.3 mM (Madsen 91) representing 28 mg/l of DIC (Bowen 79); calculates to be 122-140 mg/l of bicarbonates (DLW 93); are 170X the CO2 concentration of 35 uM (Beer 97); free CO2 in seawater is 10 uM (Hellblom 99)

lakes have bicarbonate users, streams obligate CO2 users; increased water HCO- magnifies the differences, incr CO2 does not (**Iversen 19**);

levels in natural waters: ave for world’s rivers is 58 mg/l (ranging from 31 for South America to 95 for Europe) (WW170) or up to 10 mM (Madsen 93); summer decrease due to ppt of CaCO3 (**WW178**)

limitations of plant use (Allen 72, 81; Horst 85; Madsen 91; Nielsen 93; Prins 89; Svedang 92; Titus 90; W219), such as need for transport system (Bowes 91; Prins 89; Reiskind 89); one-half can be taken up as CO2, the other half is bound and unavailable for PS (Rabinowitch 69)

mechanisms of uptake: three routes, two involving carbonic anhydrase and a third involving acidification by ATP ases (**van Veen 21**); main ones are direct uptake and extracellular leaf acidification converting HCO3 to CO2 (**Beer 97**; Hussner 16); active, energy requiring uptake of HCO3- (transport into the cell) followed by dehydration within cytoplasma--via carbonic dehydrase--and excretion of OH- (WW202) measurement of uptake by adjusting pH to 6 for CO2 uptake v. pH 8.3 for bicarbonate uptake, using 10 mM NaHCO3 in the measurement media and measuring pH changes (**Horiguchi 19**

pH changed to only 7.7 following addition of saturating conc (200 mg/l) of bicarbs (Pilon 02)

reduction of Cu toxicity by $CuCO_3$ formation- Pagenkopf 86

SAMs need some in the water (Huebert 83) or not (Smits 92)

species variation: comprehensive list of bicarbonate v. CO2 users containing many aquarium plants (**Iversen 19**); native species from acidic lakes in Adirondacks (**Pagano 07; Titus 17**); about half of aquatic plants can use bicarbonates (Duger 17); plants from hardwater that can't use bicarbonates (Hutchinson 75; **Sand-Jensen 83**); species that can and cannot use bicarbonates (**Iversen 19; Prins 82; Yin 17**); bicarbonate use in 8 *Myriophyllum* species correlates with better growth rate (**Dulger 17**); amphibious plants can't use bicarbonates (Bowes 87, 93; Bristow 69), but some can (Frost 95) such as *H. difformis* (Horiguchi 19) and two stream species (Nielsen 93)

storage (battery-like) of CO2 for PS- Allen 72; King 72; Titus 90

streams *See above under* 'lakes'

uptake by plants (**Allen 81**; Madsen 91b; **Prins 89; Sand-Jensen 87**); is inhibited by high CO2 (**Adamec 93**); variation in 10 species, costly and must be induced; high CO2 will suppress bicarbonate capacity (**Hussner 16**); plants prefer CO2 to bicarbonates 10:1 (WW 202); causes release of OH- and biogenic decalcification (Adamec 93; Allen 81; Reiskind 89); confers competitive advantage (Madsen 91b); uptake by seagrasses (**Hellblom 99**) less efficient than marine macroalgae (Beers 97); polar v. non-polar uptake (Prins 82)

world-wide distribution of bicarbonate users (**Iversen 19**)

Biofilms-

algae, biofilms formed on by mycobacteria (**Marsollier 04**)

amoeba and other protozoa feed on biofilm bacteria- LeChevallier 04; Lederberg 00; **McKinney 04**;

anammox-nitrification- Pynaert 03

antibiotics and bactericides less effective when used on bacteria in a biofilm: nitrifying bacteria from nitrapyrin (**Powell 92**), *Pseudomonas aeruginosa* from antibiotics (Costerton 86), and SDS (Davies 98); *Nitrosospira* from DNA extraction techniques (freeze-thawing/hot phenol/SDS)(Schramm 98); mycobacteria from bleach and other chemicals (**Bardouniotis 03**)

Bacillus produce biofilms (Hong 05); degrade biofilms of gram-negative bacteria with extracellular enzymes (Moriarty 98)

bacteria shedding from biofilms (Bardouniotis 03; Hall-S 98; 99); shedding of *S. aureus*, *P. aeruginosa*, and *M. fortuitum* (**Hall-S 05**); increased water nutrients stimulates shedding (**Hall-S 99**)

$CaPO_4$ ppt in a wastewater biofilm- Christensen 89

chemotaxis, motility, and O2 sensing in- Ash 02

clay particles trapped with a biofilm- Costerton 80 communication between bacteria essential for biofilm structure (**Davies 98)**; commnunication with algae **(Joint 02)**

degradation of biofilms by *Bacillus* enzymes- Moriarty 98

denitrification (Dalsgaard 92) better in a thicker biolfilm (Christensen 89); occurs throughout all layers (**Masuda 91**)

dental plaque- **London 96; Ellen 96**

dormant nitrifying bacteria within the center- Schramm 99

drinking water biofilms common (LeChevallier 04); vigorous EM growth on silastic rubber in sterile tapwater (**Hall-S 99**)

exopolysaccarides (EPS) of bacteria characterized (Davies 98; **Read 87)**; most released into the media and can't be degraded by the producing bacteria (Read 87); formation has a metabolic cost (Belas 96); resistance to bacterial degradation but fungi can slowly degrade them (McKinney 04); EPS are an extension of the bacterium's capsule (N66; WW577); extracellular polymeric substances (EPS) in soil biofilms (**Cai 19**)

experimental models for studying biofilm development by mycobacteria under high and low nutrient conditions (**Hall-S 99; LeChevallier 04**)

FISH studies of filter bacteria- Burrell 01; Crocetti 00; Gieseke 01; Pynaert 03; Strous 99

floc formation in sewage tx; floc composed of ordinary soil bacteria species that aggregate once they have completed rapid growth phase (**McKinney 04**); when flocculants (e.g., alum) added, DOC colloids aggregate and bridge with living and/or dead cells (WW737); 19% of DOC becomes bacteria-rich, N-deficient POC aggregates during decomposition (WW 652)

genetic exchange in biofilms- London 96

glycopeptidolipids essential for biofilm formation in mycobacteria (**Recht 01**)

growth of bacteria faster in a biofilm than planktonic culture (**Hall-S 99; 98**; Marsollier 04); biofilm development under high and low nutrient conditions (**Hall-S 99**)

hydrophobicity of surface affects structure (**Dalton 94**), biofilm formation in mycobacteria requires a hydrophobic outer layer of glycopeptidolipids (**Recht 01**); formation on plastic and rubber (Hall-S 99)

intestinal microflora exist as mixed biofilms attached to mucosal epithelium- Eckburg 05; Hong 05

layer studies of biofilms show gradients of oxygen, bacterial activity (Masuda 91) cross-section wise and longitudinally (**Schramm 99**)

maturation of wastewater biofilm took 5 weeks (Masuda 91); but only 48 hr for mycobacteria (Hall-S 98; 99); requires quorum sensing of bacteria's population density (N186), area and height of developing biofilm (**Hall-S 99**) *See also* 'Bacteria shedding…'

metabolic activity and density in biofilm layer (**Dalsgaard 92; Masuda 91; Schramm 99**); e.g., fermenters and methanogens (Ash 02)

metabolic exchange in biofilms- London 96

metal corrosion due to SRB- Costerton 87 microenvironments, not just horizontal layers in a biofilm (**Masuda 91**; Peiffer 94); anaerobic microenvironments created by aerobes depleting all O2 (N270)

miscellaneous examples- natural flora of human body, ruminate digestion, infection of medical implant devices (**Costerton 87**; Potera 96); tapwater pipes (Hall-S 99; **LeChevallier 04**)

model of discrete columns of bacteria separated by water-filled voids (Dalton 94; Marshall 96; Potera 96; WW584) show biofilm maturation (Hall-S 98); no homogeneity (Christensen 89)

motility of bacteria within a biofilm- **Hall-S 05**

mulm *See* ‘Biofilms’: ‘floc’

nature of a biofilm- **Christensen 89; Dalton 94; Davies 98**; Lion 88**; N89; Read 87; Masuda 91**

neuston (WW134) is a type of biofilm- Fletcher 96; Mills 96 *See also* ‘surface scum’

nitrification (**Cox 80; Gieseke 01**); species of ammonia oxidizers and nitrite oxidizing bacteria are associated together (**Pynaert 03; Schramm 98,99)**

nitrification-denitrification (Masuda 91; Timberlake 88) and nitrification-Anammox (Jetten 99; **Pynaert 03**)

nutrients in water stimulate shedding but don’t affect the size of the biofilm (**Hall-S 99**)

oxidizing and reducing bacteria in same biofilm (Ash 02; Labrenz 00); dormant nitrifiers in an anaerobic filter (i.e., anammox)- Jetten 99

periphyton is synonomous with biofilm- WW132

pipes, size and composition greatly affect biofilm growth**- LeChevallier 04**

polysaccharides *See* ‘exopolysaccharides’

Pseudomonas aeruginosa linked to disease, material fouling, natural environment- Davies 93

quorum sensing (**Davies 93**)

S cycling (Habicht 03; Peiffer 94; **Zinder 78**); S ppt with Zn by SRB (Ash 02; **Labrenz 00**)

slime and bacteria in a nitrification filter (Cox 80) and in nature (Geesey 78)

soil biofilms, organization and structure, review (**Cai 19**); not the same as trickle filter biofilm (Cox 80)

soil processes- **Mills 96**

strategies for bacterial adhesion- Belas 96; **Silverman 84**

stream-associated bacteria and algae- **Geesey 78**

surface attachment activates gene for EPS production- **Davies 93**; Fletcher 96

surface scum, formation of foam by hydrophobic polysaccarides, which attract hydrophobic bacteria like the mycolata (*Nocardia*, etc) (de los Reyes 97; McKinney 04) and mycobacteria (Primm 04); fungi will grow at air-water interface (McKinney 04); neuston, water surface association of algae, bacteria, and protozoa (WW134); natural waters have a 0.1 mm “microlayer” consisting of hydrophobic organic molecules and enriched 1.6 to 341 X in nutrients N,P,C as compared to the bulk water (**Mills 96**); hydrophobic DOC collects at surface (Primm 04)

surfaces in nature possess a negative charge that attracts cations and food for bacteria- Marshall 96 wastewater biofilm contains aerobic and anaerobic heterotrophs throughout all layers (Larbrenz 00; **Masuda 91**; Pfeiffer 01)

water treatment systems: water pipe biofilms are source of mycobacteria in drinking water (**Falkinham 01**; Torvinen 04; Tsintzou 00)

water channels in biofilm (Bardouniotis 03) are 5-50 um- WW584

C (Carbon)-

accclimation and loss of PS efficiency with increasing levels of either bicarbonates or CO2 in *Ranunculus aquaticus* (**Madsen 93**); acclimation in Elodea and Ranunculus but not CO2-obligate using Callitriche (**Madsen 96**) similar to terrestrial plant species (Hussner 16; Madsen 96); plants acclimated for 35 days to low CO2 showed much greater PS than non-acclimated plants for bicarbonates (**Hussner 16**)

C:N ratios: 3:1 for bacteria, 10:1 for protozoa (NRCS 2007); 6.6 in seawater increases with increasing atm CO2 (Riesbesell 07); C:N of sediment humus is 20-26 and peat at 35 is low reflecting a low N content (WW 632) and 12 to 29 for POC and DOC in lake water (**WW 224**)

cycling: in freshwater (**Allen 72**; **King 72**) and oceans (**Azam 98; Elderfield 02; Riesbesell 07**); lakes are a source (not a sink) of CO2 (Cole 94); DIC from both respiration and photo-oxidation of DOC (Graneli 96); oceans as a C sink (Ash 02); bacteria greatly affect oceanic primary production (**Azam 98**)

DIC: DIC rises with CO2 injection from 0.40 mM to 0.8-0.95 mM in nutrient media; at 0.85 DIC, “high” CO2 at pH 6.7 is 263 uM and “low” CO2 (air equilibrium) at 8.2 is 12 uM (**Hussner 16**); *Myriophyllum* species tested with 0.5, 1, 1.5, and 2 mM DIC increasingly better with higher concentrations (**Duger 17**); LC (44 uM DIC) and HC (246 uM DIC) were kept--with HCl titration--at pH 6 where 71% of DIC was CO2; HC (‘high CO2’) produced much higher growth of plants (**Pagano 07**); DIC of seawater varies from 2 to 2.3 mM (Madsen 91); this is 24-28 mg/l C or 1 mM DIC = 12 mg/l; ½ tsp of baking soda added to 1 gal of tank water (KH = 3) increased KH by 2 degrees (from 3 to 5) (DLW 9/2022); alkalinity recommended for regular media and hardwater media is 0.85 and 1.8 DIC (**Smart 85**); with DIC of 0.85 mM for LC and HC, at pH 6.8 (HC), ~27% is CO2 (230 uM CO2) or about 23X air equilibrium while at pH 8.3 (LC), ~3% CO2 and is 26 uM or about 2X air equilibrium (**Dulger 17**, **DLW 2022)**

drawdown of atmospheric CO2 increases water C (Martin 90; Post 90; **Schindler 72**); increases DIC and acidifies seawater (Riesebesell 07)

freshwater median levels of C in freshwater are 11 mg/l with range of 6-19 (Bowen 79; or 5-5,000 uM DIC (Cole 94)

seawater median levels of C are 28 mg/l (Bowen 79) or 2-2.5 mM of bicarbonates (Madsen 91; Reiskind 89)

global cycling (**Bowes 91, 93; Post 90**; Rabinowitch 69; Raven 93); effect of oceans on (Riesbesell 07) *See also* ‘Eutrophication:global warming’ limiting nutrient of marine phytoplankton (**Holbrook 88; Raven** 93) and seagrasses but not macroalgae (Beer 97)

measurements of flux (Kelly 84; King 72; **Rich 78**; W694-704; Wild 88) in oceans (Riesbesell 07)

non-living C much more than living C- W506, 668

peat to coal- Brown 00

Redfield Ratio (C:N:P) is 106:16:1 for marine algae but 474:24:1 for seagrasses reflecting their structural demands for C (Touchette 00)

sources of DOC are PS (both aquatic and terrestrial)- W681

stability of concentration- Kelly 84; W680; Wild 88

strategies for plant C uptake (**Bowes 87**; **Yin 17**) *See also* ‘CO2 Uptake Strategies’

Ca (Calcium)

ammonium preference linked to calcifuges- Foy 78; Gigon 72; Lewis 86; Rorison 60a, 60b, 84

binding to humus, DOC, vitamins, and metals (Otsuki 74) is less tight than heavy metals (Hepler 85; Martin 84; Nieboer 80)

biogenic decalcification removes Ca from hardwater lakes, especially during the summer months (**WW178**); depletes KH (**Horst 86, p79**) *See also*‘Bicarbonates:biogenic decalcification’

Ca ppts: in animals (Roesijadi 94); plant Ca in oxalate crystals is unavailable to the plant (Brewbaker 63); CaPO4 ppt in biofilms due to denitrification-induced pH increase (Christensen 89)

calcicole versus calcifuge plants (Lewis 86; **Rorison 60a, 60b, 84**); organic acid composition or root exudates (Tyler 95; Huang 95); Ca requirements and tissue accumulation (**Clarkson 65; Jeffries 64**; Sabba 93)

calcification is due to pH rise caused by PS use of either CO2 or bicarbonates (Reiskind 89); calcification causes Ca and C loss (**Otsuki 74**) and micronutrient loss from DOC binding to $CaCO_3$ (Wetzel 72) and a decrease in conductivity (W191)

calcifuge plants, common in tropics and associated with Al tolerance and an ammonium-based nutrition (Davies 97; Donahue 83; Foy 78; Gigon 72; Lewis 86; Rorison 84, 86); P and micronutrient deficiencies when grown on calcareous soils (**Tyler 96; Zohlen 97**)

deficiency symptoms in aquatic plants (Huebert 91; Krombholz T6(5); Newman 88); death without it in the water (**Huebert 83**; Newman 88) may be due to metal toxicity (Huebert 83; Smit 92)

exocytosis, definition of- Cruetz 84

functions as extracellular stabilizer (Nieboer 80; Wood 92); association with pectin (Brewbaker 63); secondary messenger role in animals (Alema 84; Creutz 84; Martin 84; Silbergeld 80) and plants (**Bush 94; Hepler 85**; Sabba 93); essential for lamina production and petiole extension in a waterlily (Smit 92), circadian rhythm in Euglena (Lonergan 90), exocytosis in barley grain (**Gilroy 92; Zorec 92**), chloroplast movement in duckweed (**Thalke** 93), red light stimulation of wheat phytochromes (**Shacklock 92**)

general- W188

growth and bicarbonate utilization- **Barko 83a**

inhibition of calcifuge species (Rorison 60A, 60B, 84; **Sabba 93**; Vickery 84) is enhanced by nitrates (Rorison 84); no toxic effect on calcifuge mosses (**Bates 90**); moderate inhibition of Najas flexis above 20 ppm (Hutchinson 75)

intracellular Ca levels kept low to prevent precipitation of organic phosphates (Helpler 85)

intracellular calcium channels: Fe uptake in pea plants (Cohen 98); types in terrestrial plants (Felle 91; **Huang 94; Pineros 97**) and Riccia fluitans (**Felle 91**) are common to all organisms (Hepler 85; Huang 94); inactivated by heavy metals (Huang 96; Marshall 94; Pineros 93, 97) heavy metals can compete with Ca for uptake by these channels in animals (**Markich 94**; Roesijadi 94; **Scharff 96**) and plants (Marshall 94; Shacklock 92); involvement in moss reproduction (**Conrad 88**)

K antagonism (Donahue 83; Rorison 60a) and toxic metals (**Markich 94**; Winner 92) due to competitive uptake by calcium channels (Kostyuk 80; Markich 94; Roesijadi 94; Scharff 96; Zia 94) or gating control (Felle 91); assists Ca (Brewbaker 63)

lake levels of: summer decrease due to ppt of CaCO3 (**WW178**)

lime-induced chlorosis (**Rorison 60a, b, 84**; Russel 73; Wild 88) not due to Fe (Tyler 96; **Zohlen 97**)

P and K deficiencies of plants on calcareous soils- Rorison 60a; Tyler 96

peat as metal chelator (Spinti 95: Bailey 99); can absorb 4% of its dry wt as metal (Brown 00)

plant development, role in- **Bush 94; Hepler 85**

release from clay during waterlogging- Ponnamperuma 81

reproduction in animals (Weber 94) and plants (Bush 94; Gopal 69; Hepler 85; Sabba 93); required for pollen germination (**Brewbaker 63**), budding (**Conrad 88**), rhizoid elongation (**Miller 83**), and spore germination (Iino 87)

resistance to Al toxicity (Davies 97; Lewis 86; Rorison 60a, 60b, 84; Russel 73; Wild 88) due to malate secretion in wheat roots (Huang 96)

root uptake from apical portion only- Wild 88

sea shells contain $CaCO_3$ and about 15% $MgCO_3$- **Dickson 02**

sediment levels of- Painter 88

storage of excess Ca in vacuoles (Rorison 84); high levels in cell walls (Hepler 85)

toxicity of Ca to organisms much less than heavy metals (Nieboer 80)

uptake by plants (Brinson 76; DeMarte 77; Gerloff 75; Glass 89; Gopal 86; Huebert 91; W188+), fish (Perry 85), and algae (Gerloff 75; Otsuki 74; W188); uptake competitive with K (Donahue 83; Rorison 60a) and metals (McCracken 87; Nieboer 80; Wood 92)

water Ca essential for some aquatic plants (Huebert 83; Newman 88; Smit 92); natural softwater with 4-5 ppm Ca is probably enough for aquatic plants (Huebert 83; Welsh 93); *Lemna triscula* needs 1.1 ppm of external Ca (Huebert 91); *N. peltata* needs 1.2 ppm (Smits 92), *Potamogeon pectinatus* needs 2 ppm (Huebert 83)

Zn toxicity to plants in soils can be neutralized by Ca and neutral pH- Foy 78; Rorison 84

Chelators-

Al toxicity decreased by root tip release of malate- **Huang 96**

artificial chelators, types of- **Anderson 82**; Polar 86; Whittaker T92a

caffeic acid as Fe chelator- Hether 84; Hopkins 95; Romheld 83

Cd toxicity and accumulation in duckweed reduced by chelators (Polar 86)

citric and oxalic acid are released by calcicole roots and do remove Fe and P from the soil (**Tyler 95**)

definition of, binds at 2 or more sites- Nieboer 80

EDTA used to reduce metal toxicity in fish (Fitzgerald 69; Russo 85) and phytoplankton (Goldman 73); binds to metals more than Ca (Martin 84); prevents Hg uptake in duckweed (Mo 89); can be a source or sink for Fe (Anderson 82; Polar 86; Rich 90); chemical structure of (Hopkins 95)

Fe and Mn compete- Ponnamperuma 81

Fe binding inhibits algae (**Anderson 82**; Rich 90) and non-siderophore bacteria (Spanggard 01)

Fe chelators in blue-green algae (**Wilhelm 94**), diatoms (**Anderson 82**), and plants (Cohen 98; Hopkins 95; Romheld 83) *See also* Algae:siderophores

ferrozine traps Fe^{2+} and prevents algae growth; EDTA traps Fe^{3+} and is less effective- Rich 90

humic acid and EDTA both bind metals and prevent plant uptake by water hyacinth (Mo 89; Nor 86) and toxicity in fish (Sprague 85); humic, fulvic, hydrophillic acids make up 75% of lake water DOC (Thurman 85)

organic compounds, such as citrate (Lacroix 93) and amino acids are not efficient chelators (Martin 84; Nor 86); but may work *in situ* (Tyler 95); stability constants of EDTA v. organic acids (**Martin 84**)

problems with cation switching- Lindsay 84; Reddy 77

siderophores and oxalate increase Fe dissolution rates (Ash 02) *See also* ‘Bacteria: Siderophores’

stability constants of EDTA and Ca, Mg, Mn, Fe, Zn (Anderson 82; Brand 83; Martin 84; Reddy 77; Romheld 83) and Hg, Cu, Pb, Zn, Ca, etc with humic acids (Markich 94; Thurman 85); EDTA & DPTA v. organic acids (**Martin 84**)

stability of chelator (Reddy 77) and susceptibility to photooxidation (Bisson 92)

studies using- Allen 72; Giesy 78; Goldman 72; Reddy 77; Wetzel 72; Wurtsbaugh 88

CO2-

aquarium levels- 23 ppm (Horst 1986, p. 167)

acclimation and down-regulation of PS with increasing CO2 (**Dulger 17**), both CO2 and bicarbonates for Elodea and Ranunculus but not CO2 plant Callitriche (**Madsen 96**);

affinity of plants for (Allen 81; Barko 91b; Bowes 87, 89; Krombholz T4(4); Lloyd 77; Madsen 91; Salvucci 82) correlates with their growth rate (**Nielsen 91; Pagano 07**)

air diffusion enough? <u>Yes</u> (Martin 90; **Morton 72**; Nielsen 93; **Schindler 72**); surveys of lakes show 3-30X more CO2 than would occur with air diffusion (WW189); diffusion of CO2 is generally adequate to meet C requirements in lakes that are not ultra softwater or heavily contaiminated with N&P (WW277); No, even 10 X air equilbrium not enough (**Madsen 91b**; Smart 85), even for marine algae (Holbrook 88; Raven 93); air diffusion levels with adequate DIC are considered LC (Low-carbon, pH 9) in comparisons to HC (High-carbon at pH 6) (Hussner 16) *See also* 'Gases; CO2 levels…"

air equilibrium conc. of CO2 is 10 uM and 0.5 mg/l at ~25°C in pure water (**WW188**) *See also* 'Gases; CO2 levels…"

amount from metabolism of proteins, fats, CHs- **Linder 91**

atmospheric v. decomposition as source- Cole 94; Otsuki 74; Titus 90; W205

availability in hardwater lakes low despite huge carbonate reservoir- Wetzel 72

bacterial metabolism as a source (Burns 72; Kelly 84; Kerr 72a,b; King 72; Nielsen 93; Rai 79; Roeloffs 84; Sand-Jensen 91; Svedang 92; Wetzel 85); 90% of ocean CO2 from bacteria (Rheinheimer 85)

biogenic decalcification reaction releases CO2 into marine waters- Elderfield 02

cellular uptake decreases internal pH (Pokorny 85; Reid 00; Warren 62; Weber 79); nighttime acidification due to (Sharma 95)

compensation points (Γ) (Allen 81; Frost 95; Lloyd 77; Madsen 91; Nielsen 93; Wetzel 90) and saturation levels (Allen 81; Bowes 87, 89; Madsen 91; Salvucci 82) as a measure of photorespiration (**Salvucci 82**); Γ is often 20-70 ul CO2/l or 1-3 uM in water (Sand-Jensen 83); Γ of 3 aquatic plants (**Van 76**)

depletion due to PS- Allen 72; **Keeley 83**; King 72; Madsen 91; Otsuki 74; Svedang 92; Wetzel 85

diel cycling of (**Allen 72; Van 76**)

diffuses across cell membranes (Warren 62), more easily than bicarbonates (Bowes 91)

diffusion in water 10,000 X slower than in air (Ross 89), but its solubility in water is 200 X greater than O2 (W202; Wild 88); diffusion increases at higher pH (King 72; Morton 72)

end pH as measurement of CO2 affinity- Allen 81; **Nielsen 91**

equilibria with carbonate, bicarbonate- King 72; Titus 90; W202

toxicity of: to plants, >1mM (or 50 mg CO2/l) inhibit PS (Adamec 93; Nielsen 93; **Pokorny 85; Weber 79**) by causing a reduction of cytoplasmic pH that inhibits RUBISCO (Pokorny 85; Weber 79); inhibition exacerbated by acidic pH (Allen 81; Pokorny 85) and fast water flow (Madsen 83); may be toxic during waterlogging (Ponnamperuma 81); decreased root biomass in terrestrial plants (Shaw 02); to fish, causes respiratory distress (Atz 52; Fivelstad 99; Reid 00); and disease susceptibility (Walters 80)

fertilization with CO2 in terrestrial plants: causes increased DOC release (Jones 98) and marine algae (**Riesebesell 07**); decreased root biomass (Shaw 02)

fertilization with CO2 for SAMs (**Barko 91b;** Bowes 91, 93; **Bristow 69**; Gaudet 73; Madsen 91; Nielsen 93; Smart 85; **Smith 93**; **Svedang 92**; Titus 90; Wetzel 85); stimulates growth in the short term but falls off with time due to starch accumulation (Hussner 16); short-term growth spurt but long-term results are acclimation and neg. feedback/down-regulation (i.e., less chlorophyll, more starch stored in roots) and these effects are accentuated by high temp and high light intensitity similar to that of terrestrial plants (**Dulger 17; Hussner 16**; Titus 17) air for FAMs (**Idso 90**; Nielsen 93), algae (Morton 72) and marine algae (**Riesebesell 07**); poor response from species using bicarbonates and with C-concentrating mechanism, good response from C3 plants (Bowes 93; Titus 17); increased root biomass more than leaf biomass (**Dulger 17**)

fertilization with CO2, growth rates: 14 species 3.5 mM DIC, above-ground parts, growth at pH 8 (Nielsen 91); measured growth for 35 day using 0.85 mM DIC, pH 6.7 for HC and 8.3 for LC 8 species of *Myriophyllum* (**Dulger 17**) and with same procedure (pH 6.7 and 8.2, 0.85 mM DIC) 10 species of bicarbonate users (**Hussner 16**); 21 Adirondack species tested with pH 6 where 71% of DIC would be CO2, LC = 44 uM DIC and HC 246 uM DIC, so **both** CO2 and DIC were 5.6 X higher for the HC (**Pagano 07**); growth of *V. americana* and *E. canadensis* grew best with bicarbs, but ± bicarbs (4.4 mM HCO3) had no effect with CO2 fertilization (1% CO2 in air (**Smith 93**)

fixation enzymes (**Bowes 91**; Madsen 91; W218); RUBISCO most abundant protein on the planet (Bowes 91); lower concentration in submerged plants ? (Frost 95)

global warming will have little effect on plant composition in natural waters because bicarbonates are so much greater, but increasing bicarbonate will (**Iversen 19**)

groundwater has 30 X more than atmospheric equilibria (Otsuki 74); groundwater with Ca and CO2 from soil perking and CO2 dissolution of rock limestone (WW188)

importance to plant- Boston 89; Bristow 69; Idso 90; Kane 87; Kerr 72; Madsen 91,91b; Morton 72; **Nielsen 91**; **Overath 91**; **Paffen 91**; Riemer 84; **Titus 90**; **Svedang 92**

inhibition in plants: PS meaured in air saturates the aerial, floating and submerged leaves of amphibious plants at 30 uM (700 ppm); it inhibits PS at 1900 to 2400 ppm (**Nielsen 93**)

interstitial water- Barko 83; Madsen 91; Roelofs 84; Sand-Jensen79; Wild 88

levels in nature: some Danish streams have 100 uM CO2 (Nielsen 93); in freshwaters, free CO2 may range from 0 to over 14 mg/l or 0.35 mM (**Bowes 87**); seawater are only 10 uM (Hellblom 99) lake waters have CO2 concentrations > atm. equilibria (**Cole 94**); natural streams have more obligate CO2 users than lakes, but with increased CO2 this difference is lost [reflects plant preference for CO2 by all SAMs (DLW)]; lakes have more bicarbonate users than streams; but with increased bicarbonates this difference increases (**Iversen 19**) two obligate CO2 users were able to compete successfully with two bicarbonate users in hardwater streams (Sand-Jensen 83); levels in lake water and the underlying sediment (4 cm depth) (**Titus 17**)

measurement of water levels (Greenberg 92); calculated measurements agree with direct measurements (Cole 94)

microzone- Boston 89; Caffrey 91; Paffen 91; Sand-Jensen 87; Wild 88

N_2 fixation enhanced by increased atm CO2 (Riesbesell 07) pH- 90% less CO2 at pH 5 than 7.5 because of bicarbonate loss (Titus 90; Wetzel 85); at pH 6, CO2 predominates; at pH 9, HCO3 predominates (Hussner 16); free CO2 predominates below 6.4; above HCO3- does (Pagano 07); general (Allen 72, 81; Bristow 9; Keeley 83; Morton 72; Nielsen 91; Prins 89; Raven 88; Riemer 84; Sand-Jensen 87; Schindler 77; Svedang 92; **Titus 90**; Wetzel 72, 85; WW189; Wild 88)

pH v. KH v. CO2 (**Horst 1986, p. 182**)

seagrasses, uptake of DIC- **Hellblom 99**

solubility in water 200 times greater than O2 (WW188)

temperature: effect on water solubility (Engineering Tool Box 2013)

terrestrial plant requirements for- **Bowes 91, 93**; Bristow 69

uptake as nutrient (**Allen 72**; Boston 89; Bowes 87; Bristow 69; Kerr 72; **Madsen 91**; Morton 72; Prins 89; Rai 79; Rattray 91; Sand-Jensen 87; Schindler 72; Sculthorpe 67; Titus 90; W202+, 219) corresponds to maleic acid accumulation (Keeley 84,87) and oxygen production (King 72; Raven 88) uptake increases with water movement (Keeley 83; Morton 72; W219) and decreases intracellular pH (Adamec 93; Pokorny 85; Sharma 95; Weber 79); but increases extracellular uptake (Reiskind 89); 'uptake' occurs as simple diffusion (Reiskind 89) sediment levels of (Barko 83; Bristow 69; Caffrey 91; Madsen 91; Painter 88; Roelofs 84; Sondergaard 79; Svedang 92), and as a source of CO2 (Kelly 84; Ohle 78; **Titus 90;** Wetzel 72); algae uptake enhanced by increased atm CO2 (**Riesbesell 07**)

CO2 Uptake Strategies-

aerial growth (Blom 90; Boston 89; Bowes 93; Botts 90; **Frost 95**; Idso 90; **Salvucci 82**); CO2 fertilization counteracts aerial leaf strategy **(Madsen)**

aerial, floating, and submerged leaf comparison (**Frost 95**; **Nielsen 93**) aerial leaf of amphibious plants in water with low levels of CO2 (Bowes 93)

bicarbonate use by aquatic plants (Barko 83a; Bristow 69; Gaudet 73; Madsen 91a,b; Morton 72; Nielsen 93; **Prins 89**; Raven 88; **Sand-Jensen 87**; Smart 85; W219, 529; Wetzel 85) and marine macroalgae (Reiskind 89); carbonic anhydrase releases the CO2 (Lee 89)

CAM (Boston 89; Hostrup 91; Madsen 91; Raven 88; Reiskind 89; WW543; Wild 88) and nighttime acidification within the plant (**Sharma 95**)

CCM (CO2 concentrating mechanism) (Bowes 93); Hydrilla's inducible mechanism (**Resikind 97**)

emergents use pressurized gas flow and mostly atm CO2- Wetzel 90

FAM uptake from water of CO2 (Boston 89; Gopal 87) and bicarbonates (Gaudet 73) is probably less than atm. uptake (Wetzel 90)

leaf gas films on emergent plant leaves (**Pedersen 10**)

Ottelia alismoides has C_4, CAM, and bicarb uptake (**Han 20**)

refixation, internal (Boston 89; Bowes 93; Lloyd 77; W532; Wetzel 85); need for lacunal reservoir and PEPcase (Wetzel 90) review (Boston 89; **Bowes 87, 89, 93**; Madsen 91; Sand-Jensen 87; Wetzel 85, 90; **Yin 17**)

sediment utilization- Bowes 87, 89; Dacey 82; Hostrup 91; Madsen 91; **Raven 88**; Roelofs 84; Sand-Jensen 79; Smits 90a; **Sondergaard 79**; W532; **Wetzel 85**); shown for *Eleocharis acicularis* and *Myriophyllum tenellum* as well as Isoetid—type plants, their competitive ability inhibited by increased water CO2 **(Titus 17**), but they still respond to increased CO2 (**Pagano 07**); uptake by plants (Val and Ludwigia) other than Isoetids, is substantial in DIC poor habitats, correlates with root porosity, small size, and low water CO2 (**Winkel 09)**

Cu (Copper)-

availability *in situ* (Bowen 79; Pagenkopf 86; W314); deficiencies common in peat soils (Davies 97)

binding to DOC (Bingham 86; Bisson 92; Pagenkopf 86; Russel 73; W314; Wild 88); aquatic DOC reduces toxicity to minnows (Welsh 93) and daphnia (Giesy 83; Winner 85)

cellular uptake via Fe transporter- Cohen 98

CuS formation results in deficiencies in some sediments- Binhgam 86; Ponnamperuma 81; Reddy 77; W308

deficiency symptoms in plants- Sauchelli 69; Wild 88

enzyme assoc.- Raven 88; Smith 84

free form taken up- Bingham 86; Pagenkopf 86

intracellular concentration of Cu is zero- Rae 99

Mo, competitive uptake- Martin 86; Sauchelli 69

sediment availability dependent on redox (Beckwith 75; Reddy 77; W340); toxic levels of (Gambrell 91; **Isolda 91**)

species of Cu in water and soil- see 'Metal Toxicity'

subcellular distribution of in plants- van der Werff 79

toxicity of (Bennet 71: Bingham 86; Bowen 79; Frank T5(1); Goldman 72; Keating 77; Smart 85; W196, 313; Wild 88); toxicity to algae comparable to allelopathic phenols (Aliotta 90; Greca 89); to daphnia (**Giesy 83**), minnows (Welsh 93) and duckweed (Mo 89) to adult brine shrimp v. fish (Trieff 80); to brine shrimp nauplii (**MacRae 91**); to Cardinal tetras, effect of black water DOC (**Cremazy 16**); effect of copper binding in its toxicity to rainbow trout (**Cremazy 17**)

uptake by algae (Bisson 92) and SAMs (**Marquenie 79**);

Decomposition and Metabolism-

acidity inhibits (Kelly 84; Roelofs 94; Ross 89; **Schoenberg 90**; W489; Westerman 93); adding bicarbonate can stimulate decomposition (**Roelofs 94**)

aerobic faster than anaerobic (Barko 91; Gambrell 91; Rheinheimer 85; Ross 89; Russel 73; W162, 504, 703; Wild 88) but more wasteful (Pfeiffer 01); organisms responsible for are protozoa, fungi, bacteria (Westerman 93); results in less phenols and more carboxylic acid groups in aquatic humus v. soil humus (Thurman 85); fungi and protozoa are aerobic (McKinney 04)

allelochemical leaching speed herbivore and snail consumption- Newman 91, 92

ammonification (Barko 83; Boon 86b; Blotnick 80; Capone 82; Dennison 87; Furch 88; Gunnison 89; Kemp 72; Kistritz 78; Nakajima 81; Reddy 84; Rheinheimer 85; Short 87; Toetz 71; Van Wijk 92; W233, 669); a sediment process stimulated by plants (**Boon 86b**) and waterlogging (Ponnamperuma 81; Ross 89; Wild 88)

anaerobic (Furch 88; Russel 73; W599+; Westerman 93; Wild 88) raises pH (**Kelly 84**)

aquatic plant decomposition, nutrient cycling in situ (**Hill 79**; Newman 91; Otsuki 74; **Rai 79**);by snails/bacteria after SAM is dead (Rogers 83); DOC release from and decomposition (**Mann 96**); formation of humus (Thurman 85); POC formed from plant DOC (Alber 94)

ATP generation in bacteria, rate v. yield (**Pfeiffer 01**)

autolysis of cell contents of SAMs and algae is rapid, cell walls take longer; 4-34% of phytoplankton released immediately (**WW511**)

bacterial and microbial population successions (Mann 73; **N762**; Ross 89; W610+; Wild 88); fermentors eventually replaced by respirous bacteria (Pfeiffer 01); bacteria replaced by Actinomycetes and fungi (McKinney 04)

biphasic process (Mann 96; W612; Wild 88) mostly due to bacteria (Westerman 93); slow phase due to slower degradation of cellulose, lignin, bacterial polysaccharides (McKinney 04)

C released from (Graneli 96; Kelly 84) is captured by 'alkalinity battery' (King 72)

Ca release- Parmenter 91; W211

cellulose and lignin, resist decomposition (Egglishaw 72; Parmenter 91; W489; Wild 88) but are slowly degraded by Actinomycetes (McKinney 04)

CO2 release may be 5-10 X more than oxygen consumed- Rich 78

composting, Actinomycetes important for- McKinney 04

DOC decomposition as follows: 58% used by bacteria, 23% unused, 19% form aggregates containing large densities of bacteria (WW652); DOC versus bacterial growth in water distributions systems (LeChevallier 04)

DOM formed from DOC- WW652

energy gain from various energy sources and terminal e-acceptors (**N156**)

fermentation (Ross 89) always uses pyruvate or an organic cpd as an e- acceptor (**N152**); bacterial fermentation v. aerobic respiration (**Pfeiffer 01**) provides H_2 for methanogenisis (Ash 02); anaerobic degradation of humic acids by EM(**Wang 06**)

fungi are major decomposers in aerobic sediments (Westerman 93) and decaying plants (Barlocher 94); succeed bacteria because they require less N and tolerate acidity (~pH 4.5) (McKinney 04)

humic acids, resistance to- Graneli 96; W516; Wetzel 93; Wild 88

importance- Capone 82; Juttner 81; Mann 72, 73; Rich 78; W669, 688, 699

lignin *See* ‘cellulose and lignin’

marine environment, organic carbon fluxes are important- **Azam 98**

methanogenisis, most important route of decomposition in lake sediments where inorganic electron acceptors are usually lacking; methanogens use CO2 as their e- acceptor (Westerman 93) (*See also* 'Bacteria:methane producers')

Mg and P release, less in animals than plants- Parmenter 91

N enrichment may occur with decomposition (Barko 91; **Egglishaw 72**; Hill 79; Mann 72; 73) from N_2 fixation (Ross 89);); N goes to colonizing fungi (Barlocher 94)

nutrient release from (Barko 83; Burns 72; **Furch 88**; Gopal 87; Hill 79; Kerr 72; **Kistritz 78;** Newman 91; **Parmenter 91**; Rich 78; Ross 89; Sand-Jensen 79; **Short 87**; van Wijck 92; Wetzel 72; W211, 609; Wild 88) and use by aquatic bacteria (Mann 96)

open water, primary site for- W669

oxygen consumption and PS- DeBusk 89; King 72; Moorhead 88; W166+

oxygen consumption during- Andersson 78; Burns 72; Carpenter 83; Elwood 88; Furch 88; Kistritz 78; Rai 79; Sand-Jensen 89; W161, 168, 210, 688

P gains during- **Elwood 88**

photolysis/photo-oxidation: of humic substances, importance of (Morel 83); photo-mineralization of allochthonous DOC is responsible for 10% of greenhouse gas emissions (Morris 21); PAR effective in photolysis of a plant leachate, within 2 hr, PAR releases 43% of the CO2 released by full sunlight (**WW 763**); releases chelated metals (Bisson 92; Borgmann 83; **Brezonik 94; Finden 84; Morel 83; Sunda 83**), fatty acids from humic acids (WW506, 762), and enzyme-humic acid complexes (Wetzel 93); decomposition/Fe, Mn release/algal growth correlated (**Finden 84**; Morel 83; **Rich 90**); photolysis of humic acid releases DIC and DOC that can be used by bacteria (Kaiser 97; Williamson 95); oxygen radicals produced by photolysis can destroy hydrophobic pesticides (**Latch 06**) *See also* 'Light, general: photo-oxidation'

plant release of nutrients and DOC into water (Brinson 76; Christiansen 85; DeMarte 77; Gopal 87; Kufel 91; Mayes 77; McRoy 72)

protozoan decomposition of POM can accelerate decomposition- Wetzel 92

pH- Barko 83; Furch 88; Kelly 84; W211

plant growth enhancement from- Krombholz T4(4); Paffen 91; van Wijck 92

POC (W681+) decomposition regulated by N, particle size, temperature and O2 (Mann 72; W597, 612); accelerated by protozoa- Wetzel 92

rates of (Andersson 78; Barko 83; Furch 88; Kistritz 78; **Mann 96**; Parmenter 91; Rheinheimer 85; Rich 78): fastest to slowest is carbohydrates-amino acids-amino sugars > humic cpds > lipids (WW632); faster in nutrient-rich streams (Egglishaw 72); DOC only 1% per day (Wetzel 90)

respiratory quotients (RQ)- **Rich 78**; Wild 88

sediment loss due to decomposition- W688, 730, 740

snails and bacteria complete food chain by converting detritus into food for zooplankton (**Mann 72; 73**); snails consume fungi and bacteria (Barlocher 94; Rogers 83) soluble cpds metabolized first- Newman 91

surface area necessary for bacteria-assoc. decomposition- Wetzel 92

surface scum from accumulation of hydrophobic cpds that resist decomposition- McKinney 04

stability of, in lake ecosystems- Kelly 84; W703

swamp conditions slow decomposition dramatically- WW736

water and sediment CO2- Allen 71, 72; Andersson 78; Barko 83b; King 71; Otsuki 74; Rai 79; Rich 78; W698+; Wetzel 85

Denitrification-

alkalinity generated by- McKinney 04

aquarium filters, denitrification probably occurs as filter ages (Adey 91; Dalsgaard 92)

bacteria species responsible for (Payne 73; W237) are mostly motile *Pseudomonas* (**Gamble 77**); but many bacteria denitrify in wastewater treatment (McKinney 04)

bacterial uptake of ammonia resulting from denitrification- Boon 86a

biofilms supporting denitrification (**Christensen 89; Masuda 91**) in trickle filters (Dalsgaard 92)

DAP v. denitrification (Boon 86a; Dalsgaard 94; Gilbert 97; Jones 81; Sorensen 78)

general- Armstrong 75; Bertani 87; Blotnick 80; Boon 86a ; Brezonik 72; Burns 72; Chen 88; Ernst 90; Kuenzler 86; Laanbroek 90; Nakajima 81; Peverly 79; Reddy 83, 84; Ross 89; **Seitzinger 84**; Spotte 79; Tenny 72; WW217; Weber 85; Yamassaki 92

H_2S, inhibition of- Kemp 90; Ohle 78

Lake Tanganyika denitrification acts as a sink for N- Edmond 93

N-N bond formation as in N_2O and N_2 defines denitrification- Takaya 02

N losses- Burns 72; Edmond 93; Gambrell 91; Kurtz 80; Nakajima 81; Reed 88; Reddy 83a; Ross 89; **Seitzinger 84**; van Wijck 92; Weber 85; Westerman 93; Wild 88

N_2, CO2, N_2O gases generated by (Gamble 77; Ohle 78; Ross 89; **Seitzinger 84**); N_2 bubbling from (Christensen 89)

NO may be reduced because it is toxic- Takaya 02

N_2O from denitrification destroys ozone- Seitzinger 84; Takaya 02; Wild 88

nitrate reduction to nitrites more common than denitrification- Gamble 77

nitrate removal enhanced by DOC (**Masuda 91; Obenhuber 91**) and sediment (Reddy 87)

nitrification-denitrification are linked (Kemp 90; **Masuda 91**; Seitzinger 84; Westerman 93), but most denitrification is not linked to nitrification (Risgaard 94)

nitrite accumulation v. denitrification (Gamble 77); nitrites can be used in denitrification (Pynaert03)

O2 levels in water must be <5-20 uM (Dalsgaard 92; Edmond 93: Westerman 93); PS-generated O2 inhibits denitrification (**Risgaard 94**); effect on rates of N removal (Masuda 91)

organic C requirements- Kurtz 80; Lewis 85; Obenhuber 91; Ross 89; Sommer 91

raises pH of sediment (Giblin 91; Kelly 84) and biofilms, enough to precipitate CaPO4 (Christensen 89) rates of (**Gersberg 76**) limited by nitrification (Masuda 91; Westerman 93) and other factors during wastewater treatment (**McKinney 04)**

roots of aquatic plants stimulate (**Caffrey 92**)

sediment association- Reddy 87; Risgaard 94; Seitzinger 84; Spotte 79; W238

soil type influences- Ponnamperuma 81

temperature, effect on nitrate removal from wastewater (Masuda 91)

Diseases and Predators of Aquatic Plants-

bacteria plus fungi infection (Gunner 88; **Pennington 85)** stimulates synthesis of phytoalexins (Stafford 90)

bacterial secretion of pectinolytic enzymes and gibberellin (Gunner 88); enzymatic degradation of cell wall (Rogers 83)

bacterial infection of quiescent but not actively growing explants of Anubias (Huang 94); decomposition of dead SAM leaves, SEM of invasion (Rogers 83)

Cryptocoryne 'rot'**- Triemer 89**

disease and predation minimal- **Newman 91**; W543; Zattau 88

fungus of water hyacinth (Martyn 83a,b), only when plant dying (Sharma 85)

herbivory and grazing (**WW 558**)

insect herbivores (Newman 91); grazing of Myriophyllum (Painter 88)

marine plant diseases- Harvell 99

moth feeding on Hydrilla prevented with malathion- Sutton 96

review- **Freeman 77**

DOC and POC-

algal secretion of- Allen 72; Mann 73; W392, 407, 503

amount and composition (Allen 72; **Hama 80**; **Thurman 85**; W668, 676); the majority may be allelopathic phenols (Hama 80; Kim 93; Wetzel 93); decomposition only 1% per day (Wetzel 90)

autochthonous DOC produced within aquatic ecosystem by algae and bacteria v. allochthonous DOC (orignates from terrestrial sources, mainly from the breakdown of lignin) (Sadauskas 21; **Thurman 85**)

bacterial association with transparent colloids common (**Azam 98**); hydrophobic bacteria attach to particles (LeChevallier 04)

bacterial respiration, 50% of DOC production (W698) is 2% per hour in wastewater tx (McKinney 04)

binding to membranes of algae and fish gills, especially a low pH, promoting Na+ homeostasis, DOC protection from acidity not just due to metal chelating, acclimation protects, effects on Na+ transport, membrane permeability, and electrical properties (TEP) (**Wood 11**) blackwater DOC from Amazon River basin has aromatic rings and protects fish best (**Duarte 16**)

C:N ratios increase in lake waters containing high amounts of DOC (**WW224**), because the precious N has been taken up by organisms leaving only stripped DOC behind (DLW 23)

Ca protection against metal toxicity similar but uses a different mechanism than DOC (**Cremazy 17; Morris 21**); (Martin 84; Otsuki 74; Wetzel 72); heavy metals, gill cells, and Ca suggested by fact that protection persisted after an acclimation period (**Morris 21**)

cAMP release may have diverse effects- Wetzel 90

clay binding to (Wild 88)

colloids are transparent, hydrophillic DOC of 0.001 to 1 uM size (WW736) that are colonization sites for 24-68% of bacteria (**Azam 98**); flocculation of colloids (**WW736**); in ocean C cycling, they increase flocculation of POC and and increase C uptake (Riesbesell 07)

cycling of, majority reenters food chain- Kerr 72; W690

destruction (mineralization) by photooxidation- Bisson 92

ecological stability, provision of- Reddy 83; W140, 673, 680, 703

fish, DOC's effect on: 5 different DOC types (land and aquatic-based origins) protects Zebrafish by increasing activity of Na+, K+ ATPase and v-type H+ ATPase (two enzymes critical to ion fluxes) in fish gills at pH 7.0, but this protection lost at pH 4.0 (**Sadauskas 21**), but dramatic DOC protection of zebrafish at pH 4.0 shown in earlier study, 2 wk acclimation to DOC/pH 7 provides protection from acidity because DOC binds to surface membranes of gill cells (**Duarte 16**) including ammonia excretion (Duarte 18); DOC storage anomolies (**Sadauskas 21**); DOC can stabilize pH of the gill micro-environment (Sadauskas 21); protection against heavy metals (**Morris 21**); natural Amazon black water protects Cardinal tetras against Cu toxicity (**Cremazy 16**) and acid toxicity (Duarte 16); maple leaf-derived DOC protected trout (i.e., increased 3 day LC 50 from Cu over 10 fold) (**Cremazy 17**); multiple fish species protected from acidity by DOC (**Duarte 18**)

general- W676): C content 50%, detailed example of a humic acid and a fulvic acid chemical structure (**Morris 21**)

humic acid (Aldrich), which is derived from coal and peat, different from natural DOC (Morris 21)

humus *See under* 'Humus'

ionophores, DOC that increase metal uptake- Borgmann 83; Eichenberger 86; Winner 91

labile DOC: AOC and BDOC in drinking water is 0.1 and 0.38 ppm, respectively (LeChevallier 04)

levels in natural waters, 1-30 mg/l (W668); much of it humic acids (Hama 80; Thurman 85; Wetzel 93); SAC (specific absorption coefficient) at 300-350nm (normalized to [DOC] useful indicator of metal binding and effect on organism physiology (**Morris 21**)

littoral zone, DOC source for pelagic zone- Allen 72; Serrano 92

maple leaf degradation by bacteria over 100 days to produce DOC shown to protect against Cu toxicity in trout (**Cremazy 17**) metal binding (**Giesy 78**; Otsuki 74; Russel 73; Thurman 85; Wetzel 72, 93; W196, 313, 315, 368) correlates with reduction of Cu toxicity (**Cremazy 16**) as compared to EDTA (Martin 84) controls their toxicity (Bisson 92; Pagenkopf 86; Lacroix 93; Sculthorpe 67) and nutrient availability (Barko 83b; Brand 83; Glass; Rich 90; Serrano 90; Wetzel 72; W196, 303, 313+, 368, 677); humic acid prevents Cu uptake by plants (Nor 86); protects fish from Al toxicity (Gundersen 94) leaf increases survival from Cu in trout (**Cremazy 17**) and with Rio Negro DOC in cardinal tetras; effect on gill ion regulation (**Cremazy 16**); daphnia and minnows from Cu toxicity (Giesy 83; Welsh 93)

N decreases during ammonification of- Ross 89; W668+

N, equal amounts of DOC-N and inorganic N- W232, 239

oxygen consumption, chemical- W174

POC formation from DOC; 19% of macrophyte DOC forms aggregates containing bacteria and extracellular material (Alber 94; WW652) *See also* 'Sediment: organic matter: mulm' *and* 'Biofilms: floc…'

precipitation with metals in acidified lakes (Urban 90) and $CaCO_3$ in hardwater lakes (W206, 686)

protein binding by phenols may inactivate enzymes (Wetzel 90; 92; 93)

quantity 10 X more than POC- Sutcliffe 81; W140, 506, 667+, 683; Wetzel 90

release by SAMs (**Harrison 80; Wetzel 69, 72**); DOC release by emergents, and bacteria decomposition of (**Mann 96**): 30-45% of macrophyte net productivity is released as DOC (Alber 94); SAMs excrete only 1-10% of fixed CO2 as DOC (Hough 75; W534; **Wetzel 72**), but in terrestrials, it may be 15% (Tang 86); release not related to photorespiration (**Hough 75**); but it was 2X greater in presence of algae (Hough 75); release is 4% in healthy plants and 40 % in senescing or dead plants (Hough 75; **Mann 96; Otsuki 74**; Wetzel 72) *See also* "DOC:root release…." *below*

root release increased by CO2 fertilization (Jones 98); root exudates of calcicoles identified (**Tyler 95)**

sediment and interstitial water- Barko 83

size, DOC ≤0.5 microns and POC > 0.5 microns (WW736); or what can pass through a 0.45 µ pore (Duarte 16; Thurman 85), but transparent organic colloids may be 0.02 to >100 µ (**Azam 98**)

storage in lab for 2 years of refrigeration changes DOC chemistry and physiological effects on fish (**Morris 21; Sadauskas 21**)

surface scum removal by protein skimmers (Spotte 79); DOC accumulation at water surfaces (Marshall 96) *See also* 'Biofilms: surface scum…'

surface tension reduction- W13

toxicity in sediment- Barko 83b; Ponnamperuma 81; Wild 88

light: UV and blue light decomposes DOC (Giesy 83; **Graneli 96**; Wetzel 72, 92) and increases Fe and Mn availability; produces reactive oxygen radicals that can decompose a pesticide (Mirex) and other hydrophobic cpds (**Latch 06**) *See* ‘Fe:photoreduction’, ‘Mn:photoreduction’, ‘Light, general: photo-oxidation of DOC’)

Ecology, natural interactions-

acidification, effect on all ecosystems (**Roelofs** 86), species composition, nitrification (Roelofs 83); microorganisms in acidified lakes are more vulnerable to UV, because lakes have less protective humus (Williamson 95)

algal/bacterial: bacteria feeeding off diatom mucus could affect algal blooms (Azam 98); symbiosis with SAMs (**Allen 71**; Moorhead 88; W534, 569+; Wild 88); epiphytic periphyton uptake of gases and nutrients (Wetzel 90); association within a natural biofilm (Geesey 78)

algae/protozoa interactions- Keating 87; **Williamson 95**

allelopathy and competition between SAMs and surrounding biota- Cuny 95; de Villele 95; **Gopal 93**

anaerobic conditions and seed germination of water lilies- **Smits 95**

artificial biosphere- BIOS 93

aufwuchs (Riemer 84; Sand-Jensen 89; W569) role in control of algae (**Burton 78**; Saunders 72; W464); zooplankton find home on plants (Gopal 93; Newman 91; W587); sessile nature of rotifers (W411) and others (**Fairchild 81**; W563); DOC uptake by marl encrustration of SAMs (Hough 75)

bacteria/geochemical processes; mineral ppt & solubilization (Warren 03)

bacteria/protozoa (Wild 88); protozoan decomposition of POM can accelerate decomposition (Wetzel 92); bacteria/snail decomposition of dead leaves (Rogers 83)

biofilms on the water surface- Lion 88; Potera 96

C cycling in a soft water lake (**Allen 72**) and oceans (**Azam 98)**

climax plants inhibit nitrification and the loss of N (**Rice 92**)

CO2 fertilization, effect on terrestrial ecosystems- **Jones 98**

decomposition processes- Rich 78; W167

DOC, stabilization of lakes- W140, 680

evolution and taxonomy of plants- **Brown 99**

food chain- Riemer 84; Tarifeno 82; W145, 692

fungi, freshwater (Gunner 88; Gunnison 89; Pennington 85; Rheinheimer 85; W606, 678; Westerman 93; Wild 88); saltwater marshes (Barlocher 94)

lake fill-in not a eutrophic process (W737); evolution of SAMs to emergent growth (Barko 83b; W741); Sphagnum moss accelerates (W736, 743)

littoral zone, more important to lake that pelagial- W **135**, 579-584

man, lobsters, sea urchins, sea otters, and kelp allelochemicals- Hay 88; Mann 73

marine ecosystems, diseases in- **Harvell 99**

marine snow important for sequestering C in sediments and maintaining atmospheric O2 levels (Ash 02)

N cycling (Brezonik 72; Nakajima 81; Raven 88) between bacteria, animals and plants (Porath 82)

neuston, water surface association of algae, bacteria, protozoa- W139

nutrient pumping from sediment- McRoy 72; Nakajima 81; W266, 537; Wild 88

oxygen, earth's main source is Blue-green algae (Ash 02)

phage keeps algae blooms and bacteria in check (**N326**)

productivity linked to greater species diversity- **Hector 99**

rhizosphere, root secretion of organics and oxygen linked to aufwuchs in the water (**Coler 69**) and sediment bacterial activity (**Blotnick 80**)

rivers/streams are unstable habitats (Newman 91)

SAMs, a metabolically active area- Fairchild 81; Sand-Jensen 89; W571; Wetzel 90

sludge filters- protozoa and bacterial succession during filter maturation (**McKinney 04**)

snails, fungi, bacteria (**Barlocher 94**); decomposition of dead leaves (**Rogers 83**)

Elements and size of earth's inhabitants-

algae- **Fabregas 86**; Tarifeno 82

animals, fish, plants, bacteria, algae, crustaceae, fungi have same elemental composition and susceptibility to toxic metals- Bowen 79; **Kirchgessner 86**; Nieboer 80; **Sposito 86**

bacteria (Bowen 79; Kistritz 78; Rheinheimer 85; Ross 89; Tenny 72; Wild 88); size ranges from 1-5 um with most being 1 um (Internet) while protozoa are 2-2000 um (Ash 02); eukaryotic cells are 10 um (Internet); chemical composition of (**McKinney 04**)

bioactivity determined by physical factors- **Martin 86; Nieboer 80; Sposito 86**

chemical composition of waters, soils, flora, fauna, etc- **Bowen 79**

covalent binding ability- Martin 86; Sposito 86

DNA- 100 fg DNA equivalent to 20 Mycobacteria- Puttinaowarat 02

duck- Parmenter 91

electron exciting ability- Shkolnik 84

electronegativity (electron-attracting ability)- Nieboer 80

enzymes with similar biochemical mechanisms contain same micronutrients- Eichenberger 86

eukaryote (10 um) has 1000 X the volume of a prokaryote (i.e., bacteria)- Internet

Fe requirements universal- Smith 84

fish (Bowen79; Fraser 82; Kirchgessner 86; Parmenter 91; Shearer 88) are about 70% water (Parmenter 91)

freshwaters, marine waters- Bowen 79; Sposito 86; W180+; Whittaker T92

fungi contain 5% N while bacteria contain 12% N (McKinney 04)

hydrolysis in water- Martin 86; Nieboer 80; Sposito 86

invertebrates- brine shrimp (**Bengston 85**) and daphnia (Tarifeno 82)

ionic potential (Martin 86; Nieboer 80; Sposito 86); as ratio of charge to ionic radius (Brown 00)

ligand exchange rates- Martin 86

mammal- rat (**Bernhart 66**)

marine phytoplankton fix 1/3 of earth's CO2- Bowes 93

microorganisms: relative size of protozoan cysts, algae, bacteria, and viruses and filtration from water (LeChevallier 04)

oxidative state and form of elements required for biota- Smith 84

protozoa are 2-2000 um (Ash 02)

requirements of plants and animals (Bowen 79; Eichenberger 86; Wild 88) and horses (Maynard 79)

sediment levels of elements (Huebert 83; Painter 88) and metal contaminants (Lee 07)

size comparison of microbes/protozoa (LeChevallier 04; **N10,14**) *See also* "bacteria…."

water content of bacteria is 70% (Nester, p.107); dry matter is 6.7% in SAMs but 20% in terrestrial plants (Bowes 87)

Energy transformations- (all numbers are per mole)

aerobic respiration 3 X more efficient than fermentation (Ross 89); but more wasteful (**Pfeiffer 01**); generates 32 ATP v. only 2 ATPs for fermentation (Pfeiffer 01); maximum ATPs generated by aerobic respiration is 34 (N151)

alcohol fermentation deprives plant of C skeletons for ammonium uptake (Koch 90) and deprives plant of energy (Koch 90; Wild 88)

ammonium uptake by roots requires energy- Koch 90

ammonium oxidation to nitrate by nitrifying bacteria is -84 Kcal (WW216); ammonia oxidizers get 42% of the energy contained in ammonia (McKinney 04)

anammox: anaerobic autotrophic bacteria convert ammonium plus nitrite (as e- acceptor) to N_2 with hydroxylamne (NH_2OH) and hydrazine (N_2H_2) as intermediates- Jetten 99

arsenic as an e- acceptor; As V to As II = 135 mV (Oremland 03)

CH burning releases 470 KJ, CH synthesis requires 1,400 KJ- Lawlor 87; Wild 88

CO2 reduction requires 460 KJ- Lawlor 87

electricity generated by *Geobacteria* when provided with graphite electrodes (**Bond 02**)

electron acceptors: O2 v. nitrate v. sulfate v. CO2 (N156; Payne 73); graphite electrodes (**Bond 02**); energy gain comparison for various energy sources and electron acceptors (**Nester, p156; Zinder 78**)

electrons, 24 generated from each glucose (Raven 92, p. 96); 8 generated from acetate (Bond 02)

energy/synthesis relationships during aerobic decompositon about 1/3 of the energy obtained by either bacteria or protozoa is used to convert the other 2/3 to new cell mass; a minor portion (2%/hr) is used for endogenous respiration (McKinney 04)

glucose, bacterial oxidation (2,800 KJ) v. fermentation (75 - 180 KJ) (Ross 89: Wild 88); oxidation (670 Kcal) v. fermentation (21 Kcal) (Rabinowitch 69)

iron oxidation inefficient (-11 Kcal) [W310];); growth of *Geobacter* using Fe^{3+} is 20% that of using O2 as e^- acceptor (Kostka 02) metabolism is aerobic, anaerobic or fermentative (**Nester, p148**; **Ross 89**); anaerobic metabolism in stressed fish lowers muscle pH to 6.8 and increases plasma levels of lactate (**Veiseth 06**)

minimum requirements for reactions is –20 kJ (Ash 02)

methanogenisis, primary route of decomposition in lake sediments, because of lack of inorganic electron acceptors (Westerman 93); methanogenisis of acetic acid yields 1/20th the energy of aerobic oxidation (Boyd 95; N156)

nitrate oxidation to nitrite = 66 Kcal (WW215)

nitrate reduction by algae (162 Kcal) is 23.4% of energy from combustion of glucose (Hageman 80) which yields 670 Kcal (Adey 91)

nitrate reduction by plants (-83 Kcal or 347 KJ) (Lewis 86); reduction by bacteria yields only 83% of the energy they could get using oxygen (McKinney 04)

nitrification (-349 KJ) v. anammox (-358 KJ) provide same energy to bacteria (Jetten 99) v. comammox (**van Kessel 15**)

nitrite oxidation to nitrate = 18 Kcal (WW216)

organic matter can be oxidized or used for synthesis- Rabinowitch 69

surface area/mass ratio greater for bacteria than fungi; this gives bacteria the advantage in obtaining nutrients (McKinnery 04)

Eutrophication-

acid mine wastes due to pyrite oxidation (Ash 02; Nester, p277; WW294); Thiobacilli speed up the process (**Zinder 78**)

acidification (Andersson 78; Fraser 82; Giblin 90; Grise 86; Kelly 84; Schuurkes 86; Titus 90; Urban 90; Wetzel 85) influences species succession (**Roelofs 84**); effect of lake liming (**Roelofs 94**); Al toxicity to fish (Lacroix 93); more susceptibility to UV of plankton (Williamson 95)

algal bloom pH and O2 changes (**Nakajima 81**); suppression of bacteria and other algal species (Juttner 81; Keating 77; 78); bloom associated with biomass of 10-40 mg/l dry weight (Morton 72); presence of Blue-green algae (King 72; Schindler 72); water levels of N and P > 0.3 and 0.015 ppm (Barko 91; Gerloff 75; Schindler 77; W256); release of toxins (Carmichael 94; Hallegraeff 93)

algal elimination of SAMs (Moeller 88; Ozimek 91; Simpson 86) not due solely to N and P (**Balls 89**); but removal of zooplankton by fish (Balls 89; Ozimek 90; W464)

arsenic release from well-drilling- Oremland 03

aquaculture contamination of sediment and seawater- Burford 01; Christensen 00

bioremediation (reversal of eutrophication) (**Ozimek 90**; Shapiro 90) using biostimulation and bioaugmentation (N791)

dead zones in the Gulf of Mexico- N765

diseases in marine ecosystems- **Harvell 99**

general- W293, 731 *See also* ‘Wastewater Treatment’ global warming: CO2 increases, effect on PS (**Bowes 93; Cowling 99**); possible long-term negative effects on root biomass (Shaw 02); CO2 produced by marine biogenic decalcification (Elderfield 02); acidification of seawater (**Riesebesell 07**); methane from wetlands and oxic lake waters (**Tang 16; Vroom 22**)

gluteraldehyde: metabolism in sediment and water (**Leung 01**); effect on algae, invertebrates and fish fry (**Sano 05**)

heavy metals in contaminated sediments (**Lee 07**)

indicators are algal growth (Nakajima 81; W380, 384); CO2 accumulation (W214); oxygen deficit (W172+); and high R/Q (Rich 78)

metal recovery from mixed ores using S-oxidizing, acid-generating bacteria (N157) the flip side of acid mine waste production (N277)

methane, a greenhouse gas and IR absorber is increasing 1% per year (Westerman 93); source is human waste (**N784**) and ruminant belching (N775) *See also* ‘global warming’

nitrites in Indian drinking water, removal by aquatic plants (**Rawat 12**)

nutrient excess (Balls 89; Sand-Jensen 91; W586), especially P (**Forsberg 90**; **Schindler 77**)

oil spill clean ups using Geobacter and electrodes- Bond 02

oxygen depletion of hypolimnion (Sand-Jensen 91; W176) decreases nitrification-denitrification (Kemp 90)

P,N,pH, PS and O2 changes- Nakajima 81

SAMs replaced by emergents with increasing eutrophication- Barko 83b, 86; Keeley 83; W586, 685, 741

SAMSs modify nutrient levels in Florida lakes (**Bachmann 02**)

sediment POM accumulation (Barko 83b, 86, 91; Kemp 72); contaminated sediments (**Lee 07**)

size of algal species increases- W401

species diversity is reduced- Keating 77; W379

zooplankton predation by fish may cause algal bloom (Balls 89; Ozimek 90); UV killing of zooplankton may allow algae to grow (Williamson 95)

Fe (Iron)-

ammonium fertilization increases Fe availability- Lindsay 84; Romheld 84; Wild 88

Artemia cyst production stimulated by Fe- Versichele 80

availability in water/sediment (Pulich 82; Spencer 89b; Urban 90; W303, 309, 314, Wild 88) and unavailability in terrestrial soils (Cohen 98)

bacterial reduction to soluble form (Fe^{2+}) is complicated and may not be relevant, because fermentation alone yields more energy, review of (**Lovley 91**); mostly involves an abiotic process with a humus intermediate (**WW304**); (Geobacter) solubilization of iron oxides (Ash 02) and clay Fe (Kostka 02)

biofilms entrap deposits of Fe and Mn- Lion 88 cellular transporter induced by Fe deficiency- **Cohen 98**

chelation with organics (Dooris 82; Giesy 78; James 71; O'Connor 71; Ponnamperuma 81; Russel 73; Tyler 95; Urban 90; W303, 309; Wild 88) essential for surface water solubility (Bienfait 83; Bowen 79; Urban 90; W309); siderophores in blue-green algae (Anderson 82; **Wilhelm 94**) and plants (Hopkins 95); bacterial siderophores help release Fe into the environment (Ash 02); Fe sequestering by siderophores of *Pseudomonas* bacteria (**Spanggard 01**; Verscheure 00a) *See also* 'Chelators', 'Bacteria:siderophores' *and* 'Algae:siderophores'

chelators of (Anderson 82; Romheld 83); recipe for FeEDTA stock sol (Versichele 80); humic acid analog AQDS for chelating Fe (Kostka 02)

citrate keeps Fe soluble in the xylem (Bienfait 83), in serum (Hutner 72), and is used for root washing (van Wijck 92); and as a root exudate for removing Fe from soil (Tyler 95; Zohlen 97)

clay as Fe source- Kostka 02

colloidal Fe (hydrous oxides in water) not taken up by algae (**Rich 90**), but adsorbs metals (Kirk 95; Otte 89), controlling Cu, Zn toxicity (Bingham 86) and micronutrient availability (Barko 91; Beckwith 75; Bingham 86; Gambrell 91; Ponnamperuma 81; Sauchelli 69; W316; Wild 88)

competitive uptake with Mn (Basiouny 77; Foy 78); Zn in plants (Bingham 86; Sauchelli 9; Wild 88) and Zn in fish (Wekell 86)

critical concentration for algae- Bowen 79; Gerloff 75

cycling of Fe in the water (**Anderson 82**; Brand 83; **Rich 90**; Urban 90); bog iron deposits (Westerman 93); light dependence on diel cycling of Fe (McNight 88; Morel 83)

deficiency and chlorosis induced by metal toxicity (Bingham 86), such as excessive Cu (Lindsay 84) or lime (Tyler 95)

deficiency symptoms in terrestrials (Donahue 83; Horst 85; Rorison 60b; Wild 88) a little different from aquatic plants (Krombholz T6(5); Newman 88)

EDTA and other chelators are traps for Fe^{3+}- **Anderson 82**; Rich 90

electroactivity highest of all elements- Smith 84; W300

enzymes containing Fe- Bowen 79; Raven 88; Smith 84

Fe-reducing bacteria (*Geobacteria*) are common and solubilize iron oxides (Ash 02; Meth 03) even in clay (Kostka 02)

Fe/Mn/S interaction- Gambrell 91; Giblin 90; Peiffer 94; Ponnamperuma 81; Pulich 82; van Wijck 92; Wild 88

ferrosoferric hydroxide and Fe as sediment buffer- Connell 68; Lindsay 84; Ponnamperuma 81; Ross 89; Wild 88

ferrous form essential for utilization by plants (Bienfait 84; Smith 84; Spencer 89b; Wild 88) and fish (Roeder 66) and algae (Brand 83; Rich 90); oxidized at 0.14 ppm O2- James 71

fertilization with to counteract global warming- **Chisholm 91**; **Falkowski 95**; **Kerr 94**; Martin 90

function in plants- Doucette 91a; Krombholz T6(5); Raven 88; Smith 84; W308 levels in freshwater: ave. for world’s rivers (0.67 ppm), mostly as Fe3+ (**WW170**), typical conc. in oxygenated water, pH 5-8 is 0.05 to 0.2 ppm, mostly as bound Fe3+ (**WW294**); quantitation and testing of water levels (Greenberg 92)

liver and eggs are good sources- Bowen 79; Maynard 79; NAS 77

micronutrients, coprecipitation with FeOHs- Barko 91; Bingham 86; Gambrell 91; Otte 89; Ponnamperuma 81; Russel 73; W316

N2 fixation- Raven 88; Wurtsbaugh 88

neutralization of H2S toxicity- Barko 83b; Connell 68; Ross 89; van Wijck 92; Wild 88

nitrate uptake- **Doucette 91a, 91b**; Hageman 80; Lewis 86; Martin 91; **Raven 88**; Reddy 84

nutrient requirements for phototrophic (v. heterotrophic) metabolism higher (Barko 83b; Sigel 86; W302) and 1,000 X more Fe required than Zn or Mn for marine algae (Brand 83)

oceans levels potentially limiting- Brand 83; Bowen 79; **Chisholm 91**; **Falkowski 95**; **Martin 90, 91**; Rich 90

oxidation states- DeMarte 74; Kuenzler 86; O'Connor 71; Smith 84; Wurtsbaugh 88

P binding (Barko 91; Burns 72; Gunnison 89; Ponnamperuma 81; Riemer 84; Saleque 95; Wild 88; Williams 72) on Fe root coatings (van Wijck 92); formation of Fe ppts and binding to Fe oxides (**WW252**)

peat used to remove Fe from water- **Brown 00; Spiniti 95**

pH, effect on availability- Glass 89; Grise 86; Lindsay 84; Romheld 84; Russel 73; Schat 84; Urban 90; Whittaker T92a; Wild 88

photoreduction of Fe^{3+} to Fe^{2+} (Brand 83; Faust 94; Rich 90) by blue light (Rich 90) releases Fe from the chelator (Anderson 82; Brezonik 94; Cohen 98**; Finden 84; McNight 88; Morel 83**)

precipitates (Barko 83b, 91; Burns 72; Chen 88; Giblin 90; O'Connor 71; Ponnamperuma 81; Rich 90; Wetzel 72; W302; Wild 88) due to water aeration (**Cooley 80**); can be filtered out with 0.1 um pore size (Anderson 82)

pyrite *See* “Fe (Iron):sulfides”

redox effect on availability (Burns 72; Chen 88; Lindsay 84; Ponnamperuma 81; Reddy 77; Wild 88; W301, 303) and algal uptake (Anderson 82)

root uptake (**Romheld 83**) from apical tip only (Wild 88); root coating of iron oxides (Otte 95; Zohlen 97); associated with Fe-oxidizing bacteria (**Emerson 99**)

secretion of Fe chelators by plant roots- Cohen 98; **Hether 84**; Hopkins 95; **Romheld 83**; Tyler 95

sediment levels of (Painter 88) are higher in organic muds (Misra 38); iron not necessary in the water for pondweeds (Huebert 83)

sedimentation greater than release into water- Bowen 79; Urban 90

siderophores, bacteria and algae chelators *See* “Fe (Iron):chelation with organics”

solubility in sediment (Foy 78; Westerman 93) regulated by CEC, pH, S (Ponnamperuma 81) and redox (Reddy 77); solubility in water regulated by O2 (O'Connor 71)

sorbitol/Fe complex, model for cytosolic Fe- Martin 91; Rich 90 species variation in uptake and translocation- Zohlen 97

stimulation of Cu, Mn, Mo uptake- Tarifeno 82

stimulation of growth (Allen 72; Basiouny 77; Brand 83; Goldman 72; Wurtsbaugh 88) up to 33,000 mg/kg in Hydrilla tissue (Cooley 80)

storage by plants (**Bienfait 83**; Raven 88; **Smith 84**; Spencer 89b); humans (Bowen 79; Maynard 79; Sigel 86; Tsai 88) and bacteria (Basiouny 77; Smith 84; Wild 88)

strategies to increase uptake by plants (Bienfait 83; Hether 84; **Lindsay 84**; **Romheld 83,84**) and bacteria (**Tsai 88**) and blue-green algae (Ash 02; **Wilhelm 94**)

sulfides of Fe exchange with more toxic metals such as Zn (Rozan 00); FeS_2 oxidation by bacteria generates acid mine wastes (Ash 02)

toxicity (Allen 72; Dooris 82; **Foy 78**; Grise 86; Horst 85; Laanbroek 90; Ponnamperuma 81; Pulich 82; Smith 84; **van Wijck 92**; Wild 88) and mechanisms of (Bienfait 83; **Halliwell 84;** Rorison 86) and symptoms of excess in aquatic plants is brown, rusty deposits (Cooley 80; Horst 86; van Wijck 92)

uptake from water (**Basiouny 77**; Spencer 89b) and sediment (Barko 83b, 86; Brinson 76; DeMarte 74; Grise 86); by algae requires light (Wilhelm 94)

Fish-

acidity kills due to reduced active Na and Cl uptake and their passive loss resulting in reduced plasma levels and circulatory failure (Morris 21)

age of fish affects nutrient uptake and excretion- Newman 88

ammonia excretion coupled to Na intake (Morris 21)

anesthetics and euthanasia: natural opiates in some fish reduce hyper-respiration and immunosuppression due to stress (Wendelaar 97); clove oil as fish anesthetic: did not depress immune function (**Bresslrer 04**); clove oil suppressed cortisol and lactate response to stress (**Small 04**); vet anesthetics (Lewbart 01; **Noga 10**)

aquaculture: water chemistry (N species, Cl, pH) of clean influx water and rearing water in 3 Tilapia fish facilities that had massive die-offs due to nitrite toxicity (**Svobodova 05**); disease transmission to wild fish (Diamant 00)

autopsy procedures for fish disease diagnosis (**Stephen 09**)

bacteria that colonize fish depend on site: Rainbow trout skin and gills have Pseudomonads and *Acinetobacter/Moraxella* with gills also having Enterobacteriaceae; gut has Enterobacateriaceae and Vibrionaceae (**Spanggaard 01**); species that colonize Zebrafish gut (**Rawl 04**) normal microflora of undiseased tropical fish (**del Rio-Rodriguez 99**) EM colonize the intestine before other organs (**Harriff 07**); bacteria found in trunk kidneys of healthy fish were *Aeromonas, Edwardsiella tarda, Pseudomonas, Flavobacterium*, etc at 10^3 to 10^4/g tissue whereas diseased fish had 10^7 to 10^8 (**Walters 80**); skin ulcers due to *Aeromonas* are common in Koi (Wildgoose 99); obligate pathogens are *Yersinia ruckeri*, *Edwardsiella tarda* and *Aeromonas salmonicida* (del Rio-Rodriguez 99); innate immunity keeps intestinal microflora in check (**Ismail 09**; Rawlson 04)

Ca taken up by gills and skin (Perry 85); fish don't need any in the food (Flik 93); carp and trout easily get Ca from water containing 5-20 ppm (Hilton 89), but if there's none in the water, they'll get it from the food (Robinson 87); therefore, Ca deficiencies in fish rare (Hilton 89); depolarizes TEP in lung cells (Sadauskas 21); Ca can counteract gill damage from low pH but increased toxicity in acid lakes (**Morris 21)**

carp can efficiently suppress stress-induced hyper-ventilation (Wanderlaar 97)

catecholamines (epinephrine and norephinephrine), restingly levels are <5 nM but increase to 1,000 within 1-3 min following stress; can remain at high levels for hours and days (Wendelaar 97)

chloride (Cl-) competes with nitrite so need to add NaCl to prevent nitrite toxicity problems, especially in ponds and aquaculture facilities (**Noga 00; Svobodova 05**)

cortisol- regulates osmotic homeostasis (“seawater hormone”) and energy metabolism; rapid elevated levels is classic indicator for stress (DiBattista 05; Wendelaar 97); resting level is <5 ng/ml and 10 ng/ml enough to reduce disease resistance…half of 82 investigations reported fallaciously high cortisol in control fish (**Pickering 89**); cortisol, like other corticosteroids, when injected into fish reduces immunity and resistance to pathogens (Wendelaar 97); cortisol injected into fish reduced growth rate and made fish behave submissively (**DiBattista 05**); chronically high cortisol blood levels due to injection and/or diet increased susceptibility to disease (**Davis 03; Wang 05**) but not to catfish challenged with *E. ictaluri* (**Small 05**); fish bred for lower cortisol response to stress (Pickering 89; **Pottinger 99**; Scott 97; Trenzado 03; Wendelaar 97; Veiseth 06) were resistant to opportunitistic disease (**Pickering 89**) and experimental diseases (**Fevolden 93**); cortisol elevation is a primary response to stress, while glucose, lactate, osmolarity, muscle pH changes are secondary effects (Veiseth 06) and immunosuppression is a tertiary effect (Wendelaar 97); huge individual variation in fish cortisol levels after stress, and association with small size (**Ramsay 06**); stress-induced cortisol levels reduced within 6 h by exercise (**Veiseth 06**) and returned to normal within 24 –48 hr (**Maule 80**) from acute stress but required 4 weeks for chronic stress (**Pickering 89**), but doesn’t return to baseline even at 14 days (**Trenzado 03**); clove oil reduced cortisol response 74% in stressed fish (**Small 04**); cortisol released by gills (Scott 07); water cortisol levels can be measured and reflect fish production of cortisol (**Scott 07**); release by infected fish (**Ellis 07**); effect on leukocytes *in vitro* (**Esteban 04**); higher cortisol concentration (after injection) correlated with susceptibility to opportunistic pathogens (**Pickering 81**); cortisol injected with cocoa butter has slow-release action (**Wang 05**)

decomposition of fish and nutrient release from- Parmenter 91

digestibility of fishfood ingredients- Lall 89; Hinshaw 92; NRC 83

disease susceptibility increased by poor water quality (**Ackerman 06; Walters 80**), stress (**Davis 02; Peters 88; Small 05**), dietary cortisol (**Davis 03; Small 05**), injected cortisol (**Pickering 81**), CO2 at 6 mg/l (**Walters 80**), and fish selected for high cortisol response (**Fevolden 93**); brief stress (30-60 sec in a net) enhanced disease resistance (**Maule 80**); crowding with 5 days of fasting (**Ramsay 06**); carp immunity to viruses decreases in winter at cold temperature (van der Sar 04b)

disease, experimental models of: Zebrafish model for studying specific viral and bacteria diseases; dissemination of fluorescent-labeled bacteria within the embryo (**van der Sar 04b**);

diseases, non-parasitic: pondfish diseases and treatments (**Lewbart 01**); 10% of all cultured fish are lost to disease (Heppell 00); 63% of 70 Czech aquarium fish that died and were examined had MB (**Lescenko 03**); veterinarian for Florida fish farms discusses MB (**Yanong 01**); virus in carp common in winter months (van der Sar 04b); fish diseases that can be transmitted to humans (**Novotny 04)**; diseased fish released cortisol into the water (**Ellis 07)**; *Aeromonas* spreads from intestine to blood, kidney, liver, and spleen within 11 hr (**Peters 88**); opportunistic diseases are *Saprolegnia* (saphrophytic bacteria and fungi) fin-rot, and furunculosis (boils) (Pickering 81) *Salmonella* and *Mycobacterium* co-infection in frog model (**Cosma 04**); *Aeromonas* and VHS virus in salmon (**Ellis 07**) and trout (**Peters 88**); enteric septicemia in catfish (**Small 05; Wise 93**); CCV and Ich in catfish (**Davis 02, 03**); *Vibrio* in salmon (**Maule 89**); *Aeromonas* in catfish (**Walters 80**); opportunistic pathogens in salmon (Pickering 89) and catfish (**Walters 80**); *Aeromonas* in grass carp (**Wang 05**)

DNA vaccines in fish (**Heppell 00; Pasnik 05**) are more stable than those injected into mammals and provide long-term protection (Heppell 00)

eggs: disinfection with iodophor and methylene blue (Sanders 01); egg production and disinfection method for producing germ-free Zebrafish involves hypochlorite baths and antibiotics (**Rawl 04**); Zebrafish can lay up to 200 eggs/week (van der Sar 04b)

element composition of fish (Kirchgessner 86) depends on tissue analyzed (Wekell 86)

embryos of fish produce macrophages and granulocytes within 2 days (**van der Sar 04b**); embryonic macrophages can quickly eradicate non-pathogenic bacteria (Davis 02); development of intestine and its flora in zebrafish (**Rawl 04**)

excretion of N and P (**Hinshaw 92**) and Zn (Ishihara 86; Newman 88)

exercise speeds recovery of normal cortisol levels, etc following acute stress (**Veiseth 06**))

fatty acid requuirements of coldwater marine fish- Dhont 02

Fe, Ca, PO4 uptake from water opportunistic- **Yarzhombek 87**

feces, release nutrients (**Windell 78)** and contain live mycobacteria (**Perez 01**); no species of mycobacteria found in normal Zebrafish gut **(Rawl 04)**

foods for fish: livefoods for aquarium fish (**Malla 15**); nutrition, general- NRC 83); foods should be 30-40% protein and contain 9-11% lipids, pellets better than flake food, DHA (n-3 HUFA) enhance fecundity, growth, and stress resistance (Kithsiri 07); fish oil worked better than coconut, safflower, and linseed oil as food additive for guppies (**Kithsiri 07**)

gill maintenance of electrolyte balance (**Bond 96**, p404; **Spry 85**; Twitchen 94; **Wendelaar 97**; Wood 92); effect of Al (Witters 90) and stress (**Wendelaar 97**); smaller fish always have a higher gill surface area than larger fish (Scott 97); DOC affects respiratory exchange of CO2, O2, and ammonia gases (Morris 21)

gluteraldehyde toxicity to embryos and fry (**Sano 05**)

goldfish specific disease is GFHNV, a Herpes-live virus (Stephens 09)

gourami specific disease (Stephens 09)

growth- growth hormones stimulate, but catecholamines and cortisol are the major hormones that inhibit growth (Wendelaar 97); cortisol (slow-release injection) inhibited trout growth (**diBattista 05**); stress inhibited growth (**Peters 85**)

guppies *See under its own heading* 'Guppies'

hsp (heat shock proteins)- indicators of cellular stress from heat, toxicants, and ammonia- Ackerman 06

homeostatic control (Bowen 79; Eichenberger 86; **Frieden 84**; Hinshaw 92; Kirchgessner 86; Martin 86; **Mertz 86, 87**; Newman 88; Wekell 86); gill uptake of Na, Cl, gill excretion of NH3, pH regulation, DOC involvement (**Duarte 16; Wood 11**)

hormones- review list of fish hormones, passive release from the water via the gills (**Scott 07**); degradation of hormones within days (Scott 07); rapid uptake from water, transfer between fish, and biomagnification within the fish (**Scott 07**); cortisol released into the water (**Ellis 07**)

Ich disease severity increased by stress (**Davis 02**), chronic MB (Talaat 98) and dietary cortisol (**Davis 03**)

immunity in fish (**Heppell 00);** white blood cells described (**Peters 85**); major components of, and relation to stress (**Wendelaar 97**), is evolutionary novelty of jawed fish, which contain both innate and adaptive immune system; macrophages and granulocytes appear within 2 day old embryos (Davis 02: **van der Sar 04b**); development of adaptive immunity in Zebrafish embryos requires 4 weeks (**Rawls 04**) genetic manipulation in Zebrafish of adaptive immunity and disease resistance (**Swaim 06**); stimulation of innate immunity to intestinal pathogens by gut bacteria (**Ismail 09**; Rawls 04); acute stress may stimulate and/or suppress immune system (Ackerman 06; Small 05; Wendelaar 97); brief stress *enhanced* disease resistance (**Maule 80**); immunologically activated wbc's release oxygen radicals during "respiratory burst" that can damage self wbc's (Ackerman 06); immune function of specific cells depressed by anesthetics (**Bressler 04**), stress and cortisol (Davis 03); cortisol on leukocytes *in vitro* (**Esteban 04**); APC's (antigen-producing cells) decreased after brief stress (**Maule 80**); brief stress v. strong or chronic stress on lysozyme activity (**Mock 90; Wang 05**); immune cells (neutrophils) get worn out from stress (Ackerman 06); stress destroys kidney and splenic tissues and cells (**Peters 85**); high dose cortisol shrank spleens significantly and hurt macrophage function (**Wang 05**); serum contains factors other than lysozyme that kill bacteria (**Wang 05**) *See also* 'Mycobacteriosis : immunity in fish'

ion regulation: ion kinetics explained (e.g., Discus from Na+ depleted habitats have a high Km (>250 uM/l) meaning they take it up rapidly, while other species from same habitat have low Km (<50 uM/l) meaning they probably conserve Na+ instead to maintain homeostasis (**Zimmer 21**) intestine- development and microbial colonization of (**Rawls 04**); immunity in (**Ismail 09**; Rawls 04); gut of embryonic fish is colonized by what's in the water, so the microbial microflora of the rearing tank is critical (Verschuere 00b); EM enter through mouth and colonize intestine (**Harriff 07**); intestinal injury allows bacterial penetration (Ismail 09) *See also* 'Bacteria:intestinal…'

kidney (anterior or head) primary blood-cell forming (haemopoietic) organ- Broussard 07; Esteban 04)

lysozyme, part of innate immunity (Bressler 04; Wang 05); enzyme that degrades the peptidoglycan layer of gram positive bacteria (Mock 1990); levels correlated with blood levels of infectious bacteria (**Small 05**)

melatonin- hormone produced in response to darkness (Scott 07)

Mg, most (84%) taken up from food not the water (Flik 93)

mineral requirements (**Fabregas 86, Lall 89**; NRC 83; **Tacon 83**)-- Ca, P (**Andrews 73;** Cowey 76); K (Maynard 66; **Shearer 88**); Zn (Eichenberger 86; **Wekell 86**); Mg (**Cowey 76**); Fe (Maynard 79; **Roeder 66**)

muscus layer of fish *See under* 'Parasitic Diseasess of Fish'

Na regulation and their K_m and J_{max} in various tropical fish with explanations of (**Zimmer 21**)

neurotransmitters in, as affected by stress (diBattista 05; **Wendelaar 97)**

O2 uptake highly efficient (Yarzhombek 87); stress increases repiratory rate of most fish, but not carp and eel, who can decrease their metabolic rates (Wendelaar 97)

osmolarity balance- regulation by saltwater fish differs from that of freshwater fish; [salt] of fish blood 1/3 that of seawater and 100X that of freshwater; role of cortisol, metal toxicit, stress (**Wendelaar 97**) ; plasma osmolarity increases from 330 to 423 mOsm/kg after fish are stressed (**Veiseth 06**); salinity tolerance of (Stappen 02); stress resistance of aquarium fish (live bearers and black neon tetras) measured by their resistance to osmotic shock (2h of high saline) (**Lim 02**); acidity affects osmoregulation (Duarte 16)

parasites of fish *Separate indexes for* 'Parasitic Diseases of Fish' and 'MB'

pH sensitivity of fish to pH <4.7 (Borgmann 83; Kelly 84; Wood 92); acid interferes with Ca uptake (Fraser 82); limit is pH 6 for some fish (Welsh 93); Rio Negro fish (pH 4) protected by DOC (**Duarte 16**)

probiotics used in treating fish diseases- **Hong 05; Spanggaard 01**

protein, not CHs, the energy source for fish (NAS 77); means high N (~10%) content of the fish (Parmenter 91) and the fishfood (Adey 91)

quarantine, state sponsored- Australia requires a 1-3 week quarantine for all imported fish (Stephen 09)

reproduction: aquarium fish that produce small fry; decapsulated Artemia eggs could replace rotifers as the food for fry (Dhert 97)

rigor mortis, stress, exercise and fillet quality in salmon (**Veiseth 06**)

salinity tolerance and adjustment *See* 'osmolarity balance' skeletal deformities from reduced Ca uptake- Fraser 82

smoltification- adjustment to saltwater by salmon (Ackerman 06)

social behavior- submissive fish naturally have higher cortisol, lower plasma osmolarity, and lower tolerance for Cd toxicity (**Wendelaar 97**) and are darker (Baretto 06); within paired fish, 5% greater length and/or cortisol injections, significantly confers dominance of one fish over the other; a corticol antagonist (mifepristone) blocked cortisol's effect (**diBattista 05**); dominate fish were scored as those first to get food, didn't hide, & attacked the subordinate fish (**diBattista 05**); fish crowding induced several stress effects (**Veiseth 06**)

stress: review (**Scott 97; Wendelaar 97**); 4 types of stress (Barreto 06); chronic stress requires 4 weeks for cortisol to return to normal (**Pickering 81**); chronic stress depresses growth (**diBattista 05)** reproduction, osmotic homeostasis, immune system, disease resistance, resistance to further stress (Wendelaar 97) and filet quality (**Veiseth 06**); cortisol increases from stress due to handling, confinement, tagging, crowding (**Veiseth 06**), noise (Scott 07); acute stress increased plasma cortisol, lactate, osmolarity, and rigor mortis, while it decreased glucose and muscle pH (**Veiseth 06**); stress exacerbates metal toxicity (Nikinmaa 92), pollutant toxicity to immune system not the same as stress-induced immunosuppression (Wendelaar 97); social stress and electroshock equally raised cortisol levels (**Baretto 06**); high ammonia increased susceptibility to *Vibrio* disease in Salmon (**Ackerman 06**); 'low-water treatment' increased disease susceptibility to Ich (**Davis 02**) and *E. ectaluri* (**Small 05; Wang**); great variability in individual response to stress (**Ramsay 06**) may result from disturbed homeostasis (Peters 88); feeding greatly reduced the stress of crowding Zebrafish for 5 days (**Ramsay 06**); exercise brought stressed fish back to normal more quickly (**Veiseth 06**) ; stress from high nitrates and low oxygen causes fish skin to produce more mucus cells (**Vatsos 10**) *See also* 'catacholamines', 'cortisol' *and* 'social behavior'

transparent fish- "see-through Medaka" for disease study (**Broussard 07**) and Zebrafish embryos (**Davis 02**)

vaccines in fish (**Heppell 00; Pasnik 03, 05**) *See also* 'DNA vaccines'

viral diseases in (Lewbart 01; van der Sar 04b); CCV in channel catfish (Davis 02); VHS in Rainbow trout (Ellis 07); phage reduced bacterial disease (**Ellis 07**)

water composition of a fish is ~30%- Kirchgessner 86

water quality parameters for pond fish (NH_3 and NO2 <0.01 ppm; NO_3 <20 ppm) (Lewbart 01)

water uptake of cpds: nutrients (NRC 83: Tacon 83); Ca taken up equally from the gills or skin (NRC 83; Perry 85; Wood 92), gill uptake of Fe (Roeder 66), and Zn uptake from water (Eichenberger 86; Newman 88; Wood 92); water uptake of DNA vaccine via skin and gills (Heppell 00)

Zebrafish as lab animal (**Astrofsky 00; Christianson-H 04; Kent 04; Rawl 04; van der Sar 04a, b**) for real-time studying of immune system in embryos (**van der Sar 04b**); Sanger Institute to determine genome in 2005 (25 chromosomes with 1.7 X 10^9 bp) (van der Sar 04b); re-infection with *M. marinum* (**Cosma 04**); model for human tuberculosis (**Prouty 03**); model for bacterial colonization and intestinal ecology (**Rawl 04**) *See also* 'MB (mycobacteriosis):experimental infections'

Zn uptake- Kirchgessner 86; **Newman 88**; Wekell 86

Fishfood-

Artemia *See under* 'Invertebrates'

Ca, Cu, Fe, Mn, N, P, Zn excreted in feces (Ishihara 86) and B, N, and Mo excreted in the urine by animals- Bowen 79; Hinshaw 92

element composition of prepared fishfoods (**Crawford 72; Hardy 84; Shearer 88; Tacon 83**; Wekell 86); the ingredients used in fishfoods (Bowen 79; **NAS 77**; Parmenter 91) and live foods, such as brine shrimp (Bengston 85), marine algae (Fabregas 86)

metal toxicity of- Tacon 83

mineral supplements (Bernhart 66; NAS 77; **Poston 76**; Wekell 86) considered unnecessary (Hardy 84)

probiotics *See under* 'Bacteria'

sediment fertilization using fishfood ingredients- Pulich 85

source of nutrients for aquatic plants- Krombholz T6(5); NAS 77

variation in element composition of fishfoods- Tacon 83

Vitamin C, importance of in stress resistance- Dhert 97

wound healing in Koi helped by either Stress Coat, povidone, or salt (3 g/l) (**Shivappa 17**)

Gases-

air, CO2 is 0.035% (350 ul/l) and expected to double next century (Bowes 91; Post 90); air and water both contain 10 uM CO2 (WW188); density (mg/l) of water is 775 times that of air (WW12)

anoxia, < 30 uM oxygen v. oxic > 130 uM- Burns 72

bacterial generated gases include CH_4, N_2O, CH_3Cl, CO2, dimethyl sulfides- Ash 02

bicarbonate- Allen 72; Bowes 89; King 72; Rai 79; Sand-Jensen 86; Schindler 72

bubbling of N_2 and CH_4- Jones 81

carbonate, bicarbonate, CO2- Allen 72

CO2 levels inside plant may be >70uM such that they counteract O2 effects on RUBISCO (Bowes 93); in waterlily, CO2 level is 0.6 to 5% (Dacey 82)

CO2 uptake (1 mg) corresponds to 0.507 ml of PS-generated O2- Johnson 74

degassing increased by aeration (

DIC in air equilibrium is about 10 uM (Madsen 91) or about 17 uM in NY lakes (Titus 90); for expts on RGR, 16 uM is air CO2 conc at 15 C (Madsen 96); range in most lakes is 5-2,500 uM, but DIC is much higher in African lakes (Cole 94); for example, it is 6 mM in Lake Tanganyika (Edmond 93) exchange within aquatic plants (Sorrell 91); leaf gas films of emergents (**Pedersen 10**); morphology for (Armstrong 91a, 91b; Hostrup 91; Jaynes 86; Madsen 91; Rao 90; Raven 88; Salvucci 82; Sand-Jensen 87; Smits 90a) due to transpiration (diel cycle), diffusion, and pressurized flow (water lilies, diel cycle) due to simple gas conc. factors (**Vroom 22**); active flow of emergents (**Armstrong 91b; Bendix 94**; **Dacey 80, 82, 87**; Grosse 91; **Tornbjerg 94**; W530); CO2 and O2 movement in waterlily (Dacey 82); gas movement in a lotus leaf (**Dacey 87**); molecular diffusion (only) in SAMs (Armstrong 91a; Madsen 91; **Sorrell 91; Vroom 22);**

CO2 levels: "as air CO2 dissolves in water, the water contains CO2 at about the same conc. by volume (10 uM) as air and then forms bicarbonate by a slow reaction (half time of 15 sec) (**WW 188**); 0.35% CO2 in air = 350 ppm (by volume) (DLW); air equilibrium in pure water is 10 uM and 0.5 mg/l at ~25°C (WW188); if air contains 350 ul/l, water will contain 10-12 uM (Bowes 91; Cole 94); the amount of CO2 in 1 liter of water at air equilibrium is equal to amount of CO2 in 1 liter of air (Madsen 91a); in natural freshwaters, range is 0- 350 uM or 0-14 mg/l (Bowes 87) or 100- 4,100 u atm (Cole 94); CO2 in equilibrium with air is about 15 uM (Nielsen 93); CO2 in marine water is 10- 46 uM, while bicarbonates are 2-2.5 mM (Lee 89; Reiskind 89); high expt CO2 is >1000 uM, while ecologically relevant conc. is only 15-90 uM (Mommer 06)

conversion factors for CO2 (DLW 2022): m.w. CO2 = 44; 1 mM = 44 mg/l; 350 uM (0.35 mM) = 15 mg/l; 10 uM = 0.44 mg/l; if air contains 350 ul CO2/l or 0.35%, then water will contain ~10 uM CO2

degassing much faster due to aeration, reduces KH as well as CO2 (Horst 86, p77)

H2S is 30 uM in the thermocline of Lake Tanganyika (Edmond 93); release from landfills (Wang 06)

methane (Barko 83b; Ohle 72); current atm levels is 1.6 ppm (Ash 02); release from sediments through rice lacunae (Westerman 93) and waterlily (Dacey 82); levels within waterlily are 0.7 to 1.5 % (Dacey 82); release from sediments by both bubbling and gaseous diffusion (Thurman 85); and landfills (Wang 06) and wastewater treatment (McKinney 04)

N2 in water is 15-20 ml/l (Seitzeinger 84; W224); bubble formation in wastewater treatment filters (Christensen 89)

N2O produced during denitrification destroys ozone- Seitzinger 84; Wild 88

O2 in air is 21%; water levels in equilibrium with air are 240-260 um/l, but can become 500 uM (200% air saturation) in areas of active PS (Bowes 91; 93; Prins 89; W160); 80% air saturation is 228 uM (Gieseke 01)

rice have air coating on the leaves that helps oxygenate the roots- **Raskin 83**; Wetzel 90

solubility of O2 and CO2 in water (Madsen 91); CO2 is 200X more soluble in water than O2 (WW 188)

storage in lacunae (Madsen 91; W529), which makes up 70% of plant volume (W528)

Heterophylly and Emergent Growth-

aerial growth of amphibious plants more productive (**Botts 90**); able to use more light and CO2 (**Lloyd 77**; Madsen 91; **Salvucci 82**)

bicarbonate- *H. difformis* acclimates to the submergence by changing leaf morphology and using bicarbonates (**Horiguchi 19**); submerged leaf form of *Batrachium peltatum*, an amphibious plant, can use bicarbonates (**Nielsen 93**)

cells of submerged leaves have higher turgor pressure than terrestrial leaves (turgor loss due to transpiration) such that they have longer epidermal cells; shoot apex is the part that responds to water levels (**DesChamp 84**; Raven p510; Lin 05)

definition of heterophylly- extremely different leaf forms on a single plant, can be due to a variety of environmental changes (**van Veen 21**); leaf morphological changes due to temperature (20C to 25C) and light (15-90 PAR) not as great as those due changing water levels (**Nakayama 14**)

factors other than water level inducing heterophylly (**van Veen 21**): blue light, gibberellin, phytochrome, osmotic stress, light intensity (Lin 05): cold temp and hypoxia all induce submerged form (**Kim 18**); high temp (30C), mannitol (0.2M), and ABA (**DesChamp 84,** Raven p510) and more FR light (i.e, a low R/FR) plus blue light (470 nm) induced terrestrial form (**Momokawa 11**)

evolution of heterophylly in some Potamogeton species is from parallel evolution within the genera from true aquatics (**Iida 09; Koga 21**)

flavonoid chemistry of aerial and submerged forms are different- **Les 90**

gas diffusion resistance in terrestrial leaves was 15,000 X higher than in air (Mommer 06)

general- recent review (**van Veen 21**); others (Boston 89; Botts 90; Bowes 87; Bristow 69; **Hostrup 91;** Huang 94; Kane 88; **Kasselmann 03;** Lloyd 77; Nielsen 93; Raven 88; Salvucci 82; Sculthorpe 67; **W525)**

hormonal control- hormones regulate genes for heterophylly (**Kim 18; Koga 21**); regulation of GA levels via KNOX1 genes (**Nakayama 14**); ethylene incr. submerged form, ABA (abscisic acid) incr terrestrial form (**Koga 21**) and the two hormones interact (**Kuwabara 03**); ethylene induced the same increased PS in *H. difformis* as submergence alone (**Horiguchi 19**); GA instead of ethylene stimulates submerged form in *Rorippa aquatica* **(Nakayama 14)**

light wavelengths: High R/FR causes submerged leaves, while low R/FR causes aerial leaves, but blue required to show this effect (**Monokawa 11**)

low O2, not just hormones, induced submerged form (**Kim 18**)

leaf length:width ratio (L/W) increases over two-fold in stem plant due to either submergence or ethylene treatment (**Kuwabara 03**); used to measure effect of submergence (Monokawa 11)

marsh plants: cannot adapt to submergence; cannot photosynthesize, they either elongate stems drawing on energy from roots or they enter a quiescent state: *A. philoxeroides* can survive for 3 months on stored CHs (**Peng 21**); because *R. palustris* is unable to get enought CO2, the plant cannot produce enough PS oxygen for aerobic respiration and survival (**Mommer 06)** morphological changes in submerged v. emergent forms: pictures of *R. aquatica* (**Nakayama 14**)

osmotic stress via polyethylene glycol (PEG) shows that true aquatic Potamogeton species more resistant than the amphibious cohort to osmotic stress, matches tolerance to NaCl findings (Iida 06)

plant species studied: <u>amphibious plants</u> (review) (**van Veen 21**), *Batrachium peltatum* (**Nielsen 93**), *Hygrophila difformis* (**Horiguchi 19**), *Callitriche heterophylla* (**DesChamp 84**, Raven, p510); *Callitriche palustris* v. land plant *C. terrestris* (**Koga 21**); *Ranunculus trichophyllus* v. land plant *R. sceleratus* (**Kim 18**); *Ludwigia arcuata* (**Kuwabara 03**); *Rorippa aquatica* (**Nakayama 14**), *Marsilea quadrifolia* (**Lin 05**), *Rotala hippuris* (**Momokawa 11**) *P. wrightii* v. true aquatic *Potamogeton perfoliatus* (**Iida 06**); <u>marsh plants</u> (*Alternanthera philoxeroides*, alligator weed) (**Peng 21**) and *Rumex palustris* (**Mommer 06**);

Potamogeton genera contains both amphibious and true aquatic species (**Iida 06**)

R/FR light, increased R/FR (i.e., less FR) traits for submerged leaves (less stomata, narrower leaves, etc, but required blue light to do it (**Momokawa 11**)

response to submergence: 40-fold lowering of resistance to CO2 diffusion in submerged leaves compared to emergent leaves in semi-aquatic *Rumex palustris*, lowering of CO2 compensation point from 14 to 4 umol/m2/s, morphological changes (**Mommer 06**); stem aquarium plant (*L. arcuata*) produces new leaves adapted to submergence--and vice versa (**Kuwabara 03**)

response to desubmergence: more diffusion resistance in stimulation of (Bowes 86; Bristow 69; Raven p510; W526) by high temperature, intense light and more FR (i.e., low R/FR) (**Bodkin 80**; Spence 81); growth hormones (**Kane 87**; Raven p510); low CO2 (Bowes 93), turgor pressure (Raven, p 510), and photoperiod >12 hr (**Kasselmann 07**); 15 hr (v. 12hr) photoperiod for water lilies (Kasselmann 07); increased reproduction correlates with increased heterophylly (Kasselmann 07)

salinity: increased salinity (osmotic stress) tolerated by true aquatics (e.g., *Potamogeton perfoliatus*) more than the amphibious species (e.g., *P. wrightii*) (**Iida 06**)

stem aquarium plant (*Ludwigia arcuata*) produces new leaves adapted to water level changes (**Kuwabara 03**)

sugars, exposure to sucrose stimulates aerial growth of Marsilea (Edwards 56) and mannitol stimulates aerial growth of Callitriche (Raven p510)

temperature: cold temp. (4C), not just hormones, induced submerged form (**Kim 18**); increased temperature (20-25C) caused less dissected leaves (**Nakayama 14**); effect on emergent and submerged leaves of *Ranunculus flabellaris* (**WW532**)

See also Aquatic Plants:emergent' Aquatic Plants:submergence', *and* 'CO2, Strategies..: aerial'

Hormones, Plant-

abscisic acid (ABA), multiple effects (germination and growth) on a variety of terrestrial and floating plants, comparison of effect of ABA isomeres on *Marsilea quadrifolia* (**Lin 05**); stimulates aerial morphology (**Deschamp 84; Kane 87**; Raven p510); precedes turion formation in Hydrilla (**MacDonald 08**) *See also* 'Heterophylly…'

artificial propogation, use of hormones in- Hartman 87; Kane 88b, 90

bacterial production of (Donahue 83; Gunnison 89; Wild 88) ethylene (Smits 95)

Ca signaling in plant development (Bush 94; Hepler 85; Gilroy 92) and reproduction (Conrad 88)

cytokinin in a moss- Conrad 88

ethanol, stimulation of seed germination of water lilies- **Smits 95**

ethylene (Armstrong 75; Blom 90; Bodkin 80; Bowes 87; Capone 82; Donahue 83; Gunnison 89; Hartman 83; Jackson 90; Ross 89; Smits 95; Wild 88; W526) produced in response to wounding (Stafford 90) effect on germination (Smits 95); used for plant buoyancy (Blotnick 80); a senescence hormone that can't diffuse out well when plant submered, so it causes emergent growth to senesce (P.C. Tom Barr, 2007) *See also* 'Heterophylly…'

gibberellin (GA) (Gunner 88; **Lembi 92**); stimulates submerged growth (**Deschamp 84)** *See* 'Heterophylly…'

growth- Donahue 83; Hartman 83; Kane 87, 88a, 88b, 90; Linsmailer 65

heterophylly involves ethylene, abscisic acid (ABA) and gibberelin (GA) (Horiguchi 19) *See also* 'Heterophylly…'

Humus-

absorbtion of UV light and fluorescence of (Graneli 96); photo-oxidation breaks humus down into more labile DOC that stimulates bacterial growth (Kaiser 97; Williamson 95); light-triggered release of reactive oxygen radicals (**Latch 06**)

acidity of (Russel 73; W185; WW765) is mostly from carboxyl groups, which give humus its solubility and ability to bind metals (**Thurman 85**; Wilson 81); little effect except in very softwater (WW765)

aquatic v. soil humus- **Myneni 99; Thurman 85**

bacteria: degradation of humus, is considerable (WW504); humic and fulvic acids stimulate mycobacteria (**Kirschner 99**); but the phenols, quinones, phenolic, carboxylic acids of humus inhibit bacteria and fungi explaining the long-term preservation of human bodies in peat bogs (WW736)

bogwater humic acid and soil humic acid protect equally against Al toxicity in fish (Witters 90)

C, N, P, S composition- Barko 86; Russel 73; Thurman 85; Sutcliffe 81; W677

CEC is pH dependent- Ross 89; Wild 88

charcoal filtration used to remove DOC- Welsh 93

chelator properties, comparison to EDTA (Anderson 82; W303; Wetzel 93); Fe chelation by humic acid analog increases bacterial access to clay Fe (Kostka 02)

clay binding of (Hoagland 85; Thurman 85; Wild 88); precipitation and coating of soil and sediment particles (**Myneni 99**) clear, uncolored water can still contain considerable amounts of humic substances- Graneli 96

colloidal nature- Hartman 83; Wild 88

color of water a good general measure of DOC protection from metal toxicity in soft, acidic natural waters (Hutchinson 87)

dead duckweed humic acids protect against metal toxicity- Mo 89

DIC generated from humus- Graneli 96

DOC makes up 50-80% humic substances (WW 504) with a significant organic colloids (**Azam 98**)

fulvic acid solubilizing ability (W677; Wild 88); solubility greater than humic acid (Thurman 85)

general- Donahue 83; Thurman 85; W591+, 676+; Wild 88

humic acid (Aldrich Chemical Co) protects fish and daphnia from metal toxicity (Gundersen 94; Winner 85), but not fish against acidity (Duarte 16); humus as minor metal chelator in peat (Brown 00); humic acids protects plankton from UV light (Williamson 95); nature of Aldrich humic acid (Latch 06)

inhibition of decomposition (W678; Wetzel 93) in organic sediments (Myneni 99)

levels in freshwaters are 1-10 ppm (Graneli 96; Serrano 92; Thurman 85)

metal binding (Russel 73; Sutcliffe 81; W677; Wild 88) is 1 microequivalent per g humus (Thurman 85); changes structure (Myneni 99)

mulm *See under* “Sediment:organic matter”

nutrient availability increased by humic substances- Foy 78

origin (Russel 73; W489; Wild 88) from algal DOC (Thurman 85) as well as plant phenols (Buikema 79; Hoagland 85; Wetzel 92); including allelochemicals (Wetzel 93); from polymerization of quinones from oxidation of plant phenols (Haslam 89; Serrano 92); origin of aquatic humus (**Thurman 85**)

origin, potential precursors of humus are carbohydrates, lipids, amino acids and lignin (Wilson 81)

peat *See under* “Soils, terrestrial”

photooxidation of by light (**Graneli 96**) generates DOC and stimulates bacteria (Kaiser 97; Williamson 95; WW506, 762) releases oxygen radicals that degrade hydrophobic cpds (Latch 06) *See also* ‘Light, general:photo-oxidation’

protects organisms (Giesy 83; **Hutchinson 87**; Welsh 93; Winner 85) from metal toxicity and UV light (Graneli 96; Kaiser 97; Williamson 95) and possibly hydrophobic cpds (Latch 06)

protein binding to, inactivation of extracellular enzymes (Wettzel 90, 92, 93)

soil humic acid is more hydrophobic than aquatic humic acid (Thurman 86) and has less carboxyl groups (Wilson 81); comparison of functional groups (Thurman 85; Wilson 81) and protection of organisms from metal toxicity (Gundersen 94)

Invertebrates and Protozoa

aquaculture, penaeid shrimp in Indonesia- **Moriarty 98**

amoeba *See under* ‘MB…’

brine shrimp- *See* Artemia (Brine shrimp) below

daphnia: element composition of (Tarifeno 82); food for (Winner 91); *Ceriodaphnia* not as good a food source as decapsulated Artemia eggs (**Adewolu 09; Lim 02**) Moina not as good as naupli or decapsulated eggs for survival and growth of guppies **(Lim 02);** inhibition by aquatic plants (Newman 91; Pennak 73; W555) and heavy metals (Winner 91); main grazers of phytoplankton (**Saunders 72; Shapiro 90**)

diseases of: Vibrio in penaeid shrimp controlled by *Bacillus* probiotics (**Moriarty 98**)

hydra- use Flubendazole or Fenbendazole at 2 mg/l to kill (**Nogoa 10**)

nematodes are a major component of benthic invertebrates reaching densities of a million per m^2 (1,000 liters) of substrate surface under certain conditions (springtime in oligotrophic sediments containing aquatic plants); intolerant of low oxygen so not found in eutrophic substrates; many different species not all parasites, some feed on debris, others bacteria; fertilized eggs laid outside the body develop in 1-10 days and hatch into well developed young; most species require 20-30 days for development and reproduction (WW670); soil nematodes include plant pathogens as well as those in organic-rich, but aerobic soils feeding on bacteria, protozoa and other nematodes (Russell 73, pp. 518-20)

population succession of protozoa and bacteria in wastewater tx (**McKinney 04**); bacteria, daphnia and dragonflies (**Kazda 00)**

protozoa, characteristics of (**McKinney 04**); stimuate plants and bacterial growth (**NRCS 2009)** *See also* “Ecology, natural interactions”

rotifers, densities higher in vegetated areas (W412); feed on bacteria and small algae (W409); value as a life food and disease transmission to fish (Verschuere 00b); common in wastewater tx (**McKinney 04**); easier to boost with HUFA than Artemia (Dhert 97)

size and global distribution of protozoa and microbes- Ash 02

sea shells contain ~15% $MgCO_3$- Dickson 02

soil, # of portozoa in ranges from 1,000 to 106 per tsp (NRCS 2009, BLM 2009)

worms and intvertebrates in wastewater tx (**McKinney 04**); invertebrate burrowing in sediments can increase microbibal activity four fold (WW651); oxidation of sediments by (Ash 02)

Artemia (Brine shrimp)-

algae for brine shrimp food *See* ‘foods….’

ammonia (up to 50 ppm) tolerated (Bossuyt 80); 24 h LC50 for newly hatched Artemia is 840 ppm (**Chen 89**); high summer-time levels in GSL (Porcella 72)

aquaculture industry need for brine shrimp cysts; past demands and future predictions (**Lavens 00; Sorgeloos 80, 01**); probiotic cultures added to farmed shrimp, scallop, turbot larva help (**Verschuere 00b**)

artificial culture of Artemia to adulthood (**Dhert 93)** using microalgae **(Sorgeloos 85**) not all that pracatical or that nutritious (Leger 86) bacteria associated with culturing and population growth (**Gorospe 96**), no known fish pathogens (**Austin 81**); nauplii are born bacteria-free (Austin 81), population changes and *Artemia* survival; culture bacteria can come serendipitously from the cysts, food, tank, and seawater (**Verschuere 97**); only about 1 bacterium/dry cyst but this is often the starting inoculum, which consists of *Bacillus, Erwinia, Micrococcus, Staphylococcus* and *Vibrio* spp; once food added to brine shrimp tank, bacteria quickly multiply feeding on the food and unhatched eggs (**Austin 81; Gorospe 96**); *Pseudomonas* preferred by *Artemia* over other bacteria (**Gorospe 96**) adding helpful bacteria beforehand protect *Artemia* from a later disease challenge; bacteria that do best with *Artemia* can ferment (Verschuere 00a); effect of added bacteria differs with food quality fed to *Artemia* (**Marques 05**)

boosting with fatty acids (**Leger 86**; **Tamaru 1997)** begins 8 after hatching when nauplii start feeding; require more DHA than EPA; necessary to increase the nutritional value of GSL nauplii for marine animals **(Sorgeloos 01)**

cold storage of nauplii (**Leger 83**); for more convenient feeding; only 2.5% loss of dry wt with 24 hr storage at 4C (**Sorgeloos 01**); compared to a 26% decrease in total lipids at 25C, insignif loss at 4C; 90% of nauplii alive at 48 hr, don't advance to Instar II stage; store at up to 8,000/ml of saltwater at 4C (**Leger 83**)

conditioning the culture media- adding brine shrimp to saltwater containing a thriving mixed culture of "good bacteria" greatly enhanced *Artemia* survival; in contrast, *Artemia* grown in sterile seawater or seawater conditioned by a bio-filter only showed much lower survival (**Verschuere 99**); pre-conditioned water benefits fish (Verschuere 00b)

culture conditions (**Dwivedi 80**)– food mix of phosphates, pig dung, oil cake, and yeast (added to open ponds) stimulated algae and yielded excellent *Artemia* growth (Dwivedi 80); typical media is saltwater supplemented with NaCl to 0.5-8% with food such as algae or brewer's yeast (D'Agostino 80); rice bran for culturing (**Gorospe 96**)

cyst harvesting and processing-- effect of dehydration time and temperature on later hatching efficiency (Versichele 80); effect of salinity (Lavens 00); country of cyst origin affects hatching efficiency and crab larva survival (Dhont 02)

cysts produced by *Artemia*, culture conditions for (**Nambu 05**; **Versichele 80**); 1 g of San Franscisco Bay cysts contains 230,000 bacteria or ≤1 bacterium/cyst (Austin 81), contains 360,000 eggs (SFBB 06) and produces about 260,000 nauplii (Dhont 02; SFBB 06; Sorgeloos 80); cysts produced even under optimal conditions (Nambu 04); cysts from Great Salt Lake v. from San Francisco Bay (SFBB 06); hydration required for hatching (Stappen 02)

cyst shells (chorion): undigestable and carries potential pathogens; chorion contains iron and air chambers conferring buoyancy (**Sorgeloos 77)**, cause starvation in fish (Karen O'Connell 2019 PC; **Leger 86**)

decapsulated cysts; decapaulation procedure (**Sorgeloos 77**); have major advantages over nauplii in ornamental fish culture; promoted better growth, fecundity, and salt tolerance (stress) in livebearers and neon tetras; dried v. brine cysts; fatty acid, PUFA and HUFA composition of nauplii, cysts and

Moina (**Lim 02**); energy content of Decap-eggs is 30-57% higher than in freshly hatched nauplii (Leger 86); brine v. dried eggs for growth and survival of guppies (**Baboli 12; Dhert 97**); produced better results than those fed on top quality starter feed (Dhert 97); supported better growth and egg production in Zebrafish than nauplii (**Tye 04**); quality of a commercial preparation not as good for crab growth and survival as fresh preps (**Kouba 11**); superior to nauplii, live daphnia, and dry food for weight gain, growth, and survival of catfish (**Adewolu 09**); size of 0.2 mm (v. 0.4 mm of nauplii) makes them available as food for small fish fry (**Malla 15**); dry decap cysts better because they don't sink as fast (Leger 86)

development: molted into 2nd instar stage at about 8 hr after hatching when their alimentary canals open up (Sorgeloos 01)

diapause- hibernation/resting state encourages cyst production over live young; signifies less favorable conditions (Wang 17)

disease process due to *Vibrio proteolyticus* is slowed by pre-emptive colonization with non-pathogenic Vibrio (**Verschuere 00a**); bacteria, fungi, and spirochetes that are pathogenic to Artemia (Verschuere 00a)

Dunaliella, the primary food source in nature is a flaggelated green alga, grows at 1/3 the rate of green algae (**Porcella 72**) 1-3 day doubling time; culture conditions (**Abu-Rezq 10**); environmental niche- *Artemi*a, due to superior osmoregulation, prospers in hypersaline lakes safe from fish and other predators (Stappen 02; D'Agostino 80); life in hypersaline lakes around the world (**Mohebbi 10**); geographical distribution is in dry, non-humid environments (Stappen 02); poor source of EPA and not that great a food for nauplii (**Leger 86**)

exoskeleton thin (1 micron thick) making it more digestible- Sorgeloos 80

fatty acids of Brine shrimp are same Omega-3 fatty acids (DHA and EPA) found in fish oil human supplements: explanation of their chemistry and importance (**Tamaru 97**); EPA levels in *Artemia* (and other live foods) correlate with successful rearing of marine fish and shrimp (Dhont 02); actual profiles of HUFA, PUFA, etc in nauplii and decapsulated eggs (**Lim 02; Tamaru 97**); boosting to get more DHA (Docosahexaenoic Acid or 22:6n-3) in and increase the DHA/EPA EPA (Eicosapentaenoic acid or 20:5*n*-3) ratios (Dhert 97); procedures and use of Selco, menhaden, cod liver, sardine oil for boosting (**Leger 86**; **Tamaru 97**); freshwater fish can make their own EPA so don't need it; marine fish can't, so EPA deficient Artemia from GSL cause real problems for marine fish (Leger 86)

Fe contributes to brine shrimp fecundity, survival, bright color and cyst production; FeEDTA dosing (**Versichele 80**); haemoglobin and Fe involvement in production of cysts, which have haematine-like substance impregnated in outer shell (Versichele 80); *Artemia* hemoglobin contains 0.29% Fe (Bowen 76); Fe has low toxicity to nauplii (**Gajbhyiye 90**; **Kokkali 11**)

foods for and feeding– in nature, feed on unicellular algae, mostly species of *Dunaliella* (**Mohebbi 10**); eat anything that is their particle-feeder size range, grow muct faster on *Dunaliella* than yeast, especially *nauplii* (**Porcella 72**); effect of separate strains of bacteria, yeast, algae on brine shrimp growth and survival (**Marques 05**); in oceanic flow-through system, brine shrimp fed on microalgae *Chaetoceros* *curvisetus* culture (**Sorgeloos 85**); bacteria not a good sole food source (D'Agostino 80); suspension of brewer's yeast fed weekly (D'Agostino 80); powdered tropical fishfood (Holliday 90); *Artemia* as non-discriminate filter-feeders eat anything between 3-50 microns, but mostly algae and bacteria (Persoone 80), has mandibles that chew on the food (Mohebbi 10); but seem to prefer eating Pseudomonas over other bacteria (**Gorospe 96**); mix of rice bran and Spirullina recommended for cyst production (Versichele 80); pea/corn residue (80/20%) (Verschuere 97); agricultural byproducts such as rice bran, corn bran, soybean pellets, lactoserum as more cost-effective than algae; example of overfeeding is 100 mg food/ day/liter/25,000 brine shrimp and overpopulation is 10 to 20 nauplii/ml (**Verschuere 99**); yeast not a good food as cell wall hard to digest (**Marques 05**); "Baby Shrimp Food" (Nambu 04); rice bran works well (**Gorospe 96**); for reproduction studies, investigators used a 1:1 mix of spirulina algae and shrimp powder (Wang 17)

glycerol released by hatching brine shrimp is good feeding media for bacteria (Sorgeloos 01)

growth and size increase of Artemia from 0.5 mm to 7 mm with artificial culture (**Dhert 93**)

GSL (Great Salt Lake); ecology of the BS and the *Dunaliella* alga it feeds on, algae cultured in salinity of 20% to mimic GSL conditions (Porcella 72); in the spring of 1971, salinity 5-27% (Wikipedia 2019); GSL brine shrimp are deficient in HUFA (Bengston 91) especially EPA (**Leger 86**; Sorgeloos 98); ½ tsp of eggs = 1 gram = 280,000 eggs (GSL 2019); poor nutrient source for marine larva, because deficient in EPA; freshwater organisms okay with GSL eggs (**Leger 86**)

guppies: growth, survival and salt tolerance for guppies fed on dry food, nauplii, daphnia, and both dry or wet decap-eggs (**Baboli 12**; **Lim 02**)

hatching requirements: optimum of 15-35 ppt salinity, minimum pH of 8.0, saturated oxygen, strong illumination, maxiumum egg-water density of 2 g eggs/liter (1 tsp/liter) (Sorgeloos 01)

hatching efficiency 70% in 3.5- 4% salinity but reduced to 45% in 7% (Dwivedi 80); hatching conditions for (**Sorgeloos 80);** can hatch at 0.5%, but won't hatch above 8.5% (Persoone 80); San Francisco strains won't hatch above 8.5% because hydration level is insufficient (Stappen 02); is 3X better for eggs produced in 9% v. 3.5% salinity (Versichele 80); 50% inhibition by copper at 0.0064 ppm and zinc at 0.065 ppm at 28°C(**MacRae 91**); "hatching efficiency" (HE) is #nauplii produced per gram of cysts, varies between <100,000 and >300,000 (**Bengston 91**)

hemoglobin development in nauplii required as cysts are anaerobic; HB makes up 20% of soluble protein (**Moens 89)** and contains 0.29% Fe (Bowen 76); red coloration due to hemoglobin, stimulated by iron supplementation and low oxygen (**Versichele 80)**

Instant Ocean salt mix, composition of- Trieff 80

intestinal colonization of nauplii during first two weeks is mainly *Vibrio* (**Gorospe 96**); gut of aquatic animals is colonized by what's in the water, so the microbial microflora of the rearing tank is critical (Verschuere 00b)

ionic composition of natural Artemia habitats shows wide variation- Stappen 02

iron *See* 'Fe'

juveniles are more nutritious than nauplii (Dhert 93; **Sorgeloos 80)** life cycle– 2 weeks to maturity and 6 month potential life-span – Sorgeloos 80

light- larvae don't grow or reproduce with only a 10 hr photoperiod at 20C (Nambu 04); *A. urmiana* grow better with a 12 hr photoperiod than continuous light (**Asil 12**); need some light (e.g., 2 hr photoperiod) to trigger hatching, but not 12 hr or 24 hr (**Asil 12**); effect of longer photoperiod favored live young over cyst production (**Nambu 04; Wang 17**); produced 92% nauplii with 18 hr photoperiod, but with 6 hr of light, only 28% (**Wang 17**); generally, 2000 lux at water surface required for hatching (Sorgeloos 01) but not growth (**Asil 12**), at least during first hours after complete hyrdration (Stottrup J and McEvoy L (eds). 2003. Biology, tank production and nutritional value of Artemia in book *Live Feeds in Marine Aquaculure*, p. 181); continuous light at 1,000 Lux recommended for best hatching (Sorgeloos 80)

maintenance practices of cleaning and sterilizing ponds prior to stocking do not provide a stable bacterial community- Verschuere 00b

metabolism, anaerobic under low oxygen- D'Agostino 80

metal toxicity- hatching process extremely sensitive to heavy metals (Cu, Zn, Pb, Ni**) (MacRae 91)**; however, the adult shrimp is extremely resistant with a Cu and Zn LD_{50} of 2.33 and 63 ppm, respectively (Gajbhyiye 90; Kokkali 11; Trieff 80) toxicity to nauplii LC50s for Cd, Cu, Fe, Ni, Zn, acute synergistic effects (**Gajbhyiye 90**); low-dose effect of Cd, Cu, Fe and Zn on nauplii motility (**Kokkali 11**)

moult dailey- Verschuere 97; add a phyllopodia with sodium pumps after each of 11 molts (**Holliday 90**)

nitrite nitrite, 24 hr. LC50 is 1610 ppm, 321X more than LC50 for penaeid shrimp (**Chen 89**)

nutritional value of shrimp increases with growth (42% protein of nauplii v. 60% in adults)- (Gorospe 96; Leger 86; Sorgeloos 80); afte 8 hr nauplii develop into Instar II, which provide less energy than freshly hatched (Dhert 97; Sorgeloos 80); nauplii are deficient in 4 amino acids (Sorgeloos 80); best food for many marine animals (**Sorgeloos 80**); decap eggs, nauplii, daphnia and food source for tropical fish (guppies, neon tetras, etc) (**Lim 02**)

osmoregulation system in brine shrimp best in animal kingdon (Leger 86; Persoone 80); energy-requiring process characteristic of freshwater organisms that excrete ingested NaCl (D'Agostino 80); increasing salinity from 1/2 (1.7%) to 4X (14%) that of seawater (3.5%) involves increased pumping and synthesis of Na/K ATP ase, brine shrimp use chloride cells similar to those of marine fish; anatomy of (**Holliday 90**); *Artemia* grow and reproduce just fine at 2% salinity (**Nambu 04**); isotonic at 30% seawater or 0.1% (Holliday 90); survive 0.5 to 1 hr in freshwater (Malla 15); adults better able to cope with salinity stress than nauplii (D'Agostino 80), probably because their chloride apparatus take about a week to respond by increasing Na/K ATP ase; requires Mg++ and K+ (**Holliday 90**); Artemia eggs- protected from high salinity by shell which is imperable to salts but not water; nauplii are born with temporary osmoregulation (via neck organ/dorsal salt gland) that is later replaced by coxal gill structures in adults; both invove Na pump (Na+/K+ ATPase) (**Charmantier 01**); pump needs K+ to work; chloride cell involve Na pump (Bond 96, p 411); chloride actively transported out (Holliday 90); add a phyllopodia with sodium pumps after each of 11 molts (**Holliday 90**) oxygen- *Artemia* tolerate oxygen levels down to ~2 ppm (Bossuyt 80; Leger 86) or 1 ppm because oxygen is inversely proportional to salinity (Personne 80); nauplii develop 3 types of hemoglobin (I,II,III) with different oxygen binding affinities (**Moens 89**; D'Agostino 80); co-colonization with fermenting bacteria (Verscheure 00); lower survival at 3.4 mm oxygen unless shrimp are supplemented with iron for increased hemoglobin (**Versichele 80**); saturated oxygen considered optimal for hatching (Asil 12)

pH below 8.0 inhibits hatching; hatching requires ≥8.0 (Sorgeloos 80, 01); adults okay at 7.5-8.5 (SFBB 06)

population density: in nature, GSL supports peak summer densities of 3 adults/liter; the more productive Mono Lake, 6-8 adults per liter (Mohebbi 10); lab density of 10,000/liter (Leger 86)

probiotics used to protect fry/larva feeding on nauplii from destructive *Vibrio* species (Sorgeloos 01); development of effective probiotic bacteria must, in order to have long-lasting effect, be able grow well in the animal's environment or gut; potential mechanisms of probiotic action **(Verschuere 00b**); effect of *Vibrio alginolyticus* strain LSV8 not due to chemical release since filtrates had no effect on disease challenge, probably due to its ability to grow well in the *Artemia* culture (Verschuere 00a);; probiotic effect may be only nutritional (**Marques 05**)

reproduction: 100% fecundity at 7% salinity v. 84% at 4.5% salinity; optimum fertility shown by females becoming sexually mature in 12 days with 76 eggs/brood sac; successive batches released every 4-5 days (Dwivedi 80; Sorgeloos 80); dual mode of reproduction where ovoviviparity (live young) insures population explosion under optimal conditions; however, under certain conditions they can form cysts (Persoone 80); live nauplii produced under favorable conditions (Wang 17); effect light & temperature on producing cysts (oviparity) v. live nauplii (ovoviviparity) (**Nambu 04; Wang 17**); 300 nauplii every 3-4 days (SFBB 06)

salinity: for body length, fertility, survival, 7% was best (4% survival at 15 days with 30% salinity), but for hatching 3.5-4% was best (Dwivedi 80); *Artemia* can just survive at 34%; cysts won't hatch above 8.5% (Stappen 02); *Artemia* grow and reproduce just fine at 2% salinity (**Nambu 04**); cysts hatch in 0.5%-8.5% (Persoone 80); GSL has 20% salinity and hatched BS grew just fine in it (**Porcella 72**); tolerate 0.1% to 20% (D'Agostino 80); isotonic at 30% seawater or 0.1%; adults require 1 week to adjust to increased salinity (Holliday 90)

salt, type for growth; non-iodized salt should be used for long term immersion of fish (Noga 10, p.414); iodized salt is toxic for fish and not recommended (**Wangen 12**)

strain variations between GSL, SFBB, for size and as an animal food (SFBB; **Leger 86**; **Sorgeloos 80**); length of cysts and nauplii (**Leger 86**; D'Agostino 80); 6 species and where found (SFBB 06); GSL supplies 70% of world's eggs, but poor in fatty acids (Bengston 91), especially EPA (**Leger 86**)

temperature: for producing cysts v. nauplii (**Nambu 04; Wang 17**); constant temperature of 25-28C is optimal (Sorgeloos 01)

tolerate wide fluctuations in salinity (0.1-20%), temperature, oxygen (D'Agostino 80; Persoone 80), and ammonia/nitrite (**Chen 89**) vitamin C requirements- Sorgeloos 01

Snails-

algal grazing protects SAMs (**Borum 86; Bronmark 90**; Gopal 93; Rogers 83; Sand-Jensen 91; **Underwood 91)**

aquarium- Reimer T91; Sliz T5(5)

association with SAMs may be species specific, a function of allelochemicals- Gopal 93

bacteria, interaction with during decomposition (Mann 73; **Rogers 83**); passively host EMand excrete viable EMin feces **(Marsollier 04a)**

consumption of live SAMs is minimal (Newman 91; Rogers 83); eat bacterial biofilms on plants (Marsollier 04a); damage to leaf after its dead and conditioned by bacteria (Rogers 83)

decomposition accelerated by reducing particle size- Mann 72

epiphytic consumption (Borum 87; Bronmark 91;Sand-Jensen 91; Underwood 91); shown graphically by SEM with photos (**Rogers 83**); protects plants (**Jernakoff 97**)

MTS recommended, because they aerate the substrate (Kasselmann 03)

nutrient release stimulates SAM growth- **Underwood 91**

K (Potassium)-

algal and plant interspecies competition for- Gerloff 75

Ca channels and membrane potential- Felle 91

competitve uptake with Ca/Mg (Donahue 83; Rorison 60a; Wild 88) but only in calcicoles not calcifuges (Roelofs 86; Rorison 86); K+ v. NH4+ (Beck 91; Khademi 04); K+ v. Na+ (**Jampeetong 09a**)

cycling in lakes minimal- W193

deficiency symptoms in aquatic plants [Krombholz T6(5); Newman 88] and terrestrials (Wild 88)

limiting nutrient in situ?- Gerloff 75; Steward 84

preferential uptake from water- Amundsen 82; **Barko 82**, 88, 81b; Gerloff 75; Huebert 83; Overath 91

sediment a sink, not a source for (Barko 88: Carignan 85; Sutton 96)

sodium, competition with causes K deficiencies and injures plant (**Jampeetong 09a**); substitution by Na to maintain internal ionic balance, is present at 25 ppm in his nutrient solution- Huebert 83

uptake (Barko 82, 88; Beck 81, 91; Gerloff 75; Glass 89; Reddy 89; Smart 85; Steward 84; W194) from sediment very inefficient (Barko 82; Huebert 83)

water K necessary (Barko 82) for optimal growth and flowering (**Huebert 83**)

water levels of (Shearer 88; Steward 84); 0.01-0.1 uM (0.4 to 4 ppm) in natural habitat of *Riccia* (Felle 91)

Lake rhythms

daytime-

alkalinity decrease- Allen 72; W555

bicarbonates depleted- W219

Ca depleted- King 72

CO2 depleted (Allen 71, 72; Keeley 83; King 72; Svedang 92); greater CO2 uptake by liverworts (**Miyazaki 85**)

DOC release increases- Allen 71, 72; W509

fish activity (Steele 89; Weber 94); larger zooplankton move to downward to darker depths to escape fish feeding on them during the daytime (Williamson 95)

general- Reddy 81; W509

light intensity fluctuations- **Kasselmann 03**

malate and acidity increase within plant- Raven 88; Sharma 95

nitrate uptake much greater- Nelson 80

oxygen increase (Allen 71; Burton 78; Hasler 49; King 72; WW154); O2 below masses of floating plants (Jedicke 89)

pH/photosynthesis/CO2 (Allen 72)

pH increase- Allen 72: Keeley 83; King 72; W555

photorespiration increases as lacunal O2 accumulates- W533

PS increase (Allen 72; W169); midday peak in *Euglena* under biological clock control (Lonergan 90)

sediments O2 increase- Ash 02

temperature increases- Allen 72

zooplankton grazing decreases (W509); larger zooplankton move downwards and smaller ones move upwards (Williamson 95)

summertime-

ammonium/nitrate depletion of water- Kuenzler 86; W241

plant biomass high (Gopal 87; Sutton 85; Titus 83; W549); increased productivity under biological clock control (Huebert 83); seasonal effects on plant parts and elements (**Peverly 79)**

Ca depletion via biogenic decalcification (WW178)

carbohydrate accumulation by plants- Spence 81

CO2 accumulation- Burns 72; W214

DOC increase- Winner 91

fish, seasonal rhythms in behavior- Weber 94

fish kills from oxygen depletion- W168, 170

nutrient levels in sediment increase from enhanced decomposition of OM- Pulich 85

rosette, tuber, turion formation (Spence 81; Sutton 85; Titus 83) for winter hibernation (Kasselmann 03) springtime clear water phase due to bloom of zooplankton that graze on algae- Williamson 95

tissue levels of nutrients high- Gopal

Lake, River, Ocean and Aquarium Ecosystems-

acidic waters (Catling 86; Miyazaki 85) due to acid rain will change plant species composition due to higher bicarbonates (**Iversen 19**); field study (Adirondacks) showing that acid lakes (pH < 6) favor obligate water CO2 users but not sediment CO2 users (**Titus 17**)

Amazon basin: plants, animals, ecology, water chemistry of (**Marlier 67**); DOC characteristics of blackwater, clear water, and white water rivers (**Kasselmann 03**); comparison on white and black water Amazon rivers in Cardinal tetra physiology (**Cremazy 16**); DOC in Rio Negro protect fish against water's extreme acidity (**Duarte 16)**

aquaculture- Gilbert 97

aquarium (Fitzgerald 69; Moe 89; **Spotte 79**); balanced aquarium a myth (Atz 52; 71)

Black water rivers (W185) are humus-rich (Janzen 74); Amazon black water rivers have low pH (pH ~4) and are inhospitable to plants (Kasselmann 03), but not fish which are protected by its DOC (**Duarte 16**); low pH (<4) and salts (e.g., 5-50 uM Na+) would be toxic to most fish, but contain they contain 8% of world's freshwater species, potential toxcity compensated for by high DOC (5-35 mg C/l) (**Morris 21**);

bogs- Westerman 93; W743

brown water lakes- W737+

eutrophic- Ozimek 90

hardwater lakes- (Allen 71; Otsuki 74; Rich 78; **Wetzel** 69**, 72**; W733+) contain 40-60 ppm Ca and 15-25 ppm Mg (Wetzel 90)

Lake Tanganyika (**Brichard 78**; Coulter 91; **Edmond 93**); plant species found in (Kasselmann 03)

lakes (Gaudet 73; Goldman 72; Schindler 77; Wetzel 90); most lakes supersaturated with CO2 (**Cole 94**; Titus 90); lakes have more bicarbonate users than streams (**Iversen 19**)

oceans- the water has less DOC (Bowen 79; Bulthuis 81; Williamson 95) and sediments have more sulfides than freshwaters (Jones 81); CO2 uptake by algae enhanced by increased atm CO2 (Riesbesell 07)

oligotrophic natural waters- Goldman 60, 72; Sand-Jensen 79

productivity of marine ecosystems (Mann 73) and plant ecosystems (W547)

Sacramento River (CA), chemistry of water and sediment (Leung 01)

salt lakes- Wurtsbaugh 88; W187

sewage lagoons- King 72; McKinney 04

softwater, eutrophic (Allen 72); softwater lakes (Giesy 83; Hutchinson 87; Roelofs 91; Welsh 93)

streams have more CO2 than lakes, which affects plant species composition; less obligate CO2 users downstream due to decreased CO2 levels (**Iversen 19**)

swamps (Rai 79; Schoenberg 90; van Wijck 92; Westerman 93) tropical waters of the rainforest (**Cushing 91**; Horst 86; **Junk 80; Mansor 94; Marlier 67; Schmidt 72**); water parameters of (**Kasselmann 03)**

USA lakes- aquatic plant species composition of hardwater v. softwater lates in MN (**Moyle 45**)

wetlands- Westerman 93; Wetzel 90

world's waters, chemistry and evolution of**- Gibbs 70**

Light, biological effects-

absorption does not mean use- Lawlor 87; Rabinowitch 69; Wild 88

adjustment to new intensity or spectrum (**Richardson 83**) takes 3 days for algae (Rich 90); adjustment to low light, short photoperiod by *Potamogeton pectinatus* clones (**Pilon 02**)

allelochemical production- Grossman 94; Hanson 81; McClure 70

Artemia reproduction- **Nambu 05**

Ca fluxes in response to light stimulation**- Bush 94; Iino 89; Helpler 85; Shacklock 92**

cell volume of algae, effect of light on- Thompson 89

chlorophyll in leaves increases as light decreases (Barko 83c; **Pilon 02**; Richardson 83); Chl *b*, relative to Chl *a*, the more efficient pigment, increases (**Sultana 2010b**)

chloroplast movement (Attridge 90; Dong 95; **Seitz 82**); blue light photoreceptor and Ca fluxes required (**Thalka 93**)

chromatic adaptation of PS pigments (Kirk 94; Lee 89; Richardson 83; Pilon 02; Spencer 86) and effect on morphology of blue-green algae (Bennet 73)

cytoplasmic streaming and chloroplast movement in aquatic plants (Haupt 94; Hepler 85; **Seitz 82**)

efficiency of light use for algae, shade or sun plants (**Berry 82**); is 5-10% (8-10 quanta) for terrestrials (Lawlor 87; Wild 88), but < 1% for aquatics (W390); increases in dim light (Lawlor 87); maximum possible efficiency is 18% (Kirk 94); adjustments to low light (**Pilon 02**)

flowering (**Lumsden 87**; Wooten 78) stimulated by sunlight, heat, long photoperiod, chelating agents, phenols (**Gopal 90**) light, temperature, and photoperiod in tropical seagrasses **(McMillan 82**) depends on plant species (Thomas 97); occurred only with 16 hr photoperiod in *Potamogeton wrightii*, not 8h or 12 hr (**Sultana 2010a**) *See under* Aquatic Plants

general effects on plants- **Attridge 90; Spence 81**

growth- **Barko 81a**, **91b**; Gaudet 73; Madsen 91b; **Pilon 02**

heterophylly induced by low R/FR- **Bodkin 80**; Spence 81; W526

Hydrilla can PS in low-light, a competitive advantage**- Van 76**

latitude- Northern latitudes have more total light supply at summer soltice than tropical latitudes (WW52); log increase in daylength with increasing latitude (**Pilon 02**); clones from different latitudes respond similarly to changes in light intensity and photoperiod (**Pilon 02**); monoecious Hydrilla more adaptable to higher latitudes than dioecious Hydrilla (Spencer 86)

leaf morphology changes from dissected leaves at 90 PAR to less dissected leaves at 15 PAR, but changes not as great as those due to fluctuating water levels (**Nakayama 14**) minimal levels and compensation points (Balls 89; Berry 82; Boston 89; James 86; **Lloyd 77**; Madsen 91b; Martin 91; Pokorny 85; Reiskind 89; **Richardson 83**; Riemer 84; **Sand-Jensen** 91, **91b**; Thompson 89; W538; Wetzel 85); differences in species requirements (Trebitz 93); competitive advantage for Hydrilla over other SAMS (Van 76)

morphological adaptations to photoperiod in grasses (**Hay 90**) and a submerged aquatic plant *P. wrightii* (**Sultana 2010a**), light levels and photoperiod in aquatic plants (**Pilon 02**)

nutrient uptake- Barko 91; DeMarte 74; Goldman 72; Thompson 89

photoinhibition (Barko 81a; Berry 82; Bowes 89; Carpenter 85; **Gopal 90**; James 86; Richardson 83; Riemer 84; W355, 537; Wild 88); excess light can stimulate a systemic protective response in plants (Karpinski 99) and algae (Kaiser 97); when plants exposed to light intensity that exceeds their PS capacity, they undergo oxidative stress (generate excess energy and H202) (**Horiguchi 19**)

photooxidation/photolysis of DOC *See under* ‘Decomposition’

photoperiod for plants (PP): flowering in tropical seagrasses need daylength of 14 hr or more (McMillan 82); scientists use 16:8 light dark cycle for bicarbonate user experiments (Husser 16); in nature, PP is 12 h in the tropics (Gaudet 73; Sculthorpe 67) and 10-14 in the subtropics (Kasselmann 03); recommended PP for aquarium plants is 12-13 hr (**Kasselmann 03**); 8-10 hr photoperiod for aquarium plants not enough for growth; need >12 hr for reproduction and emersed growth (Kasselmann 03, **07**); effect of nutrient levels on PP of *Potamogeton wrightii* (**Sultana 2010b**); duckweed had 44% (37%-62%, 4 expts) more biomass after 8 days growth with 24 hr daylength than 18 hr (**Polar 86**); 3 clones of *Potamogeton pectinatus* grew 91% (25%-235%) better after 56 days with 24 hr than 13 hr in 6 expts (**Pilon 02**); decreasing daylength from 16 hr to 10 hr stimulated turion production but did not affect growth in *Hydrilla* (**MacDonald 08**); growth rate of grasses increased by extending the photoperiod but not the total light supply (**Hay 90**); physiological and morphological changes (**Hay 90; Pilon 02; Sultana 2010a**); no significant difference in *Hydrilla*’s growth rate with either 10, 12, 14 or 16 hr PP (**Spencer 86**); for *Potamogeton wrightii*, 16 hr PP produced longer stems/shoots and bigger leaves than plants raised with 8 and 12 hr PPs, especially under low nutrient conditions; more leaf senescence with 8 hr PP (**Sultana 2010a**); plants had low PS rate and collapsed at 56-70 days with 8 hr PP and high nutrient situation (**Sultana 2010b)**; 8 h. of 200 PAR used for *H. difformis* study of heterophylly (**Horiguchi 19**) and 24 hr photoperiod, 80 PAR for *L. arcuata* (Kuwabara 03)

photoreduction of iron oxides and release of Fe (Anderson 82; **Rich 90**); release of DIC (**Graneli 96**)

photorespiration- balance between electrons generated by photosynthesis v. availability of electron acceptors (CO2 and O2), shading decreases electron generation and photorespiration (Mommer 06); can release 50% of fixed CO2 (**Bowes 93**)

phototrophism (bending to blue light)- Attridge 90; Hart 88; Huala 97

reproduction-- germination promoted by R, reversed by FR (Attridge 90; Hart 88; Spence 81) and turion formation in duckweed stimulated by high R/FR (Attridge 90); tuber formation in Hydrilla

(Barko 86b) strongly stimulated by shorter day (10 hr v. 16 hr photoperiod) (**MacDonald 08**); germination of water lily seeds (Smits 95); inhibition of flowering by FR at the end of the day (Lumsden 87); short day v. long day plants (Raven 92; Thomas 97); formation of adventitious plants requires a photoperiod longer than 12 hr (**Kasselmann 07**)

root oxygenation of sediment (Caffrey 90; Carpenter 83; **Pedersen 98**); root growth decreased with decreasing light, but stems/leaves increased (Pilon 02)

Salvinia, effect of light intensity on morphology- Kasselmann 03

saturation levels for plants (Barko 81; Berry 82; Boston 89; Bowes 86, 89; Gopal 87; Lloyd 77; Thompson 89) much higher for aerial than submerged growth (**Salvucci 82**); low for marine algae (Lee 89; Reiskind 89); Vallisneria can be acclimated to moderate levels [800 uE/m2/sec] (Boston 89); lower for growth than PS (Lee 89); comparison of plants and algae (Kirk 94)

shade avoidance as a competitive strategy (Smith 94) self-shading limits growth (W383)

shade plants may have more green and FR absorbing pigments (Berry 82); adaptation to shade strategies via decreasing the Chlorophyll *a/b* ratio (more Chl *b*) and light compensation points (**Mommer 06**)

species variation in light requirements (**Kasselmann 03**), growth v. light intensity (Hutchinson 75; **Pilon 02**); clonal variation (**Pilon 02**)

stem length and leaf area increase with low R/FR and low light (Attridge 90; **Holmes 77c**; Spence 81; Tasker 77d); Crypts with large wide leaves are shade Crypts (Kasselmann 03)

stimulus localized to one part of plant can trigger a systemic response- **Karpinski 99**

synergism of R, B, G and FR light (Emerson effect)- **Emerson 57, 58**; Govindjee 82

temperature and light have combined effect on growth- Barko 81a; W538

UV light degrades DOC (Graneli 96; Wetzel 72) and releases enzymes from humic acid complexes (Wetzel 92); inhibits algae (**Culotta 94**) and kills microorganisms (**Hijnen 06; Jacangelo 02; LeChevallier 04**); UV inhibits bacteria more than algae because of algae's protective pigments and larger size, but bacteria can repair the UV damage via photoenzymatic repair mechanisms (Kaiser 97); complexity of UV light's effect of lake productivity (**Williamson 95**)

See also Pigments

Light Properties and Artificial Lighting-

aquatic light not like any terrestrial light (Reiskind 89), depleted in B and R, rich in G, has high R/FR (1-23) [**Attridge 90**; **Spence 81**; W58] as compared to terrestrial light (0- 1) [Smith 77b], because water absorbs longer wavelengths preferentially (Bodkin 80; W56); light quality a function of water depth (Wooten 78)

blue light less efficient because of carotenoid absorbtion (Emerson 60; Lawlor 87); causes photo-reduction of Fe and release of Fe2+ (Rich 90; Spiers T4:1)

canopy shade, light passage through forest leaves, enriches G and FR (Attridge 90; Berry 82; Spence 81) and differs from ordinary shade which is rich in B (Holmes 77a); affected by season and tree species (**Tasker 77d)**; canopy shade (terrestrial) has more FR than aquatic light (Spence 81); incandescent and FR light source used to simulate canopy shade (Holmes 77c)

colors- blue (430 nm); red (660 nm); far red (730 nm)

definition of light- Smith 75

depth, water: PAR decreases 18% and 32% with 10 and 20 cm distance from the water surface (**Mommer 06**)

DOC absorbs UV and B- Graneli 96; Spence 81; W58

fluorescent light: Cool-white alone used in artificial propagation of Crypts (Kane 90) and works well when combined with other light sources (Gaudet 73; **Richards 87);** Sylvannia Gro-Lux somewhat inefficient but good for plant growth (Kassselman 03)

FR will rise underwater at dusk- Spence 81

infrared light for physical therapy and electronic device sensing is 880 nm (Internet) v. FR which is 730 nm

intensity varies in nature due to cloud cover and time of day, LUX measurements of- **Kasselman 03**

lighting sources for the aquarium- **Kasselmann 03**; Moe 92

PAR (photosynthetic active radiation of 400-700 nm wavelengths): PAR decrease with water depth in a clay pit, presence of floating algae decreases it 95% (**Mommer 06**); quantitation in µmol/m^2/s PAR (Hopkins 95); PAR at water surface in my tanks is 100-200 µmol/m^2/s and decreases to 1/3 and 1/10 at 6” below the water surface (**DLW 2020**); PAR decreases 18% and 32% with 10 and 20 cm distance from the water surface (**Mommer 06**)

PPFD- photosynthetic photon flux density- same as PAR

quantitation: in uE units (Barko 86; Lee 89; **Smith 75**; Richardson 83; Thompson 89; W53); 5,000 lux = 115 mE (Dendene 93); full sunlight is 1,500 to 2,000 PAR (Richardson 83);

R/FR is 8.2 for fluorescent daylight (Holmes 77c), but only 0.64 for incandescent (Holmes 77c; Smith 77b); decreases in summer (**Tasker 77d)**; because of PS absorption of R light, the R/FR decreases via passage through aquatic leaves (Spence 81) and algae (Mommer 06) and the lowered R/FR triggers a shade canopy signal to plants (Mommer 06); R/FR increases via passage through water because water absorbs FR more than R (Momokawa 11)

shade, defined as ≤20 PAR for plants and triggers a canopy shade signal (Mommer 06); it is diffuse light and richer in Blue than sunlight (Attridge 90; Holmes 77a)

spectra- natural v. artificial light (Gaudet 73; James 86; Riemer 84; W47); shade, canopy shade, sunflecks, sunlight are different (Attridge 90; **Holmes 77a)**

sunflecks are higher in R/FR (0.63) than surrounding canopy shade (0.10) [Attridge 90; Holmes 77c; Smith 77b], but lower than sunlight (1.15) [Smith 77b; Tasker 77d]; quantum flux is 4 X more for sunflecks than surrounding shade [Smith 77b]; and there is more R because passage through trees depletes the diffuse B light [Holmes 77a]

temperature, (Kelvin color ratings)- 2700-4000 recommended for aquariums (Kasselmann 03)

UV absorption by glass (Wetzel 92) but passes through quartz (Kaiser 97); borosilicate glass absorbs all light below 300 nm (Graneli 96); UV-A (320-400 nm) and UV-B (280-320 nm) (Graneli 96); UV light penetrates >20 m (Kaiser 97) and affects zooplankton reproduction at 6 m (Williamson 95); UV-B radiation level of 0.4 watts/m approximates field conditions (Kaiser 97)

Metal toxicity, fish-

age and size of fish- Fraser 82; **McKim 85**; Newman 88

apetite suppression (Waiwood 78a) by Al (Gundersen 94)

behavior, hormones, and neurotransmitters (**Weber 94**); courtship behavior of guppies (**Schroder 88**); synchronous behavior (Weber 94)

brine shrimp and fish, compared toxicity (LD50s) of Hg, Pb, Cu, and Zn to (Trieff 80); toxicity of Cu, Zn, Pb, and Ni to hatching efficiency (**MacRae 91**)

Ca amelioration of metal toxicity symptoms (Bjerselius 93; **Cremazy 17**; Leland 85; Markrich 94; Miller 80: Silbergeld 80; Wood 92); metals enter through calcium channels (**Zia 94**)

Ca concretions, storage of metals- Roesijadi 94

chelators prevent metal toxicity- Fitzgerald 69; Sprague 85

Cu toxicity in trout (survival) affected by DOC and Ca, but not Mg or pH (**Cremazy 17**); natural DOC has huge protective effect on cardinal tetras, correlated with Na+ influx and binding to gill tissue (**Cremazy 16**)

cyanide poisoning, symptoms similar to those of metal toxicity on reproduction- Ruby 93

dirunal activity levels, effect of Cu on- **Steele 89**

early life stage tests are best predictors of toxicity- **McKim 85**

egg fragility increased- McKim 85

excretion of Pb by fish- Leland 85

feeding behavior of schooling fish, Pb- **Weber 91**

general- Borgmann 83; **Fraser 82**; Leland 85; Newman 88; Nikinmaa 92; Pagenkopf 86; Spotte 79; Spry 85; Tacon 83; **Waiwood 78a, b**; Wood 92

gills, ion fluxes disturbed by (**Cremazy 16**; Spry 85; **Morris 21**; Waiwood 78b; **Witters 90**; **Wood 92**); ulceration by (**Lacroix 93; Leland 85**)

growth- Waiwood 78a

hormone levels (Weber 91) and release (Ruby 93)

ingested metals are not the problem; they are either insoluble or under homeostatic control- Eichenberger 86; Martin 86; Newman 88; Nieboer 80; Tarifeno 82

individual metals have different effects (Leland 85); Zn accumulation is regulated, but Pb is not (Kraak 94)

mechanism of toxicity to fish: failure to maintain Na+ homeostasis. Mortality occurs when fish lose ~30% of their plasma Na+ (**Cremazy 16**) Metals compete with Na+ for intake gill cells. Metal binding to gill cells disrupts membrane channel proteins (e.g., Na+/H+ exchangers) involved in

Na+ uptake. Metals also displace the extracelular Ca “glue” making the tissue leaky, thereby allowing Na” to diffuse out (Morris 21). Freshwater fish naturally lose Na+ by diffusion into the more dilute external media. To maintain blood plasma levels of Na+, they actively take up Na+ from the water.

metal release from animals is a two-stage process- Roesijadi 94

metallothioneins, protection against- Kraak 94; Leland 85; Roesijadi 94

mixture of Al, Zn, Cu as affected by natural DOC- Hutchinson 86

mucus secretions protect (Wood 92) gills from Al toxicity (Lacroix 93)

neurotoxic effect, Cd on touch sensitivity of worms (Rogge 93); Cu on olfactory receptors of fish (Bjerselius 93)

neurotransmitters and hormones are essentially the same (**Wendelaar 93),** in that both require exocytosis (Creutz 84)

Pb, Ca, and neurotransmission- Leland 85; **Silbergeld 80**

RBC's effected by- **Nikinmaa 92**

reproduction (Sprague 85), decrease in spermatogenisis (**Ruby 93)**

sea catfish has a copper LC50 of 3.6 ppm (Steele 89)

smell, effect of Cu on- **Bjerselius 93**

stress increases toxicity (Nikinmaa 92); stressed fish are more susceptible to Cd showing lower plasma osmolarity and higher plasma cortisol (**Wendelaar 97**)

swimming performance altered because of gill problems- Waiwood 78b

uptake of metals- Spacie 85

Metal toxicity, general-

absorbtion of heavy metals to FeOH, AlOH and SiOHs (Beckwith 75; Bingham 86; Eichenberger 86; Pagenkopf 86) and POC (**Giesy 78**); humic and fulvic acids (Nor 86; **Thurman 85**); chelators (Sprague 85)

acidity decreases (Sprague 85), because of H^+ competition with metal uptake (Borgmann 83); however, metals are more toxic in acid waters (Miller 80; Waiwood 78a, 78b; Welsh 93)

Al toxicity (Fraser 82; Grise 86; Lacroix 93; Nieboer 80; Urban 90) to fish reduced by water hardness and humic acids (Gundersen 94)

alkalinity (carbonate formation) decreases- Borgmann 83; Miller 80; Pagenkopf 86

aquatic organisms, review- **Borgmann 83**; Eichenberger 86); on brine shrimp (**Gajbhiye 90; Kokkali 11; MacRae 91**)

arsenic cycling in well water- Oremland 03

bacteria killed by (Bisson 92; Borgmann 83), but bacteria more tolerant than plants (Lederberg 00); EM more resistant than other bacteria; metals used as disinfectants (N124) *See* ‘MB (mycobacteriosis)...: metal toxicity’ bioaccumulation (**Wang 97**) and toxicity of Cu, Cd, Zn as affected by humic acid and water hardness (**Winner 86**)

bioassays of (**Bisson 92**; Borgmann 83; Kraak 94; Sakaguchi 81; Winner 91); brine shrimp hatching (**MacRae 91**); toxicity to nauplii brine shrimp LC50s for Cd, Cu, Fe, Ni, Zn much less than for hatching, acute synergistic effects (**Gajbhyiye 90**); low-dose effect of Cd, Cu, Fe and Zn on brine shrimp nauplii motility (**Kokkali 11**)

biological organisms share susceptiblity (Borgmann 83; Nieboer 80; Sposito 86), because they all have Ca channels (Markrich 94; Roesijadi 94)

Ca channels blocked in both animals (Zia 94) and plants (Marshall 94; Pineros 93)

Cd a strong Ca channel blocker- Kostyuk 80

chronic exposure- Bisson 92; Spry 85; Waiwood 78a, b; Winner 91; Wood 92

Cu toxicity (Bingham 86; Bisson 92; Bjerselius 93; Borgmann 83; Eichenberger 86; Ernst 92; Frank T5(1); Marquenie 79; Miller 80; Pangenkopf 86; Waiwood 78a, 78b; Winner 91; Wood 92) reduced by natural aquatic DOC (Giesy 83; Welsh 93; Winner 85); reduced by metal sulfide formation (Rozan 00)

DOC's effect unpredictable (W368; Winner 91) and provides less protection than metal ppt with sulfides (Rozan 00); DOC can decrease toxicity [Bingham 86; Bisson 92; Bowen 79; Eichenberger 86; Nieboer 80; Urban 90] through chelation by allelopathic phenols [Serrano 90; Wetzel 93], or increase toxicity (ionophores ?) [Beckwith 75; Bingham 86; Borgmann 83; Bowen 79; Eichenberger 86; Nieboer 80; Winner 91]; DOC reduces metal toxicity in fish and daphnia (Giesy 83; Welsh 93; Winner 85; **Witters 90**); no difference between aquatic and soil humus (Witters 90)

environmental cycling of toxic metals- **Tarifeno 82**

essentiallity and toxicity unrelated- Eichenberger 86; Martin 86

free metals only are taken up and toxic- Eichenberger 86; Nor 86; Pagenkopf 86

general- Bowen 79; **Nieboer 80**; Sposito 86

humans, nervous system affected by Pb poisoning (**Silbergeld 80)**; neutrophil membrane depolarized by (**Scharff 96**)

insolubility decreases- Nieboer 80; Reddy 77; Urban 90

mechanisms of toxicity- Eichenberger 86; **Markrich 94; Nieboer 80**

mercury inactivation by bacteria- N762

metallothionein proteins bind metals- Roesijadi 94; Weber 91

Mn toxicity- Bingham 867; Fraser 82; Urban 90; Wood 92

Mo toxity- Sakaguchi 81

mussels, bioaccumulation and toxicity of metals Pb and Zn- **Kraak 94**

N source influences toxicity to terrestrial plants- Rorison 84

OH- of Al and Cu are toxic- Gundersen 94; Welsh 93

peat as a metal remover (Bailey 99; Brown 00; Spiniti 95)

Metal toxicity, plants-

release of Cu from plant after accumulation- Charpentier 87
root/shoot uptake of Pb and Cd- Mayes 77; Nakada 79
symptoms of for Cd, Cr, Cu, Ni, and Zn- Sela 89
tolerance to (Bingham 86; Ernst 92; Nieboer 80) associated with calcifuge, tropical plants (Davies 97; Foy 78; Rorison 84); plants less tolerant than bacteria; metal-tolerant plants can imporove soil quality and bacterial ecology (Lederberg 00)
uptake of Hg and accumulation to 1800 ppm by duckweed- Mo 89
vacuolar storage, internal detoxifiers- Bienfait 83; Cohen 98; Ernst 92; Nieboer 80

Mg (Magnesium)-

aquatic plants may require some Mg in the water (Barko 86b); to grow well and flower (Huebert 83)
availability from decomposition of animals is limited- Parmenter 91
deficiency symptoms- Krombholz T6(5); Wild 88
functions as intracellular stabilizer and reaction center of chlorophyll (Nieboer 80)
general- W191+
levels in freshwater about 0.1 to 0.3 mM (Flik 93)
metal toxicity, Mg not a substitute for Ca in ameliorating metal toxicity- Bjerselius 93; Huebert 83; Markrich 94; Rorison 60a
redox affects availability in sediment- Reddy 77
sea shells contain ~15% $MgCO_3$- Dickson 02
sediment levels of- Painter 88
toxicity of, to *P. pectinatus* (Huebert 83); inhibition of *Najas flexilis* (Hutchinson 75) and terrestrial plants (Foy 78)

Micronutrient Nutrition-

adsorption to MnOH, FeOH, AlOH controls availability (Bowen 79; Ponnamperuma 81; Sigel 86) of sediment Zn (**Kirk 95**)
animal metabolism as source- Bowen 79; Martin 86
availability of in terrestrial soils (Cohen 98; Sauchelli 69); soil depletion by plant uptake neglibible (Spositio 86)
bacteria requirements in wastewater treatment- McKinney 04
beneficial nutrients are Co, Na, and Si (Wild 88); Si use by Equistem (W334)
cycling in algae and daphnia- Tarifeno 82
deficiencies in calcifuges forced to grow on limestone soils- Tyler 96; Zohlen 97
enzyme needs for metals common to biota- Martin 86; Smith 84; Sposito 86
free metals only taken up- Bingham 86; Bowen 79; Brand 83; Rich 90; Wild 88
general- Allen 72; Barko 91; Bowen79; Brand 83; Eichenberger 86; Glass 89; Goldman 72; Moorhead 88; **Shkolnik 84**; Smart 85; Wild 88

genetic linkage of micronutrient requirements- Brand 83
limitation on algal growth- **Brand 83**
membrane transporter for Fe also takes up micronutrients- Cohen 98
Ni as a required nutrient (Hopkins 95); essential for methane bacteria (**McKinney 04**)
no universal optimum composition- Eichenberger 86
bacterial reduction of Mn and Fe in sediments is complicated and may involve humus intermediate (**Lovley 91; WW360**)
sediments can provide all to *P. pectinatus* (Huebert 83) and Hydrilla (Smart 85)

Mn (Manganese)-

availability in situ- Brand 83; Fraser 82; Painter 88; Pulich 82; Urban 90; W305, 314+
bacterial reduction to soluble Mn is not that relevant or prevalent, review (**Lovley 91**); respiration of *Shewanella* bacteria solubilizes Mn oxides- Ash 02
binding to DOC, EDTA- Bingham 86; Brand 83; Giesy 78; O'Connor 71; Russel 73; Sunda 83; Urban 90; W304
chelator stability < ferric Fe- Bingham 86; Brand 83; Lindsay 84; Urban 90
deficiency symptoms (Shkolnik 84; Wild 88)
depletion of P- **Davelaar 89**
Fe antagonism- Bingham 86; Lindsay 84; Pulich 82; Wild 88
nitrate reduction- McKee 62; Notton 83; Shkolnik 84
pH buffering action of Mn in sediment- Connell 68
photoreduction of Mn-DOC complexes- **Sunda 83**
redox effect on its solubility- Beckwith 75; Bingham 86; Reddy 77; W303; Westerman 93; Wild 88
reduced form required by plants- Glass 89; Sauchelli 69
release from sediments (Barko 83; Brand 83; Burns 72; Reddy 77; Urban 90) by *Shewanella* bacterial solubilization of Mn oxides (Ash 02)
root secretions/microbial growth effect solubility- Russel 73
sediment levels of- Painter 88
solubility in water (O'Connor 71) greater than Fe (Pulich 82; Reddy 77; Urban 90; W305, 308)
tissue levels regulated by sediment H_2S- Pulich 82
toxicity to plants (Bienfait 83; Bingham 86; Foy 78; Gambrell 90; Grise 86; Laanbroek 90; Rorison 60a,86; Sauchelli 69; W309) common in the tropics (Davies 97); symptoms of toxicity (Bingham 86; Foy 78; McGrath 82; Sauchelli 69); tolerance to of calcifuges (**McGrath 82**); toxicity to algae at > 1 ppm, neutralized by Ca (WW302)
uptake and nutrition (Allen 72; Davelaar 89; McKee 62; Pulich 82; Shkolnik 84); requirements higher for phototrophic metabolism of algae (Eichenberger 86)
See also Micronutrient Nutrition

Mo (Molybdenum)-

association with FeOH ppts- Ponnamperuma 81; Sauchelli 69; Wild 88

availability in situ, water/sediment (Kufel 91; Ponnamperuma 81; W314+) and ocean/freshwater (Bowen 79; Howarth 85)

cycling in lakes- Goldman 60; **Kufel 91**

deficiency symptoms- Horst 85; Notton 83; Sauchelli 69; Shkolnik 84; Wild 88

enzyme association in plants (Lewis 86; McKee 62; Notton 83; Raven 88; Shkolnik 84; Smith) and animals (Bowen 79; Sigel 86)

fertilization results in reduced water levels of N and P (Goldman 72) and increased PS (Goldman 60; Wurtsbaugh 88)

levels in plant tissues- Kufel 91; Wild 88

methanogenisis, stimulation of- Capone 82

'mobile' nutrient- W315+; Wild 88

N cycle- Howarth 85; Kufel 91; Goldman 60; Raven 88; W236+; Wurtsbaugh 88

N_2 fixation- Capone 82; Howarth 85; Raven 88; Shkolnik 84; Wild 88; Wurtsbaugh 88

nitrate processing, Mo required for- Eichenberger 86; **Raven 88**; **Shkolnik 84**; Wild 88

reduces toxicity of excess Cu, Co, Mn, Zn- Eichenberger 86; Sauchelli 69

stimulation of growth- Allen 72; Goldman 60, 72; Howarth 85; Wurtsbaugh 88

sulfate levels in ocean water reduce Mo uptake except in anoxic microzones? (Howarth 85; Wurtsbaugh 88)

sulfate reduction by bacteria inhibited by Mo- **Skyring 88**

toxicity in ruminants (Sauchelli 69); algae (Sakaguchi 81) and bacteria (Skyring 88; Tsai 86)

uptake by algae- Howarth 85; **Sakaguchi 81**

water levels required by algae- Eichenberger 87

N (Nitrogen)-

algal growth- Fitzgerald 69

availability in sediment (Barko 91; Chen 88; Christiansen 85; Iizumi 82; Painter 88; Pulich 82; Short 84) and water (Beck 91; Brezonik 72; Gopal 87; Iizumi 82;Kuenzler 86; Nichols 76; Ozimek 90; Rattray 91; Reddy 83; Riemer 84; Sculthorpe 67; Short 84; van Wijck 92; W241)

bacteria processes for cycling (**Al-Ajeer 22**); (Boon 86a; Gilbert 97; Jones 81,82; Payne 73; Rheinheimer 85); bacteria families involved in (**WW513**); nitrification and anammox (Pynaert 03)

cycling in the sediment (**Boon 86a, b**) and in the water (**Brezonik 72;** Edmond 93; **Reddy 83a**)

leaf and root uptake rates equivalent for duckweed (**Fang 07**)

limiting nutrient in Lake Tanganyika is N- Edmond 93

marine water N limited by sulfate antagonism of Mo uptake? (Howarth 85; Wurtsbaugh 88)

nitrite, nitric oxide pathway- **Darwin 03**

N_2 fixation (Adey 91; Barko 91; Blotnick 80; Brezonik 72; **Bristow 74**; **Buckley 78**; **Capone 82**; Dennison 87; Egglishaw 72; Gunnison 89; Mann 72; Raven 88; Sand-Jensen 89; Schindler 77; Shkolnik 84; W225+; Wurtsbaugh 88) only when there's an N deficit (Adey 91; Capone 82; Wild 88); N_2 fixation by algae and bacteria is common (W567); inhibition by allelochemicals (Rice 92); Azolla (**Chakraborty 86**; Reddy 84; Riemer 84; Wild 88); enhanced by increased atm CO2 in marine algae (Riesebesell 07)

proteins, N conc is 16% (WW224)

symptoms of excesses and deficiencies in terrestrial plants (Wild 88) and aquatic plants (Fitzgerald 69; Huebert 91; Newman 88)

uptake and nutrition by plants- Barko 82, 83b, 91; Best 78; Bulthuis 81; Cary 83; Chen 88; Christiansen 85; **Edwards 56**; Gerloff 75; Huebert 91; Iizumi 82; Ingemarsson 84; **Lewis 86**; **Nelson 80**; **Nichols 76**; Ozimek 90; **Pedersen 97**; **Reddy** 83a, 87; **89**; **Schuurkes 86**; Sculthorpe 67; **Short 84**; Thompson 89; **Thursby 82**; Toetz 71, 74; **Tucker 81**; Yamasaki 92; van Wijck 92; W241

uptake rates for ammonia, nitrite, nitrates by pond algae (Adey 98); enzyme uptake rates for NH4 and NO3 (Jampeetong 09)

urea as N source (Cary 83; Edwards 56; Gaudet 73; Katoh 80; Reddy 83b; van Wijck 92) hydrolyzed to NH3 and CO2 when added to sediment and stimulated growth (**van Wijck 92**); quickly hydrolyses to NH3 (via enzyme urease) when applied as a terrestrial fertilizer and a large NH3 dose is main cause of its toxicity (Wild 88, p691)

water nitrogen not necessary if sediment has plenty (Huebert 83; Nichols 76), but leaf uptake much faster (**Pedersen 97**)

Na (Sodium)-

baking soda additions: 1/2 tsp NaHCO3 per 10 gal tank provides 25 ppm Na and raises KH by 3-4 degrees (DLW 2022)

culture media, general contains N = 16 ppm, K = 6 ppm (**Smart 85**) and Na = 10 ppm and K = 20 ppm (**Yin 17**); higher amounts for increased alkalinity contain up to 200 ppm Na and 59 ppm K stimulated increasing PS due to the increased associated bicarbonates (Horiguchi 19)

freshwaters contain median of 6 ppm (range 0.7-25) (Bowen 79); N. American and S. American river waters contin 9 and 4 ppm, respectively (WW170)

levels of Na in 5 aquatic plants (SAMS) (**Zimba 93**)

quanitation: 0.1% NaCl = 1,000 ppm NaCl and 400 ppm Na (DLW 2022)

seawater: 1/3 artificial diluted seawater is ~160 mM NaCl (Iida 06);

sodium, competition with causes K deficiencies at 50 mM NaCl (0.58% salinity), less competition with Ca and Mg (**Jampeetong 09**); substitution by Na to maintain internal ionic balance, is present at 25 ppm in his nutrient solution (Huebert 83)

See also: ‘Aquatic Plants:salinity’

Nitrates-

absence in submerged soils (Ponnamperuma 81) and anoxic zones of lake waters (Edmond 93)

ammonium inhibition of uptake- (Abrol 90; Chisholm 91; **Dortch 90, 91**; Guerrero 81; Ingemarsson 84; Kuenzler 86; Nichols 76; Ohmori 77; **Orebamjo 75**; Paffen 91; Schwoerbel 74; **Ullrich 84**) even in terrestrial plants that prefer nitrates (Tinker 79); some terrestrial plants can bypass this inhibition (Foy 78)

assimilation by plants (Ingemarsson 86; Lewis 86; Short 84; Thompson 89; **Touchette 00**) and bacteria (Payne 73); most energy requiring reaction in plants (Touchette 00)

bacterial reduction of nitrates: association with fermentation (Boon 86a; Smith 82), metal sulfide oxidation (Schulz 99) and e- reduction of sulfates **(Daalsgard 94**); nitrates converted to ammonia for assimilation (Payne 73); to ammonia for respiration (*See* ‘Bacteria:DAP process’); to N_2 (*See* ‘Denitrification’); and to nitrite (*See* ‘Bacteria:nitrate respiration’)

cell uptake of nitrates, because interior is negatively charged, requires active H+ extrusion (Ullrich 84) and a carrier (Guerrero 81; Touchett 00); sulfide-oxidizing bacteria that store nitrates (Schulz 99)

concentration effects uptake rate- Nelson 80

groundwater contamination- Obenhuber 91; **Patrick 87**; Ross 89; Wild 88

light required for nitrate uptake (Nelson 80; Schwoerbel 74; Toetz 71; **Touchette 00**) except for Zostera marina (Burkholder 92)

losses from agricultural soils- Kurtz 80; Rice 92

metal toxicity, enhanced by nitrates for calcicoles- Rorison 84

micronutrient requirements for assimilation- **Doucette 91a, b**; Gaudet 73; Hageman 80; Howarth 85; Lewis 86; Martin 91; McKee 62; **Notton 83; Raven 88**; Shkolnik 84; W309

nitrite preferred over nitrate (Ferguson 69), or plant growth about the same (Edwards 56); easier to use by sulfate-reducing bacteria (Daalsgard 94)

protect plant roots (Bertani 86; Trought 81; Wild 88) by counteracting soil anaerobicity (Wild 88)

NR (nitrate reductase enzyme) (Blotnick 80; Boon 86a; Goldman 60, 72; Gunnison 89; Ingemarsson 86; Kurtz 80; Lewis 86; Nichols 76; Notton 83; Orebamjo 74; Reddy 83a, 84; Seitzinger 84; Thompson 89; **Touchette 00**) reduced levels of NR in climax terrestrials (Rice 92); lag phase in induction of nitrate uptake system (Nelson 80)

nitrite reductase competes with photosynthesis by using same ferredoxin complex- Touchette 00

reduction of nitrates via bacteria *See* ‘DAP’ *and* ‘dentrification’ under ‘Bacteria’

removal from water by epiphytic algae (**Adey 91**) and denitrification (Edmond 93; Obenhuber 91; Reddy 87; Risgaard 94; Seitzinger 94)

storage by plants (McKee 62; Reddy 89; **Tucker 83**; Whitehead 87; Wild 88) and bacteria (Schulz 99) toxicity to fish: nitrates considered to be non-toxic to fish (Russo 85); toxic at 400 mg/l (Spotte 79) 3 day LC_{50} to sturgeon is 400-1,000 ppm (Hamlin 06); are stressful at 700 ppm, caused an increase in mucus cells in sea bass (**Vatsos 10**)

toxicity: to aquatic plants: at 100 mg/l (Best 80; Gaudet 73); inhibited growth under 4 different condition for alpine pondweed **(Boedeltje 05**); smaller leaves, less chlorophyll in nitrate-fed Salvinia plants (**Jampeetong 09**); to seagrasses**:** inhibits growth of *Zostera marina* (**Burkholder 92, 94, 07; Touchette 03**) due to unregulated nitrate uptake,but does not inhibit *Halodule wrightii* and *Ruppia maritima* (**Burkholder 94)**; kills seagrass *Halophila decipiens* **(Bird 98)**; 0.2 to 2 ppm nitrate causes disintegration of *Z. marina* **(Burkholder 92**

uptake requires light and energy and is substrate-dependent for *Pistia stratiotes* (**Nelson 80)** respiration doubled by nitrate uptake **(Touchette 00);** carbohydrates and sucrose required **(Burkholder 94; Touchette 00);** drains energy from the plant **(Burkholder 07)**

water pollution from soil leaching- Alsaadawi 92; Lewis 86; Ross 89; Wild 88

Nitrification-

acidity inhibits nitrification (Gigon 72; **McGrath 82; McKinney 04**); species of *Nitrosospira* inhabit both acid and neutral soils (**Stephens 98**); nitrification destroy 2 moles alkalinity for every mole produced by denitrification (McKinney 04)

allelochemicals secreted by plants reduce nitrification (Planas 81; Putnam 86; Rice 74) especially in climax ecosystems (Rice 92)

ammonia oxidizers: multiple species of *Nitrosomonas* in same biofilm (Gieseke 01)*; Nitrosomonas* found in saturated ammonia (>1mM or 18 ppm) environments whereas *Nitrosospira* found in nature (Schramm 98); rate of ammonia oxidation by *Nitrosospira* is saturated at 300 uM or 6 ppm (**Schramm 99**); AOA at lower concentrations (0.1 mg/l) in freshwater biofilters (Sauder 11)

ammonium concentration determines which genera (*Nitrosomonas v. Nitrosospira*) is doing the ammonia oxidation (**Burrell 01**; Schramm 98); AOA operate at low concentrations, below 0.1 mg/l (Sauder 11)

amammox bacteria (N770): bacteria responsible for anaerobic conversion of ammonia plus nitrite to N2 gas (N770); is the anaerobic oxidation of NH3 (Al-Ajeer 22; Jetten 99) and found in wastewater tx along with nitrifiers (**Pynert 03**)

aquaponics (growing fish plus vegetable), nitrifiers dominated by CAOB (**Al-Ajeel 22**)

archaea ammonia oxidizers (AOA), secondary organisms to comammox in freshwater aquarium biofilters (**McKnight 21**); share nitrification with AOB in saltwater filters (**Sauder 11**); predominate in low oxygen, low ammonia, low pH environments such as in rice paddy soils (**Wang 15**); share nitrification in rhizosphere of SAMs (**Huang 16**)

bacteria, newer data recorded here in 2022: nitrifiers surveyed with PCR now include CAOB (comammox ammonia oxidizing bacteria), which are natural energy-efficient mutants of *Nitrospira* that do both nitrification steps; AOB (ammonia oxidizing bacteria), AOA (ammonia oxidizing archaea) (**Osburn 20**); nitrification in terrestrial soils (**Osburn 20; Poghosyan 19**); nitrifiers found in aquarium filters (salt and freshwater) from 38 tanks (**McKnight 21**); nitrifier relationship with other N-processing bacteria (anammox and DAP) (**Al-Ajeel 22**);

bacteria, old data (Anthonisen 76; Capone 82; Carpenter 77; Lewis 86; N277; Rheinheimer 85; Spotte 79; **Thimann 63**; Vanzella 90; W235; Wild 88) are delicate and not essential to the N cycling in many ecosystems (Gieseke 01; Rice 92); slow growth rate (McKinney 04); *Nitrospira* and *Nitrosospira* spp. work together (Schramm 98, 99); species involved (**Hovanec 96)**

biofilm formed by pure cultures of nitrifying bacteria (Cox 80; Schramm 98), which form extracellular material (Powell 92); biofilm contains mixed cultures *See also* “Nitrification:FISH studies of”

biofilters: review (**Al-Ajeel 22**); survey of 38 tanks with PCR showed nitrifiers in following rankings: for freshwater COAB>AOA; for saltwater AOA and AOB and no COAB (**McKnight 21**); RAS filters had following rankings: CAOB >> AOA > AOB (**Al-Ajeel 22**) freshwater aquariums mostly due to CAOB and AOA (**McKnight 21**); not due to the usual *Nitrosomonas* and *Nitrobacter*, which are AOB (**Burrell 01**; **Hovanec 96**); rather it is due to species of archaea or AOA (**Sauder 11**); nitrite oxidation due to *Nitrospira* not *Nitrobacter* (Burrell 01; Hovanec 98; Schramm 98,99)

CO2 consumption (**Dodds 91**; O'Connor 71; Rich 78; Thimann 63; W235; Wild 88); CO2 fixed via RUBISCO by nitrifying bacteria (Schramm 98)

comammox bacteria (CAOB), discovered in 2015, abundant in freshwater biofilters but not found in saltwater biofilters and uncommon in wastewater treatment (**McKnight 21**); terrestrial soils has both clades A and B (**Poghosyan 19**); abundant in forest soils and more relevant to nitrate production than AOB or AOA, because they are more energy efficient (**Osburn 20**); discovery of these new bacteria and energy gained from nitrification (**van Kessel 15**); niche bacteria for low ammonia environments (biofilters, aquaponics, soils), difficult to cultivate (**Al-Ajeel 22**)

competition with heterotrophs in a biofilm- Burrell 01; Timberlake 88

control by PS-generated O2- Gersberg 76; Moorhead 88; Reed 88; Schuurkes 86; Weber 85

denitrification is linked to nitrification (Caffrey 92; Kemp 90; Masuda 91; Risgaard 94; Seitzinger 84; Timberlake 88) and DAP (Gilbert 97; Jones 82)

DNRA (dissimilatory nitrite reduction to ammonia) or DAP - Al-Ajeer 22

DOC inhibits nitrifiers in culture (Thimann 63); soil DOC inhibits nitrifiers AOA, COAB, and AOA (**Osburn 20**)

dormant nitrifiers in an anammox biofilm- Jetten 99

energy obtained low, so do not produce a high cell mass- McKinney 04

enzymes required for: ammonia oxidation to nitrite = AMO (ammonia monooxygenase) and HAO (hydroxylamine dehydrogenase); nitrite oxidation via NXR (nitrite oxidoreductase) (**Poghosyan 19**); AMO of the CAOB are different than AOA bacteria (**van Kessel 15**)

fertilizer losses from- Kurtz 80; Lewis 86; Ross 89; Wild 88; Yamasaki 92

FISH studies of- Burrell 01; Gieseke 01; Pynaert 03; Schramm 98,99

incomplete nitrification- accumulation of nitrites in biological filters (Russo 85) *See also* ‘Nitrobacter’ below

inhibition by Al, Ni, acid (Tsai 86), tannin/humus (W236), and allelochemicals (Rice 92)

interference with municipal water treatment systems- O'Connor 71

light senstivity of bacteria- **Vanzella 90**

nitrite oxidizing bacteria (NOB); lineage of (Gieseke 01); nitrite oxidation *in situ* due to *Nitrospira* not *Nitrobacter* (Burrell 01; Hovanec 98; Schramm 98,99); *Nitrospira* not yet cultured, very small size (Schramm 99); rate of nitrite oxidation extremely low (i.e., 0.02 fmol/cell/h) up to 2,000 times lower than cultured *Nitrobacter* (Schramm 99); are difficult to study (Wang 15) *See also* ‘comammox bacteria’

Nitrobacter much more sensitive to several factors than *Nitrosomonas* resulting in incomplete nitrification, nitrite accumulation, and fish death in aquaculture facilicities (**Kroupova 05**); more sensitive to ammonia and nitrite than *Nitrosomonas* (**Anthonisen 76**), less tolerant of cold & high pH (WW216), low O2 (Pynaert 03), antibiotics erythromycin and neomycin (Noga 00, p67); and other environmental stressors (Zsoldos 98)

Nitrosomonas eutropha does do anaerobic oxidation, but very inefficiently- Jetten 99

oxygen depletion by (O'Connor 71; Seitzinger 84; Thimann 63; Weber 85); 4.3 mg O2 required for every mg of NH3 oxidized (Moorhead 88); bacteria stimulated by O2 (**Masuda 91**; Weber 85); competition with PAO for oxygen in wastewater tx (Gieseke 01)

plants in acidic environments have developed an ammonium-based nutrition because the acidity inhibits nitrification and nitrate production (Davies 97; Lewis 86; Schuurkes);

pollution from nitrate runoff and N2O generation make nitrification an environmental concern- Wang 15

RAS (recirculating aquaculture systems) modeled on prevalence of *Nitrosomonas* and *Nitrobacter* may be misleading (**Al-Ajeel 22**)

rates of, in marine sediments- **Gilbert 97**; Kemp 90: Rysgaard 96;

reagents for inhibition- Lewis 86; Nichols 76; Powell 92; Putnam 86; Reddy 83b; Ross 89;Wild 88

redox above 400 mV required- W234

salt: saltwater AOA species may differ from freshwater AOA species (Sauder 11); salt-tolerant nitrifiers (Gross 03)

soil N leaching, water pollution, disease incidence due to- Alsaadawi 92

soil containing nitrifiers: ammonia oxidation levesl v. soil pore or void size (**Fair 94**); *Nitrosomonas* and *Nitrosospira* in (Stephens 98); comammox in (**Osburn 20; Poghosyan 19**); disturbed forest soils with their increased O2 have more nitrifiers in following ranking CAOB > AOA >>AOB (**Osburn 20**)

starter cultures for nitrification are ineffectual (Hovanec 98); soil used successfully to do nitrification in aquaculture biofilters (**Gross 03**) symbiosis with FAMs- Moorhead 88; Reed 88

taxonomy: species reclassifications (Schramm 98); most ammonia-oxidizers are β-Protobacteria (Burrell 01) and AOA archaea (**Sauder 11**) and comammox (**McKnight 21**); PCR identification of bacteria using the *amoA* gene (**McKnight 21**) as their AMO enzymes are different (**van Kessel 15**); genetic difficulties distinguishing NOB from COAB, because the bacteria are so phylogenetically similar (**Al-Ajeel 22**)

Nitrites

accumulation due to nitrate respiration, incomplete nitrification and denitrification and DAP (**Phillips 02**; Russo 85)

ammonium inhibits cellular transporter and nitrite reductase (Lindell 98; Stewart 72); inhibits nitrate uptake but not nitrite uptake (de la Haba 90)

antimicrobial properties of (in macrophages) involve conversion to NO- **Darwin 03**

aquarium levels should be kept below 0.10 mg/ l (Noga 00)

bacterial processes causing nitrite accumulation in aquatic environments, review (**Phillips 02**); from nitrate respiration, incomplete nitrification, denitrification, and DAP (Anthonisen 76; Gamble 77; Payne 73; Smith 82; Wild 88, p. 619, 691); *E. coli* detoxifies nitrite by converting it to ammonia (N151)

cellular transporter for uptake must be induced (Lindell 98; Zsoldos 93)

denitrification, nitrites can be used in (Pynaert 03)

chloride protects fish from nitrite toxicity- Palackova 94; Russo 85) via the Cl-/HCO3- exchanger; keep Cl:NO3 ratios at certain level to protect fish (**Kroupova 05**)

invertebrate susceptibility and tolerance for nitrites- **Chen 89**

levels used for culturing duckweed are over 50 ppm- Ferguson 69; Stewart 72

nitrite preferred over nitrate (Ferguson 69) or growth about the same (Edwards 56)

NO (nitric oxide) connection to nitrite via nitric oxide synthase (Darwin 03)

nitrite reductase (enzyme for nitrite assimilation) must be induced (Lindell 98; Stewart 72); not inhibited by NH4+ (**de la Haba 90**); genes for found in Geobacteria suggest these bacteria can reduce nitrites (Methe 03)

pH effect on toxicity (Anthonisen 76; Russo 85; Zsoldos 98); toxic to bacteria at pH 5.5 (Darwin 03); pH not a factor in fish toxicity (Kroupova 05); toxicity greater at lower pH (Anthonisen 76)

soil accumulation of, not common (Gamble 77; Wild 88, p. 623, 658; Zsoldos 98)

sulfate-reducting bacteria easily reduce nitrites- Daalsgard 94

toxicity to: fish review (**Kroupova 05**) and (Darwin 03; Nikinmaa 92; **Palackova 94**; **Russo 85**; Spotte 79); long-term (>6 months) exposure to 0.05 to 0.2 mg/l nitrite, so for tropical fish should keep nitrite levels below 0.1 mg/l, converts hemoglobin to methemoglobin and reduces blood’s capacity to carry oxygen (Noga 00); massive deaths in 3 aquaculture facilities due to nitrite toxicity (**Svobodova 05**); need to maintain 50 mg/l NaCl to prevent problems (**Noga 00**); or 170 mg/l NaCl in overstocked aquaculture facilities (Svobodova 05); shrimp (Gross 03); plants, terrestrial (Hopkins 95; Wild 88, p619; Zsoldos 93); bacteria (Darwin 03; Gamble 77; N126) and nitrifying bacteria (**Anthonisen 76**)

uptake by aquatic plants (Edwards 56; Ferguson 69); 8 aquatic plant species tested for removal from nitrite polluted drinking water in India (**Rawat 12**), algae (Adey 98), and terrestrial plants (Lerdau 00)

water levels correlated with algal growth (Linton 98)

Nutrient Cycling (Seasonal)-

Al, Fe, Mn, DOC release into acidified lakes- **Urban 90**

bicarbonates/alkalinity (**WW195**)

C- Allen 72; **Kerr 72**; Kelly 84; **King 72**; Schindler 77

Ca (**WW178**)

Fe/Mn/P/Ca/S interaction- Pulich 82; Riemer 84; Ross 89; Williams 72); Fe/S/Mn cycling (**WW295**)

general- Brinson 76; Furch 88; Kuenzler 86; Kufel 91; Moeller 88; Peverly 79; Sondergaard 79; **Twilley 85**; Urban 90

gas bubbling, upwelling of nutrients- Kemp 72; Kerr 72; Ohle 78; W606

N- Brezonik 72; Bristow 73; Edmond 93; **Kuenzler 86; Lewis 86;** Nakajima 81; Riemer 84; Schindler 77; **WW220**

P- Burns 72; Edmond 93; Elwood 88; **Kuenzler 86; McRoy 72;** Moeller 88; Nakajima 81; Riemer 84;**Williams 72; WW258**

S- **WW315**

Nutrition-

alkalinity as a C source- Huebert 83; Overath 91

anion/H^+ cotransport (for NO_3-, SO_4-^{2}, and NO2) requires energy - Ullrich 84

apical stem tip is the site of fastest N uptake- **Miyazaki 85**

assimilatory reduction is when inorganic cpds are used for nutrition (e.g., chemical reduction of nitrates to ammonium so that the N can be assimilated into amino acids) (Zindev 78)

Ca uptake- DeMarte 77; Gerloff 75; Huebert 91; Smart 85; Smits 92

carbohydrate storage- Ralph 92

chloride is an essential element- Edwards 56

chlorosis can be caused by allelopathy (Elakovich 89; Frank 80); liming of terrestrial soils (Lindsay 84; Romheld 84; Rorison 60a,b; Russel 73; Wild 88); metal toxicity (Binhgam 86; Sauchelli 69; Wild 88); root anaerobiosis (Smart 85); S deficiency (Newman 88; Wild 88); measurement of chlorosis (Gaudet 73) competitive uptake of nutrients (Foy 78) such as NH4+ and K+ (**Beck 91**); Zn and Cd (Huebert 92; Polar 86); Mo and SO4 (**Howarth 85**); Fe and Mn (Basiouny 77); Ca and Mg (WW01, p. 182); K and Na (**Jampeeton 09a**)

critical concentration- Barko 86; Christiansen 85;Donahue 83; Doucette 91a; **Gerloff 75**; Grise 86; **Huebert 91**; Peverly 79; Raven 88; Sutcliffe 81

deficiencies (Fitzgerald 72; Glass 89; Goldman 72; Huebert 91; Krombholz 6(5); Notton 83; Shkolnik 84; Sutcliffe 81; Wild 88); symptoms in aquatic plants (**Newman 88**) and terrestrial plants (**Wild 88**); induce increased allelochemical production (**Tang 95**)

diffusion distance for leaves (Bowes 87; Madsen 91; Prins 89; Sand-Jensen 91; W219, 528) and roots (Barko 86; Madsen 91; Wild 88)

dilution of nutrients and metals inside plant during rapid growth- Overath 91; Titus 90

DOC release- Barko 81a; Nichols 76; Russel 73; Wild 88

essentiality and toxicity not correlated- Eichenberger 86

Fe uptake- **Basiouny 77**; Chen 88; DeMarte 77; Hether 84; Lindsay 84; Pulich 82; Romheld 84; Smith 84

fertilization with one nutrient increases uptake of another- Barko 86; Best 78; Davelaar 89; Goldman 72; Martin 91; Reddy 89; Schindler 72, 77

functions of nutrients- Eichenberger 86; Glass 89; Martin 86; Nieboer 80; Wild 88

general- **Gerloff 75; Glass 89**; Huebert 91; **Riemer 84**; Smart 84

growth, multiple and interactive influences of light, water, sediment and CO2- Barko 91; Overath 91

heterotrophic augmentation: glutamine and Bacto-tryptone as an N Source (Katoh 90)

ionophores- Borgmann 83; Eichenberger 86

leaf v. root uptake: leaf uptake easier than roots (Sculthorpe 67) required for Ca, K, and Mg in *P. pectinatus* (Huebert 83); N uptake by duckweed equal (**Fang 07**)

light (Barko 91b; DeMarte 77); effect on N & C uptake (Miyazaki 85; Nelson 80)

lilies, uptake of nutrients from underside of leaf- W524

limiting water concentrations of N, P, Ca for duckweed (Huebert 91) and of Ca for P. pectinatus (Huebert 83)

luxury consumption- Barko 86; Brinson 76; Cary 83; Fitzgerald 72; Gaudet 73; Gerloff 75; Glass 89; Gopal 87; Huebert 91; Reddy 89; W535; Whitehead 87

metalloenzymes- Bowen 79

metals stored as chelates- Ernst 92

mobile nutrients (Mo, N, P, K, Cl) v. immobile nutrients (Fe, Zn, Cu, Ca, B, S)- Bienfait 83; Donahue 83; Glass 89; Krombholz T6(5): Rorison 60b; Russel 73; Smith 84; Wild 88

nutrient medias- *See under* 'Artificial Propogation'

optimal composition of nutrients not necessary- Eichenberger 86

pH (Sutcliffe 81); effect on availability in soils (Ag. Ext 92; Wild 88)

reduction of C, Fe, H, N, S required before utilization- Smith 84; Thompson 89 root/shoot uptake (Best 78; **Bristow 71**; Gerloff 75; Hutchinson72; Iizumi 82; Marquenie 79; **Nichols 76; Overath 91**; Rattray 91; **Schuurkes 86; Short 84**; Sondergaard 79; Thursby 82; Whitehead 87); Ca, K, and Mg needed in the water (Huebert 83; 91)

storage of nutrients by young plants- Aiken 80; Pulich 82; Rorison 60a; Wild 88

sugar (glucose or sucrose) as C source- Bodkin 80; Edwards 56; Gaudet 73; Katoh 80; Kane 87; Rao 81; Schindler 77; W287

translocation of nutrients (Barko 88; Brinson 76; Bristow 71; Christansen 85; **DeMarte 74**; Hostrup 91; Iizumi 82; Kufel 91; Nichols 76; Pedersen 93; 97a; Schat 84; **Toetz 74;** van Wijck 92) *See also* ‘water transport and nutrient translocation’

vacuole physiology- Ernst 92

water hardness, a source of Ca, Mg, Na, K, S, Cl (Barko 82; W179); water Ca, K, and Mg may be required for growth, flowering, and survival (Barko 86b; **Huebert 83**; 91; Newman 88)

water movement and nutrient uptake (**Boeger 92**; Boston 89; Keeley 83; Nichols 76; Prins 89; Weber 85; W219+, 528) *See also* ‘artificial propogation/water movement’

water transport and nutrient translocation- Pedersen 93a,b, 97a

Oxygen-

aquatic plants don't contribute as much to aquariums as air diffusion- Atz 52

atm. levels determined by ocean algae- Ash 02

bacterial oxygen requirements quite specific- Ash 02

bubbles on plants is not a valid meausre of PS and represents only a small portion of the total (**WW538**)

CO2 consumption and oxygen production- W153

diel cycling: O2 levels in eutrophic v. non-eutrophic planted streams (**WW154**); and underneath floating plant masses in Amazon (**Jedicke 89**)

diffusion in water 10,000 X slower than in air- Ross 89

FAMs inhibit O2 diffusion- Reddy 84

inhibition of PS (Salvucci 82) and RUBISCO (Bowes 91)

loss due to chemical oxidation- Carpenter 83; W162, 174

minimal levels for fish is 2 mg/l (W170); for brine shrimp is 1 ppm (Persoone 80) or 2 ppm (Bossuyt 80); recommended range for aquariums is 5-8.6 ppm (Kasselmann 03); low levels (<4-5 ppm can inhibit growth; fish stressed by 58% saturation levels (**Vatsos 10**)

regulation of decomposition (Allen 71; DeBusk 89; Dew 80; King 72; Moorhead 88; Patrick 64; W162, 210) and aufwuchs activity (Burton 78)

sediment consumption by decomposition and nitrification- Burns 72

temperature and O2 saturation levels- Kasselmann 03

supersaturation due to PS- Hasler 49; W164, 168

toxicity of oxygen to bacteria- Ash 02; **N96** uptake from water by fish- Yarzhombek 87

water movement used during SAM cultivation for growth rate determinations to decrease excess O2 and boundary layers (**Nielsen 91**)

P (phosphorus)-

algae control by keeping it out of the water and in the sediment- Huebert 83

aquarium levels of- Spotte 79

availability *in situ* (Balls 89; Barko 91; Brinson76; Carignan 80; Chen 88; Christiansen 85; Edmond 93; Jaynes 86; Kuenzler 86; McRoy 72; Ozimek 90; Pulich 82; Riemer 84; Schat 84; Twilley 85; Wetzel 72; W256, 267); sediment and interstitial water (Painter 88)

bacterial removal of phosphates *See under* 'Wastewater Treatment' and 'Bacteria'

deficiencies in calcifuges growing in calcareous soils- Tyler 96; Zohlen 97

extracellular enzyme (phosphatase) stimulated by P deficiency- Foy 78; Kim 93

Fe limits availability (Riemer 84); P binding to Fe oxides (**WW252)**

general- **WW239-288**

limiting nutrient *in situ*- Barko 83a; Edmond 93; Kemp 72; King 72; Schindler 77; W255, 287; Wild 88

measuring water P levels, methods- Greenberg 92

nutritient uptake and use in seagrasses (**Touchette 00**)

organic and inorganic sources of (Greenberg 92; King 72; Saleque 95; Short 87; W255+); most P in water is organic (W255)

reaction with Ca in the water (Huebert 91) and in biofilms for denitrifying bacteria (Christensen 98)

sediment: preferred P source for plants (Barko 82; Bristow 71; **Carignan 80**; Christiansen 85; DeMarte 77; **McRoy 70**, 72; Reddy 87; W535); sediment uptake decreases slightly when P levels increases in water (Carignan 80; Steward 84); sediment components associated with P (Saleque 95), Fe oxides (**Jensen 95**), roots (van Wijck 92), and denitrifying bacteria (Christensen 98); sediment P mostly inorganic (Saleque 95; W261); P release from aquaculure contaminated sediments (**Christensen 00**)

solubilization (Andersson 78; Gunnison 89; Ponnamperuma 81; W258) from Fe precipitates (Edmond 93; **Jensen 95;** Saleque 95)

species of P in the water (Nakajima 88) and sediment (Saleque 95)

storage as phytates, indigestible to fish- Halver 89; NRC 83

symptoms of P deficiency in terrestrial (Foy 78; Krombholz T6(5); Tyler 96; Wild 88) and aquatic plants (Huebert 91; Newman 88)

tropical soils hold P tightly- Raven 92, p. 240

uptake by plants (Best 78; **Brinson 76**; Bulthuis 81; Gerloff 75; Huebert 91; Moeller 88; Reddy 83b, 89; Steward 84) mostly from sediment minerals not the intersitial water (Brinson 76; Steward 84); P uptake by PAO bacteria (**McKinney 04**) uptake by clay suspended in water (Kuenzler 86) or precipitation by Ca (Christensen 89; Reddy 87)

water uptake by plants not necessary if sediment has it- Huebert 83

Photosynthesis (PS)-

acclimation and down-regulation of PS with excess CO2 and bicarbonates (**Madsen 96**); CO2 fertilization shows short-term stimulation that decreases over time, terrestrial analogy (Hussner 16)

adjustment to changes in growth conditions (Madsen 91) and increased atmospheric CO2 (**Bowes 93**)

aquatic plants, PS in: 50% bicarb use, 8% CAM and 4% C4 (Han 20)

bacteria that PS *See under* 'Bacteria'

alkalinity, effect on PS- Wetzel 85

biomass increase will decrease PS- Wetzel 69

C_3 v. C_4 (Berry 82; Bowes 91; Cowling 99; Madsen 91; WW540; Wild 88); nearly all SAMS are C3, only 4% have C_4 (Han 20), which makes them vulnerable to O2 inhibition of RUBISCO, but this PEPCase can reverse this inhibition (**WW541**); terrestrial species are 95% C3, 1% C4, and 4% CAM; C3 plants can benefit from higher CO2 (Bowes 93); most submerged aquatic plants are C3, which is inefficient due to photorespiration and inhibition by O2 (WW540); association with climate conditions of earlier ages and evolution (**Cowling 99**); *Hydrilla* has a flexible PS (C3/C4 combination) (WW 541); *Ottelia alismoides* has CAM, C4, and bicarb uptake (**Han 20**)

Ca depletion from bicarbonate uptake- Otsuki 74; W190

CAM- night time CO2 uptake in 5/30 SAMs (**Yin 17**), present in 8% of aquatic plants (Han 20)

carbonate inhibits- Pokorny 85

chloroplasts, because of their bacterial origin, are sensitive to antibiotics that target bacterial ribosomes (Raven p21); plastids as separate genetic entities (Gewolb 02)

CO2 compensation point, above 40 ul/l for C3 plants v. 0-10 ul/l for C4 plants (Salvucci 82; WW540); lowered in plants adapting to shade due to decreased gas diffusion resistance (increased CO2 assimilation and decreased photorespiration) and lower dark respiration; shade adaptation in *R. paslustris* lowered it from 14 to 4 umol/m2/s (**Mommer 06**)

DOC release- Wetzel 69

effect of high pH (Allen 72; Wetzel 72); PS above pH 9 means bicarbonate use (Adamec 93)

efficiency (Madsen 91; W390, 530+), quantum yields (Berry 82; Kirk 94), rates of (Barko 81a; Bowes 87; Lloyd 77; Nielsen 91; Raven 88; Salvucci 82), and rate measurements (Allen 72; W152)

general- **Govindjee 82; Karpinski 99; Kirk 94; Rabinowitch 69; WW540**

inhibitors of- Karpinski 99; Seitz 82

Kranz anatomy ('wreath') is assoc with C4 plants where vascular tissues have an outer ring of mesophyll cells and an inner ring of bundle sheath cells (van Veen 21)

marine macroalgae- **Reiskind 89**

Na^+ increaes PS- Wetzel 69

O2 pressure within plant increases during PS (Sorrell 91) decreasing PS (Bowes 93; Salvucci 82); O2 is slowly released into water and can be used for plant for respiration even in darkness (Santamaria 94; W529); oxygen atom generated by PS comes from water molecule (N159)

oxygen production (from PS) & growth not always correlated (Santamaria 94); bubbles on plants is not a valid meausre of PS and represents only a small portion of the total O2 produced by PS (**WW538**); correlation coefficient for growth and PS was not significant (r= 0.333), whereas carbon affinity and growth was r=0.765 and was statistically significant (**Nielsen 91A**); Myriophyllum species with best growth (i.e., M. spicatum and M. triphyllum) produced the least amount of O2 (Net PS) and two with the worst growth produced the most PS oxygen (*M. tuberculatum and M. verticillatum*) (Dulger 17); O2 production at different light levels (**Jilon 02)**

pearling and O2 bubbling on plants: See ‘oxygen production’

PEPC, assoc. with C4 metabolism and used to reverse photorespiration (WW540), was found in 6 of 12 SAMS (**Yin 17**); increased presence at low CO2 in *O. alismoides* (**Han 20**)

pH increase due to either CO2 or bicarbonate uptake (Prins 89; Reiskind 89) can decrease CO2 levels and PS (King 72; Nielsen 91; Wetzel 69)

photorespiration (**Cowling 99**) decreases PS efficiency (Reiskind 89) by about 20-25% for C3 plants and 50% of fixed CO2 (Bowes 91) or as much as 50% in C3 terrestrial plants (WW540); can be counteracted by high internal CO2 (Bowes 93); induced by high temp and low CO2 in terrestrial plants (**Cowling 99**); it is the reverse of PS (Rabinowitch 96); not related to DOC release in SAMs (Hough 75);

Prochlorococcus, the cyanobacteria ancestor responsible for all current PS- Ash 02

productivity: net PS of SAMs at C saturation is 10 to 250 umol C/mg chl/hr- Madsen 91

respiration (dark time) measured in 10 species shows O2 consumption of 1 mg O2/g dry wt/hr, whereas O2 provided by PS is ~1 mg at with low CO2 and 10-15 at high CO2 (**Hussner 16**); maintaining the PS enzymatic machinery is a major respiratory cost (Sand-Jensen 91b); seasonal adaptation of respiration (Mann 73)

root oxygenation of sediment- Caffrey 91; Carpenter 83

Rubisco accounts for majority of earth's protein and organic N; functioning of RUBISCO (Bowes 91; Cowling 99); pH optima of 8 (Weber 79); inhibited by oxygen (WW540); genetic variants of Rubisco in *Potamogeton* genera provide information on its evolution into heterophyllous and homophyllous species (**Iida 06**); selection for *rbcl*, a chloroplast gene that encodes a catalytic subunit of RuBisCO is associated with land plants and heterophylly (**Iida 06**)

shade adaptation, total chlorophyll conc. increases (Kirk 94); ratio of Chl *a* to Chl *b* increaes only slightly (Barko 83c); part of plant can be shade-adapted and another part can be sun-adapted (Karpinski 99)

temperature- effect on growth, PS (**Barko 81a;** Bowes 87, 89, 91; **Cary 83;** W357) and photorespiration (Cowling 99; WW540) water movement, high flow rates inhibit PS- **Ghosh 94; Madsen 83**

See also Pigments

Pigments-

anthocyanins- flavonoids for visual attraction (Hart 88); filtration of toxic UV light (Grossman 94; Les 90); sensitive indicator of allelopathy (Leather 86); relationship to flavonoid allelochemicals (Haslam 81; McClure 70); associated with red aquatic plants and shallow water (Spence 81) and P deficiency in terrestrial plants (Krombholz T6(5); Wild 88); protect plants from excess e- damage and O2 radicals at combined high light and low temperatures for aquarium plants (**Pedersen 2022**)

bacteriochlorophyll is pigment unique to the purple and green anaerobic bacteria (N158, 273); bacteriorhodopsin of the extreme halophiles (N289); are widespread among marine bacteria (N226)

blue light receptors in plants and animals (**Suarez-Lopez 98**; **Thomas 97**); one for seedling phototrophism not yet found (Attridge 90; Hart 88) but intermediate protein has been identified (**Huala 97**)

carotenoids: structure and fat solubility (Raven p105); are found in green algae and plants only (not red algae or cyanobacteria (Raven p269); protect plant from oxygen radicals (Lawlor 87); carotenoid levels increase with increasing light (**Spencer 86**); protect zygote chlorophyll (Raven p279) and are found in younger plants (Schagerl 00); are not energy efficient (Emerson 60); inhibition of carotenoid synthesis by fluridone (**MacDonald 08**)

chlorophyll (Gaudet 73; W343); chemical structure like heme (Hart 88); its quantity affected by light levels (Thompson 89; W354) and Fe (Basiouny 77); needs Mg to absorb red light (Nieboer 80); extinction coefficients and analysis of (Elakovich 89); reduction of synthesis by allelochemicals (Leather 86)

chlorophyll *a*, the main light gathering pigment (**Emerson 60**; Lawlor 87); chemical structure of (Rabinowitch 69); absorbs light at 680-710 nm, but needs help from Chl *b* (Kirk 94)

chromatic adaptation common in algae but not plants- Kirk 94

classification (N158) can be chemical (chlorophylls, carotenoids or flavonoids) or functional (photosynthetic or photomorphogenic)- **Hart 88**

color in flowering plants due to: (1) anthocyanins (a flavonoid), which are red, violet or blue; (2) flavonols, which are yellow or ivory; and (3) carotenoids, which are red, orange, or yellow (Raven p428)

flavonoids include chalcones, flavones, flavonols, isoflavones, and anthocyanins (Hosel 81)

photosynthetic pigments of plants, algae (W344), and bacteria (Kirk 94; **Lawlor 87;** Reiskind 89);

Photosystem I (Chl *a*, 680 nm) and Photosystem II (Chl *b*, 546 nm) work together for maxiumum efficiency (Kirk 94; **N158**) phycobilins are limited to red marine algae and Blue-green algae (Emerson 60; Hart 88; Lawlor 87; N158), absorb B and transfer energy to chlorophyll with 100% efficiency (Lawlor 87); aren't found in green algae or plants (Raven p269)

phytochromes, main photomorphogenic pigment (Hart 88; Thomas 97); chemical structure (Attridge 90); different phytochromes for different purposes (Smith 94); detects shading (Smith 77b), controls terretrial seed germination (Hart 88), heterophylly (Spence 81) and stem elongation (Attridge 90; Holmes 77c)

phytochrome involvement in detection of shading (**Smith 77b**); flowering (**Lumsden 87**; Wooten 78); heterophylly (**Bodkin 80**); turion formation (**Chambers 85**), turion germination (**Augsten 88**), and flavonoid production (Hanson 81; Ibrahim 81; McClure 70); and chloroplast movement in Vallisneria (Dong 95)

proanthocyanins are condensed tannins and they are allelopathic- Stafford 90

PS pigments of marine algae are adaptations to low light, not spectral quality- Reiskind 89

red leaves in aquatic plants: high light combined with low temp in aquarium plants (**Pedersen 22**)

rhodopsin pigment of marine bacteria are used for their photosynthesis (N226,230)

UV protective pigments of algae- Kaiser 97

Plant Composition and Components-

age dependent, seedlings store nutrients- Aiken 80; Center 91; Hay 88; Rorison 60a; Wild 88

alkaloids- Ostrofsky 86

amino acids- Best 80; Boyd 69; Gaudet 73

biomass- Nielsen 91; Peverly 79; Twiley 85

cell volume is 10^{-14} liters (Rae 99)

C, ash-free, is 40-60%- Bowen 79; Tucker 81; W151

chlorophyll- Nielsen 91; Raven 88; Sharma 85; Sorrell 91

elements (Barko 88; Bowen 79; Christiansen 85; Donahue 83; El-Ghazal 86; Gaudet 73; Gerloff 75; Glass 89; Gopal 87; Grise 86; Hill 79; **Hutchinson 75**; Moeller 88; Peverly 79; Pulich 82; Rattray 91; Raven 88; Sutton 85; Titus 90; Twilley 85; W286) diluted during rapid growth (Overath 91); roots/shoots/sediment/growth (Painter 88; Roelofs 94)

energy- Botts 90; Boyd 69

gases- Bowes 89

intracellular distribution- Marquenie 79

malate, internal buffer (Glass 89; Keeley 83; Sharma 95; W532)

organic C increases best reflect increased CO2 fixation, ash increase does not- Sand-Jensen 91b

P:N:C for algae/plants- Martin 91; Raven 88; W285

phenols- Boyd 69; Center 91; Kerfoot 89; McKey 78

pigments *See* "Pigments"

plant parts- Barko 88; Botts 90; Brinson 76; Bristow 71; Christiansen 85; Gopal 87; Raven 88; Twilley 85

protein, ash, CHs, fiber, water- Botts 90; Bowen 79; Boyd 69; Gopal 87; NAS 77; W544

roots/shoots- Agami 90; Best 78; Denny 72; Painter 88; Pulich 82; Roelofs 94; Ross 89; Sutton 85; W542; Whitehead 87

seasonal effects on plant parts and elements- **Peverly 79**

vacuoles- Ernst 92; Glass 89

water content high- Bowes 87; Boyd 69; McClure 70

Redox of Sediment-

anaerobic electron acceptors (CO2, Fe, Mn, NO_3, SO_4)- Ash 02; Connell 68; Reddy 77; Rich 78; Ross 89; W603; Westerman 93; Wild 88 *See also* "Energy Transformations"

biofilms make Redox zones horizontal as well as vertical (Masuda 91); O2 gradients (Ash 02)

decomposition of organic matter controls Redox- Chou 87; Ponnamperuma 81; Wild 88

denitrification- Reddy 83; Russel 73; van Wijck 92 *See also* 'Bacteria: DAP'

electricity generated in sediment by Geobacteria in presence of electrodes- **Bond 02**

eutrophication in lakes- W688

Fe/Mn/P reactions- **Burns 72**; Gambrell 91; W261+, 308, 339, 399+; Wild 88; Williams 72

fermentation- DeLaune 84; Koch 90; Ross 89; W603; Wild 88

invertebrate burrowing increases sediment Redox- Ash 02

liming of sediment (bicarbonate fertilization) increases pH, stimulates bacteria activity, lowers Redox, increases nutrients, and stimulates plant growth- **Roelofs 94**

measurements *in situ* (Chou 87; van Wijck 92) and in the laboratory (Misra 38; Steinberg 94); electrodes plus Geobacteria in sediment generate electricity (**Bond 02**)

methane formation- Barko 83b; Russel 73

oxidative processes produce acid and solubilize Zn (**Kirk 95**) oxidation of FeS_2 produces the acidity of mine wastes (Ash 02)

oxygen concentration and Redox do not correlate well in the substrate (Steinberg 94)

plant growth- **DeLaune 84**; Pulich 85

poise dictated by Fe- Ross 89; Wild 88

Redox, general- Barko 83; Burns 72; Caffrey 91; Gambrell 91; Glass 89; Kemp 72; Ross 89; **Russel 73**; W298+, 688; **Wild 88**; Williams 72

reductive processes consume acid- Burns 72; **Giblin 90**; Kelly 84; Wild 88

sulfide formation (Connell 68; Kemp 72; Ross 89; Russel 73; Wild 88; W320) and micronutrient availability (Burns 72; Reddy 77)

Reproduction

adventitious plant production in water lillies (Kasselmann 07) calcium- **Brewbaker 63; Conrad 88; Iino 89; Miller 83**; Sabba 93

flowering induced in shallow but not deep water (Wooten 78); induced by clipping of the apical meristem in pondweeds (Sheldon 86); media fertilization with K and Mg promotes flowering in *P. pectinatus* (**Huebert 83**)

light photoperiod of 15hr (v. 12hr) stimulates reproduction in water lillies (Kasselmann 07); shorter photoperiod stimulates turion production in Hydrilla (**MacDonald 08; Spencer 86**)

monoecious v. dioecious Hydrilla (**Spencer 86**)

phytochrome control of flowering in duckweed- Lumsden 87

spores of *Marsilea* last 100 years- Raven p352

temperature, effect on flowering of seagrasses- McMillan 82

Utricularia, stimulation of flowering by adding beef extract to growth media- Pringsheim 62

water ferns (*Salvinia*, *Azolla*, and *Marsilea*) produce spores- Raven p352

Roots-

acid secretion (Donahue 83; **Romheld 84**; Ross 89; Wild 88), CO2 release (Wild 88), and O2 release (Kirk 95) causes rhizosphere acidity, which solubilizes Fe (Cohen 98), Zn, and P (Kirk 95; Saleque 95); effects growth of *Typha latifolia* (Brix 02)

bacteria attached to roots (**Blotnick 80**; Russel 73) linked to DOC secretion by FAMs (Coler 69) and enhanced sediment denitrification (Caffrey 92); bacterial colonization inside the roots (Calhoun 97)

biomass of roots and rhizome of aquatic (**WW559**); growth studies should always include root biomass (WW559); biomass decreases with sediment fertility (Barko 83b; Szczepanska 71; Wild 88) and long-term CO2 fertilization (Shaw 02); root and above-ground biomass behave differently when plant's environment is manipulated (Shaw 02)

CH fermentation doesn't effect growth- DeLaune 84; Koch 90

Fe oxide sheath (Bedford 91; Christensen 98; van Wijck 92; Wild 88) adsorbs Zn and Cu (Otte 89); bacteria that associate with it (Ash 02)

gas transport within roots (Vroom 22)

light required for root production and maintenance- Sand-Jensen 91b

respiration almost solely at root tip that requires contstant O2 (Bedford 91; Caffrey 91; Glass 89; Koch 90; Wild 88; Vroom 22; Yamasaki 92) (**Vroom 22**) and Fe solubilization (Lindsay 84; Romheld 84)

methane transport to the atm from roots to atm (**Vroom 22**)

porosity correlates with sediment CO2 uptake and use for PS (**Winkel 09**) and methane transport from roots to air (**Vroom 22**)

rhizosphere bacteria, interaction with SAMs (**Gunnison 89)** and FAMs **(Coler 69)**

Salvinia "roots" are actually leaves; they bear spores- Raven p353 secretion of DOC (Blotnick 80; Coler 69; Duarte 88; Holmer 98; **Ross 89**; Tang 86; W534; Wild 88) increased by CO2 fertilization (Jones 98); DOC as allelochemicals for interspecies competition (Donahue 83; Tang 86), Fe reductants and chelators (Cohen 98; Foy 78; **Hether 84**; Hopkins 95; Romheld 83; Russel 73**; Tyler 95**), acid phosphatases (Foy 78), and malate to block Al toxicity (Huang 96); use of DOC by soil bacteria (Ross 89); artificial stimulation of DOC release (**Raskin 99**)

sediment diffusion distance v. growth- Barko 86a; Wild 88

species variation in biomass (Barko 86a, 91; Madsen 91; W542) and its location in the sediment (Titus 83)

sulfhydryl groups on root surface take up metals- Cohen 98

translocation of nutrients between individual roots (Wild 88) and rhizomes (Haslam 78)

Root Oxygen Release (ROL)-

acidity generated from oxidation of Fe, solubilizes Zn (**Kirk 95**) and P (**Saleque 95**)

aerial advantage (Barko 83b; **Chen 88**); emergents can use air O2 not PS O2 (**Dacey 80, 82**)

bacterial activity stimulated (Carpenter 83; DeBusk 89; Gunnison 89; Pulich 82; Reed 88) resulting in destruction of phytotoxins (Gunnison 89), including H_2S (Joshi 77), and increased nitrification in the sediment (Schuurkes 86) and on the roots of water hyacinth (Weber 85); denitrification stimulated in rhizosphere of *P. perfoliatus* (Caffrey 92); methane (**Calhoun 97; Grunfeld 99**) and Fe oxidation stimulated by root oxygenation (**Emerson 99**)

FAMs: ROL into water (Moorhead 88) is not enough to make up for blocking O2 diffusion into water (Reddy 83a, 84); FAMs (*E. crassipes* and *P. stratiotes*) release O2 derived from air or PS not the water (**Jedicke 89**)

Fe toxicity (van Wijck 92; Wild 88); Fe oxidation by root-associated bacteria (**Emerson 99**); iron plaques on roots decrease root porosity and gas exchange, nutrient uptake, etc (Vroom 22)

general- **Armstrong** 72, **91a, 91b;** Barko 91; **Bedford 91; Caffrey 91; Carpenter 83;** Chen 88; Dacey 81; **Pedersen 98**; Raven 88; Schat 84; Smits 90a; Sorrell 91; W530; **Weisner 89**; Wild 88

H_2S oxidation stimulated by root oxidation (**Joshi 77**) protects plants (Westerman 93)

light dependence (Caffrey 91; Carpenter 83; Holmer 98; Pedersen 95; W521) and independence (Steinberg 94); root oxygenation maintained at night (**Pedersen 98**)

metal toxicity- Foy 78

methane: ROL inadvertently enhances methane decomposition (**Vroom 22**)

mycorrhizae able to function in sediments because of root oxygen release by SAMs, FAMs, and emergent plants (WW545)

neighboring plants- Ernst 90; Foy 78; Szczepanska 71; Titus 83

nutrient availability- Carpenter 83; Chen 88; Gunnison 89; **Jaynes 86; Kirk 95; Moore 94; Salique 95**

sediment oxidation greater for emergent plants than submerged plants (Barko 86, 91; **Chen 88**) oxidized microzone a partial barrier to sediment toxicity- Pedersen 98; Wetzel 90

P release and uptake by rice- **Saleque 95**

redox of bulk sedment not influenced very much by (Bedford 91; Jaynes 86; Steinberg 94)

rice release methane (Westerman 93) and are surrounded by an air layer which aids gas exchange (Kirk 95; **Raskin 83**; Saleque 95; Wetzel 90)

SAMs release 0.01- 0.2 ug/cm2/min (WW539)

root tip, site of most O2 release- Koncalova 90; **Smits 90a**

size of root's oxygenation zone- **Pedersen 98**

species variation (**Calhoun 97; Pedersen 98**; Roelofs 84; Smits 90a); isoetids release a lot (Schuurkes 86; **Pedersen 95**; Roelofs 94); those that leak more O2 are vulnerable to low substrate Redox (Raun 07; Smits 90a)

vascularization necessary- Bedford 91; Jaynes 86; Smits 90a; Wetzel 90

water lily requires atm. exchange via floating leaves- Smits 92

younger FAMs much more effective oxygenators- Moorhead 88

Zn release from soil particles and uptake by rice- **Kirk 95**

S (Sulfur)-

bacteria involved in oxidizing and reducing S (McKinney 04; **WW 315; Zinder 78**); Beggiatoa mats under marine aquaculture cages due to sediment overload (Christensen 00)

cycling (**WW 310**); in sediments (**Holmer 98**) with biofilm model (Labrenz 00; **Peiffer 94**); and prehistoric times (Habicht 03)

deficiency symptoms in terrestrial plants (Wild 88) and aquatic plants (Newman 88)

enzyme association- Smith 84

H_2S-

ADH activity and ammonium uptake, inhibition of- **Koch 90**

Fe neutralizes H2S toxicity (Barko 83b; Connell 68; Ohle 78; Ponnamperuma 81; Ross 89; van Wijck 92; Westerman 93; Wild 88); ZnS ppts before FeS (Labrenz 00)

levels in anoxic water of Lake Tanganyika are 33 uM (Edmond 93); present in sediments with growing plants (Misra 38); levels of metal-SH complexes in oxic waters (Rozan 00)

marine sediments more susceptible to H2S production (Koch 90; Schulz 99; Westerman 93); contain 67 X more sulfates (20 mM) than a freshwater sediment (300 uM) (Habicht 03)

metal exchange (Cu of Cd for Fe) in sulfide complexes (**Rozan 00**)

marine species are more tolerant of H2S- Koch 90; Pulich 82

neutralization of Fe toxicity (Pulich 82; van Wijck 92) and the availability of other metals, such as Cu and Zn (Bingham 86; Reddy 77; Rozan 00)

nitrification-denitrification are inhibited by- Kemp 90

  - oxidation of H2S by bacteria (N771; **Zinder 78**) lowers pH (Giblin 90; Misra 38; Wild 88), is rapid (W319, 324) and energetically favorable (N156), such there is little release of H2S to the atmosphere (Westerman 93); process is common in the oxidized rhizosphere (Westerman 93), because it is stimulated by root release of O2 (**Joshi 77**); this H2S oxidation protects the plant from H2S toxicity (**Holmer 98**; Westerman 93); oxidation to S associated with nitrate reduction in bacteria (**Schulz 99**); bulking problem in wastewater treatment caused by excessive growth of filamentous S oxidizers like *Beggiatoa* and *Thiothrix* (N276); S, thiosulfate and sulfite are intermediates in H2S oxidation and can themselves be oxidized (**Zinder 78**)
  - protein degradation by some bacteria as a source (N253)
  - sediment availability (**Brouwer 95**; Painter 88) and enhancement of plant growth- Pulich 82, 85
  - SRB of freshwater sediments are adapted to low sulfates (Habicht 03)
  - toxicity to mammals, plants, fish and bacteria (Bowen 79; Brouwer 95; DeLaune 84; Kemp 90; Koch 90; Joshi 77; Ohle 78; Ponnamperuma 81; Ross 89; **van Wijck 92**; Wild 88) at 1 uM (Ross 89; Wild 88) or less (Brouwer 95); mechanism of toxicity (Koch 90)
  - source of H2S is half from decomposition and half from sulfate reduction (WW314)

levels of sulfates in freshwater lake sediment are 0.3 mM v. 20 mM in marine sediments- Habicht 03); sulfate levels (ave) in freshwater (0.3 mM) v. 28 mM in seawatera, which is 93X greater (Howarth 85

leaf uptake of SO2 gas by terrestrial plants (Hutchinson 72); bacteria and plants assimilate S as sulfate (N770)

Mo competes for uptake- **Howarth 85**

N association with- Wild 88

purple and green bacteria oxidize oxidize H2S to sulfur granules- **N273**

pyrite (FeS_2) oxidation causes acidity in acid-sulfate soils (Boyd 95) and the acidity of mine wastes (Ash 02); FeS (mackinawite) not pyrite is the expected iron sulfide below 100 degrees (Labrenz 00); oxidation is both chemical and biological (Zinder 78)

regulation of micronutrient availability and toxicity- Barko 83b; Bingham 86; Burns 72; Caffrey 91; Giblin 90; Kemp 72; Ohle 78; Ponnamperuma 81; Pulich 82; Reddy 77; Ross 89; W319+, 263; Wild 88

sediment availability (Bowen 79; Connell 68; Ponnamperuma 81; Pulich 82; van Wijck 92); S is rarely a limiting nutrient for plants (Westerman 93); species of sulfides in (**Brouwer 95**)

sulfate oxidation may be chemical or microbial (Peiffer 94); oxidation by *Beggiatoa* (Ash 02)

sulfate reduction by bacteria (SRBs) (**Holmer 98**; Westerman 93) raises pH (Burns 72; **Giblin 90**; Kelly 84; Westerman 93) and is inhibited by Mo (Skyring 88); sufates reduced to H2S before bacteria can assimilate the S (Zinder 78)

sulfates from oxidation of FeS in rocks (Peiffer 94; W184; Wild 88) and aquatic plant roots (Holmer 98)

uptake by plants (Pulich 82; Smart 85) prefered from the water (Barko 91a) water S not necessary for *P. pectinatus* if sediment has adequate S (Huebert 83)

ZnS precipitation by SRBs- Ash 02; **Labrenz 00**

Sediment-

ammonia in- Jones 82; Santamaria 94

anaerobic condition, importance of- Barko 91; Pulich 82, 85; Russel 73; W534

bacterial processes (Ash 02; Jones 82; **Westerman 93; Nealson 97)**

Ca, effect on growth- Gopal 90

carbonate buffering systems (Fe, Mn, Na, Ca) [Ponnamperuma 81] regulate P availability (Roelofs 94; Short 87)

CEC- Kyuma 89; Nichols 76; Schat 84; W185

chemical composition v. growth- **Misra 38**; Painter 88; Roelofs 94

CO2 in: 10-250 times higher than atm level of 16 uM (Winkel 09) and used by some plants (Val, Isoetids, Ludwigia for PS (**Winkel 09**)

composition of (Barko 81a, 82, 83b, 86; Bowen 79; Huebert 83; Kyuma 89; Peverly 79; Pulich 82; Rattray 91; Schat 84; Steward 84; van Wijck 92; W684); elements (**Painter 88**; Roelofs 94) in aquaculture pond soils (Boyd 95)

conductivity- Barko 83b; Ponnamperuma 81

Cu removal from solution by sediment- Boyd 95

Saltwater v. freshwater- chemistry and bacteria of (**Nealson 97**)

decomposition-

acetic acid generated under anaerobic conditions- Spencer 95

bethnic respiration, source of C (Andersson 78; Rich 78; Titus 90; **Wetzel** 72, **85**); 0.75 g CO2 released by aquaculture sediment per m2/day (Boyd 95)

bicarbonates stimulate- Roelofs 94

Fe availability- Gambrell 91; Lindsay 84; Ponnamperuma 81; Wild 88

C, N, S and P release- Kistritz 78; Pulich 85; Sand-Jensen 79

nutrient availability and growth- Roelofs 94

O2 and acidity (Andersson 78; Kelly 84; W489); effect on allelochemical accumulation (Gopal 93)

O2 consumption- Carpenter 83; W161, 259, 597

particle size (Mann 72); finer sediments have more bacteria (Adey 91)

rate affected by OM, acidity (Kelly 84; Roelofs 94) and temperature (Ponnamperuma 81; W598; Wild 88)

density a function of mineral content, not OM (Barko 86); effect on growth (**Barko** 82, **86**, 91; van Wijck 92)

depletion of N and P by plant growth- **Barko 88**; Chen 88

diffusional resistance- Barko 86; Madsen 91; Russel 73 disturbance, lack of effect (Bulthuis 81; Isolda 91); bioturbation, site for nitrification-denitrification (Kemp 90), nutrient release into the water (W606), and oxygenation (Ash 02)

DOC toxicity- Barko 83b, 86, 91; Drew 80; Patrick 64; Ponnamperuma 81; Szczenpanska 71

exoenzymes (Donahue 83) such as ureases (van Wijck 92)

fertile sediments for SAMs (**Aiken 80; Barko** 81a, 82, 83b, **86**; **Best 78; Boeger 92**; **Denny 72**; Huebert 83; Jacobsen T5(5); Langeland 83; **Pulich 85; Rattray 91**; Sand-Jensen 79; **Short 87; Smart 85; Steward 84;** Sutton 85; Szczepanska 71; Titus 83; van Wijck 92; Weisner 89); comparative study (**Misra 38**); mainly loams (Gopal 90)

fertility and bacteria population increases- Duarte 88

fertilization- **Barko** 82, 83b, **86,** 88, 91; **Bulthuis 81**; Chen 88; **Christiansen 85**; **Dennison 87**; Moeller 88; Pulich 85; Santamaria 94; Smart 85; Steward 84; **Sutton 85, 96**; van Wijck 92

gases (Barko 83; Kemp 72; Kerr 72; **Ohle 78**; Painter 88; Ross 89; W319, 599); CO2 (Misra 38) *See also* “Gases”

heavy metals in contaminated sediments (**Lee 07**)

interface between sediment and water- Andersson 78; Kelly 84; Sand-Jensen 91; W259+; Williams 72

interstitial water (Barko 86; Brinson 76; McRoy 72; Peverly 79; Ponnamperuma 81; Reddy 77; Short 87); homogeneity of (Ponnamperuma 81); elements in (**Painter 88**)

invertebrate burrowing can increase microbibal activity four fold (WW651); oxidation of sediments by (Ash 02)

liming, effect on growth (Roelofs 84; Wild 88); stimulates decomposition, nutrient release, and plant growth (**Roelofs 94**); beneficial to sediments of aquaculture ponds (Boyd 95); may alleviate Mn and Zn toxicity in acid soils (Rorison 60A, 84)

littoral (Dy) v. pelagic (Gyttja) sediments: major differences in composition, texture, color, N content; dy (C:N < 10) contains > 50% OM, remains of emergent plants, peat and unsaturated humic colloids; Gyttja contains remains of phytoplankton, inorganic ppts (C:N > 10) (WW632)

major site of decomposition *in situ*- Kelly 84

methanogenisis, primary route of decomposition in lake sediments, because of lack of inorganic electron acceptors- Westerman 93

micronutrients, 10^5 more in sediment than water (W315) can take care of plant needs (Huebert 83)

microzone of nutrients- Weber 85; W261; Williams 72

N cycling (**Blotnick 80; Boon 87a,b; Neori 17**); NH4+ conc 100 X more than NO3 (Burkholder 92)

N_2 fixation by bacteria associated with aquatic plants (**Barko 91a; Neori 17**)

nitrate removal, increased by presence of sediment (Reddy 87; Risgaard 94; Seitzinger 84); NO3 contaminated sediments recovered quickly (**Burkholder 92**)

nitrification-denitrification- Kemp 90; Risgaard 94; Seitzinger 84 nutrition- **Amudsen 82; Barko** 83b, 86, 88, **91a, 91b;** Best 78; Brinson 76; Chen 88; Christiansen 85; Denny 72; **Haslam 78**; Huebert 83; McRoy 72; Moeller 88; Nichols 76; Nielsen 91; **Peverly 79;** Roelofs 94; Sculthorpe 76; Short 87; Smart 85; Sutton 85

rhizosphere ecology**- Barko 1991a; Neori 17**

viruses in rhizosphere associated with wetland plants (**Neori 17**)

organic matter-

allelopathy of- Gopal 93

denitrification, stimulation of- Kurtz 80

density is always 0.05 mg/l (Barko 86); compression (via centrifugation) increased plant growth because it decreased root-nutrient distance (Barko 86)

humus *See* "Humus"

inhibition of SAMs more than emergents- Barko 82, 83b, 86, 91; Dooris 82; Smits 90a, 90b

labile v. refractory- Barko 83b; van Wijck 92

levels of OM reach a constant equilibrium in terms of type and quantity (Misra 38); levels above 20% are inhibitory to plants and affect sediment density (Barko 86)

metals (Al, Fe) high but Ca low in organic sediments- Misra 38

micronutrient release- Beckwith 75; Bingham 86

mulm: marine fish farm sediment has 3 billion bacteria/cc (Ash 02); DOC aggregates into large particles such that 19% of POC is derived from DOC (WW652)

N and P source- Langeland 83; Pulich 85; Sand-Jensen 79; Short 87; Spencer 92; van Wijck 92

numbers of bacteria- Duarte 88; W595

nutrient content high, but density low- Barko 83b, 86; van Wijck 92

organic acids (Ponnamperuma 81), inhibit SAM reproduction (Spencer 95)

plant growth (Barko 82, 83a,b, 86; Denny 72; Donahue 83; Langeland 83; Overath 91; Sand-Jensen 79; Short 87; **Spencer 92**; Szczepanska 71; Titus 83; **van Wijck 92**; W548) depends on species (Dooris 82**; Misra 38**; **Pulich 85; Sand-Jensen 79**; Weisner 89); OM may be stimulatory (Misra 38; Spencer 92)

sediment components- **Barko** 82, 83a, **83b,** 86; Brinson76; Christiansen 85; DeMarte 74; Donahue 83; Kemp 72; **Langeland 83;** Peverly 79; Rattray 91; Riemer 84; Sand-Jensen 79; Smits 90a; Sondergaard 79; Weisner 89; van Wijck 92

Zn association with- Kirk 95

marine v. freshwater (**Nealson 97**): marine produces more sulfides (Jones 81); sulfate levels in freshwater lake sediment are 0.3 mM v. 20 mM in marine sediments (Habicht 03)

oxidized microzone keeps nutrients and toxins in the sediment (Boyd 95; Huebert 83; W261); 1,000 X more bacteria than overlying water (WW636); barrier to release of nutrients, especially Fe and P (**WW 248**) oxygen consumption is both chemical and biological (root respiration and microbes)- Carpenter 83; Ross 89; Wetzel 90

P association with sediment fractions (Boyd 95; Saleque 95), removal from the water (Boyd 95; Misra 38)

P/Fe/Mn/S interaction- Barko 83b; **Burns 72;** Connell 68; **Jensen 95**; Ponnamperuma 81; **Pulich 82;** Roelofs 94; Ross 89; van Wijck 92; W320; Wild 88

peat *See* “Soils, terrestrial:peats and potting soils”

pH (Andersson 78; Barko 83b; Connell 68; Kyuma 89; Ponnamperuma 81; Reddy 77; Roelof 84; Titus 90; van Wijck 92; Wild 88) determines nutrient availability (Donahue 83) with 6.6 ideal (Ponnamperuma 81); pH stability of sediments (**Andersson 78;** Connell 68; Kelly 84; Ponnamperuma 81); alkaline pH of acid soil after submergence (Kirk 95); Mn toxicity at pH 5.2 (Rorison 60a); pH where plants grow is 5.4 to 8.0 (Misra 38)

pore size, penetration of roots (Ross 89; Wild 88) and overlying water (Kelly 84) *See also* ‘Soils:’void space’

protozoa pop., 100,000/ml (WW666)

species variation in plant growth on different sediments- **Biernacki 97**; Gopal 69; Hutchinson 75; Misra 38

surfaces of particles almost completely coated with OM- Thurman 85

toxicity of (Barko 83b; Bowes 89; Caffrey 91; Gamrell 91; W530), especially if there is no oxidized microzone (Boyd 95)

turbidity of sediment suspension in water can be reduced with alum, Ca, humus, or Mg- Boyd 95 *See also* ‘Wastewater treatment: flocculents’

worms, their digging helps cycling- Barko 91; W296

Zn, bioavailable and unavailable forms in the sediment- Kirk 95

Soils, terrestrial-

acid-sulfate soils are a problem for aquaculture ponds (Boyd 95); association with Al toxicity in tropical soils (Davies 97); pyrite oxidation results in acidic mine wastes (Ash 02)

acidity v. fertility (Donahue 83; Kawaguchi 77; Wild 88); acid soils stress plants more than alkaline soils (Rorison 86; Vickery 84); adaptation of plant species to (**Rorison 86**)

aggregation of soil particles due to microorganisms (Vickery 84) and organic matter (Donahue 83); filamentous, fungi-like bacteria (Actinomycetes) stabilize soil (McKinney 04)

Al & Fe oxides are part of the clay fraction (Boyd 95); they coat the soil particles (Thurman 85), which enhances bacterial attachment (Mills 96)

allelochemical binding to clay and humus- Chou 87

ammonium binding is specific for clay- Ponnamperuma 81; van Wijck 92

aquatic plant growth- **Spencer 92**

bacteria of (**N766**); 4,000 species per g. of fertile soil (N256); same bacteria found in soils and the natural environments are used in wastewater treatment (McKinney 04); 10^9 to 10^{10} bacteria/g soil (Lederberg 00); acidic Finnish soils have 10^7 to 10^9/g (Iivanainen 97); bacteria colonizing $\leq$0.5% of surface area of soil particles (Lederberg 00); bulk soil contains mostly gram-positive spore-formers while rhizosphere contains more gram-negatives (N766)

biofilms, organization and bacteria involved, artificial construction of soil biofilm, review (**Cai 19**)

CEC of soils (Ag. ext.; Boyd 94; Kyuma 89; Kuenzler 86; Kurtz 80; Nichols 76; Ross 89; Russel 73; Sutcliffe 81; W185; Wild 88); ave for sand is 2.8 and clay loam 25 meq/100 g soil (Mills 96); exc. CEC comparison of clays, organic matter, various soils (**Marchinchin 19**); OM has a CEC of 300-550 (Wild 88 p578)

clay removes metals from solution (Bailey 99); CEC of montomorillonite, v. kaolinite v. illite clays (Marchinchin 19)

composition is 50% void space containing variable amounts of water or air, 45% minerals, and 5% OM, pores allow gas and water exchange and are critical to soil biology (roots, microorganisms, etc) (Wikipedia 2022, ‘Soil’)

contamination with hazardous wastes (**McKinney 04**) *See also* MB…/PAH-contaminated soils’

element composition of soils (Bowen 79; **Kawaguchi 77; Kyuma 89**); micronutrient composition and deficiencies in tropical and temperate soils (Davies 97); analysis of Finnish coniferous soils (**Iivanainen 97**)

fungi essential for degrading lignin in decomposing plant matter (**N767, 768**)

general- **Donahue 83; Mills 96; Ross 89; Russel 78; Wild 88**

geosmins, metabolites of *Streptomyces* that give soil its musty odor (N766)

granite, an unweathered soil, is low in Fe- Bowen 79; Kawaguchi 77; Wild 88

H^+ binding- Donahue 83; Russel 73; Sutcliffe 81; W185

humic colloid binding to clays- Mills 96; Russel 73; Vickery 84; Wild 88

laterite soils, characteristics of (Russel 78; Wild 88); incorrectly defined as any tropical soil with a high iron content (Davies 97); an infertile subsoil (Davies 97; Vickery 84)

leaching of nutrients due to CO2 dissolved in rainwater- Vickery 84

loam is 40–40–20% mineral concentration of sand–silt–clay by weight, respectively (Wikipedia ‘Loam’)

metal absorption by various clays- Bailey 99

nitrifying bacteria species detected in (Stephens 98); included comammox *Nitrospira* (**Poghosyan 19**); seeding biofilters with soil to do nitrification (Gross 03)

nutrient binding (Brezonik 72; Donahue 83; Giesey 78; Glass 89; Kemp 72; Kuenzler 86; Riemer 84; Russel 73; Sutcliffe 81; W261; Wild 88); copper and phosphates (Boyd 95)

organic matter benefits soils- **Donahue 83**

P binding to Fe oxides (**WW252)**

Peats and Potting Soils

acidification upon submergence (Boyd 95; Misra 38; Ponnamperuma 81; Ross 89)
acidity of (Misra 38) inhibits decomposition (Ross 89); and aquatic plants (Kazda 00)
composition of typical potting soil contains equal parts shredded tree bark, peat moss, perlite and sand, plus added fertilizers and lime - **Hartman 83**
deficient in Cu (Davies 97; Wild 88) and Mn, Zn (Sauchelli 69)
Finnish, coniferous soils have pH of 3, assoc. with mycobacteria (**Iivanainen 97)**
high (30-60%) organic matter (Donahue 83; Hartman 83) decreases Al toxicity (Ag. Ext.)
inherent infertility- Ross 89
metal removal from water- Bailey 99; Brown 00; Spinti 95
mycobacteria colonize the grey layer of Spaghnum moss in great numbers (10^6/g soil) (**Kazda 00**)
origin of peat bog from partially decayed *Sphagnum* mosses and herbs (**Kazda 00**; **WW818;** Wild 88); lakes accumulate peat with time (**Kazda 00**; Misra 38); cellulose and lignin are major components (Bailey 99)
surface area of peat is >200 m^2/g- Brown 00

pH of coniferous soils is 3 (Iivanainen 97)
protozoa in soils mainly amoeba, pics of- (Lederberg 00)
rainwater, ionic composition of, for USA, S. America and ocean (**WW174**)
sand is quartz, SiO2- Mills 96; Wright 93 (personal communication)
site of polymerization of decompositional products- Donahue 83; W678
size of mineral particles (Glass 89; **Mills 96**; Wild 88) that make up a loam soil (Hartman 83) and a fertile soil (Kyuma 89)
surface area, size, and volume of classified mineral particles [**Mills 96 (**from USDA and Foth 1978); is 8 m^2/g for one clay, which is 20,000 times more than silt (Mills 96) but can be 1,000 m^2/g for specific particles (humus?) in fine textured soils (Lederberg 00)
tropical soils, characteristics (Donahue 83; Kyuma 89; Russel 78; **Vickery 84**; Wild 88); similar in micronutrient content to temperate soils (**Davies 97**); most nutrients replaced by Al (Vickery 84); more positively charged than temperate soils, so hold P tightly (Raven 92, p. 240)
void space makes up 50% of terrestrial soil volume, half filled with gas, half with water (Wikipedia, ‘Soil’ 2022);); nitrifying bacteria most active in soil with larger pores of 100-200 micron diameter where they have greater access to O2 (**Fair 94**)
weathering of soils (**WW172**)

Theories and Evolution-

alkalinity is a battery that stores CO2- King 72; Willliams 94
animal/plant interactions hard to measure- W679

Archean earth: low oxygen, low sulfates, high methane- Habicht 03

atmospheric gas evolution, bacteria are responsible for it (Ash 02); oxygen has increased since planet formation (Raven 88; Smith 84) due to marine algae (Ash 02)

C cycling- W679

calcifuge v. calcicole plants- Davies 97; Lewis 86; **Rorison 60a, 60b, 84**; Vickery 84

earth's energy stored in chemical bonds- W300, 338

humic acid formation in natural waters- Thurman 85

ionic potential determines metal toxicty and essentiality- Sposito 86

Mars; basalt rock plus H_2O could yield H_2 necessary for methanogenisis (and life itself)- Ash 02

micronutrient requirements of algae are genetically linked- Brand 83

multicellular organisms, evolution of prompted by more efficient aerobic metabolism (Pfeiffer 01)

natural habitat of a plant may not be optimal for that plant; it’s just a competitive niche- Misra 38

nitrogen preference depends on habitat that the plant has evolved from- **Krajina 73**; Lewis 86

primary productivity, 90% enters detrial food chain- W691+

r/k strategists- rich culture conditions promote fast-growers (Verschuere 97)

R/Q and oxygen debt describes electron energy stored in sediments- **Rich 78**; W686+

S- cycling, now and during prehistoric times- Habicht 03

Wastewater treatment-

acid mine wastes, proposed remedies using peat, clay (Bailey 99; Brown 00; Spiniti 95)

alga species of marine 'turf algal' systems (Adey 91) and stabilization ponds (McKinney 04)

ammonia removal from fish effluent using duckweed requires stirring (Porath 82) *See also* “Wastewater treatment:biofilters for N removal”

anammox combined with first step in nitrification- Jetten 99; Strous 03

Azolla and duckweed, uptake, toxicity, and depletion of Pb & Zn from the media- **Jain 90**

bacteria/algae system (**Tenny 72**)

bacterial regrowth and recontamination in drinking water distribution systems (**Falkinham 09**; **LeChevallier 04**); clear water can have 10^6 bacteria/ml and 10^7 barely turbid (N105); bacteria genera found in sludge are ordinary aquatic and soil bacteria **(McKinney 04)**; bacteria in two tx plants are α- (34%), β- (20%), γ- (6%) Proteobacteria, CF (4-20%), and mycolata (1%) (**Keith 05**)

biofilters for N removal have *Nitrosomonas* ammonia-oxidizing bacteria, whereas natural systems will have *Nitrosospira*- Schramm 98 *See also* ‘nitrification’

BOD (Biological Oxygen Demand)- N780); reduction by Waterhyacinth (**Reed 88**)

bulking problem caused by excessive growth of filamentous S oxidizers like *Beggiatoa* and *Thiothrix* (N276)

cationic polymers can be used as a primary coagulant or as an aid to coagulation by Alum or Fe (AWWA 84); their use is common (Biesinger 86; Cary 87; Fort 95; Hall 91); toxicity to fish and invertebrates (**Biesinger 86; Cary 87; Fort 95; Goodrich 91; Hall 91**); toxicity is enhanced by

Fe or Al (Fort 95) and flow-through exposure (Goodrich 91); reduction of toxicity by humic substances and clays (Biesinger 86; Cary 87; Goodrich 91; Hall 91); gill damage to fish (Biesinger 86), but no effect on growth (Goodrich 91); nonionic and anionic polymers much less toxic than cationic polymers (Biesinger 86; Hall 91); no concern to aquarium hobbyists, because water is treated with charcoal filtration **after** the cationic polymer treatment (OWASA 96, personal communication)

charcoal removal of DOC (**AWWA** 71, **84**; **James 71**; **Rosen 71**; **Symons 78**; Welsh 93) and insecticides (Awwa 71; James 71; **Symons 78**); mechanism of action by adsorption (Spacie 85; Tang 86); charcoal as colonization site for bacteria (LeChevallier 04)

chlorine, chloramine, chlorine dioxide, ozone, UV, filtration- efficicacy of sterilization towards bacteria, protozoa, viruses, etc in processing drinking water **(LeChevallier 04)**

COD (chemical oxygen demand) is faster and has less variation than BOD- **McKinney 04**

cyst removal *See* ‘protozoa…’

diatomaceous earth will remove some algae, efficacy compared with other water purifiers- LeChevallier 04

disinfectant efficacy in water treatment (**LeChevallier 04; N123)**

DOC in drinking water: median BDOC (biodegradable organic carbon) is 0.38 mg/l (LeChevallier 04)

duckweed, uptake and toxicity of Cd to, depletion of Cd from the medium- **Charpentier 87**

Elodea, uptake of Pb, Cd, Cu, Zn- **Nakada 79**

FAMs, uptake and toxicity of Cd, Cr, Co, Cu, Ni, Pb, Zn- **Gaur 94; Polar 86; Sela 89**

Fe and Mn removal- O'Connor 71

filter pore size v. microbe size in removing protozoan cysts, bacteria, viruses, algae- **LeChevallier 04**

floc formation by colloidal aggregation and bridging with living and/or dead cells (WW737) *See also* ‘Biofilms: floc…’

flocculents in wastewater treatment include $FeCl_3$, alum, $FeSO_4$, cationic polymers (LeChevallier 04; WW736); alum and Fe are much less toxic than cationic polymers (Fort 95; Hall 91); flocculation refers to formation of particles >1 um due to colloid aggregation (**WW736**)

foaming in wastewater treatment *See* ‘surface scum…’

general- Crites 92; DeBusk 89; Moorhead 88; **Reddy 83a**, 83b, **84**, 87; **Reed 88**; **Sneddon 91**; **Weber 85**; W555); wastewater treatment (**McKinney 04; N780-788**)

groundwater has less EM (Falkinham 01) and less BDOC (labile DOC) than surface water (LeChevallier 04)

hazardous waste treatment- **McKinney 04; N790**

hydrogen peroxide used as a chemical oxygenizing agent- McKinney 04

Lemna trisulca, uptake and toxicity of Cd and Zn- **Huebert 92** metal pipes, initial colonization by EM (LeChevallier 04), probably because they are resistant to heavy metals *See* ‘MB (mycobacteriosis)...: metal toxicity’

N & P removal efficiency, combination of emergent and submerged growth best- Reddy 87

nitrate removal from groundwater by encouraging denitrification- Obenhuber 91; nitrate contamination (>10 mg/l) in wells in USA (**Patrick 87**)’ maximum allowable limits are 10 pp NO3-N, which is 44.3 ppm nitrate (Portland OR drinking water standards)

nitrite levels in groundwater, surface water, and rural water in India, removal by FAMs (**Rawat 12**)

nitrification-denitrification more efficient than plant N uptake (Weber 85); aquatic (wetland) plants (Crites 92); nitrifying bacteria and PAO compete for oxygen (Gieske 01)

EM removal from drinking water, review of- LeChevallier 04

organisms (bacteria, actinomycetes, fungi, protozoa, crustacea, and worms) are the same as those found in soil- McKinney 04

ozone (LeChevallier 04) beginning to replace chlorine in wastewater treatment (N124)

peat for metal removal from acid mine wastes (**Bailey 99; Brown 00; Spiniti 95**)

phenols (Buikema 79; Rowe 82); mycolata (but not other sludge bacteria) rapidly degrade phenol (**Keith 05**)

phosphate removal by filter bacteria (Crocetti 00; Gieseke 01) and wastewater treatment bacteria (N70); PAO bacteria require oxygen (McKinney 04); PAO bacteria identified by FISH as *Rhodocyclus* and *Propionibacter* (**Crocetti 00**); poly-β-hydroxybutyrate and Volutin granules as the P storage product (McKinney 04; N71,80)

POC removal removes NTM- LeChevallier 04

problems in wastewater treatment are filamentous bacterial growth and surface scum formation- McKinney 04

protozoa, rotifers, Actinomycetes in sludge filters (**McKinney 04)**; *Cryptosporidium* oocysts most chlorine-resistant organism; *Giardia* cyst removal sets the disinfection standards (**LeChevallier 04**); protozoan cysts and their intracellular pathogen (i.e., NTM) survive water chlorination (**Adekambi 06**)

reverse osmosis reduces total dissolved solids by 95% to make softwater (8-12 ppm as $CaCO_3$) (Gundersen 94); removes viruses and particles < 0.001 micron (LeChevallier 04)

SHARON (Single reactor high activity ammonium removal over nitrite) filter combined with Anammox process in N removal- Jetten 99; **Strous 03**

silver (1 ppm) used as bacteriostatic agent- LeChevallier 04; N124

sludge recycling and multiple reactors- **McKinney 04**

stabilization ponds, ecology of- **McKinney 04**

surface scum and foaming (**McKinney 04**) create problems in wastewater treatment; 15-18% of the bacteria are mycolata and mostly *Gordona* spp (de los Reyes 97) *See* ‘Biofilms: surface scum’

tapwater and bottled water is not sterile as ‘bacterial regrowth’ often occurs (LeChevallier 04) *See also* ‘MB (mycobacteriosis)…: tapwater’ toxic metal uptake and depletion from media (**Charpentier 87;** Gopal 87; **Huebert 92; Jain 90; McCracken 87; Nor 86;** Reddy 84)

waterhyacinth, uptake & depletion of Cu from media - **Nor 86**

UV sterilization, efficacy of (**LeChevallier 04; N120**); UV causes thymine dimeres in the DNA (**N197, 360**); inhibits viruses, protozoa, microsporidia, and bacteria (**Hijnen 06; Jacangelo 02**)

Zn removed by SRB (**Labrenz 00**)

Waterlogging, Effect on Plants

ADH enzymes, stimulation of- Koch 90: **Smits 90b**

aeration from neighboring plants- Schat 84

aerenchyma: development (Armstrong 75, 79; Blom 90; Jackson 90; Smits 90a; **Webb 86**; Wild 88); when stem is cut, flooding of aerenchyma is prevented by cross diaphrams and tubular capillarity (Wetzel 90); lacunae are essential for SAMs (Wetzel 90)

aerial leaf- Armstrong 79; Barko 83; Blom 90; Dacey 82; Weisner 89

ammonia release substantial, due to decreased nitrification- Ross 89

bacterial cycling of plant nutrients- **Laanbroek 90**

CHs- Armstrong 79; Koncalova 90; Titus 77; **Webb 83; Weisner 89**

DOC injures roots (**Patrick 65**); fatty acids toxic to plant roots (Westerman 93)

energy (ATP) depletion in plant- Bertani 87; Koch 90; Wild 88

ethanol production (DeLaune 84; Drew 80; Ernst 90; Glass 89; Koch 90; Koncalova 90; Schat 84; **Smits 90a, b**; Wild 88) not toxic and essential for survival (Smits 90a); CO2 production from (Bertani 87); stimulation of seed germination (Smits 95)

ethylene- Jackson 90; Wild 88

H2S (Koch 90) and other phytotoxins (Armstrong 75, 79, 91a; Gambrell 91; Ernst 90; Koncalova 90; Laanbroek 90; Patrick 64; van Wijck 92; Wild 88)

general- Armstrong 75; Blom 90; Drew 80; Ernst 90; Koncalova 90; Patrick 64; Ponnamperuma 81; Russel 78; Schat 84; Wild 88

N losses from denitrification and ammonification- Armstrong 75; Bertani 87; Ernst 90; Laanbroek 90; Yamasai 92

N uptake by plant decreases- Koch 90; Trought 81; **Yamasaki 92**

nitrates added for protection of seedlings- **Bertani 87**; Trought 81; Wild 88

nutrient uptake during- **Schat 84**

rice leaves are surrounded by air layers which increase gas exchange with atm.- Wetzel 90

root adaptation (Jackson 90; Koncalova 90; Russel 73; Schat 84; Wild 88); just a single root provided with O2 and nutrients can protect the entire plant (Trought 81)

soil reactions to loss of O2: ammonium release, conductance increase, macro and micronutrient release (**Beckwith 75**; Bingham 86; **Gambrell 91**; Ponnamperuma 81; **Reddy 77**; **Ross 89**;

Sauchelli 69); instability is temporary (Beckwith 75; Gambrell 91; Kelly 84; Ponnamperuma 81; Wild 88)

survival, one month (Schat 84; W522; Wild 88), but symptoms are within hours (Bertani 87)

symptoms of plant injury are NADH increase, release of amino acids, etc.- Bertani 87

waiting period recommended before planting rice- Wild 88

Water Chemistry, General-

alkalinity defined as all anions (Roelofs 84; W207; Whitaker T92a); high levels of, reduce toxicity of Cu to fish (Pagenkopf 86); keep above 20 ppm for fish and 50 ppm for invertebrates in aquaculture ponds (Boyd 95); levels in 5 lakes (Smits 92); calculations of, and conversion factors (Booth 97); recommended levels for aquariums are 2-8 dH (Kasselmann 03); high natural alkalinity (3.7 meq/l) with a high DIC (3.3 to 3.8 mM) (**Nielsen 91**)

aquatic plant species, relationship to water chemistry (*See* Aquatic Plants: water chemistry and species variation)

brackish water has >100 mg/l of Cl- (Kadono 82) or 0.2-0.5% NaCl (Ferguson 89)

buffering in lakes by carbonate (W203+) and reductive processes (Giblin 90; Kelly 84)

Ca, pH, bicarbonate, alkalinity highly correlated- Catling 86; Kadono 82; Vitt 90

chloride: average concentration in natural waters is 8.3 mg/l (WW01 p. 182)

CO2 solubility (Bristow 69; Keeley 83; Titus 90; Wetzel 72; W204); total DIC (Titus 90); and absorbtion from atmosphere (Morton 72; Titus 90; W205)

color of water (absorbance at 310 nm) is a good indicator of DOC protection from metal toxicity (Hutchinson 87); may affect plant growth (Catling 86)

conductivity (Barko 83a; Smart 85) related to K^+ uptake (Amudsen 82), plant nutrients (Huebert 83; Spencer 92), equation for conductivity (**WW173**)

coprecipitation of ions in oxygenated water- Barko 91

DIC levels in situ- Edmond 93; Titus 90

DOC mainly humic and fulvic acids- Thurman 85

DON v. inorganic N- Rattray 91; W232

element composition- Bowen 79; Edmond 93; Roelofs 84; W180+

hardness (W207+) as a plant nutrient source (Barko 82, 86b; Huebert 83; W179); may decrease allelopathy (Wetzel 93) and metal toxicity (Huebert 83; Markrich 94; Miller 80); keep above 20 ppm for fish and 50 ppm for invertebrates in aquaculture ponds (Boyd 95); examples of soft, moderate, and hardwater have 58, 115, and 230 mg/l of $CaCO_3$ (Winner 86); quantitative scale for (**Adey 91**); 1 dGH = 7.1 ppm Ca (DLW 2021)

ions: competition for sites on nutrient uptake carriers (Glass 89); especially Ca and divalent metals (Markrich 94)

measurement of CO2, Fe, phenols, Zn, and phosphate- Greenberg 92; Serrano 92

mechanisms that determine chemistry of natural waters- **Gibbs 70** moderately hardwater, description of- pH = 7.2-8.2; conductivity = 230-320 umhos/cm2; alkalinity = 46-70 pp as $CaCO_3$; hardness = 90-140 ppm as $CaCO_3$ (Hall 91)

movement, high flow rates inhibit plant (Barko 86b; Madsen 83) and alga PS (**Ghosh 94**); circulation required for ammonium uptake (Porath 82) and possibly bicarbonate uptake (Sand-Jensen 83)

nutrient uptake (Sutcliffe 81) and plant growth (Bowes 87, 89; **Grise 86**; Overath 91; Roelofs 84; Titus 90)

osmolarity (Elakovich 91); effect on seagrasses (Hellblom 99)

pH (W208+) reactions that change pH (Spotte 79)

phenols from degradation of plant matter (Buikema 79; Wetzel 93) make up only a small part of DOC (Thurman 85)

quality standards & current levels of contamination, hardness, alkalinity- **van der Leeden 90**

rain water, ionic composition of- Cushing 91; Gibbs 90

reactions that change pH- Spotte 79

salinity: salinity from NaCl due to both ionic toxicity and pure osmotic stress via PEG (polyethylene glycol) (**Iida 06)** *See also*, 'Aquatic Plants: salinity'

saltwater Instant Ocean, mineral composition of- Trieff 80

seawater is 3.5% salt and a density of 1.028 g/ml at 4C (WW 12,185); Na/K ratio is 28, Cl/carbonate is 137, Cl/sulfate is 7 (Stappen 02); seawater contains10.8 g/l Na and 0.4 g/l K (for a 27:1 ratio) (Bowen 79); "Instant Ocean"; contains 10.2 g/l Na and 0.370 g/l K (for a 2:1 ratio (**Trieff 80**)

softwater, composition of- Hutchinson 86; **Kasselman 03**; Welsh 93

turbidity of sediment suspension in water can be reduced with alum, calcium, humus, or magnesium- Boyd 95

Zn (Zinc)-

analysis for- Greenberg 92

bacterial removal of Zn from water by SRB- **Labrenz 00**

binding to DOC, EDTA, FeOH (Bingham 86; Bisson 92; Brand 83; **Kirk 95**; Pagenkopf 86; W315; Wild 88), root iron plaque (Otte 89), and sulfides (Labrenz 00)

composition of plant tissue (Bingham 86; Marquenie 79; **Wehr 87**); and enzyme carbonic anhydrase (Nieboer 80)

deficiencies common in tropical soils (Davies 97) and due to sulfide formation in some sediments (Bingham 86; Ponnamperuma 81; Reddy 77)

deficiency symptoms- Shkolnik 84; Wild 88

excretion of Zn by animals mainly in the feces- Ishihara 86

Fe competes with Zn uptake in plants (Bingham 86; Lindsay 84; Sauchelli 69; Wild 88) and fish (Wekell 86)

free metal only is biologically active- Bingham 86; Brand 83; Kirk 95

malic acid binding within plant prevents Zn toxicity- Nieboer 80 peat moss removes Zn from water very effectively- Spiniti 95

Redox, effect on availability- Beckwith 75; Bingham 86; Reddy 77

root oxygenation of sediment, acidity, effect on availability- **Kirk 95**

swamp levels fairly high- Kirschner 92

toxicity (Bennet 71; Bingham 86; Sauchelli 69; Marquenie 79; Wild 88) LD50 to adult brine shrimp and fish (Trieff 80) and brine shrimp nauplii (**MacRae 91**)

uptake (**Marquenie 79**; Sauchelli 69; Wild 88) is passive, affected by temperature and plant maturity (Shkolnik 84)

ABBREVIATIONS

ADH- alcohol dehydrogenase enzyme
AOA- archaea ammonia oxidizers
AOB- ammonia oxidizing bacteria
AOC- assimilabile organic carbon
B- blue light
BBA- black beard algae, a red alga
BDOC- biodegradable dissolved organic carbon
CAOB- comammox ammonia oxidizing bacteria
CCM- CO2 concentrating mechanism (*See* Bowes 1993)
CEC- cation exchange capacity
CF- Cytophaga-Flavobacteria
CH- carbohydrates
CO2- carbon dioxide; Γ- symbol for CO2 compensation point (where CO2 fixation = CO2 loss due to respiration)
DAP (dissimilatory ammonium production)- bacterial reduction of nitrates to ammonium
DGGE- denaturing gradient gel electrophoresis
DIC- dissolved inorganic carbon (CO2, bicarbonate, carbonate)
DNRA- dissimilatory nitrate reduction to ammonium
DOC- dissolved organic carbon (same as DOM)
DON- dissolved organic nitrogen
DT- population doubling time
EM- environmental mycobacteria
EPS- exopolysaccharides See under ‘Biofilms’ and ‘Bacteria’
FAMS- floating aquatic macrophytes
FISH- fluorescent *in situ* hybridization   *See under* “Bacteria”
FR- far red light, 730 nm
G- green light
GFP- green fluorescent protein
HS- humic substances
HUFA- highly unsaturated fatty acids
IR- infrared
LC_{50}- 'lethal concentration of toxicant' is the ppm conc that kills 50% of organisms within a specified time period
MB- mycobacteriosis
mulm, fish   *See under* ‘Sediment:organic matter’ and ‘Biofilms: floc’

N- Nester’s textbook *Microbiology. A Human Perspective* (2007)
NO- nitric oxide
NOB- nitrite oxidizing bacteria
NR- nitrate reductase enzyme of plants
PAH- polycyclic aromatic hydrocarbons
PAL- phenylalanine ammonia lyase, diverts phenylalanine from synthesis of proteins to allelochemicals
PAO- polyphosphate-accumulating organisms
PAR- photosynthetically active radiation
PEPcase- phosphoenolpyruvate carboxylase- C4 type metabolism & refixation of CO2
POC- particulate organic carbon *See also* ‘Biofilms: floc’
PS- photosynthesis
R- red light, 660 nm
R/Q- respiratory quotient
RAS- recirculating aquaculture system (aquaculture biofilters)
Raven- author of textbook *The Biology of Plants* (1992)
RBC- red blood cells
ROL- root oxygen release
RUBISCO- ribulose bisphosphate carboxylase/oxygenase
SA- surface area
SAMs- submersed aquatic macrophytes
SEM- scanning electron microscope
SRB- Sulfate-reducing bacteria
W- Wetzel’s second edition of *Limnology* published in 1983
WW- Wetzel’s third edition of *Limnology* published in 2001

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