DEFINITION OF TERMS (AND SOME COMMON ABBREVIATIONS)

TABLE OF CONTENTS

List of Tables

Terms

Comment

This list of terms began as an update to definitions provided by Dr. Karl Banse to his UW Oceanography classes in the 1970s. I have supplemented his original listing considerably.

Abscissa and ordinate the x and y dimensions of a graph

Acclimation the physiology or behavior of the individual changes in response to the external environment **Falkowski & Raven (1997, p. 263)** refer to **phenotypic or physiological adaptation** as **acclimation**. This nicely avoids the misuse of the term **adaptation** for physiological or behavioral response of an organism to its environment.

Accuracy refers to the difference between the measured or computed value and the true value; it is also called the systematic error (*cf.* **precision**)

Adaptability the degree to which an organism or species can remain or become adapted to a wide range of environments by physiological or genetic means (**Endler 1976, p. 48**)

Adaptation the process of becoming adapted or more adapted. **Mayr's (2001, p. 283)** definition is less circular, "Adaptation: Any property of an organism believed to add to its **fitness**" Unfortunately, adaptation is also used as a synonym for **adaptive trait**.(**Endler 1976, p 42**) [*cf.*, **natural selection**]

Adaptedness the degree to which an organism can live and reproduce in a given set of environments: the state of being adapted (**Endler 1976, p. 42**).

Adaptive trait an aspect of the developmental pattern of the organism that enables or enhances the probability of surviving and reproducing. This is often referred to merely as an adaptation. There are two distinct senses of **adaptation** when the term is being used to mean adaptive trait:

Phenotypic or physiological adaptation the physiology or behavior of the individual changes in response to the external environment. **Falkowski & Raven (1997, p. 263)** use the term **acclimation** to refer to short-term physiological adaptation (*e.g.*, **light adaptation**).

Genetic adaptation the change in gene frequency in populations, *i.e.*, short-term natural selection.

Sometimes a third meaning of 'adaptation' is implied, such as "The phytoplankton assemblage was **shade-adapted**." Such adaptation at the community level could be due to physiological or genotypic adaptation or **succession**.

Advection-diffusion equation [**advection-diffusion-reaction equation**] The advection-diffusion equation is the most widely used equation in all of oceanography. There are various forms of the equation in most physical and biological disciplines. In fluid dynamics, the partial differential equation with this form is called the **Navier-Stokes equation**. There are equivalent forms of the equation in probability (the Kolmogorov forward equation), in population genetics (the Wright-Fisher diffusion equation), and in studies of bioturbation (**the Goldberg-Koide equation**). In biological oceanography, the equation describes the effects of mean flow (advection) and turbulent motion on properties of biological interest (*e.g.,* nutrients, Chl *a*, phytoplankton cells). This is the form of the advection-diffusion equation:

$$\frac{dC}{dt} = \frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} \approx K_x\frac{\partial^2 C}{\partial x^2} + K_y\frac{\partial^2 C}{\partial y^2} + K_z\frac{\partial^2 C}{\partial z^2} + R, \qquad \textbf{(1)}$$

where, C is a scalar quantity (*e.g.*, salinity, O_2, NO_3^-) [*e.g.*, Molar, μg atm l^{-1}, g cm^{-3}], (u, v, w) are the advection in the x (South →North, y (West → East) and z (Surface → Deep) directions [cm sec^{-1}], (K_x, K_y, K_z) are the **kinematic eddy diffusion** coefficients in the x, y, and z directions [cm^2 s^{-1}], $\left(\frac{\partial^2 C}{\partial x^2}\right)$ is the second derivative (*i.e.*, curvature) of the concentration gradient in the x direction, and R is the *in situ* **production** or utilization term (*e.g.*, R could equal the nitrate uptake by phytoplankton) [*e.g.*, Molar or g cm^{-3} per unit time].

For low **Reynolds number** processes, the **kinematic eddy diffusion** coefficients could be replaced with the kinematic molecular diffusivities.

$\frac{dC}{dt}$ is by definition the **total derivative**, and if the scalar quantity is a function of only (t, x, y, and z), this total derivative is equal to the 4 terms in the first equality. These four terms are the partial derivatives of C with respect to (t, x, y, and z) and are called the local rate of change $\left(\frac{\partial C}{\partial t}\right)$ and the horizontal and vertical advective terms.

The mean flow in the ocean (*i.e.*, u, v, w) is never constant and the deviations from the mean flow (the eddy diffusivity terms) can dominate the transport of substances in the ocean. The solution of the total derivative involves the assumption that the non-linear interaction among the deviations from the mean flow in the x, y and z directions can be analyzed using eddy diffusivities. Often assumptions are also made about the terms of the advection-diffusion equation (*e.g.*, $\frac{dC}{dt} = 0.$) producing:

$$\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} - w\frac{\partial C}{\partial z} + K_x\frac{\partial^2 C}{\partial x^2} + K_y\frac{\partial^2 C}{\partial y^2} + K_z\frac{\partial^2 C}{\partial z^2} + R. \qquad \textbf{(2)}$$

If the concentration of the scalar quantity (*e.g.*, mM NO_3^-) remains unchanged at the fixed site under consideration, then one may assume **steady-state**, meaning the local rate of change is assumed to be zero (*i.e.*, $\frac{\partial C}{\partial t} = 0.$). For given situations, often the advective terms or one or more eddy diffusive terms can be dropped from the equation (*e.g.*, the horizontal eddy diffusivity can be dropped in discussions of vertical water-column gradients).

Goldberg-Koide equation A form of the **advection-diffusion equation** used to model the movement of sediment constituents such as radioisotope activities:

$$\frac{\partial A}{\partial t} = \frac{\partial}{\partial z}\left[D_b \frac{\partial A}{\partial z}\right] - \omega \frac{\partial A}{\partial z} - \lambda A. \qquad \textbf{(3)}$$

where, A is the activity of the substance of interest, D_b is the **bioturbation** rate, ω is the sedimentation rate, and λ is the reaction rate or the decay rate for radioisotopes (see **half lives** for reaction rates).

Aerobic anoxygenic phototrophic bacteria As reviewed by **Schwalbach & Fuhrman (2005)** these microbes, discovered by Shiba et al. (1979), supplement **heterotrophy** with light-derived energy, with chlorophyll b as the major light harvesting pigment.

Alkalinity The concentration of cations needed to balance the negative charge of anions in seawater. In ordinary seawater the only anions of weak acids present at significant concentrations are the bicarbonate, carbonate and borate ions. The concentrations of these ions largely control alkalinity. The part of alkalinity associated with the carbonate system is called the **carbonate alkalinity**.

Allochthonous Particles produced outside the system of interest (Rocks transported down rivers are allochthonous particles with respect to the oceans, whereas coral reefs are **autochthonous**)

Allogenic originating external to a local area (*e.g.*, weather) [*cf.*, **autogenic**, **allogenic succession**]

Allopatric Not occurring in the same geographic area. Allopatric speciation is believed to be the major mode of speciation, with geographic isolation preceding reproductive isolation [*cf.*, **sympatric**]

Amensalism A biological interaction that decreases the population growth rate (or, in a weaker usage, the abundance, biomass, or spatial range) of one population while leaving the growth rate (abundance, biomass, or spatial range) of the other unaffected. (see **biological interactions — classification**)

Trophic group amensalism Coined by **Rhoads & Young (1970)**. A biological interaction between deposit feeders and suspension feeders in which sediment modification by large deposit feeders leads to enhanced sediment suspension and restriction of the spatial distribution of suspension feeders.

Anabolism (**anabolic**, adj.) Biochemical pathways, requiring energy (endothermic), that produce new biomolecules. *cf.*, **catabolism**.

Anaerobes Organisms that live without oxygen. Anaerobes acquire energy through **anaerobic respiration** or **fermentation**, in which organic compounds are the terminal electron acceptors. A **facultative** anaerobe can grow under both anaerobic and aerobic conditions. An obligate anaerobe can grow only under anaerobic conditions [*cf.*, **denitrifiers**, **methanogens**]

Anammox Anaerobic ammonia oxidation was discovered only in the 1990s. Anammox can be described by the reaction: $NH_4^+ + NO_2^- = N_2 + 2H_2O$. In this reaction, ammonium ion is the energy source and nitrite serves as the terminal electron acceptor for anaerobic respiration. (*cf.,* **denitrification**)

Annual refers to changes among years (*cf*., **seasonal**).

Assimilation number Assimilation number is a synonym for P_{max} in equations relating photosynthetic rate to light intensity (*e.g.*, **the Jassby-Platt equation**). **Parsons *et al.* (1984 p. 73)** state, "assimilation number is P_{max} in the **P *vs.* I curve**." It is expressed as the rate of photosynthetic carbon assimilation per weight of chlorophyll *a*. [*i.e.*, mg C (mg Chl $a)^{-1}$ h^{-1} or mg C (mg Chl $a)^{-1}$ d^{-1}] and is also known as the maximum chlorophyll-specific production. There may have been another meaning for assimilation number. Eppley (**1972**, p. 1073) sates:

> *"A convenient way of expressing photosynthetic rate per unit phytoplankton standing stock is the 'assimilation number,' i.e., the rate of photosynthetic carbon assimilation per weight of Chl a. The terms 'assimilation ratio' and 'photosynthetic index' are common synonyms for assimilation number."*

Thus, in **Eppley's (1972)** terminology, P_{max} is an assimilation number, but so too are the other points on the **P *vs.* I curve**. Eppley's apparent usage of assimilation number is no longer accepted: assimilation number refers to the asymptote of the P vs. I curve. **Harris *et al.* (1989)** argue that the physiological maximum assimilation number (P_{max}) is approximately 6.2 mg C (mg Chl $a)^{-1}$ h^{-1}. Falkowski puts the theoretical maximum at 21 mg C (mg Chl $a)^{-1}$ h^{-1}. Faulty methods, particularly not subtracting the dark bottle ^{14}C incorporation, may have led to many reports of assimilation numbers higher than this.

Autecology The study of a single population and the factors affecting it (cf. **synecology**).

Autochthonous (from the Greek for self & soil) Particles produced within a local site (*cf.*, **allochthonous**)

Autogenic originating within a local area (*e.g.*, self-shading by plants can lead to an autogenic succession *cf.*, **allogenic**, **autogenic succession**)

Autotrophs [**autotrophic**] plants and bacteria, that utilize CO_2 as their sole carbon source. The major groups include the **photoautotrophs**, utilizing light for energy, and the **chemoautotrophs** utilizing reduced inorganic compounds for energy (*e.g.*, **nitrifying bacteria**, **ammonia-oxidizing bacteria**, sulfur-oxidizing bacteria). Autotrophs use **RuBPCO** to fix CO_2 into 3-carbon compounds [*cf.*, **auxotrophs**, **chemoautotrophs**, and **heterotrophs**].

Auxotrophs plants, including bacteria, that require small amounts of organic matter (*e.g.*, vitamins or amino acids) for growth but do not use organic matter as an energy source (*cf.* **autotrophs** and **heterotrophs**).

Benthic boundary layers The interface between the sea floor and overlying water. There are a number of benthic **boundary layers**, consisting of the Ekman layer, log layer, **viscous sublayer**, and molecular diffusive sublayers. The bottom Ekman layer marks the outer limit of the benthic boundary, the maximum extent of frictional influence on the near-bed flow. The viscous sublayer ins a thin layer (fractions of a mm to a few mm's) of flow next to the boundary in which viscous shear stress predominates over turbulent shear stress – flow is not entirely laminar within the viscous sublayer, sometimes there are bursts of turbulence (**Middleton & Southard, 1984, p. 5-6**). The thicknesses of all of the various benthic boundaries are determined by the near-bed flow and boundary roughness.

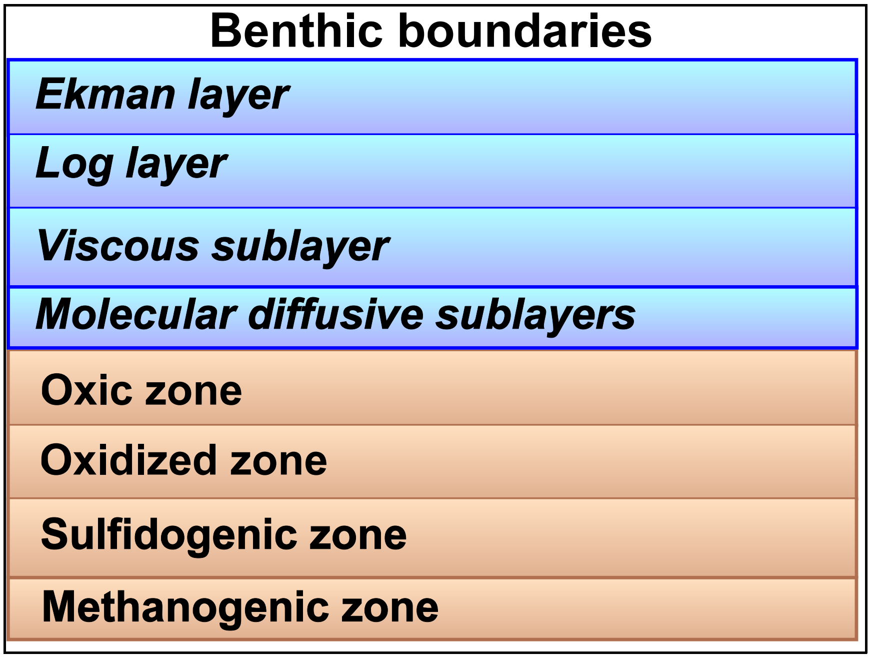

Figure 1. Benthic boundary layers (not to scale). The molecular diffusive sublayer may extend from 200 µm to about 2 mm. The thicknesses of the boundaries are described in Table 1.

Table 1 from **Wimbush (1976)** describing typical thicknesses of benthic boundary layers. The estimates are just for broad informational purposes.

Parameter	Deep-Sea	Shelf	Description
U (cm/s)	3	30	average water velocity
U_* (cm/s), boundary shear velocity	0.1	1	Boundary shear velocity (the square root of boundary shear stress/seawater density)
ν_e (cm^2/s)	2	200	characteristic eddy viscosity
z_f (cm)	500	5000	Ekman depth
z_l (cm)	100	1000	log layer thickness
z_v (cm)	2	0.2 to 1	viscous sublayer thickness
z_γ (cm)	1	-	thermal conductive sublayer

Table 1 from **Wimbush (1976)** describing typical thicknesses of benthic boundary layers. The estimates are just for broad informational purposes.

Parameter	Deep-Sea	Shelf	Description
z_δ (cm)	0.2	0.02-0.1	diffusive sublayer thickness $z_\delta=z_\nu/\{Sc^{1/3}\}$, where Sc is the dimensionless Schmidt number $=\nu/\delta \approx 600$ δ = molecular diffusivity

Benthos Originally used by Haeckel (1890) for organisms associated with the sea bottom, and now extended to all processes at the sediment (or rock)-water interface. The Greek etymology means “the depths of the sea,” so the often-used phrase “intertidal benthic ecology” is an oxymoron.

Bet hedging An alternative explanation for the trends explained by **r- & K-selection** based on the analysis of fluctuations in adult and juvenile mortalities (**Stearns 1976, p. 4**)

Beta particle (beta emission) http://hyperphysics.phy-astr.gsu.edu/hbase/nuclear/beta.html

Biodiversity One broad definition (**NRC 1995**) is ‘the collection of genomes, species, and ecosystems occurring in a geographically defined region.’ **Hubbell (2001, p. 3)** defines biodiversity to be synonymous with species richness and relative abundance in space and time. I tend to concur with this definition which makes biodiversity a synonym for **community structure**. Others prefer the broader definition that **Hubbell (2001, p. xi)** decries: *“ ... the term biodiversity has been coopted by the policy community, where the term has become too inclusive. In policy discussions, biodiversity covers an enormous and heterogeneous array of subjects, scales and questions. “Biodiversity” in policy parlance is the sum total of all biological variation from the gene level to single-species populations of microbes to elephants, and multispecies communities and ecosystems to landscape and global levels of biotic organization. In some usages, it also includes all ecological interactions within and among scales of biological organization.”*

Bioirrigation Movement of porewater and porewater constituents by animal activities [*cf.*, **bioturbation**]

Biological interactions — classification

Table 2. A table showing the major biological interactions between species A and B. If possible, asymmetric interactions or ordered such that A is larger than B. A + indicates that one species leads to an increased individual growth, population growth, or reduced mortality of the other species. A - indicates decreased growth or increased mortality.

Description	Effect of A on B	Effect of B on A
Mutualism	+	+
Commensalism	+	O
Parasitism	+	-
Altruism	+	-
Neutralism	O	O
Amensalism	-	O
Competition	-	-
Predation	-	+

Biological pump The process that removes DIC from the euphotic zone and reduces atmospheric CO_2 concentrations. Usually the process involves photoautotrophs fixing CO_2, reducing the partial pressure of CO_2 in the surface ocean, increasing the **flux** of CO_2 (gas) from the atmosphere to the ocean. This fixed carbon is removed from the euphotic zone by phytoplankton sinking or by the flux of fecal pellets from **macrozooplankton**.

Biomass Amount of biological mass (usually of a specific component, such as phytoplankton) per unit area or unit volume. Biomass is usually represented as g C m^{-2} or g C m^{-3}. Phytoplankton biomass is usually measured as mg Chl *a* m^{-3} or µg Chl *a* l^{-1}. Other units for mass can be used, including g nitrogen and g organic matter.

Bioturbation [*cf.*, **bioirrigation**] Movement of sediment particles by animals. While bioturbation must also move some sediment porewater fluids, the movement of sediment fluids alone is called **bioirrigation**. Bioturbation is often modeled as being analogous to eddy diffusion and modeled using the **Goldberg-Koide model**. Bioturbation can involve large vertical and horizontal displacements of sediment grains, and such non-diffusive mixing is usually called **non-local mixing**. **Boudreau (1997)** provided this definition of **bioturbation**.

> *"...bioturbation comprises all kinds of displacements within unconsolidated sediment and soils produced by the activity of organisms (paraphrased from Richter, 1952). These activities include burrow and tube excavation, and their ultimate collapse*

*and infilling, ingestion and excretion of sediment, plowing through the surface sediment, and building of mounds and digging of craters. During these activities, both solids and pore fluids are moved." (**Boudreau, 1997, p. 41**)*

Note, that Beaudreau uses the term 'excretion,' which usually means the release of dissolved nutrients or organic matter. He may have meant to use 'defecation.'

Boundary layer The zone of flow near a solid surface or boundary in which the motion of the fluid is affected by the frictional resistance exerted by the boundary (**Middleton & Southard, 1984**, p. 61). See **benthic boundary layers**

Brackish Oceanographers use this term frequently to refer to seawater that is diluted with freshwater. The dictionary definition is simply 'salty or briny', but this is not the sense used by oceanographers. When an oceanographer refers to brackish water, he is usually referring to seawater that is significantly diluted with freshwater as from a river. A brackish plume is a mass of lower salinity seawater at the surface of river mouths.

Bulk density (**Specific gravity**). The mass of a volume of sample divided by the same volume of distilled water. The **sediment bulk density** is $\rho = (1 - \varphi)\,\rho_s$, where ρ_s is the bulk density of solids and φ is the sediment **porosity**.

C_3 photosynthesis [*cf.*, **Calvin-Benson cycle**, **C_4 photosynthesis**] CO_2 is first fixed by **RuBPCO** to make 3-carbon compounds in the **Calvin-Benson cycle**. CO_2 is combined with the 5-carbon Ribulose 1,5 bisphosphate by **RuBPCO** to produce two 3-carbon compounds [*cf.*, **C_4 photosynthesis**]

C_4 photosynthesis [**Hatch-Slack photosynthesis**; *cf.*, **C_3 photosynthesis**] CO_2 is first incorporated into a 4-carbon compound. PEPCase or PEPCKase catalyzes the **β-carboxylation** (so called because the additional carbon is added at the 2nd carbon position, not the end) of a C_3 precursor (phosphoenolpyruvate or PEP) to a C_4 acid (oxyloacetate), which is in rapid **equilibrium** with other C_4 compounds malate and aspartate. The reaction can be catalyzed by many **β-carboxylases**, but two appear most important: PEP carboxylase (PEPC) and PEP carboxykinase (PEPCK). Malate and aspartate appear as the primary stable products. Net CO_2 assimilation continues to depend on an active **Calvin cycle** permitting regeneration of the C_3 precursor via a decarboxylation reaction.

In true C_4 photosynthesis, the carboxylation and decarboxylation reactions occur in different types of cells (*i.e.*, **mesophyll** and **bundle sheath**, respectively). The first step in C_4 photosynthesis is the conversion of CO_2 to HCO_3^- in the mesophyll cells (**Hatch & Burnell 1990**), where it is carboxylated to C-4 compounds. There are no true aquatic C_4 aquatic plants. However, there are many aquatic plants with inducible adaptations to reduce photorespiration. (see **C_4-like metabolism**, **CO_2 pump**).

C_4 metabolism Coined by Benedict and used by **Morris (1980)** to describe the pattern of metabolism in which the flow of carbon originates with the C_3 intermediates of the **Calvin cycle** and involves transformations leading to the intermediates of the tricarboxylic acid (TCA) cycle with subsequent synthesis of associated amino acids and proteins. This term was invented to distinguish the presence of high rates of C_4 synthesis in many aquatic plant species. Only multicellular plants can have true **C_4 photosynthesis**, which requires separate cell types for the carboxylation and decarboxylation reactions involving C-4 compounds. [See also **CO_2 pump**]

Carbonic anhydrase The enzyme that catalyzes the conversion from bicarbonate (HCO_3^-) and carbonate to CO_2. It has the highest activity of any known enzyme, and the reaction rate is limited by the rate of diffusion of substrate to the active site. From **Wikipedia** Carbonic anhydrase (carbonate dehydratase) is a family of zinc-containing enzymes that catalyze the rapid interconversion of carbon dioxide and water into carbonic acid, protons, and bicarbonate ions. It increases the efficiency of the reaction about a million-fold. Its active site contains a zinc ion. The primary function of the enzyme, which is found on red blood cells, is to catalyse carbon dioxide.

$$CO_2 + H_2O \xrightleftharpoons{\textit{Carbonic anhydrase}} H_2CO_3$$

CO_2 pump [**DIC pump**, **bicarbonate pump**, **Carbon Concentrating Mechanism (CCM)**] A set of chemical reactions that increase the CO_2:O_2 ratio at the **RuBPCO** active site to reduce **photorespiration**. The **CO_2 pump** is found in most phytoplankton and probably all macroalgae. The pump usually consists of two parts: active transport of HCO_3^- across the **plasmalemma**, the phytoplankton cell membrane, or the thylakoid in cyanobacteria and conversion of HCO_3^- to CO_2 near the **RuBPCO** active site by **carbonic anhydrase.** **Carbonic anhydrase** and RuBPCO often occur in very close proximity within the cell. In cyanobacteria, RuBPCO is found within the proteinaceous caboxysome, which contains carbonic anhydrase. There is usually an increase in **β-carboxylase** activity in diatoms using a CO_2 pump, but it is uncertain what percentage of the C eventually fixed was first carboxylated to a 4-carbon intermediate compound. **Raven & Lucas (1985)** calculate that the energetic costs of fixing CO_2 using a CO_2 pump are high, raising the minimum **quantum requirement** of photosynthesis from 8 photons per C to 25 photons per C. **Badger & Price (2003)** describe the evolution of CO_2 concentrating mechanisms **CCM** in cyanobacteria. [See also **C4 photosynthesis**]

Calvin-Benson cycle [Calvin cycle, reductive pentose phosphate cycle, photosynthetic carbon reduction cycle, PCRC]. This three-step process is summarized by **Morris (1980, p. 1400)**

1. The primary reaction is the carboxylation of ribulose-1,5-bisphosphate (RuBP) to yield (via an unstable C_6 intermediate) 2 molecules of 3-phosphoglycerate (**3-PGA**). The enzyme catalyzing this step and confined to them is **RuBPCO**, ribulose-1,5-bisphosphate carboxylase/oxygenase.

2. On each side of this central carboxylation reaction are the reactions requiring the products of the **light reaction** of photosynthesis, the phosphorylation of ribulose-5-phosphate (Ru-5-P) to RuBP (requiring ATP) and the reduction of **3-PGA** to 3-phosphoglyceraldehyde (3-GAP) (requiring ATP and NADPH).
3. The remainder of the Calvin-Benson cycle involves a series of rearrangements between various sugar phosphates (containing 4, 5, 6, or 7 carbon atoms), permitting the regeneration of the CO_2 acceptor and the accompanying net CO_2 fixation.

Carotenoid an accessory pigment (along with the phycobilins) used in photosynthesis; long poly isoprenoid molecules having conjugated double bonds (p. 597 Lehninger). There are two major classes: **carotenes** [no oxygen] and **xanthophylls** [contain oxygen]

Catabolism (**catabolic**, adj.) Biochemical pathways, producing energy (exothermic), that break down biomolecules. *cf.*, **anabolism**

Cell quota [Q, q, **internal nutrient pool**] The amount of nutrient per cell or per unit biomass. Used in the **Droop equation** and some versions of the **Monod equation** to explain the **specific growth rate** (μ) of phytoplankton in terms of the internal nutrient pool. The **minimum cell quota**, at which μ=0, is Q_o in Caperon's version of the **Monod equation** and k_q in the **Droop equation**.

Cenozoic era From **Wikipedia** The Cenozoic Era (sen-oh-ZOH-ik) meaning "new life" (Greek kaino = new + zoikos = life) (sometimes still Caenozoic in the United Kingdom) is the most recent of the four classic geological eras. It covers the 65.5 million years since the **Cretaceous**-**Tertiary** extinction event at the end of the Cretaceous that marked the demise of the last dinosaurs and the end of the **Mesozoic Era**. The Cenozoic era is ongoing. The Cenozoic is divided into two periods, the Palaeogene and Neogene, and they are in turn divided into epochs. The Palaeogene consists of the Paleocene, Eocene, and Oligocene epochs, and the Neogene consists of the Miocene, Pliocene, Pleistocene, and Holocene epochs, the last of which is ongoing. Previously the Cenozoic was divided into periods (or sub-eras) named the Tertiary (Paleocene to Pliocene) and Quaternary (Pleistocene and Holocene). However, they are no longer recognized. Cenozoic gets its name from the Greek words ceno (new) and zoo (animals). The Cenozoic is the age of mammals.

Chemoautotrophs [**Chemoautotrophic**] Bacteria that use reduced inorganic compounds (*e.g.*, H_2S, NH_4^+, H_2) as their energy source and fix carbon dioxide (with **RuBPCO**).

Chemostat A method of growing microbes (autotrophs or heterotrophs), in which the culture vessel volume, V, is held constant while new growth medium is added at a constant rate, I. The dilution rate, D=V/I, equals the specific growth rate μ of the microbes at **steady state**.

Climax In Clements' theory of succession (e.g., **Clements 1936**) the mature community that ends a succession is called the climax. **Community structure** & **community function** should be in a relative **steady state**, as described by **Whittaker (1975, p. 179)**: *"We can say only that the climax is relatively stable compared with the successional stages that lead up to it, and that changes in the climax community are fluctuations around a mean, whereas those during **succession** are trends of directional change."*

climax pattern hypothesis Whittaker (**1953**, **1975**) The climax is not a fixed entity controlled by regional climate. It is a localized intersection of species responding to complex and interrelated gradients in the physical environment. The climax stage is recognized only generally as an approximate steady state of species turnover, biomass, organic matter production, decomposition, and nutrient circulation (**Whittaker 1975**). The climax pattern hypothesis couples Clementsian dynamics in time with **Gleasonian dynamics** in space. It recognized the observed patterns represent the distribution in space of processes operating in time.

CNESS Chord-normalized expected species shared. A metric version of NNESS, developed by Gallagher and described in **Trueblood et al. (1994)**

$$CNESS_{ij|m} = \sqrt{2 * \left(1 - \frac{ESS_{ij|m}}{\sqrt{ESS_{ii|m} * ESS_{jj|m}}}\right)} \quad . \qquad \textbf{(6)}$$

Coevolution A net change in the gene frequency of one population in response to the changes in the environment caused by changes in the gene frequency of another population. *[Cf.*, **evolution**, **natural selection**]

Community **Mills (1969)** reviews the concepts and provides this new definition "Communities are groups of potentially interacting populations that occur in a given area and are separable from other such groups by ecological survey." **Hubbell (2001, p. 5)** bases his theory of neutral community structure on a restrictive definition of community, which is, as he notes, more similar to others' definition of **guild**: "…I define an ecological **community** as a group of trophically similar, **sympatric** species that actually or potentially compete in a local area for the same or similar resources" **Hubbell (2001, p. 5)** also adapts the definition of **metacommunity** for his theory: "The **metacommunity** consists of all trophically similar individuals and species in a regional collection of local communities. However, unlike species in the local community species may not actually compete because of separation in space or time." The usual definition of metacommunity would not restrict the class to trophically similar individuals, nor to those that are potential or actual competitors.

Community drift **Hubbell's (2001)** term for local changes in species frequencies due largely to chance phenomena. In Hubbell's neutral theory it is a direct analogue to Wright's **genetic drift**.

Community function While **community structure** focuses on species diversity and changes in the relative abundance of species, **community function** addresses trophic interactions, energy & nutrient flow within communities and the effects of communities on biogeochemistry.

Community structure Usually includes a concise description of the number of individuals of each **species**, their relative abundance in space and time, biomass occasionally, and more rarely food-web interactions. *"In statistical terms, community structure, which is composed of the distribution, abundance, trophic interactions and diversity of its component species, is a multivariate response "vector", or an integrated set of dependent variables."* **Menge & Sutherland (1987, p. 736)** [*cf.*, **community function**, **biodiversity**]

Compensation depth The depth at which the gross primary production equals respiration, *i.e.*, the depth at which net primary production is zero. The concept was developed by Gran between 1912-1915, and the term compensation point was first used by Marshall and Orr in 1928 (**Mills, 1989**)

Compensation light intensity The light level at which respiration rate = gross photosynthetic rate

Competition

Interspecific competition is a process in which an increase in the abundance, biomass or growth rate of one population leads to a decrease in the abundance, biomass or growth rate of another population and vice-versa.

Intraspecific competition is a decrease in population growth rate caused by increased abundance, biomass or growth rate of the population (*cf*,. **Biological interactions—classification**)

Another widely accepted definition is that competition is the utilization by two populations of a shared resource that is demonstrably in short supply.

There are two broad mechanism of competition: **interference competition** and **exploitative competition** (also called scramble competition). In interference competition, one organism limits its competitor's access to the shared resource. In exploitative competition, the resource depletion caused by one organism affects the fitness of another organism.

There are a number of models of competition, with the **Lotka-Volterra** model being the most famous.

Continuum concept Due originally to Gleason (especially **Gleason 1927**), and sometimes called **Gleason's individualistic view** or **Gleasonian dynamics**. Gleason criticized Clements theories of succession, which described communities as superorganisms with a succession analogous to ontogeny. Gleason wrote that communities are not superorganisms but just collections of individuals distributed according to their own environmental requirements.

Conveyor-belt species **Don Rhoads' (1974)** descriptive phrase for a **subsurface deposit feeder** that feeds at depth and defecates at the sediment surface. **Rhoads & Young (1971)** described the conveyor-belt feeding of ***Molpadia oolitica***, a sea cucumber that fed on sediments at 20 cm below the sediment-water interface in Cape Cod Bay and defecated at the surface. A small feather duster worm, the sabellid polychaete ***Euchone incolor***, typically settles in large numbers on the fecal mound, an example of **commensalism**, since the feather duster uses the topography of the mound to feed in a higher flow regime, outside the viscous sublayer (it is unlikely that *Molpadia* benefits from *Euchone*, hence the commensalism). A **reverse conveyor-belt feeder** feeds at the surface and defecates at depth. Both feeding modes are called **non-local mixing** because the movement of particles doesn't fit the commonly used diffusion analogy [*cf.*, **bioturbation**]

Correlation A statistic reflecting the linear association between two variables. Pearson's product-moment correlation (r) is a standardized form of covariance obtained by dividing the covariance of two variables (x and y) by the product of the standard deviations of x and y. Non-parametric correlation **statistics**, based on ranks, include **Kendall's τ** and **Spearman's ρ**. The latter is merely Pearson's r after the data have been converted to ranks.

Covariance a measure of association between two variables; covariance is the mean of the cross products of the centered data; or, the expected value of the sum of cross products between 2 variables expressed as deviations from their respective mean. The covariance between two z-transformed variables is also known as the Pearson product-moment correlation ®.

Cretaceous period From **Wikipedia**: The Cretaceous period is one of the major divisions of the geologic timescale, reaching from the end of the Jurassic period, about 146 million years ago (Ma), to the beginning of the Paleocene epoch of the **Tertiary period** (65.5 Ma). The end of the Cretaceous also defines the boundary between the Mesozoic and Cenozoic eras.

Critical depth (=Sverdrup's critical depth) The depth, above which, the depth-integrated daily gross **primary production** equals respiration, *i.e.*, the depth above which integrated net daily primary production equals zero. The critical depth can also be defined as the depth above which the average light intensity for the water column equals the **compensation light intensity**. [*cf.*, **compensation depth**]

$\delta^{13}C$ Pronounced ("δ-C13"). Carbon isotopic composition of a sample. $\delta^{13}C = [(R_{sample}/R_{std})-1] \times 10^3$, where R is the ratio of ^{13}C to ^{12}C and the standard used for **normalization** is Peedee Belemnite (limestone) that has been assigned a $\delta^{13}C$ value of 0. Due to the scarcity of Peedee Belemnite, a new standard has been chosen (I'll find the reference to this new standard).

$\delta^{15}N$ Pronounced ("δ-N15"). Nitrogen isotopic composition of a sample. $\delta^{15}N = [(R_{sample}/R_{std})-1] \times 10^3$, where R is the ratio of ^{15}N to ^{14}N and the standard used for **normalization** is atmospheric nitrogen gas that has been assigned a $\delta^{15}N$ value of 0.

$\delta^{18}O$ Pronounced ("δ-O18"). Oxygen isotopic composition of a sample. $\delta^{18}O = [(R_{sample}/R_{std})-1] \times 10^3$, where R is the ratio of ^{18}O to ^{16}O, and the standard used for **normalization** is calcite in the phragmacone of a belemnite from the Late Cretaceous Pee Dee Formation of South Carolina (PDB). A major use of $\delta^{18}O$ is as a paleotemperature indicator.

Dark reaction [**Calvin-Benson cycle**] reduction of CO_2 via NADPH (reducing power) and ATP (energy) [*cf.*, **light reaction**]

Dark respiration [Mitochondrial respiration, as opposed to **photorespiration**] Usually assumed to be about 10% of $\mathbf{P_{max}}$.

DCMU [3'(3,4 diclhorophenyl)1',1' dimethyl urea] A herbicide that blocks non-cyclic electron transport in the **Photosystem II** trap (**Parsons *et al.* [1984 p. 63]**).

Diagenesis *"**Diagenesis** refers to the sum total of processes that bring about changes in a sediment or sedimentary rock subsequent to deposition in water. The processes may be physical, chemical, and/or biological in nature and may occur at any time subsequent to the arrival of a particle at the sediment-water interface. However, if the changes occur after contact of the particle with the atmosphere, as a result of uplift, they fall under the heading of **weathering**, and if they occur after exposure to elevated temperatures after burial, they are referred to as **metamorphism**."* (**Berner, 1980, p. 3**)

diagenesis (early) Processes affecting the top meters of sediment, including dewatering, **bioturbation**, bacterial decomposition of organic matter, dissolution of carbonates and redox reactions (**Berner 1980, p. 3**).

Denitrification [**denitrifiers**] The utilization of nitrate or nitrite as a terminal electron acceptor for **anaerobic respiration** and its conversion to gaseous N_2O and N_2 by heterotrophic, generally **facultative**, **anaerobic** bacteria. Denitrification is also called **dissimilatory nitrate reduction**. [*cf.*, **anammox**, **assimilatory nitrate reduction**]

Deposit feeder A benthic organism that ingests sediment particles in bulk. The food of deposit feeders can include the organic coatings on mineral grains, bacteria, **microphytobenthos**, detritus, and other small organisms. **Subsurface deposit feeders** feed on particles beneath the sediment-water interface and **surface deposit feeders** feed at the sediment-water interface.

Derivative From **Mathworld**: The derivative of a function represents an infinitesimal change in the function with respect to whatever parameters it may have. The "simple" derivative of a function *f* with respect to *x* is denoted either $f'(x)$ or $\frac{df}{dx}$.

Partial derivative from **Mathworld**: Partial derivatives are defined as derivatives of a function of multiple variables when all but the variable of interest are held fixed during the differentiation. Usually indicated with a δ (pronounced del) instead of a d, as in $\frac{\partial C}{\partial x}$.

Total derivative If a function *f* is a function of time, and variables x, y, and z, the total derivative expresses the infinitesimal change in the function with respect to t, x y and z in terms of simple and partial derviatives:

If $C = f\{t, x, y, z\}$.

$$\frac{dC}{dt} = \frac{\partial C}{\partial t} + \frac{dx}{dt}\frac{\partial C}{\partial x} + \frac{dy}{dt}\frac{\partial C}{\partial y} + \frac{dz}{dt}\frac{\partial C}{\partial z}.$$

See: Eric W. Weisstein. "Total Derivative." From MathWorld--A Wolfram Web Resource. **http://mathworld.wolfram.com/TotalDerivative.html** cf, **advection-diffusion equation**

DIC Dissolved inorganic carbon (*cf.*, **DOC**, **POC**). At oceanic pH, the dominant form of DIC is **bicarbonate**, HCO_3^-, which is rapidly converted to CO_2 (aq), the form fixed by **RuBPCO**. Carbonate, CO_3^{--2}, is the third major form of DIC.

Diel refers to periods of 24 h; has replaced diurnal which is now contrasted to nocturnal.

Diel vertical migration refers to the commonly observed migration pattern of zooplankton: up at night, down during the day.

Reverse diel vertical migration down at night, up during the day.

Diffusion (eddy & molecular)

Dynamic eddy diffusivity usually abbreviated A_x, A_y, or A_z and having units of [g cm sec^{-1}]. A coefficient expressing the **flux** or local rate of change of scalar quantities (*e.g.*, nutrients, temperature, salt) due to the turbulent structure of mean flow.

Kinematic eddy diffusivity the **dynamic eddy diffusivity** (A) divided by seawater density (ρ, pronounced *ρ*) and usually abbreviated K_x, K_y, or K_z and having units of [cm^2 s^{-1}]. In the advection-diffusion equation, the kinematic eddy diffusivity coefficient is multiplied by the second derivative of the concentration gradient to predict the time rate of change of a scalar quantity (*e.g.*, nitrate, O_2, salinity) in a parcel of water. The need to use the second derivative is sometimes confusing. **Fick's first law** states that the **flux** into a parcel (or box) of seawater is inversely linearly proportional to the eddy diffusivity times the concentration gradient. However, if the concentration gradient is linear (=zero second derivative), then the **flux** into the box will equal the **flux** out of the box and there will be no local rate of change in the scalar property (*e.g.*, nitrate) in the box. However, if the second derivative is positive, there will be an increase in the concentration of the scalar quantity in the box due to diffusion. **Berg (1983)** provides a good description Fick's laws and the diffusion process at low Re.

Though oceanic horizontal eddy diffusivity ($\nu \approx 0.5$ to 5×10^6 cm^2 sec^{-1}) often exceeds vertical eddy diffusivity by approximately 10^6, since the second derivative of the vertical concentration gradient is so much greater than that of the horizontal, vertical eddy diffusion often dominates diffusive flux and can rarely be ignored.

Molecular diffusion The random migration of molecules arising from the motion due to thermal energy. Molecular diffusion, though minute compared to eddy diffusion, controls the rate of change of scalar properties in many low **Reynolds number** situations.

Diffusive flux (molecular) **Fick's first law**: $J_x = -D \frac{dC}{dx}$, where J_x is the net **flux** in the x direction, D is the diffusion coefficient with dimensions of $\frac{L^2}{T}$, and $\frac{dC}{dx}$ is the concentration gradient . Or, in words: the net **flux** of a scalar quantity C (*e.g.*, O_2, NO_3^-) in the x direction is equal to minus 1 times the concentration gradient times the diffusion coefficient.

Dimensional analysis A technique to create appropriate derived dimensionless variables for expressing the relationships among variables in a process. Dimensional analysis is based on the Buckingham Pi theorem. Dimensional analysis is based on the international system of units (**http://physics.nist.gov/cuu/Units/units.html**).

Diversity (species) There are dozens of meanings, definitions and indices for describing diversity. There are two major components of measurements of diversity, and different scales over which diversity is measured. The two major components of diversity, at any scale are:

Species Richness The number of species

Equitablilty or Evenness The distribution of individuals among species. Maximum equitability is when all species are equally abundant

One must also specify the spatial scale over which diversity is measured. **Whittaker (1967)** produced a set of terms for the different components of diversity in space:

α diversity A term coined by **Whittaker (1960)**. See also **Cody (1986)**. The number of species found in one uniform habitat type in one relatively local area.

β diversity Change in species composition along environmental gradients. β diversity is usually measured in half-change units, which are dimensionless, per unit of environmental gradient. The half-change unit is the distance along an environmental gradient associated with a decrease in α diversity to ½ that observed among replicate samples in one local area. As such, β diversity can be likened to the **half-life** of a radioisotope. An environmental gradient associated with 5 half-change units produces a nearly complete turnover in species composition. In benthic ecology, the change in species composition observed between sand and mud or shallow and deep would contribute to β diversity.

γ diversity To **Whittaker (1967)**, γ diversity was the sum of α and β diversity. Since these diversities have different units, such a sum can't be performed. **Cody (1986)**

redefined γ diversity to be the change in species composition observed in the same habitat type in different geographic regions. **Whittaker (1967)** had called this δ diversity, a term which has never caught on. In benthic ecology, the change in species composition observed between an intertidal mudflat in Boston and an intertidal mudflat in Denmark would be an example of γ diversity.

Diversity indices

Diversity indices sensitive to both species richness and evenness:

Gini diversity (and related indices, from **Bhargava & Doyle 1974**)

Simpson (1949)

$$\begin{aligned} \textit{Simpson's } D &= 1 - \sum_{j=1}^{S} \frac{N_j\,(N_j - 1)}{N\,(N-1)}. \\ \text{where, } N_j &= \text{abundance of species } j. \\ N &= \text{total individuals.} \\ S &= \text{number of species.} \end{aligned} \qquad \mathbf{(7)}$$

Gleason's D Number of species per sample divided by natural log of the number of individuals (**Gleason 1922**, **Washington 1984**)

$$\textit{Gleason's index } D = \frac{S}{\ln N}.$$

H' see **Shannon-Wiener diversity**

Hurlbert's expected number of species E(S_n):

$$E(S_m) = \sum_{k=1}^{S} 1 - \frac{\binom{N-N_k}{m}}{\binom{N}{m}}. \qquad \mathbf{(9)}$$

$$\begin{aligned} \text{where, } \binom{N}{m} &= \text{binomial coefficient.} \\ &= \text{No. of different ways of sampling } N \text{ objects, } m \text{ at a time.} \end{aligned}$$

Shannon-Wiener diversity (**Shannon & Weaver 1949**):

$$\boldsymbol{H}' = -\sum_{i}^{S} p_i \log p_i \ ,$$

$$\begin{aligned}
&\textit{where},\\
&p_i = \textit{frequency of species i in sample}.\\
&p_i = \frac{N_i}{N}.\\
&N_i = \textit{Number of individuals of species i}.\\
&N = \textit{Total individuals in sample}.\\
&S = \textit{Number of species}.\\
&\log \textit{ could be base } 2,\ 10,\ \textit{or natural} \log.
\end{aligned} \qquad \mathbf{(10)}$$

Brillouin's (1951) diversity An information-based diversity statistic, appropriate whenever information-based diversity is being measured from a sample or full census. It is always highly correlated with but slightly smaller in magnitude than the Shannon-Wiener H'.

$$\begin{aligned}
\textit{Brillouin's } H &= \frac{1}{N} * \ln\left(\frac{N!}{N_1!\ N_2!\ \ldots\ N_s!}\right).\\
&= \frac{1}{N} * \ln\left(\frac{N!}{\prod_{k=1}^{S} N_k!}\right).\\
\textit{where}, N &= \textit{Sample total}.\\
N_k &= \textit{Abundance of species k}.\\
\frac{N!}{N_1!N_2!\ \ldots\ N_s!} &= \textit{No. distinguishable permutations with the } N_i^{\prime}s.
\end{aligned} \qquad \mathbf{(11)}$$

Equatability or evenness:

Pielou's (1966) J':

$$J' = \frac{H'}{H'_{\max}}. \qquad \mathbf{(12)}$$

or Hurlbert's measure of evenness for **Shannon's H'**:

$$V = \frac{H' - H_{\min}}{H_{\max} - H_{\min}}.$$

$$\begin{gathered}\textit{where,}\\ V = \textit{Hurlbert's evenness index for } H'.\\ H' = \textit{Shannon's } H'.\\ H_{\max} = \textit{value parameter would assume}\\ \textit{if all } \boldsymbol{S} \textit{ species were equally abundant.}\\ H_{\min} = \textit{value parameter would assume}\\ \textit{if one species was represented by } N-(S+1) \textit{ individuals}\\ \textit{and the other species by one individual each.}\end{gathered} \tag{13}$$

DOC Dissolved organic carbon (*cf.*, **DIC**, **POC**) It is usually operationally defined as material passing through a fine filter, usually 0.2 µm

DOM Dissolved organic matter. It is usually operationally defined as material passing through a fine filter, usually 0.2 µm

Doubling time ln(2) / **specific growth rate** = ln (2)/µ ≈ 0.693/**specific growth rate** [usually in days]

Doublings per day the inverse of doubling time [usually in days^{-1}] = µ/ln(2)

Droop equation A two-parameter equation, proposed by **Droop (1968)** describing the relationship between **specific growth rate**, µ, the **cell quota** q, and **the minimum cell quota** q_o or k_q (*cf.*, **Michaelis-Menten equation**, **Monod equation**)

$$\mu = \mu_m' \left(1 - \frac{q_o}{q}\right) = \mu_m' \left(1 - \frac{k_q}{q}\right).$$

$$\begin{aligned} \textit{where, } q &= \textit{the cell quota of the limiting nutrient.}\\ q_o &= k_q = \textit{minimal cell quota.}\\ \mu_m' &= \textit{the specific growth rate as } q \textit{ approaches } \infty.\\ \mu &= \textit{the specific growth rate.}\end{aligned} \tag{14}$$

Easterly winds Winds blowing from the east to west.

Eddy diffusivity see diffusion

Efficiencies

Assimilation efficiency $\frac{assimilation}{ingestion} = \frac{growth+respiration}{ingestion}$

Fenchel (1982): 60% assimilation efficiency for protozoa.

Ecological efficiency The amount of energy extracted from a trophic level/amount of energy supplied to that trophic level (**Slobodkin 1961**). **Steele (1974)** states that the ecological efficiency of a population is the **gross growth efficiency** averaged over a sufficiently long interval that **steady state** is achieved. An ecological efficiency of 10% is often assumed, but may be much higher.

Gross growth efficiency GGE $= \frac{growth}{ingestion}$.

Fenchel (1988) estimates the GGE of phagotrophic microbes at ≈30%. **Rivkin & Legendre (2001)** reviewed the bacterial literature and found a temperature-dependent (R^2 =54%) bacterial growth efficiency: BGE=0.374 [±0.04] -0.0104 [±0.002] T [r^2=0.54, n=107, F=84.27, p<0.001]. Thus BGE is about 50% near 0° C declining to about 10% at 30°C.

Net growth efficiency $\frac{somatic\ growth}{growth + respiration}$

"Annual net growth efficiency [as a percentage] *is approximated here by* $\frac{100\ P_a}{P_a + R_a}$, *$P_a$ and R_a being the annual production and respiration rates of populations per unit area."* ***Banse (1979)***

Note that the gross growth efficiency=Assimilation efficiency * Net growth efficiency.

E_H The redox potential. The thermodynamic relation between the redox potential of a solution to its composition is given by the Nernst equation (**Stumm & Morgan, 1981**, p. 436). The E_H is positive in the presence of oxygen and is usually positive in the presence of nitrite and nitrate. [*c.f.*, **oxidized zone**, **r.p.d.**]

Eigenanalysis The process of finding the eigenvalue-eigenvector pairs of a square matrix **A**. The eigenvalues are the elements of the diagonal matrix **L** and the eigenvectors are the columns of **U** where **A=U'LU**. In biological oceanography, eigenanalysis is used to analyze the structure of species composition along environmental gradients, demographic statistics for populations, and the patterns in remotely sensed images. The techniques using eigenanalysis include: principal components analysis, factor analysis, analysis of Leslie matrices, and empirical orthogonal function analysis (for remotely sensed images) [*cf.* **eigenvalues**, **eigenvectors**]

Eigenvalues (=**characteristic values, latent values**) a set of real or even imaginary scalars which can be used with their associated eigenvectors as an alternate description of a square matrix **A**. An N x N matrix **A** is said to have an eigenvector **u** and corresponding eigenvalue λ if

$$\mathbf{A}\ \mathbf{u} = \lambda\ \mathbf{u}.$$

Every square, full-rank matrix **A** can be decomposed into a product of the diagonal eigenvalue matrix **L** and eigenvector matrix **U** such that: **A=U'LU**, where **U'** is the transpose of the **U** matrix.

Eigenvectors a column vector associated with its respective eigenvalue; Normalized eigenvectors of unit length (sum of squares of elements equal 1.0) are the principal components.

right eigenvectors $\mathbf{u}_R$ satisfy: $\mathbf{A}\ \mathbf{u}_R = \lambda\ \mathbf{u}_R$, where λ is the eigenvalue associated with the eigenvector and **A** is a square matrix.

left eigenvectors $\mathbf{u}_L$ satisfy: $\mathbf{u}_L\ A = \lambda\ \mathbf{u}_L$.

Every left eigenvector is the transpose of a right eigenvector of the transpose of **A**. The left and right eigenvalues are identical.

Ekman layer Depth of frictional influence determined largely by the balance of friction and Coriolis forces. Brink defines the `surface Ekman layer' as the portion of the upper water column where turbulent shear stresses are non-negligible and where the applied wind stress is absorbed. Note that there are both surface (wind-induced) and bottom (bottom current induced) Ekman layers.

Ekman spiral The clockwise spiral in the Northern hemisphere of water velocity with increasing depth. At the Ekman depth, water velocity is opposite that of the surface water direction and approximately $e^{-\pi}$ of surface water velocity in magnitude ($0.043*V_o$, where V_o is surface water velocity). Ekman spirals can also occur at the benthic boundary layer, where a unidirectional bottom current drives the spiral.

Ekman mass transport The depth-integrated flow resulting from the Ekman spiral. The net transport is 90º to the right of wind direction in the Northern hemisphere and 90º to the left of wind direction in the Southern hemisphere. Ekman mass transport can lead to **upwelling**.

El Niño Named after *Corriente δ Niño* or 'Current of the Christ Child' which was an unseasonably warm current that occurred during Christmas 1892. El Niño is a period when upwelled water is warmer than usual due to deepened sea-surface isopycnals (*i.e.*, warm water at the Eastern ocean boundary is nearer the surface). The El Niño effects on coastal **upwelling** are part of an oceanic scale phenomenon known as the **El Niño Southern Oscillation (ENSO)**, characterized by weakened **easterly winds** and deeper isopycnal surfaces on the Eastern boundaries of oceans and at the **equatorial divergence**. **Mann & Lazier (1996, p. 283)** state, "In this oscillation the usual pressure gradient from the region of high atmospheric pressure in the southeast Pacific Ocean to the region of low pressure in the area of Indonesia becomes higher or lower than average. A lower-than-average pressure gradient favors El Niño conditions, while the higher-than-average situation has been called La Niña." ENSO events affect **primary production** along the coast and along the equatorial divergence. They are associated with increased rainfall on the West Coast of the US and droughts inland.

Environment The environment of an animal [or bacterium or plant] consists of everything that might influence its chance to survive and reproduce The components of the environment include resources, predators, and **malenities** (*e.g.*, unfortunate accidents) (**Andrewartha & Birch 1984**)

Equatorial divergence The Southeast tradewinds drive the Westward flowing South Equatorial Current (SEC). The mass transport from this current is southerly south of the Equator and northerly north of the Equator producing a zone of **upwelling** at the Equator.

Equilibrium see **steady state**

Estuary A semi-enclosed coastal body of water freely connected to the ocean and within which seawater is measurably diluted with freshwater from the land [**Pritchard 1967**]. Estuaries can be further distinguished based on vertical mixing regime and topography. **Fairbridge (1980)**, quoted in **Day *et al.* (1989, p. 6)**, provides this definition:

> *An estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors; (a) a marine or lower estuary, in free connection with the open sea; (b) a middle estuary subject to strong salt and fresh water mixing; and (c) an upper or fluvial estuary, characterized by fresh water but subject to daily tidal action. the limits between these sectors are variable, and subject to constant changes in river discharge.*

Day *et al.* (1989, p. 52-58) review the following types of estuaries, based on geomorphology:

- Coastal plain estuaries (*e.g.*, Chesapeake Bay, Delaware Bay)
- Coastal plain salt marsh estuaries (No major river, but a well-defined tidal drainage network)
- Lagoons
- Fjords
- The Fjord-like fjäds, or Scottish firths
- Tectonically caused estuaries (*e.g.*, San Francisco Bay)

Day *et al.* (1989, p. 71-72) review the following types of estuaries, based on mixing type:

- Highly stratified (*e.g.*, lower Mississippi)
- partially mixed (*e.g.*, Chesapeake Bay)
- well mixed (*e.g.*, Narragansett Bay, Boston Harbor)
- vertically homogeneous with laterally reversing net flow
- vertically and laterally homogeneous

Eulerian coordinates In an oceanographic context, a process is studied at one fixed location, for example, a one-m^3 parcel of water [*cf.*, **Lagrangian coordinates**]

Excretion The release of dissolved substances, usually nutrients or organic matter, by an organism. The dictionary definition includes defecation, the release of material – especially particulate organic matter – from the gut, as a form of excretion, but usually defecation is considered a separate process from excretion in the biological oceanographic literature. The most common use of excretion in biological oceanography is the release of dissolved nutrients from heterotrophs or the release of dissolved organic matter by autotrophs and heterotrophs.

Exponential growth equation

$$\frac{dN}{dt} = \mu\, N. \qquad \text{where, } \mu = \textit{the specific growth rate.} \tag{15}$$

After integration, the number of individuals at time t, N_t, can be calculated from the number of individuals at an earlier time, N_o:

$$N_t = N_o\, e^{\mu t}. \qquad \ln\left(\frac{N_t}{N_o}\right) = \mu\, t. \tag{16}$$

The population doubling time, T, and the specific growth rate in doublings per unit time are defined using the exponential growth equation:

$$\begin{aligned} N_t &= N_o\, e^{\mu \mathbf{T}}. \\ \ln\left(\frac{N_T}{N_o}\right) &= \mu\, \mathbf{T}. \\ \frac{\ln\, 2}{\mu} &= \mathbf{T}. \\ \textit{where, } \mu &= \textit{specific growth rate} \left[\frac{1}{\textit{TIME}}\right]. \\ \mathbf{T} &= \textit{pop. doubling time } [\textit{TIME}]. \\ \boldsymbol{\mu}\ [\textit{doublings per unit time}] &= \frac{1}{\mathbf{T}} = \frac{\mu}{\ln\, 2} \left[\frac{1}{\textit{TIME}}\right]. \end{aligned} \tag{17}$$

In the biological oceanographic literature, μ can be expressed both as doublings per day or the inverse of doubling time (*e.g.*, **Eppley 1972**) and as $\frac{1}{N}\frac{dN}{dt}$. Both forms of μ have dimensions of inverse time and both are called the specific growth rate. As shown in Equation 17, the two μ's differ by a factor of ln (2). Most recent literature defines μ as $\frac{1}{N}\frac{dN}{dt}$. With exponential growth, the specific growth rate is constant, exhibiting no density dependence. The **logistic equation** is one of many models that incorporate density-dependent limitations of growth rate.

Eutrophic area or water with high fertility (*cf*., **eutrophication**, **oligotrophic**).

Eutrophication **Edmondson (1991)** argued that **eutrophication** is an increased nutrient loading to a system. He stressed that 'increased nutrient loading' should be clearly distinguished from the deleterious environmental effects that might result from this increased loading. The deleterious environmental effects of eutrophication can include: low dissolved O_2 concentrations (**hypoxia**) or no dissolved oxygen (**anoxia**), reducing conditions and high H_2S concentrations in bottom waters and sediments, altered species composition with dominance by nuisance algal species, and harmful algal blooms. Dissolved inorganic carbon depletion resulting from **eutrophication** can lead to surface scums of cyanobacteria in freshwater lakes. Many textbooks define **eutrophication** solely in terms of harmful effects, such as low dissolved oxygen and harmful algal blooms. **Edmondson (1991)** describes how low dissolved oxygen and harmful algal blooms can occur without additional nutrient loadings and should not be considered eutrophication in the absence of increased nutrient loading.

The **National Research Council (2000)** provided a different definition of eutrophication based on **Nixon (1995)'s** pithy definition of 'an increase in the supply of organic matter to a system':

> *"Eutrophication ...is the process by which a body of water becomes enriched with organic material. This material is formed in the system by primary productivity (i.e., photosynthetic activity); and may be stimulated to harmful levels by the anthropogenic introduction of high concentrations of nutrients (i.e., nutrient over-enrichment) such as nitrogen and phosphorus. The term eutrophication is sometimes loosely used to describe any result attributable to anthropogenic nutrient loading to a system, but eutrophication* per se *is not necessarily caused by human action. It is, however, one of the processes that can be triggered by nutrient over-enrichment. The distinction in this report between nutrient over-enrichment and eutrophication is an important one, since nutrient over-enrichment can lead to a number of problems other than just eutrophication of coastal waters (such as coral-reef decline), and the excessive primary production associated with eutrophication often leads to a secondary set of problems (such as hypoxia). Confusing cause and effect can impede mitigation, as remediation efforts may not bring about desired effects if those effects are improperly targeted."*

Evolution any net directional change or any cumulative change in the characteristics of organisms or populations over many generations (**Endler, 1976, p. 5**) {*cf*., **coevolution**, **natural selection**}

Experiment A systematic set of observations of the functional dependence of a response variable in terms of conceivably causal variables in which the statistical population (*i.e.*, the objects of study) is in theory infinite (*cf.* **surveys** which analyze finite populations). **Kendall and Stewart (1961)** emphasize that the key to proper experimental design is randomization, a concept introduced by R. A. Fisher in the 1920's: *"Whenever* *experimental units are allocated to factor-combinations in an experiment, this should be done by a random process using equal probabilities."*(**Kendall & Stewart, 1961 p. 121**)

The factors influencing the dependent variable in any experiment are, explicitly or implicitly, divided by the experimenter into three classes:

(1) those incorporated into the structure of the experiment
(2) those "randomized out" of the experiment
(3) those neither incorporated nor randomized out.

A substantial part of the skill of the experimenter lies in his choice of factors to be randomized out of the experiment. If he is careful, he will randomize out all the factors which are suspected to be causally important but which are not actually part of the experimental structure. But every experimenter necessarily neglects some conceivably causal factors...Thus the choice of factors to be randomized out is essentially a matter of judgement" (**Kendall & Stewart, 1961 p. 123**).

f*-ratio** The ratio of **new production** to total production. **Eppley (1981)** called (1-f***) **the recycling ratio**.

Facilitation **Connell & Slatyer (1977)** proposed three mechanisms or models of succession: **facilitation**, inhibition, and tolerance. In all three mechanisms, there are species adapted to colonizing in higher frequency upon the opening of space in the environment. In the facilitation model, these early species modify the environment to increase the odds of later species colonizing (often while reducing the probability that they will replace themselves). In the inhibition model, early species reduce the probability of later species colonizing the area. In the tolerance model, the early species neither inhibit nor facilitate the recruitment of later succession species. [*cf.*, **succession**, **mutualism**, **commensalism**]

facultative A behavior or physiological pathway that is only one of several options available to the organism. [*cf.*, **anaerobe**]

falsificationism **Popper's (1959)** philosophy of science. His demarcation principle states that only concepts that can potentially be falsified should be considered scientific; the rest are pseudoscience

Fick's laws [*cf.*, **molecular diffusion**] **Fick's first law**

$$J_x = -D \frac{dC}{dx} . \qquad \textbf{(18)}$$

Or, in words: the net **flux** J_x of a scalar quantity C (*e.g.*, O_2, NO_3^-) in the x direction is equal to the -1 times the concentration gradient times the diffusion coefficient.

Fick's second law

$$\frac{dC}{dt} = D\frac{d^2C}{dx^2}. \tag{19}$$

Or, in words: the time rate of change in concentration (at x and t) is proportional to the second derivative (the curvature) of the concentration gradient (at x and t); the constant of proportionality is D, the **diffusion coefficient** with dimensions of $\frac{L^2}{T}$ (**Berg 1983, p. 17-20**).

fitness A measure of the ability of an individual to pass its genes on to future generations. As a crude surrogate, the fitness of an organism is related to the finite growth rate of a population, λ, but finite population growth rate is defined for populations and fitness is defined for individuals.

flux movement of a substance per unit area per unit time.

forecasting **Forecasting** extends into the future or to different situations, structural relationships among descriptors that have been quantified for a given data set. A set of relationships among variables, which simply describe the changes in one or several descriptors in response to changes in others as computed from a "training set", make up a forecasting model. In contrast, when the relationships are assumed to be causal and to describe a process, the model is **predictive**. A condition to successful **forecasting** is that the values of all important variables that have been observed (or controlled in the case of an **experiment**) be about the same in the new situation as they were during the **survey** or **experiment**. In action, forecasting does not allow extrapolation beyond the observed range of the explanatory variables. **Forecasting models** (also called **correlative models**) are frequently used in ecology, where they are sometimes misleadingly called "predictive models". Forecasting models are useful, provided that the above conditions are fulfilled. In contrast, predictive models describe known or assumed causal relationships." **Legendre & Legendre 1998**, p. 493. See also **predictive models**.

Formation **Clements (1916, opening line)** *"The developmental study of vegetation necessarily rests upon the assumption that the unit or* ***climax*** *formation is an organic entity. As an organism the formation arises, grows, matures and dies. ...The life-history of a formation is a complex but definite process, comparable in its chief features with the life-history of an individual plant."* **Whittaker, (1975, p. 126)** "A major kind of community characterized by **physiognomy** (and environment) is a formation or **biome**."

Functional groups **Woodin & Jackson (1979, p. 1030)** contrasted their functional groups with **Root's guilds**:

> *"A functional group includes all organisms which use and affect their environment in approximately similar ways. (This is rather different from the concept of a* ***guild*** *[****Root, 1967****] which is defined solely on the basis of modes of exploitation of resources). We define functional groups of benthos by the ways in which they exploit their substratum environment and the nature of their effects on the substratum."*

Genetic drift A concept introduced to population genetics by Sewall Wright in a series of papers in the 1920s & 1930s. Gene frequencies in small local populations can change due to sampling alleles from a finite population of adults. In very small populations of a few hundred or less, the result of drift is the loss of genetic diversity in local populations, with the rate of loss proportional to $\frac{1}{2N_e}$, where N_e is the effective population size. **Corn (1995)** reported only 350 Northern Right whales left.. The expected time for the loss of all genetic diversity in a population with an effective population size (breeding individuals) is about 1000 generations (variance = 510, 000 generations). If the population size were just 100, the expected time for the loss of all diversity would be 300 generations (variance of 40,000 generations). If the population size were 40, the expected time for the lose of all diversity due to drift would be 110 generations (variance of 6500).

Geostrophic currents Currents modeled by balancing the Coriolis and pressure gradient forces. The pressure gradient force is the sum of the **barotropic pressure gradient**, due to sea-surface slope, and the **baroclinic pressure gradient**, due to seawater density structure. With the assumption that only the Coriolis & pressure gradient force affect current velocity (the geostrophic assumption) and an assumed level of no motion, an oceanographer can estimate the direction and velocity of currents at a site, knowing only the latitude (needed to calculate that Coriolis force) and the depth profiles of temperature & salinity (needed to calculate seawater density with depth). The Gulf Stream has been modeled as a geostrophic current.

Gram reaction (**Stanier *et al.* 1970**) The Dane Gram invented the Gram stain in the 1880s. Gram negative bacteria have a cell wall composed of a single monolayer of peptidoglycan; gram positive bacteria have multiple layers of peptidoglycan. The Gram stain, consisting of iodine and crystal violet, stains both gram negative and positive bacteria, forming a water-insoluble precipitate. However, the destain solution, usually alcohol or acetone, can wash the precipitated stain out of only gram negative bacteria. Gram negative bacteria have a very thin peptidoglycan cell wall, but gram positive bacteria have a very thick peptidoglycan cell wall. Safranin is used as a counterstain for the gram negative bacteria, and they are pink under visual microscopy. Gram positive bacteria are blue.

Growth rate mass x time^{-1}, or mass x (time x water volume [or sea surface area])$^{-1}$.

Specific growth rate mass x(mass x time)$^{-1}$ or
Number x (number x time)$^{-1}$
has units of 1/time (=t^{-1})and is analogous to r, the per capita growth rate in the **Lotka equation**.

Population growth rate $\frac{dN}{dt}$ or $\frac{dC}{dt}$, where N is population number per unit area or volume, and C is biomass per unit area or volume. The rate of change of biomass per unit area or volume is **net production** (*cf.*, **gross production**)

Guild **Root (1967)** introduced the term 'guild' to ecologists:
"[A ***guild*** *is] a group of species that exploit the same class of environmental resources in a similar way. This term groups together species, without regard to taxonomic positions, that overlap significantly in their niche requirements."*
[*cf.*, **functional group**, **community**]

Half life Processes that exhibit 1st-order reaction kinetics, such as the decay of radioisotopes, can be defined in terms of their reaction coefficient, *k*. 1st order reaction coefficients can be converted to the half life or the time taken for a substance to decay to half its original concentration $\frac{C_o}{C_t}=2$. After 4.6 half lives, substances decay to 1% of the original concentration ($e^{-4.6} \approx 0.01$):

$$\begin{aligned}\frac{dC}{dt} &= -k\ t.\\ \textit{where},\ k &= 1^{st}\ \textit{order reaction coefficient}.\\ t &= \textit{time}.\end{aligned}$$

$$\begin{aligned}&\textit{After integration}:\\ C_t &= C_o\ e^{-kt}.\\ \ln\left(\frac{C_t}{C_o}\right) &= -kt.\\ \ln\left(\frac{C_o}{C_t}\right) &= kt.\\ \ln\ 2 &= k\ \mathbf{T}.\\ \frac{\ln\ 2}{k} &= \mathbf{T} = \textit{half life}.\end{aligned} \tag{20}$$

Table 3. Half Lives for some radioisotopes. The half life can be converted to a decay rate λ: $\lambda = \frac{\ln 2}{\textit{halflife}}$

Isotope	Half life
^{14}C	5730 years
^{7}Be	53 d
^{234}Th	24.1 d
^{210}Pb	22.3 y
^{32}P	14.2 d
^{125}I	60.1 d

Half-saturation constant In the **Monod** or **Michaelis-Menten** equations, the substrate concentration at which the growth rate or reaction rate, respectively, are at half the maximal rates. Usually abbreviated as K_s or K_M. [dimensions are grams/liter or the like]

Halocline The water-column depth stratum in which there is a rapid change in salinity (*cf.*, **nutricline**, **pycnocline**, **thermocline**)

Hatch-Slack photosynthesis See **C_4 photosynthesis**

Heterotrophs Organisms that depend on external organic matter for maintenance and growth. Heterotrophs can be further divided into **obligate heterotrophs**, all animals without plant symbionts, some plants, most bacteria, and **facultative heterotrophs**, many algae. **Aerobic anoyxgenic phototrophs** are facultative heterotrophs that don't produce oxygen. **Osmotrophic heterotrophs** use dissolved organic matter, **phagotrophic heterotrophs** feed on particulate organic matter (*cf.* **autotrophs** and **auxotrophs**).

Holling ingestion curves **C. S. Holling (1959)** described four types of functional responses of predator ingestion rates in response to increasing prey density (Figure 1), with the 1st (rectilinear), 2nd (hyperbolic, Ivlev or Michaelis-Menten), and 3rd (logistic, sigmoid, S-shaped) being the most widely used.

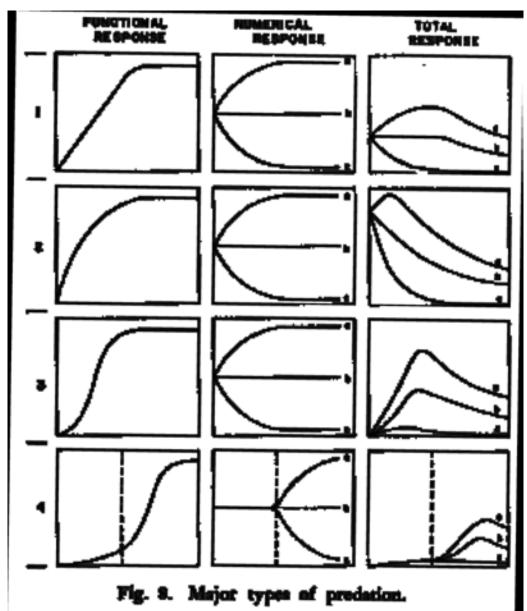

Fig. 8. Major types of predation.

Figure 1. The 4 types of functional response described by **Holling (1959)**. The Type-4 functional response — a Type III S-shaped response with a lag — is rarely mentioned in recent writings.

Homeotherms warm-blooded organisms (*cf.*, **poikilotherms**)

Huffaker's mites In a series of experiments on biological control, Huffaker (**1957**, **1958**) and **Huffaker et al. (1963)** studied a prey mite that fed on oranges and its predator. Without environmental complexity and with rapid dispersal by the predator, coexistence was limited with the predator consuming all the prey. With enhanced environmental complexity (wax paper around the oranges, vaseline to slow down the predators, poles for the prey to vault from orange to orange, coexistence was maintained for several predator-prey cycles. Huffaker's mites is often used to refer to the important role that environmental complexity plays in maintaining biodiversity. *Cf.*, National academy profile of C. B. Huffaker (1914-1995): **http://www.nap.edu/readingroom/books/biomems/chuffaker.pdf**

Interdisciplinary Interdisciplinary work is that which integrates concepts across different disciplines. New disciplines have arisen as a result of such syntheses. For instance, quantum information processing amalgamates elements of quantum physics and computer science. Bioinformatics combines molecular biology with computer science. An interdisciplinary team is a team of people with training in different fields. Interdisciplinary teams are common in complex environments such as health care. Taken from Wikipedia **http://www.webster-dictionary.org/definition/interdisciplinary**

Intermediate disturbance hypothesis **Paine (1966)** set up controlled experiments in the Pacific Northwest rocky intertidal zone, showing that when a keystone species, the starfish *Pisaster*, was removed, the dominant competitor for space, the mussel *Mytilus californianus*, became overwhelmingly dominant, reducing diversity. Paine proposed that increasing predation or disturbance lead to enhanced species diversity by freeing limiting resources for competitively inferior species. The starfish is a **keystone predator**. Paul Dayton (**1971**, **1975**) later showed that at high rates of disturbance, such as logs battering the Pacific Northwest intertidal zone, diversity declines as the community becomes dominated by only the most opportunistic species. **Connell (1978)** later extended the intermediate disturbance hypothesis to explain high species diversity in coral reef and tropical forest ecosystems.

Isopycnals Lines of constant water density.

Isotope dilution Many oceanographic rates are estimated by the addition of trace amounts of compounds labeled with either radioisotopes or stable isotopes. The isotope dilution expresses the ratio of the added isotope to the natural pool of compound present. In the C-14 method, the isotope dilution is expressed as the specific activity of the DIC pool. In the tritiated thymidine method, the assumption is often made that there is virtually no thymidine present in seawater (i.e., assumes no isotope dilution).

Iteroparous reproduction repeated reproduction by the same female. "Trickle reproduction" is a form of reproduction used by some calanoid copepods, in which discrete clutches of eggs are produced over a long period of time. [*cf.*, **semelparous reproduction**]

Ivlev equation A 2-parameter equation that describes a hyperbolic curve similar in shape to that produced by the **Michaelis-Menten** or **Jassby-Platt** equation. Ivlev equations are used to model **Holling Type II** ingestion curves.

$$I = I_m \left(1 - e^{-\delta P}\right). \qquad \textbf{(21)}$$

Jassby-Platt equation An empirical fit to **P *vs.* I curves**. The initial slope, α, and the asymptote, $P^B{}_m$ or **assimilation number**, are the two key parameters describing phytoplankton production.

$$\begin{aligned}
P^B &= P_m^B \tanh\left(\frac{\alpha\, I}{P_m^B}\right).\\
\textit{where},\ P^B &= Chl\ \underline{a}\ specific\ production\\
&= [mgC\ (mgChl\ \underline{a})^{-1}\ h^{-1}].\\
P^{B_m} &= Assimilation\ number.\\
&= the\ maximum\ photosynthetic\ rate\ at\ light\ saturation.\\
\alpha &= the\ initial\ slope\ of\ the\ P\ vs.\ I\ curve.\\
&= [mgC\ (mgChl\ \underline{a}\ h)^{-1}\ (W\ m^{-2})^{-1}],\ or\\
&= [mgC\ (mgChl\ \underline{a}\ h)^{-1}\ (E\ m^{-2}\ h)^{-1}]\\
I &= the\ light\ intensity\ of\ PAR\text{:}\quad [Watts\ m^{-2}],\ or\ [Einsteins\ m^{-2}\ h^{-1}].
\end{aligned} \qquad \textbf{(22)}$$

Kairomone 'a chemical that is pertinent to the biology of an organism (organism 1) and that when it contacts an individual of another species (organism 2) evokes in the reciever a behavioural or physiological response that is adaptively favourable to organism 2 but not to organism 1. (**Meiners & Steidle 2002**)

Kendall's horseshoe or **Kendall's arch**

Lagrangian coordinates In an oceanographic context, a process is studied while following a parcel of water as it is advected through a region. Estimates of primary production are usually expressed using a Eulerian coordinate frame, e.g., the production in one m^3 parcel of water. **Woods & Onken (1982)** modeled primary production as a Lagrangian process by tracing the growth of individual phytoplankton cells being advected through a model water column [*cf.*, **Eulerian coordinates**, **sequence**]

Lambert-Beers law $I_z = I_o\, e^{-kz}$, the change in light intensity with depth, is a familiar application of the Lambert-Beers Law relating light absorption and the concentration of absorbing substance.

lecithotrophic development A"yolk feeding" planktonic dispersal stage of a benthic organism. The larva can not feed on external food sources. Most barnacle species have a **planktotrophic** naupliar stage followed by a lecithotrophic cyprid stage

Liebig's law Maximum population size, yield, or growth rate is controlled by a single limiting factor (*e.g.*, a limiting nutrient). This "hypothesis" appears to apply to the effects of nitrogen and phosphorus, which do not interact; one or the other is limiting at a time. **Droop (1974)** and **Rhee (1978)** found convincing evidence for this law in unialgal chemostat cultures: growth is controlled by one nutrient at a time. **DeBaar (1994)** reviews the history of this 'law', one of 50 agricultural laws proposed von Liebig. **DeBaar (1994)** concludes that this law has little validity for interpreting the complexity of complex phytoplankton communities.

Light adaptation [better termed light **acclimation** to distinguish adaptive & physiological traits] (from **Parsons *et al.* 1984**, *cf.*, **shade adaptation**) A physiological adjustment to surrounding conditions which involves at least one of the following morphological or biochemical changes: 1) change in total photosynthetic pigment content, 2) change in the ratio of photosynthetic pigments, 3) change in the morphology of the chloroplast, 4) change in the arrangement of the chloroplast, 5) change in the availability of enzymes for the **dark reactions** of photosynthesis

Chromatic adaptation the adaptation to changes in light quality (*i.e.*, changes in the spectrum of available light). Many supposed examples of chromatic adaptation (*e.g.*, benthic macroalgae) are probably adaptations to light quantity.

Light reactions photochemical reactions generating ATP and reducing power with the evolution of O_2:

1. Trapping of light energy by **Photosystem I** and **Photosystem II**
2. Reduction of NADP to NADPH and formation of ½ O_2 from H_2O in **Photosystem II**
3. **Photophosphorylation** of ADP into ATP in **Photosystem I**.

Only the trapping of light energy by photosynthetic pigments requires light. [*cf.*, **dark reaction**, **P *vs.* I curves**]

Light utilization efficiency (**Parsons *et al.* 1984, p. 99**) the ratio of photosynthetic production to the total incoming solar radiation.

Logistic equation A two-parameter equation due to Verhulst & Pearl describing an S-shaped population growth curve. [*cf.*, **exponential growth**, **Lotka-Euler**, **Lotka-Volterra competition** equations, **r- & K-selection**]:

$$\frac{dN}{dt} = r\,N\left(1 - \frac{N}{K}\right). \qquad (23)$$
$$\textit{where, } K = \textit{Carrying capacity.}$$
$$r = \textit{maximum per capita growth.}$$

Lotka equation [Lotka-Euler equation] The discrete-stage form for calculating r, the instantaneous rate of population increase. r is also called **the specific growth** rate or the per capita growth rate. This equation is appropriate for metazoan populations with a defined age structure. It has been defined in both continuous and discrete form, but **Caswell (2000)** argues that the discrete form, shown below, should not be used. He makes a persuasive case for the use of the Leslie matrix and other stage projection matrices to model and estimate r

$$
\begin{aligned}
1 &= \int e^{-rx}\, l_x\, m_x\, dx \\
\text{where, } e &= \text{base of Naparien logarithms } (\approx 2.718). \\
l_x &= \text{age-specific survivorship.} \\
&= \text{Probability of a newborn surviving to } x. \\
m_x &= \text{age-specific fecundity.} \\
&= \text{Number of young born to a female, aged } x. \\
x &= \text{time.}
\end{aligned}
\tag{24}
$$

$$
\begin{aligned}
1 &= \sum e^{-rx}\, l_x\, m_x. \\
\text{where, } e &= \text{base of Naparien logarithms } (\approx 2.718). \\
l_x &= \text{age-specific survivorship.} \\
&= \text{Probability of a newborn surviving to } x. \\
m_x &= \text{age-specific fecundity.} \\
&= \text{Number of young born to a female, aged } x. \\
x &= \text{time.}
\end{aligned}
\tag{25}
$$

Lotka-Volterra competition equations The paired, six-parameter equations, that describe competition between pairs of species. The equations were introduced by Vito Volterra, but Lotka was the first to write them in their present form.

$$
\begin{aligned}
\frac{dN_1}{dt} &= r_1 N_1 \left(1 - \frac{N_1 - \alpha_{12} N_2}{K_1}\right). \\
\frac{dN_2}{dt} &= r_2 N_2 \left(1 - \frac{N_2 - \alpha_{21} N_1}{K_2}\right). \\
\text{where, } \alpha_{12} &= \text{Interspecific competition coefficient for pop. 2 on 1.} \\
K_1 &= \text{Carrying capacity for population 1.} \\
r_1 &= \text{maximum per capita growth for population 1.}
\end{aligned}
\tag{26}
$$

Lotka-Volterra predation cycles Vito Volterra applied coupled differential equations to model the growth or predators and prey. Under some combinations of parameters, cycles of increases and declines of prey are coupled to increases and declines of predators. These wave-like patterns are often called Lotka-Volterra cycles.

Macroecology "The distribution of range and abundance among species, the relation between range and abundance, the variation of diversity among sites, and the increase in diversity with area...form part of the field of macroecology, which is concerned with the description and interpretation of broad ecological patterns." Neutral macroecology refers to the modeled null patterns generated by collections of demographically identical species. **Bell (2001,p. 2413)**

Macrofauna A term for those benthic organisms whose typical adult cross-section is larger than 500-µm (or 1-mm). This cutoff has declined over time. Early workers sieved benthic organisms with 3-mm or 5-mm mesh sieves. Now, much of the macrofaunal community structure work uses a 300-µm or 500-µm mesh sieve. On the west coast of United States, most benthic macrofaunal sampling programs still use 1-mm mesh sieves. The macrofauna can be further divided into the **epifauna** and **infauna**, the organisms that live on and in the sediments, respectively. The major groups of the benthic macrofauna are the polychaete worms, molluscs (gastropods & bivalves), echinoderms (brittle starts, sea cucumbers, star fish and sand dollars), and crustacea (crabs, shrimp, isopods and amphipods) (*cf.*, **meiofauna**, **microfauna**)

Mass effect A species can persist in an area through immigration even though its local net rate of change is negative (**Rosenzweig 1995**, **Shmida & Whittaker 1981**, **Shmida & Ellner 1984**, **Shmida & Wilson 1985**).

Meiofauna A subset of the benthic fauna which is operationally defined as those organisms whose typical size allows them to be retained on a 63-µm mesh sieve but pass through a 500-µm (or 1-mm) mesh sieve. Nematodes and harpacticoid copepods are the numerically dominant members of the meiofauna in most environments. Oligochaetes are also considered a largely meiofaunal taxon, though many individuals will be retained on a 500-µm mesh. The term meiofauna includes members that live within sediments, on sediments, and on objects protruding from the sediments (*e.g.*, animal tubes, sea grasses, rocks). Most members of the macrofauna begin life with reproductive stages that are temporary members of the meiofauna (*cf.*, **macrofauna**, **mesopsammon**, **microfauna**).

Mesopsammon [literally, 'among sand'] A subset of the **meiofauna** that live within the interstices of sand grains. By definition, they can move without displacing the grains. They are also called the **interstitial fauna**.

Mesozoic Era From **Wikipedia** The Mesozoic is one of three geologic eras of the Phanerozoic eon. The division of time into eras dates back to Giovanni Arduino in the 18th century, although his original name for the era now called the Mesozoic was "Secondary" (see Tertiary.) Mesozoic gets its name from the Greek meso (middle) and zoo (animals) and is often called the "Age of Medieval Life." The Mesozoic includes three geologic periods: from oldest to youngest, they are the Triassic, the Jurassic and the Cretaceous periods. It extended from roughly 251 million years ago (Ma) to roughly 65 Ma. The Mesozoic followed the Paleozoic Era and preceded the Cenozoic Era. The lower (oldest) boundary is set by the Permian extinction. The upper (youngest) boundary is set at the Cretaceous extinction.

Metamorphosis the morphological and physiological change that adapts the animal to a new way of life, *i.e.*, from a pelagic to a benthic existence and not uncommonly from a herbivorous to an omnivorous to a carnivorous diet (**Scheltema 1979**) cf. settlement.

Michaelis-Menten equation [cf., **Droop equation**, **Monod equation**] A two-parameter equation describing the rate of an enzyme reaction as a function of external substrate concentration.

$$\begin{aligned}
V &= \frac{V_{max}\ S}{K_M + S}. \\
\textit{where, } K_M &= \textit{Half-saturation constant.} \\
&= \textit{Substrate concentration at which } V = \tfrac{1}{2} V_{max}. \\
S &= \textit{Substrate concentration.} \\
V &= \textit{Reaction velocity.} \\
&= \frac{-dS}{dt} = \frac{d\ [\textit{Product}]}{dt} \\
V_{max} &= \textit{Maximum } V.
\end{aligned} \qquad \textbf{(27)}$$

Methanogens are obligate **chemoautotrophic anaerobes**, obtaining energy from hydrogen gas, and using CO_2 as the terminal-electron acceptor, producing methane (CH_4), a process called **methanogenesis**. Environments where methanogenesis occurs are **methanogenic**.

Microclimate **Allee *et al.*'s (1949)** term for changes in the local environment caused by the organisms themselves. For example, **Whittaker (1975, p. 176)** described the effect of plants on light during forest succession, "As the height and density of above-ground plant cover increase, the **microclimate** within the community is increasingly determined by characteristics of the community itself."

Microfauna A term, with usage largely determined by Fenchel's early work on benthic ciliates, describing those members of the benthos, smaller than the traditional meiofauna but larger than most bacteria. The microfauna include ciliates, heterotrophic nanoflagellates, and some dinoflagellates (*cf.*, **macrofauna**, **meiofauna**).

Microphytobenthos Small, unicellular sediment-associated **photoautotrophs**. **Benthic macroalgae** is the term used to describe large, multicellular sediment-associated **photoautotrophs**. The microphytobenthos is dominated by **pennate diatoms**. The **epipelic** microphytobenthos photosynthesize on top of mud [*pelos* = mud {Greek}], and the **epipsammic** microphytobenthos photosynthesize on top of the sand.

Monitoring A sampling program designed to detect significant changes in the distribution of 'response' or 'criterion' variables and to account for observed changes in these variables in terms of 'explanatory' or 'predictor' variables.

Monod equation

$$\mu = \mu_{\max}\left(\frac{S}{K_m + S}\right).$$

$$\begin{aligned} \textit{where,}\quad \mu &= \textit{Specific growth rate.} \\ S &= \textit{External limiting substrate or nutrient concentration.} \\ K_m &= \textit{Half-saturation parameter} \\ &= \textit{Substrate concentration at } \mu = \tfrac{1}{2}\mu_{\max}. \end{aligned} \qquad \textbf{(28)}$$

Monod modified the **Michaelis-Menten equation** to explain the relation between the **specific growth rate** of heterotrophic bacteria and external food concentration, S. Phytoplankton growth is often modeled using Monod-type equations, where S is the external nutrient concentration. However, **Droop (1968)** showed that phytoplankton specific growth is not directly related to external nutrient concentration but instead to the **cell quota** (internal nutrient pool). Caperon (1968) and **Caperon & Meyer (1972)** modified the Monod equation to explain μ with Q, **the cell quota**, and Q_o, **the minimum cell quota**:

$$\mu = \mu_{\max}\left(\frac{Q - Q_o}{K_m + (Q - Q_o)}\right).$$

$$\begin{aligned} \textit{where,}\quad \mu &= \textit{Specific growth rate.} \\ Q &= \textit{Cell quotient.} \\ Q_o &= \textit{Minimum cell quota } (Q \textit{ at } \mu=0). \\ K_m &= \textit{Half-saturation parameter}. \end{aligned} \qquad \textbf{(29)}$$

Droop's equation (**Droop 1968**) requiring only two parameters, can also fit the asymptotic relationship between Q and μ [*cf.*, **Half-saturation constant**]

μg-atm The microgram atom. Oceanographic jargon for μmole. μg-atm/l is equivalent to Molar

Multidisciplinary "A multidisciplinary science, I suggest, has input from several different disciplines, with each of these contributing separately to an understanding of the problem at hand. Take cancer research. This, to my mind, is an example of multidisciplinary science: there are immunologists, developmental biologists, geneticists, mathematicians, epidemiologists, clinicians and pharmacologists all working in the broad area of cancer research, with each group tackling aspects of the problem from within their respective

disciplines." Alan Rodrigo **http://www.openmindjournals.com/AB2-1-Editorial.htm**
cf., **interdisciplinary**

$\delta^{15}N$ Pronounced (del-N15). Nitrogen isotopic composition of a sample. $\delta^{15}N = [(R_{sample}/R_{std})-1] \times 10^3$, where R is the ratio of ^{15}N to ^{14}N and the standard used for **normalization** is air N_2 that has been assigned a $\delta^{15}N$ value of 0.

Natural selection **Endler's (1976, p. 4)** definition. Natural selection is a process in which:
If a population has
a. variation among individuals in some attribute or trait
(*i.e.*, variation)
b. a consistent relationship between that trait and **specific growth rate** (r, μ or λ) *[Endler used fecundity, but fecundity which does not incorporate generation time is inferior to per capita growth]*
(*i.e.*, fitness differences)
c. a consistent relationship for the trait between parents and offspring which is at least partially independent of environmental effects
(*i.e.*, inheritance)
then
1. the trait frequency distribution will differ among age classes or life-history stages
2. if the population is not at **equilibrium**, then the trait distribution of all offspring will be predictably different from that of all parents, beyond that expected from conditions a and c alone

Natural selection can be divided into **sexual and non-sexual selection**, the former being based mainly on differential mating success. Natural selection should be distinguished from purely phenotypic selection (*i.e.*, within generational change in trait distribution); such phenotypic selection will lead to evolution only if the traits are heritable.

Navier-Stokes equation **http://astron.berkeley.edu/~jrg/ay202/node50.html** *cf.*, **Advection-diffusion equation**

Nekton larger organisms with significant swimming power that, therefore, can largely dodge plankton nets towed with speeds of about 0.5 to 1 m sec^{-1}. *cf.*, **plankton**

Neritic Coastal (*cf.*, **oceanic**)

Niche **Hutchinson (1978, p. 160)** provides this statement on his n-dimensional hypervolume niche concept: *"Each niche can be regarded as a set of points, each one of which defines a possible set of environmental values permitting the species to live."* The fundamental niche is the hypervolume defined only by abiotic environmental variables and food, and the realized niche includes the effects of negative interactions with other organisms. Elton (1927) described the niche as the function performed by the species in the community.

Nitrate reduction the reduction of nitrate due to at least two metabolic processes: 1) **assimilatory nitrate reduction or nitrate assimilation**: nitrate is reduced only for the building of biomolecules (*e.g.*, protein), and 2) **dissimilatory nitrate reduction** nitrate acts as the terminal electron acceptor in the electron transport system during **anaerobic respiration**. Both types of nitrate reduction can result in the formation of NO_2^-; when dis-similatory nitrate reduction gives rise to gaseous products [N_2 and N_2O] the process is referred to as **denitrification**.

Nitrification the oxidation of nitrite [NO_2^-] and ammonium [NH_4^+] to nitrate [NO_3^-]. This energy-producing reaction is due almost entirely to the **chemoautotrophic nitrifying bacteria**. One group of **nitrifying bacteria** oxidizes ammonium to nitrite (*Nitrosococcus* and *Nitrosomonas*, and perhaps other genera) and a second group oxidizes nitrite to nitrate (*e.g., Nitrobacter*) (*cf.* **denitrification** & **nitrate reduction**)

Nitracline, **Nutricline** The water-column depth strata associated with rapid changes in nitrate or nutrients, respectively.[*cf.*, **halocline**, **pycnocline**, **thermocline**]

Nitrogen fixation Uptake of N_2 (gas) and conversion to reduced nitrogen compounds. The marine aerobic colonial cyanobacterium *Trichodesmium* is the major marine N_2 fixer.

Non-local mixing. **Boudreau (1986)** defines non-local mixing as benthic animal activities that displace particles distances greater than the scale over which the concentration of a tracer changes substantially. Boudreau (1986) states that the term nonlocal mixing was coined by Edelen (1976) and introduced into geochemistry by Imboden. Non-local mixing is a subset of **bioturbation**, and **conveyor-belt feeders** are often non-local mixers. As defined here, non-local mixing is dependent on the type of tracer. A small deposit feeder might be a non-local mixer with respect to the short lived radioisotope Th-234 (22.4-d **half life**), while its feeding could be regarded as local for the longer lived isotope Pb-210. [*cf.*, **Goldberg-Koide equation**]

normalization A term often abused by environmental scientists. There are many different meanings of normalization. First, normalization can refer to the standardization of an n-dimensional vector to unit length (*i.e.*, a projection of a data point onto the unit hypersphere, **Noy-Meir *et al.*, 1975**). The etymology of this use of normalization is from *norm*, the length of a vector. Second, as detailed in **Legendre & Legendre (1998)**, normalization can refer to transformations of variables to make their distributions more closely resemble the bell-shaped normal distribution. Finally, normalization as it is usually used in the environmental sciences refers to dividing one variable by another. For examples, metal concentrations are reported after 'normalization' by organic carbon content. Stable isotopes are normalized relative to known standards (e.g., **$\delta^{13}C$**, **$\delta^{15}N$**, **$\delta^{18}O$**)

North Atlantic Oscillation (NAO) "The best-known effect of the North Atlantic oscillation is that warm winters in Europe coincide with cold winters in Labrador and West Greenland, and vice versa." A positive phase of the NAO results in colder than normal winters to the

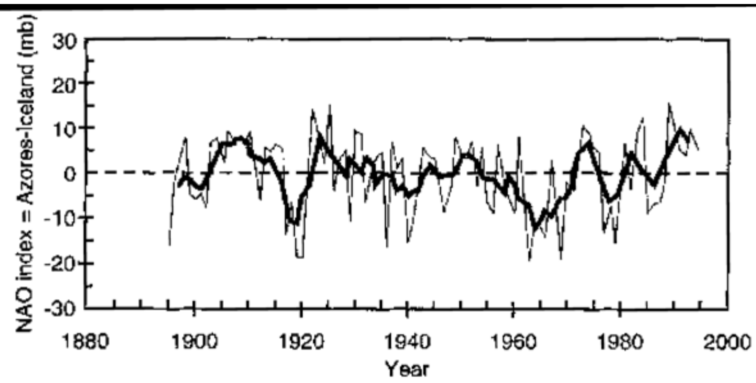

Fig. 9.06 The North Atlantic oscillation winter index based on the average pressure differences between the Azores and Iceland during the winters of 1895–1994. The heavy line is the 5-year running mean. Adapted from Rogers (1984) and updated with data from Drinkwater (personal communication).

east of the Icelandic low pressure zone and warmer than normal winters to the east of the low. The pressure difference at sea level between the Azores and Iceland indicates the status of the NAO (**Mann & Lazier's 1996** Fig. 9.06, shown in Fig. 2). Since the 1970s, the positive index has been associated with warm European winters but some of the most severe winters on record off Labrador and Greenland. **Mann & Lazier (1996, p. 290-291)** *cf.*, **ENSO**

Nutrient Any chemical substance used for physiological processes in an organism. In aquatic systems, these are often divided into the macronutrients: N, P and Si. CO_2 can also be regarded as a nutrient. The major micronutrients are iron (Fe) and zinc (Zn), required as co-enzymes (part of an enzyme molecule) for many key enzymes. **Tilman (1982)** further defines nutrients as resources as essential, hemi-essential or substituitable. Silicate is an essential nutrient for diatoms, but not for dinoflagellates. Neil Price and Francois Morel discovered that cadmium, which isn't regarded as essential for any organism, can substitute for zinc as the co-enzyme in some **carbonic anhydrases**. Some fatty acids may be essential nutrients for higher organisms.

Oceanic is usually contrasted to **neritic** (coastal) and is not synonymous with marine

ODE Ordinary Differential Equation. **Riley's (1967)** New England shelf Nitrogen model is set up as a set of coupled first-order ordinary differential equations. Ordinary differential equations can be solved using Runge-Kutta integration in MATLAB™, using their ODE23 or ODE45 programs, which stand for Runge-Kutta first and second-order integration. (*cf.*, partial differential equation).

Ockham's razor the principle of parsimony formulated by the English logician and philosopher Willam Ockham (1290-1349) states that

Pluralites non est ponenda sine necessitate
Multiplicity ought not to be posited without necessity

Unnecessary assumptions should be avoided when formulating hypotheses (**Legendre & Legendre 1998**, p. 520). Sir Karl Popper, the most influential 20th century philosopher of science, argued in **Popper (1959)** that **falsificationism** provided a reason for Ockham's razor. Simple hypotheses are easier to refute than complex hypotheses.

Oligotrophic area or water with low fertility (*cf.* **eutrophic**). While this is the definition that I learned from Dr. Karl Banse at U.W., I would modify it now to be 'area of low nutrient loading.' This new definition fits the spirit of **Edmondson's (1991)** definition of the antonym of oligotrophic, **eutrophic**, which Edmondson defined as an increase in nutrient loading. It is known now that many of the areas formerly called oligotrophic have reasonably high productivity (≈0.5 $gCm^{-2}d^{-1}$)

Optical depth

$$1\ optical\ depth = \frac{1}{k}. \quad \text{where, } k = \text{the light attenuation coefficient for PAR} \tag{30}$$

Ordinate see **abscissa & ordinate**

Ordination A term, coined by Goodall, describing a large variety of multivariate statistical procedures for analyzing a multidimensional swarm of data points in such a way that when this swarm is projected onto a two-space (*e.g.*, a sheet of graph paper) any intrinsic pattern the swarm may possess becomes apparent (after **Pielou 1984**). Ordination procedures can be broadly divided into:

Direct ordination The process of arranging sites (or species) in relation to one or more environmental (or successional) gradients or to abstract axes representing such gradients (Plotting species abundance versus salinity would be an example of direct ordination).

Indirect ordination a collective term for continuous multivariate techniques which arrange objects (*e.g.*, sites or species) along axes, regardless of the interpretation of the axes. Some common indirect ordination techniques include principal components analysis (including Gallagher's PCA-H), correspondence analysis, canonical correspondence analysis, principal coordinates analysis, and non-metric multidimensional scaling

oxic zone **Jørgensen & Revsbech 1989** defined the oxic zone in sediments as the depth of oxygen penetration, which is usually much less (≈10X) than oxidized zone, the zone of positive $\mathbf{E_H}$.

oxidized zone **Jørgensen & Revsbech 1989** defined this zone as the surface sediment layer associated with positive redox potential ($\mathbf{E_H}$). Characterized by brown coloration due to ferric oxides and oxyhydroxides. Black (pyrite) FeS_2 below. [*c.f.*, **oxic zone**, **r.p.d.**]

P *vs.* I curve [called P vs. E curves in **Falkowski & Raven (1997)**] Photosynthetic rate (**ordinate**) vs light intensity (**abscissa**) The initial slope, α, is controlled by the **light reactions** of photosynthesis and the asymptote, or **assimilation number** is controlled by the **dark reactions**. The P vs. I curve is often modeled with the 2-parameter **Jassby-Platt equation**.

P:B ratios Total annual production to mean populations biomass, proportional to specific mortality rates. Typical zooplankton P:B ratios might be 10-36, meiofauna 4.6 or lower (Giere found an oligochaete P:B ratio of 0.85). **Banse & Mosher (1980)** argued that the P:B ratio indicates the annual mortality rate of a population. Organisms like the **mesopsammon** that have low P:B ratios cannot support high specific mortality rates.

PAR See **photosynthetically available radiation**.

Parameter *vs.* Variable [see also **statistics**] A parameter is a theoretical entity, such as the population mean (μ) or the population variance (σ^2). In statistics, this theoretical entity, or population statistic, can be estimated using sample statistics, such as the sample mean ($\bar{x}$) or sample variance (s^2). **Sokal & Rohlf (1981)** define a variable as the actual property measured by individual observations. A variable can be a measurement of anything that can vary in nature. A common convention is to indicate parameters with Greek letters and variables by arabic letters. A parameter is defined with reference to a law of nature (the speed of light is a parameter), theory or model. The following distinction between variable and parameter was made by Geoff Evans in a communication to biological oceanographers in the JGOFS project (OMNET, 5/2/91):

> *"A variable describes a product of all the circumstances that created it, which vary over time and space. A parameter describes a process whose rules are the same over a sizeable region of space-time, even though different games are played according to those rules. **Primary production** is a variable; the initial slope of the **P vs I curve** is a parameter."*

PCA-H Principal components analysis of hypergeometric probabilities. This multivariate procedure was invented by Gallagher in 1992 and described in **Trueblood *et al.* (1994)**. PCA-H stands for Principal Components analysis of hypergeometric probabilities. Using this method, the species that contribute to **CNESS** distances among samples can be readily identified and graphically displayed with the Gabriel Euclidean distance biplot.

Persistence a population or species did not go extinct in a specified area during a specified time period, or if it did, it recolonized the area within the time span required for one turnover of all individuals of that species in the place. **Connell & Sousa (1983)**

Photoinhibition The decline in photosynthetic rate at high light intensities.

Photorespiration The light-dependent loss of CO_2 and incorporation of O_2 into organic compounds resulting from the oxygenase activity of **RuBPCO**. Photorespiration is initiated by RuBPCO acting as an oxygenase, producing one molecule each of the 2-carbon phosphoglycolate (P-glycolate) and 3-phosphoglycerate. The former molecule can be further metabolized by the glycolate pathway and the latter through the **Calvin cycle**. In the glycolate pathway, P-glycolate is converted to glycine via glycolate. Glycolate is converted to phosphoglyceric acid via glyoxylate, glycine, serine, hydroxypyruvate and glycerate. One quarter of the carbon of glycolate is lost as CO_2 in the conversion of glycine to serine (2 molecules of glycine (2 carbons) are condensed to one molecule each of serine (3 carbons) and CO_2) and the CO_2 produced is the considered the CO_2 lost in photorespiration. Part of the glycolate may be directly excreted into the medium by microalgae, especially cyanobacteria which lack the glycolate scavenge pathway. The rate of respiration is directly related to the O_2:CO_2 concentrations at the **RuBPCO** active site. The decrease in gross photosynthetic rate resulting from increased oxygen concentrations is called the **Warburg effect**. Phytoplankton and macroalgae have a variety of adaptations for increasing the CO_2:O_2 ratios at the **RuBPCO** active site, especially the **CO_2 pump**. [*cf.*, **respiration**, **dark respiration**]

Photosynthetic assimilation number see **assimilation number**

Photosynthetic quotient **[PQ]** Ratio of evolved O_2 to CO_2 incorporation (by atoms or moles). If the phytoplankton are growing on nitrate, a PQ of 1.2-2.0 is assumed; on NH_4^+, a PQ of 1.25 is assumed. (**Parsons *et al*., 1984**; **Williams *et al*., 1983**). **Gieskes & Kraay (1984)** review the discrepancies between the O_2 and ^{14}C methods citing values of PQ that range from 0.3 to 2.5, with PQ>1 if lipids are being synthesized and PQ < 1 if organic acids are the major products of photosynthesis. [*cf.*, **Redfield ratio**]

Photosynthetically available radiation [PAR] The quantity of light in those wavelengths that can be utilized for photosynthesis (400 to 700 nm, **Behrenfeld & Falkowski (1997)**, some earlier papers listed PAR from 300 to 720 nm).

Photosystem I & **Photosystem II**. (**PSI** & **PSII**) The light-harvesting pigments and associated enzymes are partitioned into two different physically contiguous units in the cell, called Photosystems I and II. The concept of **photosynthetic units** was proposed by Emerson & Arnold in the 1930's, and they are defined by **Falkowski (1980)**:

> *"[**Photosynthetic units** are] defined as the number of pigment molecules involved in the evolution of one molecule of oxygen or the reduction of one molecule of carbon dioxide, when the chloroplast pigments are excited by one flash so short that the components involved in the process will not function twice during their lifetime and so strong that a further increase in flash intensity does not lead to an increase in the measured value."*

Each type of photosynthetic unit has its own set of light-absorbing pigments. **P700**, a special Chl *a* pigment assembly, serves as a an electron trap in PSI. It has a maximum absorption efficiency at 697 nm and emits fluorescent light at 730 nm. Electrons expelled from the PSI trap are transferred via a series of electron-transport carriers to Photosystem II. PSII has a **P680** photosystem instead of P700 (*i.e.*, maximum light absorption at ≈680 nm). Energy absorbed at shorter wavelengths is transferred by accessory pigments to Chl *a* 670 before being used or emitted as fluorescence at 684 nm and 695 nm. Electrons expelled from the **P680** trap pass through redox carriers, generating ATP from ADP by **photophosphorylation**. The electrons come to rest at P 700. The electrons for PS II come from H_2O with release of O_2; these electrons are transferred to plastoquinone. This series of reactions, carried out in the light, are termed the **light reactions**. **DCMU**, a herbicide, blocks electron transport beyond the Photosystem II trap and the energy from absorbed light is released as fluorescence. (from **Parsons *et al.* 1984**, **Rhee 1982**) [See also **quantum yield**]

physiognomy physical structure of the vegetation, "The physiognomic approach classifies community by structure -generally by the dominant growth-form of the uppermost stratum or the stratum of highest coverage in the community. A major kind of community characterized by physiognomy (and environment) is a **formation** or **biome**." **Whittaker (1975, p. 126)**.

Pigments **β-carotene**
Chl *a* Chlorophyll *a*
chlorophyllide *a* Produced from Chl a by chlorophyllase
Chl c_1
Chl c_2
fucoxanthin
Pheophytin *a*, the demetallated form of Chl *a*.
Pheophorbide *a*, lacks the phytol side chain found in Chl *a*
xanthopyll

Phagotrophs [see **phagotrophic heterotrophs**]

Phytoplankton biochemical oxygen demand [PBOD] The oxygen required to respire the photoautotrophic biomass produced by the addition of a limiting amount of nutrient. **Officer & Ryther (1977)** noted that secondary sewage treatment in Boston Harbor and elsewhere would reduce **biochemical oxygen demand [BOD]**, the amount of oxygen required to respire the organic matter in sewage effluent, but secondary treatment doesn't reduce the amount of dissolved nutrients, which fuel increased primary production. They defined the oxygen required to respire this new production **PBOD**. Hence PBOD remains high with secondary treatment, and tertiary treatment might be required to reduce both BOD and the concentration of limiting nutrient that leads to PBOD.

Plankton [Gr. *wanderer*] organisms of greatly varying size whose geographical and local positions are largely determined by water movements including turbulence. Their swimming power may be large enough for diel vertical migration to range over a few hundred meters. Depending on the context, **phytoplankton** and **zooplankton** may refer to the plants and animals as taxonomic divisions or **functional groups**, *i.e.*, the terms may contrast autotrophic and heterotrophic forms. The **holoplankton** are organisms that spend their entire lives in the plankton. The **meroplankton**, consisting of the larval stages of benthic organisms, spend only the early part of their lives in the plankton.

Sieburth *et al.* (1978) introduced a widely used size classification of the plankton:

Femtoplankton 0.02-0.2 µm in size. includes viruses

Picoplankton Organisms from 0.2 to 2 µm in size. Other authors have referred to the size group from 0.5 to 1 µm as the **bacterioplankton** since the dominant group is the coccoid cyanobacteria, especially the genus *Synechococcus*. Many **picoplankton** are now known to be eucaryotic, so bacterioplankton is a poor term. **Li *et al.* (1983)** found that 25 to 90% of the biomass (measured as Chl *a)*, 70% of the RuBPCO, and 20 - 80 % of the **primary production** in an **oligotrophic** oceanic area were attributable to the picoplankton.

Nanoplankton 2 to 20 µm in size. **Fenchel (1988)** lists the major taxonomic groups:

phagotrophic choanoflagellates, cryptomonads, chrysomonads, bicoecids, and helioflagellates.

autotrophic: cryptomonads, chrysophytes, haptophytes, prasinophytes, some euglenoids and dinoflagellates, chlorophytes, some tiny diatoms

Microplankton 20-200 µm in size, consisting of **autotrophs** (dinoflagellates & diatoms) and **phagotrophs** (ciliates {aloricate and loricate "tintinnid" oligotrichs dominate, **Fenchel 1988**})

mesoplankton >200 µm - 2 mm

macroplankton > 2 mm

macrozooplankton & **microzooplankton** refers to heterotrophic plankton. The macrozooplankton produce fast-sinking feces, the microzooplankton do not.

planktotrophic development ["plankton feeding"] larval development in the pelagic zone, with a larval stage that feeds on other planktonic organisms (*cf.*, **lecithotrophic development**, **meroplankton**)

POC particulate organic carbon (*cf.*, **DIC**, **DOC**). Usually defined as particles retained on a 0.7-µm filter. **Colloidal organic carbon** consists of particles between 0.2 and 0.7 µm.

Poikilotherms cold-blooded organisms (*cf.*, **homeotherms**)

Pollution **http://www.hyperdictionary.com/dictionary/pollution**

Porosity Porosity, a dimensionless variable, is a property of sediments, ranging from 85% in "oozy" sediments to less than 50% in highly packed sediments.

$$\varphi = Porosity = \frac{water\ \ volume}{sediment\ \ solids\ \ volume}. \qquad \textbf{(31)}$$

Precision indicates the random or chance variability about the mean of repeated observations (*cf.* **accuracy**).

Predictive models The values of the response variables are explained in terms of causal relationships with descriptors. Predictive models can be validated through experiments (**Legendre & Legendre 1998**, p. 495). Regression models are a subset of predictive models. See also **Forecasting vs. Prediction**.

Production refers to the process as well as the product and should, therefore, be qualified:

P:B Ratio (see **Production to Biomass ratio**)

Gross production real photosynthesis (*cf.* **net production**), production before respiratory costs.

Net production gross production minus **respiration**

New production That fraction of production which can be coupled to nutrient inputs from outside the system of interest (**Dugdale & Goering 1967**). Operationally, new production is often regarded as the component of production coupled to nitrate uptake, since nitrate is the major form of nitrate below the nutracline. Occasionally, new production can include production coupled to reduced nitrogen compounds (*e.g.*, urea) from sewage and riverine input (*cf.*, ***f*** **-ratio**, **Regenerated Production**).

Primary Production production by **autotrophs**.

Regenerated production **Dugdale & Goering's (1967)** term for **primary production** coupled to nitrogen provided by regeneration within the system, usually NH_4^+ (*cf.* **new production**.)

Secondary production all animal and heterotrophic bacterial production. Earlier, secondary production was restricted to herbivores, and carnivores represented the tertiary production. Note that animal production usually comprises growth of survivors and of those which died between dates of collection and should include sexual products (reproduction).

Specific production (see growth rate and **assimilation number**). Any measurement of production scaled as a ratio having dimensions of time^{-1}.

Production to biomass ratio [P:B] (**Peters, 1983 p. 133**):

- P:B≈total annual production to mean population biomass, or
- average specific production rates of all members of the population weighted for their temporal duration or to the sum of all productivity terms associated with the life history again biased according to the number and duration of the population's members at each ontogenetic stage.
- The maximum P:B ratio for a population is **r_{max}, the Malthusian parameter**.
- **Banse & Mosher (1980)** found zooplankton annual P:B ratios ranged from 10-36, while meiofaunal P:B ratios were generally 5 or lower. In **Steele's (1974)** North Sea model, *Calanus finmarchicus* had a P:B ratio of 7. The annual P:B ratios of the **meiofaunal naidid oligochaetes *Amphichaeta sannio & Paranais litoralis*** were 18 (**Giere & Pfankuche 1982**).
- For populations at **steady-state**, the annual P:B ratio is directly related to the specific mortality rate (**Banse & Mosher 1980**). For example, the **mesopsammon** with low P:B ratios cannot support a high mortality rate.
- **Banse & Mosher (1980)** showed that the P:B ratio declines with body size (age at first reproduction) to the ⅔ power.

Propagation of error Often, a dependent variable is a function of several other measured variables. The calculations needed to determine the error in the dependent variable due to each of the measured variables is called the propagation of error (**Bevington & Robinson 1992**)

Pycnocline The depth zone in which there is a rapid change in density [*cf.*, **halocline**, **nutricline**, **thermocline**]

Q_{10} Increase in the rate of reaction (or growth rate) with a 10ºC change in temperature. For many processes, the Q_{10} is about two.

Quantum yield [Θ, φp] The ratio of carbon fixed (as moles C or moles O_2, or more rarely mg C) per mole photons (Einstein =Ein) of light absorbed by phytoplankton pigments. (mol C per mol quanta absorbed) The inverse of the quantum yield is the **quantum requirement**. The theoretical Θ_{max} = 0.125 mole C Ein^{-1} (or 1500 mg C Ein^{-1}) (**Parsons *et al*. 1984, p. 74**, **Raven & Lucas 1985**). This quantum yield can only be obtained if all of the **PSII reaction centers** are open (ready to process photons). The quantum yield is constant and high at low light intensities ($ø_{max}$), a value directly proportional to the slope of the **P *vs.* I curve**, but declines at high light intensity. In real cells, photons are absorbed by reaction centers that haven't "opened" after processing the previous photon. The energy from these photons is released as fluorescence and is not converted to chemical energy (reduced carbon). A practical upper limit for the quantum yield is probably closer to 0.07 mol C Ein^{-1} (800 mg C Ein^{-1}), corresponding to a minimum 'realistic' quantum requirement of 14 Ein (mol $C)^{-1}$. Phytoplankton grown under high CO_2:O_2 ratios must absorb at least 8 photons for every C fixed. **Raven & Lucas (1985)** calculate that phytoplankton cells using a **CO_2 pump** in low CO_2:O_2 environments must expend energy acquiring HCO_3^-, increasing the quantum requirement to 25 photons per C fixed. The quantum yield is directly related to the initial slope of **P *vs.* I curves** (α). [*cf.*, **Jassby-Platt equation**]. However, the abscissa (I) in the P *vs.* I curve is the photon flux density to which the phytoplankton are exposed, not the photons absorbed.

r- & K-selection either a label applied to the combination of reproductive strategies or an implied explanation of why those traits are found together (**Stearns 1976, p. 4**). K-selection is associated with late maturity, few & large young, a long life, and small reproductive efforts (as in "K-selected") or high parental investment in individual offspring. r-selection refers to the combination of early maturity, many & small young, a short life, and large reproductive efforts or low parental investment in individual young. The terms r and K are from the **logistic equation** (*cf.*, **bet hedging**)

r_{max} [**the Malthusian parameter**, **μ_{max}**] maximum **specific growth rate** = maximum per capita growth rate = intrinsic growth rate. In the logistic and Lotka-Volterra competition equations, r_{max} is the maximum per capita (or specific) growth rate without density-dependent limitation [*cf.*, **logistic equation**, **Lotka-Volterra equation**, **P:B**]

rpd redox potential discontinuity. The transition from positive to negative **E_H**. The zone of positive r.p.d. in the sediments usually extends to the depth at which nitrate and nitrite are available in the sediments, and is deeper than the zone of oxygen penetration. **Jørgensen & Revsbech (1989)** refer to the zone of positive E_H as the **oxidized zone** to distinguish it from the zone of negative E_H and the **oxic zone**, where detectable concentrations of O_2 are found.

Recruitment The survival of juveniles for a period of time in the habitat in which they may survive to adulthood (**Menge & Sutherland, 1987, p. 735**) [*cf.*, **settlement**]

Redfield ratio [= **Redfield-Ketchum-Richards ratio** = **RKR ratio** = **Redfield ratio**]
The elemental composition (by atoms, **not weight!**) of O:C:N:P in phytoplankton, and hence, the ratio of long-term nutrient demand and oxygen use during decomposition. The ratio also describes the ratio of C:N:P concentration in oceanic deep water, believed to be controlled by the regeneration of phytoplanktonic nutrients. The original Redfield ratio, based on **Redfield (1934)**, was N:P in a ratio of 20:1. Fleming (1940) introduced the now classic ratio of C:N:P≈106:16:1 by atoms. The C:N:P ratio is now usually cited as 106:16:1. Oxygen can be added giving an O:C:N:P ratio of 276:106:16:1. For phytoplankton requiring Silica, a Si:P ratio or 8 to 12 is often assumed. **Takahashi *et al.* (1985)** analyzed the regeneration of nutrients along deep isopycnal surfaces in the Atlantic and produced a revised Redfield ratio of 1:16:122(±18):172 for P:N:C:O_2. **Anderson & Sarmiento (1994)** analyzed 20 isopycnal surfaces and arrived at a C:N:P:O ratio of -117:16:1:-170.
A simplified oxidation reaction for typical oceanic organic matter is [**Richards 1965**]:

$$(CH_2O)_{106}(NH_3)_{16}H_3PO_4 + 138\,O_2 \leftrightharpoons 106\,CO_2 + 16\,HNO_3 + H_3PO_4 + 122\,H_2O. \qquad \mathbf{(32)}$$

Two simplified photosynthetic reactions are (**Stumm & Morgan, 1981**, p. 194) and their effects on **alkalinity**:

$$\begin{aligned} 106\,CO_2 + 16NO_3^- + HPO_4^- + 122\,H_2O + 18\,H^+ &\rightarrow C_{106}H_{263}O_{110}N_{16}P_1 + 138\,O_2. && \textit{Increased alkalinity} \\ 106\,CO_2 + 16\,NH_4^+ + HPO_4^- + 108\,H_2O &\rightarrow C_{106}H_{263}O_{110}N_{16}P_1 + 107\,O_2 + 14\,H^+. && \textit{Decreased alkalinity} \end{aligned} \qquad \mathbf{(33)}$$

Price (2005) measured the following Redfield ratio in the nutrient replete diatom. *Thalassiosira weisflogii*: 97C : 14N : 4.7Si : 1P : 0.029Fe.

Respiration All heterotrophic organisms obtain their energy from oxidation-reduction reactions: reactions in which electrons are transferred from one compound, the electron donor, or reducing agent, to an electron acceptor, or oxidizing reagent. Two forms of respiration can be distinguished, based on whether molecular oxygen is the terminal electron acceptor:

Aerobic respiration an energy-yielding metabolic process in which either organic compounds or reduced inorganic compounds serve as electron donors and molecular oxygen is the ultimate electron acceptor.

Anaerobic respiration uses an oxidized inorganic compound other than oxygen as the ultimate electron acceptor for respiration. The compounds that can so act are sulfates, nitrate, nitrite, and carbonates [*cf.*, **anaerobes**, **denitrification**, **methanogens**]

Falkowski & Raven (1997, p. 264) define respiration in photoautotrophs as the rate of electron flow from organic molecules to O_2 (or to other electron acceptors in the case of anaerobic photosynthetic bacteria).
[*cf.*, **fermentation**, **photorespiration**, **net production**]

Reproductive value The concept of reproductive value was introduced by **Fisher (1958)**

$$
\begin{aligned}
V_x &= \frac{e^{rx}}{l_x} \sum^{\omega} e^{-rx}\, l_x m_x. \\
\textit{where, } l_x &= \textit{age-specific survivorship.} \\
&= \textit{Probability of survival to age } x. \\
m_x &= \textit{age-specific fecundity.} \\
&= \textit{no. females born to a female of age } x. \\
\omega &= \textit{age of last reproduction.} \\
r &= \textit{per capita or instantaneous pop. growth rate } \left[\frac{1}{T}\right]. \\
V_x &= \textit{reproductive value of female, age } x. \\
x &= \textit{organism age.}
\end{aligned}
\tag{34}
$$

Reproductive value quantifies the effect of an individual of age x to future population growth. **MacArthur & Wilson (1967)** provide the following definition:

> *" ...The expected size of a colony (at some future time) founded by a propagule of x-year-olds. We can then divide this number by the size of a simultaneous colony of newborn individuals to make the definition of the exact time interval before the count is made."*

Slobodkin (1961) provided a slightly different common-sense interpretation:

> *"the diminution of future population increase produced by removing a single animal of a given age from a population"*

Reynolds number Named for Osborne Reynolds. The ratio [dimensionless] of inertial to viscous forces [units in **c.g.s.** indicated]:

$$
\begin{aligned}
Re &= \frac{L\ v\ \rho}{\eta}, \quad or \\
&= \frac{L\ v}{\nu}. \\
where,\ L &= characteristic\ length\ scale\ [cm]. \\
v &= velocity\left[\frac{cm}{s}\right]. \\
\rho &= fluid\ density.(\approx 1\ for\ water) \\
\nu &= 'nu' = kinematic\ viscosity\left[\frac{cm^2}{s}\right]. \\
&\approx 1\ centipoise = 0.01\ \tfrac{cm^2}{s}\ \{for\ water\}. \\
\eta &= eta = dynamic\ viscosity\left[\frac{g}{cm\ s}\right].
\end{aligned}
\tag{35}
$$

An Re >>1000 indicates that inertial forces dominate and the fluid can be regarded as turbulent, but an Re<<1 indicates that viscous forces dominate and molecular diffusion dominates. At 1 < Re < 1000, both inertial and viscous forces can be important. See also **http://en.wikipedia.org/wiki/Reynolds_number**

RuBPCO ["**Rubisco**", **RuBPCase**, **RuBP carboxylase**, EC4.1.1.39, ribulose bisphosphate carboxylase-oxygenase, ribulose 1, 5 bisphosphate carboxylase] The most abundant enzyme in the world. It is found in all **autotrophic** organisms. Used in the **Calvin-Benson cycle** for photosynthetic carbon fixation, by sulfur-oxidizing symbionts, and marine **nitrifying bacteria**. This enzyme also functions as an oxygenase. The oxygenase activity becomes increasingly important under conditions of low CO_2 or high O_2, and is the cause of both the Warburg effect and **photorespiration** in **photoautotrophs**.

Seasonal refers to seasonal phenomena (cf., **annual**).

Secchi depth The Secchi depth is the depth at which a Secchi disk is visible. A Secchi disk is a white plate, about 25 cm in diameter, divided into four quadrants painted black and white. The disk is lowered over the side of a research vessel until it disappears and then is raised until the black and white markings become visible. Poole and Atkins (1929, quoted in **Parsons *et al.* 1984, p. 71**) derived the following relationship between the light-attenuation coefficient for **photosynthetically available radiation** (k') and the Secchi depth (D_s): $k'=1.7/D_s$. Idso and Gilbert (1974, again quoted in **Parsons *et al.* 1984, p. 71**) found that this formula provides a good approximation to k in waters ranging from highly turbid (D_s=1.9 m) to clear (D_s=35 m). However, the Secchi disk only estimates the depth-integrated k to the 18% light depth $\left(18\% = \frac{I_z}{I_o} = e^{-1.7}\right)$. In areas with pronounced subsurface Chl *a* maxima or with other strong depth-related changes in light attenuation, the k' determined from the Secchi depth may not be appropriate for estimating light profiles at deeper depths.

Semelparous reproduction ['big bang' reproduction], each female reproduces at most once [*cf.*, **iteroparous reproduction**]

Sequence When community composition is studied using **Eulerian coordinates**, sequence is the change in species frequencies at a given site due solely to advection or diffusion (*cf.*, **succession**). This change in species frequencies is usually not regarded as a true succession. If the change in composition were to be modeled by an ecological version of the **advection-diffusion equation**, species change in a sequence would be determined almost entirely by the advection and diffusion terms; the local rate of change term would be negligible. **Sverdrup *et al.* (1942, p. 384-385)** noted the distinction between succession and sequence:

> *"In the interpretation of field observations on plankton, it must be remembered that the different requirements of separate species lead to a more or less complete change of the elements in the population when external factors, especially temperature and nutrients, become altered in the water mass inhabited. When such a biological change takes place within a rather well-defined water mass, whether moving or stationary, we may speak of it as an individual population* ***succession****. This must not be confused with a change of population resulting from a sequence of distinct water masses flowing with their distinct populations into a given geographical position where successive series of observations are being made. This type of change may be termed a* ***local sequence****...The changes occurring in a population may involve a succession of developmental stages of a given species. In view of this it should be noted that any biological succession observed may result from two causes. There may be (1) a change in composition of species, owing to different biological responses to physical or chemical changes ... that have occurred within the individual water*

mass, or (2) a change in the relative maturity of the population, owing simply to the passage of time and to chronologically developed stages in the life history of the individuals of one or more species."

Sere **Gleason (1927)** provided this definition, but the term was in use long before, "A **sere** may be defined as the demonstration of the succession-concept, exemplified on a single habitat, including all the various time phases in it vegetation from an initial stage to a climax, and composed of an orderly sequence of plant associations."

Seston all particulate material that can be retained by nets or reasonably fine (greater than 0.5 μm) filters. Consists of **tripton** and **plankton**.

Settlement as in 'larval settlement', includes those events that lead to the termination of a pelagic life and the assumption of an attached or sedentary bottom existence. Settlement is a behavioral response initiated through tactile and chemosensory perception by larvae *cf.* **metamorphosis**, **recruitment** (Scheltema 1979)

Shade adaptation [**Shade acclimation**] Because of the confusion with the definition of adaptation in evolutionary biology, **Falkowski & Raven (1997, p. 263)** refer to **physiological adaptation** as **acclimation**. I agree with their distinction and would recommend referring to **shade acclimation**. **Rhee (1982)**, following Jørgensen, described two types of adaptation by **photoautotrophs** to low light intensity:

Chlorella-type adaptation	organisms increase their cellular Chl *a* content with decreasing light with little difference in photosynthetic rates at adapted light intensity between high- and low-light adapted cells)
Cyclotella type adaptation	cellular Chl *a* content remains unchanged, and only the light-saturated photosynthetic rate varies.

Falkowski & Owen (1980) suggested two strategies, based on the Chl:**P700** ratio: (1) *Skeletonema costatum* adapted by increasing the **photosynthetic unit** size while the reaction centers for **PSI** (**P700**) per cell decreased, and (2) In ***Dunaliella***, the photosynthetic unit size decreases, but the number of reaction centers increased. **Perry *et al.* (1981)** reported an increase in the photosynthetic unit size in five marine species at low light intensities.

Shear stress the shear force per unit area, abbreviated as τ (*tau*)

σ_t (*Sigma-t*) If $\rho_{s,t}$ is the density of seawater at atmospheric pressure and *in situ* temperature, then σ_t is $(\rho_{s,t} - 1) \times 1000$. If density is 1.02575 g cm^{-3}, σ_t is 25.75. The effects of salinity alone on density are represented by σ_o (*Sigma-not*). The effects of pressure change on the temperature and density of seawater must be included to assess properly the stability of deep water columns. The effects of pressure are reflected in σ_Θ (*sigma-theta*), where θ is the potential temperature of the parcel of water (*i.e.*, water cools adiabatically as it is brought to the surface, and θ is the temperature of the water if brought to the surface).

Simulated *in situ* incubations Incubations done with sample bottles out of the water. The incubations usually use neutral-density filters and sunlight to simulate *in situ* light intensity (but not usually *in situ* light quality [= spectral characteristics]). Since the mid-1980s filters have been used to simulate light quality. Simulated *in situ* incubations are used to measure **primary production** or to generate **P *vs.* I curves**.

Sink species Where individuals of a species use a habitat where their carrying capacity is less than zero, that species is a sink species (**Rosenzweig 1995, p. 260**, **Pulliam 1988**)

Species **Mayr (1982, p. 251-297)** reviews the history and controversy over defining species. The most widely accepted definition of a species is called the biological species concept, which **Mayr (1982, p. 273)** defines, *"A species is a reproductive community of populations (reproductively isolated from others) that occupies a specific niche in nature."* Mayr argues that the niche occupation clause is necessary to apply the biological niche concept to asexual clones, *"It is thus customary to combine into species those asexual individuals and clones that fill the same ecological niche or that play the same role in the ecosystem."*

Specific gravity See **bulk density**

Stability **Connell & Sousa (1983)** defined stability with the following: *"For a system to be considered stable there must exist one or more equilibrium points or limit cycles (1) at which the system remains when faced with a disturbing force or (2) to which it returns if perturbed by the force. The tendency to remain at a fixed point in face of disturbance has been termed **inertia**, **persistence** or **resistance**."* Connell & Sousa recommend the latter term. If a disturbance is not document the following terms apply: constancy, persistence, conservatism or endurance.

Standard error $\hat{\sigma}_\mu = \frac{\hat{\sigma}}{\sqrt{n}}$. The standard error of the mean is the sample standard deviation divided by the square root of sample size.

Succession Succession is the directional change in species composition through time. This definition is less restrictive than most definitions of succession, but more restrictive than **Cooper's (1926)** definition which argued that succession was any change in a community whatsoever. [see also **sequence**, **facilitation**]

Standing stock the concentration of organisms (expressed either as either weight or numbers per unit area or volume); previously often called **standing crop**.

Statistics **Statistics** is defined by **Sokal & Rohlf (1981)** as the scientific study of numerical data based on variation in nature. **Statistics** can be used in another valid sense as the plural of the noun **statistic**, a computed statistical quantity (*e.g.*, the sample standard deviation *s*). Observations are used in the calculation of **sample statistics** (*e.g.*, the sample mean $\bar{x}$ and standard deviation s which are estimates of **population statistics** or **parameters** (μ, σ)). By convention, **parameters** are identified with Greek letters, variables with arabic letters. **Sokal & Rohlf (1981, p. 52)** define a **biased** statistic:

> *"... samples (regardless of the sample size), taken from a population with a known parameter, should give sample statistics which, when averaged, will give the parametric value. An estimator that does not do so is called* ***biased****. The sample mean* $\bar{Y}$ *is an unbiased estimator of the parametric mean μ."*

Steady state A system with properties that do not change with time is in **steady state**, which is not synonymous with **equilibrium**. In systems governed by chemical reactions or other rate equations, the **equilibrium** concentrations of substrates and products are governed by rate equations such as:

$$A + B \underset{k_2}{\overset{k_1}{\rightleftarrows}} AB. \qquad \textbf{(36)}$$

The chemical reaction described by Equ 36 is in **equilibrium** if the concentrations of A, B, and AB are in the ratios governed by the reaction coefficients k_1 and k_2. That is the rate of the forward reaction equals the rate of the reverse reaction. A set of reversible processes that have reached equilibrium is often called a **dynamic equilibrium** (**http://en.wikipedia.org/wiki/Dynamic_equilibrium**). In ecology, there are dynamic equilibrium models to explain local species richness as the result of species immigration and species extinction. A system can be both in **steady state** and in **equilibrium**. However, **steady state** systems need not be in **equilibrium**, and **equilibrium** systems need not be at **steady state**. For example, in Equ 36 if A or B are being added to the system with changing rates of delivery that are slow relative to the chemical reaction rates, the system can be at **equilibrium** at any one instant, but not in **steady state** over longer time periods. If the rate of input or removal of A, B or AB is rapid and constant relative to the rate of the chemical reaction, the system can achieve **steady state**, but not be in chemical **equilibrium**. In many oceanographic applications, **the steady-state assumption** is made $\left(\frac{dC}{dt} = 0\right)$. Although it is not often explicitly stated, there is usually an implied time period over which the steady-state assumption must work. For example, **Revsbech & Jørgensen (1983)** invoke the **steady-state assumption** to estimate benthic diatom production from paired light-dark dissolved oxygen profiles in sediments. For their analysis to work, **steady state** only has to be achieved for a few seconds.

Phytoplankton ecologists often assume **balanced growth** to estimate growth rates. **Balanced growth** implies that the rate of synthesis (**anabolism**) or destruction (**catabolism**) of sets of cell constituents — such as pigments, proteins, or DNA — is occurring at the same rate. Phytoplankton cells in a bottle can exhibit balanced growth, *e.g.*, the rate of synthesis of Chl *a* is the same as the rate of synthesis of new protein or total organic carbon, while the population is not at **steady state** (it is growing or declining). Individual cells can be non **steady-state**, but exhibit **balanced growth**, if the cell quotients of C, N, and P are increasing as the cell prepares for cell division, but the ratios of each pair of elements remain roughly the same. [cf., Static equilibrium **http://en.wikipedia.org/wiki/Static_equilibrium**]

Succession Succession is the directional change in species frequencies at a given locale. This is but one of many different definitions, differing drastically in meaning. **Odum (1969)** proposed a widely used definition of succession. He defined in terms of the following three processes: 1) It is an orderly process of community development that is reasonably directional and is therefore predictable, 2) It results from modification of the physical environment by the community' that is, succession is community-controlled even though the physical environment determines the pattern in the rate of change and often sets limits as to how far development can go, and 3) It culminates in a stabilized ecosystem in which maximum biomass(or in information content) and symbiotic function between organisms are maintained per unit of available energy flow.
The processes that control the rate of succession are: population growth, selection (*e.g.*, interspecific competition, predation), migration, a changing external environment, and stochastic processes (**community drift**).

Allogenic succession. Succession controlled by a changing external environment (*e.g.*, temperature changes driving changes in species composition in temperate communities)

Autogenic succession Succession controlled by the organisms themselves (*cf.* **allogenic succession**, **autogenic**)

Primary succession Succession started from an azoic state (*e.g.*, cleared rock in the intertidal, sterile soil)

Secondary succession (**old-field succession**). Succession begun with remnants of the previous community still present (*e.g.*, a seed bank in the soil from the previous plant communities).

Retrogressive succession **Cowles (1901)** studies of the colonizing vegetation on sand dunes revealed that succession is not a straight-line process. Its stages may be slow or rapid, direct or tortuous and often they are retrogressive, with earlier stages replacing later stages often due to a change in the **allogenic** environment. **McIntosh (1980)** wrote that Cowles described succession as a "variable approaching a variable rather than a constant."

Sulfate reducers Anaerobic bacteria that use sulfate as the terminal electron acceptor for **anaerobic respiration**. The usual end product is hydrogen sulfide, H_2S, which gives anaerobic sediments their "rotten egg" smell. The zone of sulfide production in sediments is sometimes called the **sulfidogenic zone** (see graphic in **benthic boundaries**)

Survey design In a survey design, the statistical population is theoretically finite and each sampling unit is in theory recognizable. The direct interest in survey sampling is in the precise estimation of population parameters (*cf.*, **Experiment**) "Statistical surveys are concerned with measuring in a probabilistic way so that statements can be made with some known amount of confidence." (**Hayek & Buzas 1997, p 7**)

Sympatric occupying the same local area (*cf.*, **allopatric**)

Synecology The study of biological interactions among populations and their environment (*cf.* **autecology**)

Synoptic sampling A set of samples taken at approximately the same time. For example, satellite remote sensing permits synoptic sampling of oceanic surface pigment concentrations.

Systematics The scientific discipline of classifying organisms and arranging them in hierarchical fashion, postulating evolutionary pathways in an attempt to explain ancestral relationships (**Hayek & Buzas 1997, p. 2**)

Tertiary period From **Wikipedia** The Tertiary period was previously one of the major divisions of the geologic timescale, from the end of the **Cretaceous period** about 65.5 million years ago to the start of the Quaternary period about 1.6 million years ago. Its use has been widespread and continues, however the International Commission on Stratigraphy no longer endorses this term as part of the formal stratigraphic nomenclature. Instead the Paleogene and Neogene periods are recommended as the primary subdivisions of the Cenozoic era. In common usage, the Tertiary has included five geologic epochs -- the Paleocene, Eocene, Oligocene, Miocene and Pliocene. The Tertiary covers roughly the time span between the demise of the dinosaurs and beginning of the most recent ice age.

Theory, hypothesis, and model **Hilborn & Mangel (1997, p. 24)** argue that there is a hierarchy from a **theory** — a systematic statement of principles involved or a formulation of apparent relationships or underlying principles of certain observed phenomena which has been verified to some degree — to **hypothesis** — an unproved theory, proposition, supposition etc, tentatively accepted to explain certain facts or to provide a basis for further investigation — to a **model**, a tool for evaluation of hypotheses. **Popper (1959)** argued that there is a deductive hierarchy from the universal statements in theories to the specific statements in hypotheses, which in turn, make predictions about observations of nature. Further, Popper in his philosophy of **falsificationism** argued that only hypotheses that can be falsified should be considered scientific; this was his 'demarcation' principle separating science from pseudoscience. **Mayo (1996, p. 36-37)** provides a sophisticated updating of Popper's falsificationism, based on Neyman-Pearson statistical inference. Scientific hypotheses can be tested using statistical tools.

Thermocline The water-column depth stratum in which there is a rapid change in temperature [*cf.*, **halocline**, **nutricline**, **pycnocline**]

Tripton all non-living particulate matter; it is also called detritus (*cf.* **seston**).

Troposphere From **Wikipedia**: The troposphere is the lowermost portion of Earth's atmosphere and the one in which most weather phenomena occur. The greenhouse effect also occurs in the troposphere. The troposphere starts at the earth's surface and extends to an altitude of 16-18 km over tropical regions, decreasing to less than 10 km over the poles. This layer contains approximately 80% of the atmosphere's total mass. Generally, jets fly near the top of this layer. The troposphere is directly below the stratosphere.

Upwelling The upward advection of water, usually only a few cm's per second. The world's largest fisheries are often located at upwelling centers on the eastern margins of ocean basins. Upwelling occurs on these eastern margins when the wind blows towards the equator. In these regions, upwelled water from only a few 10s of meters depth is often cooler and nutrient-rich. Upwelling can occur at coastal margins whenever the wind blows in a direction that sets up offshore **Ekman mass transport**. In Massachusetts Bay, upwelling occurs when the wind blows from the South or Southwest (*cf.*, **El Niño**)

Viscosity Resistance to shear. The dynamic viscosity η ('eta') has units (in the c.g.s. system) of $\left[\frac{\text{g}}{\text{cm sec}}\right] = 1\ \textit{poise}\ (\boldsymbol{P})$. The kinematic viscosity, ν ('nu'), with units of $\left[\frac{\text{cm}^2}{\text{sec}}\right]$, is the dynamic viscosity divided by the fluid density, ρ ('ρ'), with units $\left[\frac{\text{g}}{\text{cm}^3}\right]$. The viscosity of water at 20°C is 0.01 P or 1 centipoise (cP).

Westerly winds Winds blowing from west to east.

Some Common Abbreviations in Oceanography

α (G., *α*) Used in many equations, but its major use in biological oceanography is the parameter for the initial slope of the P *vs.* I curve. It is also the coefficient in allometric equations and the competition coefficient in the **Lotka-Volterra competition equations**.

atm atmospheres or sometimes atoms when used in the phrase "g-atm"

µatm 10^{-6} atmospheres (*e.g.*, The atmospheric CO_2 concentration is ≈350µatm)

CI->CVI The six copepodid stages of copepod development (preceded by six naupliar stages NI->NVI)

cf. (L., *confer*) compare with

c.g.s. In the c.g.s. system of units, the dimensions of length, mass & time are centimeters, grams, and seconds [*cf.*, **m.k.s.**]

Chl *a* Chlorophyll *a*

∂ (G., *del*) partial derivative (*e.g.*, $\frac{\partial u}{\partial y}$ is the partial derivative of south-to-north water velocity (u) with respect to increasing distance from west to east (dy). Partial derivatives are to be evaluated under the assumption that they are unaffected by other terms in the equation.

d total derivative (*e.g.*, conservation of mass can be abbreviated $\frac{d\rho}{dt}=0$).

e the base of the Naperian logarithms, e≈2.713...

f gaining increasing use as the ratio of new to total production

g gram or acceleration due to gravity

g-atm gram-atom, =1 mole

g-atm/l molar or M

mg-atm milligram-atom, =1 millimole

mg-atm/l millimolar or mM (10^{-3} Molar)

µg-atm microgram-atom, =1 micromole

µg-atm/l micromolar or µM (10^{-6} Molar)

Gt Gigatons or 10^9 metric tons (a metric ton is 10^6 g). Gigatons C used to be used for global carbon budgets, but the units are now expressed in Pg C, **petagrams** (10^9 g) of carbon

Ein. The Einstein. Avogadro's number of quanta of light. Sometimes called the mol photon

ibid. (L. *ibidem*) in the same place

K By itself K could refer to a number of different concepts. When used with r, as in **r-K selection**, K refers to the carrying capacity of the environment. The K comes from the carrying capacity parameter in the **Verhulst-Pearl logistic equation**.

K_m, K_s half-saturation constant, from the **Michaelis-Menten enzyme kinetic equation** or **Monod growth equation**.

K_x, K_y, K_z kinematic eddy viscosity in the (x, y, z) directions

l_x age-specific survivorship, the probability of a newborn individual surviving to age x, or the fraction of newborns in a population surviving to age x. [*cf.*, **Lotka-Euler equation**]

λ (G., λ) used in many equations, but especially used as to represent the eigenvalues of a matrix. In population biology, λ is the **finite population growth rate**,

$\lambda = e^{rt},\ where\ t=1\ time\ unit.$, and is equal to 1 for a non-growing population (λ is the dominant eigenvalue of the Leslie matrix in demography)

m_x age-specific fecundity

m.k.s. In the m.k.s. system of units, the dimensions of length, mass & time are meters, kilograms, and seconds [*cf.*, **c.g.s.**]

NI-NVI The six naupliar stages of copepod development

µ (G., μ) **specific growth rate** (*e.g.*, $\frac{1}{N}\frac{dN}{dt}$) with dimensions of t^{-1}. In **statistics**, µ is usually used to indicate the population mean; in hydrodynamics µ often represents the viscosity.

ρ (G., RHO) fluid density g cm^{-3}

r instantaneous growth rate in units of $time^{-1}$, or Pearson's product-moment correlation coefficient, or Spearman's non-parametric correlation coefficient.

r^2, R^2 Coefficient of determination, or amount of variance explained by the regression line in a least-squares regression.

r_M or r_{max} Intrinsic growth rate, maximum r, maximum per capita growth rate, Malthusian parameter [units of $time^{-1}$]

R_o the net replacement rate for a population $\left(\sum l_x m_x\right)$, dimensionless

Re **Reynolds number**
σ^2 In **statistics**, the population variance "σ-squared"
σ_t σ-t from (G. *σ*) defined above
s In **statistics**, the sample standard deviation, the square root of the sample variance
s^2 In statistics, the sample variance (*cf.*, the population variance, σ^2)
t time
vs. (L., *versus*) against
u, v, w water velocities in the East->West, South->North, and Up->Down (x, y, z) directions
V_{max} The maximum rate of an (enzymatic) reaction, from the Michaelis-Menten equation.
$\overline{X}$ In statistics, the sample mean (*cf.*, μ)
x, y, z In oceanography, the dimensions south->north, west->east, and down->up or up->down. The z dimension may is usually positive downward for water-column studies with 0 at the surface, positive downward with 0 at the sediment-water interface for sediment work, and positive upward for studies of flows and fluxes above the sediment-water interface.

SI Units

See **http://physics.nist.gov/cuu/Units/index.html**

Units for mass, based on SI prefixes: **http://physics.nist.gov/cuu/Units/prefixes.html**

Multiplication Factor	Prefix	Symbol
10^{18}	exagram	Eg
10^{15}	petagram	Pg
10^{12}	teragram	Tg
10^{9}	gigagram	Gg
10^{6}	megagram	Mg
10^{3}	kilogram	kg
10^{2}	hectogram	hg
10^{1}	dekagram	dag
10^{0}	gram	g
10^{-1}	decigram	dg
10^{-2}	centigram	cg

10^{-3}	milligram	mg
10^{-6}	microgram	µg
10^{-9}	nanogram	ng
10^{-12}	picogram	pg
10^{-15}	femtogram	fg
10^{-18}	attogram	ag

Some math formulae

Surface area of a sphere:

$$Surface\ area\ of\ sphere = 4\,\pi\,r^2.$$

Volume of a sphere:

$$Volume\ of\ sphere = \frac{4}{3}\,\pi\,r^3.$$

Some constants & measurements

Speed of light (in a vacuum): 299,792,458 m/s
Light year: 9.5 x 10^{12}km, distance traveled by light in 1 year.
Earth circumference (**http://en.wikipedia.org/wiki/Earth**) Equatorial 40,075.004 km Meridional 40,007.849 km; Mean 40,041.455 km
meter (1983 Systeme International definition): 1ength of the path traveled by light in vacuum during a time interval of 1/299 792 458 of a second. The meter was originally defined to be 10^{-7} × the meridional distance from the equator to the North Pole through Paris, but as documented by **Adler (2002)**, one of the two French surveyors made a mistake and the distance was miscalculated, producing the 0.02% deviation from the current estimate of the **earth's meridional circumference**.

Marine taxa

Adapted from **Barnes (1984)**

IMPORTANT PLANKTONIC TAXA

Phytoplankton (largely)

Kingdom Monera: Prokaryotes

Eubacteria A large catch-all category for those bacteria with muramic acid in the cell wall. The photosynthetic eubacteria do not evolve oxygen and do not use water as the electron donor in photosynthesis. They are not particularly important members of the phytoplankton, but can be important components of the benthic microbial community.

Oxyphotobacteria Gram-negative bacteria capable of photosynthesis using water as the electron donor and releasing oxygen; all possess Chlorophyll *a*, as well as other pigments. The photosynthetic pigments are embedded in membranous **thylakoids**.

Cyanobacteria Blue-green bacteria, formerly blue-green algae. *Synechococcus* is a cosmopolitan planktonic cyanobacterial genus.

Anoxyphotobacteria

Kingdom Protista: Eukaryotic, unicellular microorganisms

Phylum Dinophyta: "**Dinoflagellates**" Chloroplasts, when present, are brownish with Chl *a* and **Chl c_2**, **B-carotene** and various **xanthophylls**; **thylakoids** normally arranged in threes. Dinoflagellates include both autotrophic and heterotrophic species.

Common genera:

- *Alexandrium*, the red-tide dinoflagellate
- *Amphidinium*
- *Ceratium*
- *Gymnodinium*, required by 1st-feeding Anchoveta (Lasker)
- *Gyrodinium*
- *Noctiluca*, glows in the dark
- *Peridinium*
- *Prorocentrum*

Phylum Chrysophyta "Chrysomonads", "silicoflagellates". Important in fresh water. Two golden brown chloroplasts are usually present containing Chl. *a*, c_1, and c_2, **B-carotene**, **fucoxanthin** and other **xanthophylls**.

Phylum Bacillariophyta: "**diatoms**" Pigments include chlorophylls *a*, c_1 and c_2, **B-carotene** and **fucoxanthin**

Order Biddulphiales (**centric diatoms**, radially symmetrical cells, the major group of planktonic diatoms)

Some important genera:

- *Biddulphia*
- *Chaetoceros*
- *Coscinodiscus*
- *Ditylum*
- *Melosira*
- *Skeletonema*
- *Thalassiosira*

Order Bacillariales (**pennate diatoms**)
Some important planktonic genera:
- *Asterionella*
- *Bacillaria*
- *Fragilaria*
- *Nitzschia*
- *Pseudonitzschia*, some species produce domoic-acid, causing amnesiatic shellfish poisoning
- *Thlassionema*

Phylum Chlorophyta
(The green algae, the majority of planktonic species are fresh water. The green algae (e.g., Ulva is an important genus of benthic macroalgae).
Class Prasinophyceae: generally flagellated cells
Class Chlorophyceae:

Other important phytoflagellates

Phylum Chrysophyta — Chrysomonads and silicoflagellates
Phylum Cryptophyta — Cryptomonads: important nanoplankton
Phylum Euglenophyta — Mainly freshwater
Phylum Haptophyta — Many members of this group (in the Order Coccosphaerales) bear calcareous scales called **coccoliths**, and the organisms bearing coccoliths are called **coccolithoporids**. **Coccoliths** can be abundant in both neritic (Gulf of Maine and oceanic waters)

Zooplankton Plankton lacking Chl *a*. Zooplankton range from 2 µm to 10,000 or 50,000 µm (*i.e.*, 10 to 50 mm; medusae may be even larger [up to a meter]). The smaller zooplankton size classes are called the **microzooplankton**. One operational definition to distinguish the **microzooplankton** from the mesozooplankton, or larger zooplankton, is that the **microzooplankton** do not produce fast-sinking feces. Although, I have the zooplankton classified as members of the Animal kingdom, there are important grazers in the Kingdom Monera in the Phylum Ciliophora ("ciliates") and a number of groups termed the heterotrophic microflagellates.

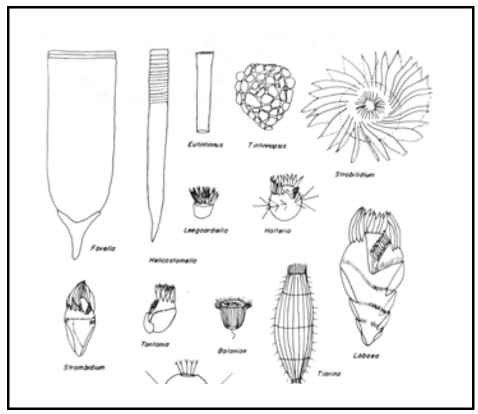

Figure 2. Ciliates from Pierce & Turner (1992, p. 141)

Kingdom Monera
- Phylum Ciliophora
  - Class Ciliatea "ciliates" (See Fig. 2)
    - Order Oligotrichida
      - ■ *Strombidium*
      - ■ *Strobilidium*
    - Order Tintinnida

Kingdom Animalia
- Phylum Arthropoda
  - Class Crustacea
    - Subclass Branchiopoda
      - Order Cladocera
        - ■ *Alonella*
        - ■ *Bosmina*
        - ■ *Ceriodaphnia*
        - ■ *Daphnia*
    - Subclass Copepoda (a life cycle with 6 naupliar and 6 copepodid stages)
      - Order Calanoida
    - Common genera and species:
      - * *Acartia*
        - + *clausi*
        - + *hudsonica*
        - + *tonsa*
      - * *Calanus*
        - + *finmarchicus*

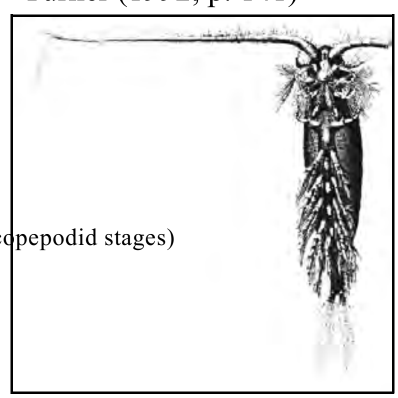

Figure 2. *Calanus funmarchicus*, photo from Barnes Invert. Zoo

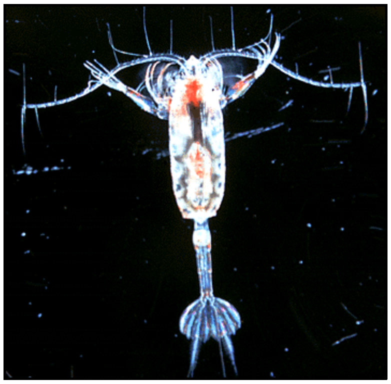

Figure 2. *Euchaeta*, photo from J. Yen.

+ *marshallae*
+ *pacficus*

* *Euchaeta*, a carnivorous calanoid
* *Neocalanus*
+ *plumchrus*
+ *cristatus*
+ *tonsus*

* *Paracalanus*
+ *parvus*

* *Pseudocalanus*
+ *newmani*

* *Rhinocalanus*

Order Cyclopoida
* *Oithona*
+ *similis*

● Order Harpacticoida (largely benthic)
○ *Huntemannia jadensis*

Subclass Malacostraca
Superorder Peracarida
Order Mysidacea
Order Amphipoda
Suborder Gammaridea
Family Hyperiida
Superorder Eucarida
Order Euphuasicaea
Order Decapoda
Order Mysidacea

Phylum Cnidaria
Phylum Ctenophora "Comb jellies" *Mnemiopsis* (predation by this genus included in **Kremer & Nixon's [1978]** Narragansett Bay model), Beroe
Phylum Chaetognatha "Arrow Worms" *Sagitta*
Phylum Chordata
Subphylum Urochordata: "Tunicates"
Class Thaliacea
Order Pyrosomida
Order Doliolida
Order Salpida
(appeared in large numbers in MA Bay in 9/97, 9/98, and 9/99)
Class Larvacea

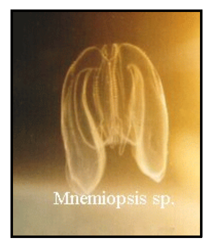

Figure 2. *Mnemiopsis*, found in Narrgansett Bay & Black Sea.

Some Important Benthic Taxa

Benthic microfauna

Kingdom Monera: Prokaryotes
Eubacteria
Oxyphotobacteria
Cyanobacteria
Anoxyphotobacteria A diverse assemblage of gram-negative photobacteria capable of anoxygenic photosynthesis using H_2S, H_2 or various organic compounds to reduce CO_2.

- Green sulphur bacteria
- Green non-sulphur bacteria
- Purple sulphur bacteria
- Purple non-sulphur bacteria

Kingdom Protista: Eukaryotic, unicellular microorganisms

Phylum Dinophyta: "**Dinoflagellates**"
Phylum Bacillariophyta: "diatoms."
Order Biddulphiales (**centric diatoms**)
Order Bacillariales (**pennate diatoms**, having symmetrical lanceolate cells, the major component of the microphytobenthos)
Some important benthic genera:
- *Gyrosigma*
- *Navicula*
- *Nitzschia*
- *Pleurosigma*

Kingdom Monera
Phylum Ciliophora
Class Ciliatea "ciliates"
Order Oligotrichida

Meiofauna & *Macrofauna*

Comment

The taxonomic status of species referred to in the course handouts is provided in this non-comprehensive list.

Kingdom Animalia
Phylum Annelida
Class Oligochaeta
Naididae
- *Amphichaeta* [48]
- *Paranais litoralis*. This naidid was one of the numerically important taxa on the Deer Island flats in the 1990s [48]

Tubificidae
- *Limnodrilus*
- *Tubificoides* There are two species of *Tubificoides* (called *nr. pseudogaster* and sp. 2) that are among the numerical dominants in Dorchester Bay and the Deer Island flats.

Class Polychaeta
Ampharetidae
- *Ampharete*
- *Hobsonia*

Arinicolidae, "lug worms"
- *Abarenicola*
- *Arenicola*

Capitellidae
- *Capitella*
- *Heteromastus*
- *Mediomastus*
- *Notomastus*

Cirratulidae, subsurface deposit feeders or interface feeders
- *Chaetozone*
- *Tharyx*

Glyceridae
- *Glycera*

Hesionidae, predators or scavengers
- *Micropthamalus*

Lumbrineridae
- *Lumbrineris*

Maldanidae, "bamboo worms". The bamboo worms can be head-down conveyor belt feeders and funnel feeders.

- *Axiothella*
- *Clymenella*
- *Maldane*
- *Maldanopsis*

Nephtyidae
- *Nephtys incisa*

Nereidae
- *Neanthes*
  - *japonica*
- *Nereis*
  - *diversicolor*
  - *virens*
  - *succinea*

Orbiniidae, burrowing subsurface deposit feeders
- *Armandia*
- *Leitoscoloplos*
  - *robustus*
  - *fragilis*
- *Scoloplos*

Paraonidae
- *Aricidea catherinae*, may feed on benthic diatoms

Pectinaridae
- *Pectinaria*, “ice-cream cone worm”, also called *Cistinedes*

Phyllodocidae
- *Eteone longa*

Sabellidae
- *Euchone incolor*, often associated with **Molpadia** mounds **(Rhoads & Young 1971**)
- *Manayunkia aestuarina*, from the Skagit flats, recruitment facilitated by *Hobsonia florida* in **Gallagher et al. (1983)**

Spionidae
- *Marenzelleria*
- *Polydora*
  - *cornuta* (formerly *P. ligni*)
- *Prionospio*
- *Pseudopolydora*
- *Pygospio*
- *Spio*
- *Spiophanes*
  - *bombyx*
- *Streblospio benedicti*

Phylum Arthropoda
Class Crustacea
Subclass Copepoda
Order Harpacticoida (largely benthic)
- *Huntemannia jadensis*, a Puget Sound harpacticoid

Subclass Malacostraca
Superorder: Pericarida
Order Amphipoda
Suborder Gammaridea (49 families, > 3000 species)
Family Ampeliscidae
- + *Ampelisca*
  - *abdita* [used for toxicity tests, abundant on E. Coast]
  - *vadorum*
  - *verilli*

Family Corophiidae
- *Corophium*

x *insidiosum*
x *salmonis*
x *volutator*
• *Crassocorophium*
x *crassicorne*
Family Gammaridae
• *Eogammarus*
x *confervicolus*
• *Gammarus*
Family Haustoriidae
Family Lysianassidae
• *Eurythenes gryllus* [deep-sea scavenger]
Superorder Eucarida
Order Decapoda:
Crab
• *Cancer*
• *Carcinus*
Shrimp
• *Crangon*
• *Paleomenetes*
Phylum Cnidaria, "Anemones"
Phylum Chordata
Phylum Echinodermata
Echinoidea, "urchins & sand dollars"
■ *Mellita*, see Figure 2
Ophiuroidea, Brittle stars
■ *Amphiura*
Holothuroidea, "Sea cucumbers & Sea pigs"
■ *Leptosynapta*
■ ***Molpadia*** [15, 67, 73]
■ *Parastichopus*
■ *Stichopus*
Asteroidea, "star fish"
■ *Pisaster*
■ *Asterias*
Phylum Mollusca
Class Gastropoda ("snails")
Subclass Prosobranchia ("mud snails")
■ *Hydrobia*
* *ulvae*
* *totteni*
* *ventrosa*
■ *Littorina littorea*, the periwinkle, intrdoced to NA from Europe
■ *Ilyanassa obsoleta*
Class Bivalvia=Pelycypoda
Lamellibranchia
■ *Crassostrea*
■ *Ensis* "razor clam"
■ *Geukensia "horse mussel"*
■ *Macoma*
* *balthica*
* *carlotensis*
■ *Mercinaria*
■ *Mya arenaria*
■ *Mytilus*
* *califorianus*
* *edulis* "edible mussel"

Figure 2. *Mellita quinquesperforata* Leske, 1778 (74 mm long) From **http://www.nhm.ac.uk/palaeontology/echinoids/GENERA/CLYPEAST/SCUTINA/MELLITA1.HTM**

- *Tellina*
    - * *agilis*

Protobranchia (deposit feeding bivalves that feed with palp proboscides)

- *Nucula*
    - * *annulata*
    - * *proxima*
- *Yoldia limatula*

Other phyla

Brachiopoda
Nematoda
Phoronida
Pogonophora
Priapulida
Rhyncocoela or Nemertina
Sipunculida

References

Adler, K. 2002. The measure of all things. Free Press, New York. 436 pp. *[62]*

Allee, W. C., A. E. Emerson, O. Park, T. Park, and K. P. Schmidt. 1949. Principles of Animal Ecology. W. B. Saunders, Philadelphia.[37]

Anderson, L. A. and J. L. Sarmiento. 1994. Global biogeochemical cycles 8: 65-80. *[50]*

Andrewartha, H. G. and L. C. Birch. 1984. The ecological web: more on the distribution and abundance of animals. University of Chicago Press, Chicago. 506 pp. [24]

Badger, M. R. And G. D. Price. 2003. CO_2 concentrating mechanisms in cyanobacteria: molecular components, their diversity and evolution. J. Exp. Botany 54: 609-622. [11, 32]

Banse, K. 1979. On weight-dependence of net growth efficiency and specific respiration rates among field populations of invertebrates. Oecologia (Berl.) 38: 111-126. *[22]*

Banse, K. and S. Mosher. 1980. Adult body mass and annual production/biomass relationships of field populations. Ecol. Monogr. *50*: 355-379.*[43, 48]*

Barnes, R. S. K. 1984. A Synoptic Classification of Living Organisms. Sinauer Associates. [63]

Behrenfeld, M. J. and P. G. Falkowski. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. Limnol. Oceanogr. *42*: 1-20. [44]

Bell, G. 2001. Neutral macroecology. Science 293: 2413-2418. [36]

Berner, R. A. 1980. Early diagenesis. A theoretical approach. Princeton University Press, Princeton N.J. 241 pp. [16]

Berg, H. C. 1983. Random walks in biology. Princeton University Press, Princeton N.J. [28]

Bevington, P. R. and D. K. Robinson. 1992. Data reduction and error analysis for the physical sciences. McGraw-Hill, Boston MA. [48]

Boudreau, B. P. 1986. Mathematics of tracer mixing in sediments: II. Nonlocal mixing and biological conveyor-belt phenomena. Am. J. Science *286*: 199-238. [40]

Boudreau, B. P. 1997. Diagenetic models and their implementation: modelling transport and reactions in aquatic sediments. Springer, Berlin. 414 pp. [10]

Caperon, J. and J. Meyer. 1972. Nitrogen-limited growth of marine phytoplankton - I. Changes in population characteristics with steady-state growth rate. Deep-Sea Research *19*: 601-618. [38]

Caswell, H. 2000. Matrix population models, 2nd Edition.

Sinauer Assoc., Sunderland MA [35]

Clements, F. E. 1916. Plant succession: an analysis of the development of vegetation. Carnegie Inst. Washington Publ. No. 242. 512 p. [28]

Clements, F. E. 1936. Nature and structure of the climax. J. Ecol. *24*: 252-284. [13]

Cody, M. L. 1986. Diversity, rarity, and conservation in Mediterranean-climate regions. Pp. 122-152 *in* M. E. Soule, *ed.*, Conservation Biology: the science of scarcity and diversity. Sinauer Associates, Sunderland MA. *[18]*

Connell, J. H. 1978. Diversity in tropical rain forests and coral reefs. Science *199*: 1302-1310. [32]

Connell, J. H. and R. O. Slatyer. 1977. Mechanisms of succession in natural communities and their role in community stability and organization. American Naturalist *111*: 1119-1144. *[27]*

Cooper, W. S. 1926. The fundamentals of vegetational change. Ecology *7*: 391-413. [55]

Cowles, H. C. 1901. The physiographic ecology of Chicago and vicinity; a study of the origin, development, and classification of Plant Societies. Bot. Gaz. *31*: 170-177. [57]

Day, J. W., C. A. S. Hall, W. M. Kemp, and A. Yáñez-Arancibia. 1989. Estuarine Ecology. John Wiley & Sons, New York. 558 pp.[24]

Dayton, P. K. 1971. Competition, disturbance, and community organization: the provision and subsequent utilization of space in a rocky intertidal community. Ecol. Monogr. *41*: 351-389. [32]

Dayton, P. K. 1975. Experimental evaluation of ecological dominance in a rocky intertidal algal community. Ecol. Monogr. *45*: 137-159 [32]

De Baar, H. J. W. 1994. von Liebig's law of the minimum and plankton ecology. Prog. Oceanogr. *33*: 347-386. [34]

Droop, M. R. 1968. Vitamin B_{12} and marine ecology. IV. The kinetics of uptake, growth, and inhibition in *Monochrysis lutheri*. J. mar. biol. Ass. U.K. *48*: 689-733. [21, 38]

Droop, M. R. 1974. The nutrient status of algal cells in continuous culture. J. mar. Biol. Ass. U.K. *54*: 825-855. [34]

Dugdale, R. C. and J. J. Goering. 1967. Uptake of new and regenerated forms of nitrogen in primary productivity. Limnol. Oceanogr. *12*: 196-206. [47]

Edmondson, W. T. 1991. The uses of ecology: Lake Washington and Beyond. University of Washington Press, Seattle. *[26, 42]*

Eppley, R. W. 1972. Temperature and phytoplankton growth in the sea. Fish. Bull. *70*: 1063-1085.[5, 25]

Endler, J. A. 1976. Natural selection in the wild. Princeton University Press, Princeton NJ.[2, 26, 39]

Eppley, R. W. 1981. Autotrophic production of particulate matter. Pp. 342-361 *in* A. R. Longhurst, ed. Analysis of Marine Ecosystems. Academic Press.[27]

Fairbridge, R. 1980. The estuary: its definition and geodynamic cycle. pp. 1-35 in E. Olausson and I Cato, eds, Chemistry and biochemistry of estuaries. Wiley, New York. [24]

Falkowski, P. G. 1980. Light-shade adaptation in marine phytoplankton. Pp. 99-119 *in* P. G. Falkowski (ed.) Primary Productivity in the Sea. Plenum Press, New York. [44]

Falkowski, P. G. and J. A. Raven (1997) Aquatic Photosynthesis. Blackwell Science, 375 pp. [2, 42, 50, 54]

Fenchel, T. 1982. Ecology of heterotrophic microflagellates. II. Bioenergetics and growth. Mar. Ecol. Prog. Ser. *8*: 225-231.[22]

Fenchel, T. 1988. Marine plankton food chains. Ann. Rev. Ecol. Syst. *19*: 19-38.[22, 46]

Fisher, R. A. 1958. The genetical theory of natural selection. [51]

Gallagher, E. D., P. A. Jumars, and D. D. Trueblood. 1983. Facilitation of soft-bottom benthic succession by tube builders. Ecology *64*: 1200-1216. [67]

Giere, O. and O. Pfannkuche. 1982. Biology and ecology of marine Oligochaeta, a review. Oceanogr. Mar. Biol. Ann. Rev. *20*: 173-308. [48]

Gieskes, W. W. & G. W. Kraay. 1984. State-of-the-art in the measurement of primary production. Pp. 171-190 *in* M. J. R. Fasham, ed., Flows of Energy and Materials in Marine Ecosystems, Plenum. []

Gleason, H. A. 1927. Further views on the succession concept. Ecology *8*: 299-326. [**14**, **54**]

Harris, G. P, F. B. Griffiths, and D. P. Thomas. 1989. Light and dark uptake and loss of ^{14}C: methodological problems with productivity measurements in oceanic waters. Hydrobiologia *173*: 95-105. [**5**]

Hatch, M. D. and J. N. Burnell. 1990. Carbonic anhydrase activity in leaves and its role in the first step of C_4 photosynthesis. Plant Physiol. *93*: 825-828. [**10**]

Hayek, Lee-Ann C. and Martin A. Buzas. 1997. Surveying Natural Populations. Columbia University Press, New York. 563 pp.[**58**]

Hilborn, R. and M. Mangel. 1997. The Ecological Detective. Confronting models with data. Princeton University Press, Princeton. [**58**]

Holling, C. S. 1959. The components of predation as revealed by a study of mall-mammal predation of the European Pine Sawfly. Canadian Entomologist *91*: 293-320. [**31**]

Hubbell, S. P. 2001. The unified neutral theory of biodiversity and biogeography. Princeton University Press, Princeton & Oxford. 375 pp. [**8**, **13**]

Huffaker, C. B. 1957. Fundamentals of biological control of weeds. Hilgardia *27*: 101-157.[**32**]

Huffaker, C. B. 1958. Experimental studies on predation: dispersion factors and predator-prey oscillations. Hilgardia *27*:343-383. [**32**]

Huffaker, C. B., K. P. Shea, and S. G. Herman. 1963. Experimental studies on predation, III. Complex dispersion and levels of food in an acarine predator-prey interaction. Hilgardia *34*: 305-330.[**32**]

Hutchinson, G. E. 1978. An introduction to population Ecology. Yale University Press, New Haven. 260 pp. [**39**]

Jørgensen, B. B. and N. P. Revsbech. 1989. Oxygen uptake, bacterial distribution, and carbon-nitrogen-sulfur cycling in sediments from the Baltic Sea-North Sea transition. Ophelia *31*: 29-49.[**42**, **49**]

Kendall, M. G. and A. Stewart. 1961. The Advanced Theory of Statistics. Hafner, New York. 676 pp.[**26**, **27**]

Kremer, J. N. and S. W. Nixon. 1978. A coastal marine ecosystem: simulation and analysis. Springer-Verlag, Berlin. [**65**]

Legendre, P. and L. Legendre. 1998. Numerical Ecology Second English Edition, Elsevier Science B.V., Amsterdam. 853 pp. [**28**, **40**, **47**]

Li, W. K. W., D. V. Suba Rao, W. G. Harrison, J. C. Smith, J. J. Cullen, B. Irwin and T. Platt. 1983. Autotrophic picoplankton in the tropical ocean. Science *219*: *292-295.*[**46**]

MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton. [**51**]

Mann, K. R. and J. R. N. Lazier. 1996. Dynamics of marine ecosystems: biological-physical interactions in the oceans, 2nd edition. Blackwell Science, Cambridge MA, 394 pp. [**23**, **41**]

Mayo, D. G. 1996. Error and the growth of experimental knowledge. University of Chicago Press, Chicago. 493 pp. [**58**]

Mayr, E. 1982. The growth of biological thought: diversity, evolution and inheritance. Belknap Press, Cambridge MA. 974 pp. *[55]*

Mayr, E. 2001. What evolution is. Basic books, New York. 318 pp. [**2**]

McIntosh, R. P. 1980. The relationship between succession and the recovery process in eco-systems. Pp. 11-62 *in* J. Cairns, ed., The recovery process in damaged ecosystems. Ann Arbor Science Publ., Ann Arbor Michigan.[**57**]

Meiners, R. J. And J. L. M. Steidle. 2002. Rich in phenomena– lacking in terms. A classification of kairomones. Chemecology 12: 161-167. [**33**]

Menge, B. A. and J. P. Sutherland. 1987. Community regulation: variation in disturbance, competition, and predation in relation to environmental stress and recruitment. Amer. Natur. *130*: 730-757. *[14, 49]*

Middleton, G. V. and J. B. Southard. 1984. Mechanics of sediment movement, 2nd edition. S.E.P.M. Short Course Number 3. *[10]*

Mills, E. L. 1969. The community concept in marine zoology, with comments on continua and instability in some marine communities: a review. J. Fish. Res. Bd. Can. *26*: 1415-1428. *[13]*

Mills, E. L. 1989. Biological Oceanography: An early history. Cornell University Press, Ithaca NY and London.[**14**]

Morris, I. 1980. Paths of carbon assimilation in marine phytoplankton. Pp. 139-159 *in* P. G. Falkowski, ed., Primary Productivity in the Sea. Plenum Press, New York.[**11**]

National Research Council 1995. Understanding marine biodiversity: a research agenda for the nation. National Academy Press, Washington D.C. 114 pp. [**8**]

National Research Council 2000. Clean coastal waters: understanding and reducing the effects of nutrient pollution. National Academy Press, Washington D. C. [**26**]

Newell, G. E. and R. C. Newell. 1963. Marine Plankton, a practical guide. Hutchinson Educational, London. [?]

Nixon, S. W. 1995. Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia *41*: 199-219. [**26**]

Officer, C. B. and J. H. Ryther. 1977. Secondary sewage treatment versus ocean outfalls: an assessment. Science *197*: 1056-1060. [**45**]

Paine, R. T. 1966. Food web complexity and species diversity. Amer. Natur. *100*: 493-532. [**32**]

Parsons, T. R., M. Takahashi, and B. Hargrave. 1984. Biological Oceanographic Processes. 3rd Edition. Pergamon Press, Oxford & New York [**5**, **16**, **34**, **44**, **45**, **49**, **53**].

Perry, M. J., M. C. Talbot, and R. S. Alberte. 1981. Photoadaptation in marine phytoplankton: responses of the photosynthetic unit. Marine Biology *62:* 91-100. [**54**]

Peters, R. H. 1983. The ecological implications of body size. Cambridge University Press, Cambridge.[**48**]

Pielou, E. C. 1984. The interpretation of ecological data: a primer on classification and ordination. John Wiley, New York. 263 pp.[**42**]

Pierce, R. W. and Turner, J. T. 1992. Ecology of planktonic ciliates in marine food webs. Rev. Aquat. Sci. 6: 139-181. [**64**]

Popper, K. R. 1959. The Logic of Scientific Discovery. Hutchinson & Co., London. [**27**, **41**, **58**]

Price, N. M. 2005. The elemental stoichiometry and composition of an iron-limited diatom. Limnol. Oceanogr. *50*: 1159–1171. [**50**]

Pritchard, D. W. 1967. What is an estuary: physical viewpoint. Pp. 3-5 *in* G. D. Lauff, ed. Estuaries Publ. 83. American Assoc. Adv. Science, Washington D.C.[**24**]

Pulliam, H. R. 1988. Sources, sinks, and population regulation. Amer. Natur. *132*: 652-661. [p. **55**]

Raven, J. A. and W. J. Lucas. 1985. Energy costs of carbon acquisition. Pp. 305-324 *in* W. J. Lucas and J. A. Berry, *eds*., Inorganic carbon uptake by photosynthetic organisms. Amer. Soc. Plant Physiol., Rockville MD. *[49]*

Redfield, A. C. 1934. On the proportions of organic derivatives in sea water and their relation to the composition of plankton. Pp. 176-192 *in*: James Johnstone Memorial Volume, University Press, Liverpool 348 pp. *[50]*

Revsbech, N. P. and B. B. Jørgensen. 1983. Photosynthesis of benthic microflora measured with high spatial resolution by the oxygen microprofile method: capabilities and limitations of the method. Limnol. Oceanogr. *28*: 749-756. [**56**]

Rhee, G.-Yull. 1978. Effects of N/P atomic ratios and nitrate limitation on algal growth, cell composition, and nitrate uptake: a study of dual nutrient limitation. Limnol. Oceanogr. *23*: 10-25. [**34**]

Rhee, G.-Yull. 1982. Effects of environmental factors and their interactions on phytoplankton growth. Adv. microb. Ecol. *6*: 33-74. [**45**, **54**]

Rhoads, D. C. 1974. Organism-sediment relations on the muddy sea floor. Oceanogr. Mar. Biol. Ann. Rev. *12*: 263-300. [**15**]

Rhoads, D. C. and D. K. Young. 1970. The influence of deposit-feeding organisms on sediment stability and community trophic structure. Journal of Marine Research *28*: 150-178.[**5**]

Rhoads, D. C. and D. K. Young. 1971. Animal-sediment relations in Cape Cod Bay, Massachusetts. II. Reworking by *Molpadia oolitica* (Holothuroidea). Marine Biology *11*: 255-261. [**15**, **67**]

Richards, F. A. 1965. Anoxic basins and fjords, pp. 611-645 *in* J. P. Riley and G. Skirrow eds, Chemical Oceanography, Academic Press, San Francisco. [**50**]

Riley, G. A. 1967. Mathematical model of nutrient conditions in coastal waters. Bull. Bingham Oceanogr. Coll. *19*: 72-80. [**41**]

Rivkin, R. B. and L. Legendre 2001. Biogenic carbon cycling in the upper ocean: effects of microbial respiration. Science *291*: 2398-2400.

Root, R. B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. Ecol. Monogr. *37*: 317-350. [**29**, **30**]

Rosenzweig, M. L. 1995. Species diversity in space and time. Cambridge University Press, Cambridge. *[36, 55]*

Scheltema 1979 [**37**]

Schwalbach, M. S. and J. A. Fuhrman 2005. Wide-ranging abundances of aerobic anoxygenic phototrphic bacteria in the world ocean revealed by epifluorescence microscopy and quantitative PCR. Limnol. Oceanogr. *50*: 620-628. [**4**]

Shmida, A. and S. Ellner. 1984. Coexistence of plant species with similar niches. Vegetatio 58: 29-55. *[36]*

Shmida, A. and M. V. Whittaker. 1981. Pattern and biological microsite effects in two shrub communities, southern California. Ecology *62*: 234-251. *[36]*

Shmida, A. and M. V. Wilson. 1985. Biological determinants of species diversity. J. Biogeography *12*: 1-20.[**36**]

Sieburth, J. McN., V. Smetacek and J. Lenz. 1978. Pelagic ecosystem structure: heterotrophic compartments of the plankton and their relationship to plankton size fractions. Limnol. Oceanogr. *23*: 1256-1263. [**46**]

Slobodkin, L. 1961 Growth and Regulation of Animal populations. [**22**, **51**]

Sokal, R. R. and F. J. Rohlf. 1981. Biometry, Second Ed. W. H. Freeman, San Francisco. 859 pp. [**43**, **55**, **56**]

Stanier, R. Y., M. Doudoroff, and E. A. Adelberg. 1970. The microbial world. Prentice-Hall, Englewood Cliffs, New Jersey U.S.A.[**29**]

Stearns, S. C. 1976. Life-history tactics: a review of the ideas. Quart. Rev. Biol. *51*: 3-47.[**8**, **49**]

Steele, J. H. 1974. The structure of marine ecosystems. Harvard University Press, Cambridge.*[22, 48]*

Stumm, W. and J. J. Morgan. 1981. Aquatic chemistry: an introduction emphasizing chemical equilibria in natural waters. John Wiley & Sons, New York. 780 pp. *[22, 50]*

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1942. The Oceans: their physics, chemistry, and general biology. Prentice-Hall. 1087 p. *[53]*

Takahashi, T. W. S. Broecker and S. Langer. 1985. Redfield ratios based on chemical data from isopycnal surfaces. J. Geophys. Res. *90*: 6907-6924. [**50**]

Tilman, D. 1982. Resource competition and community structure. Princeton University Press, Princeton.[**41**]

Trueblood, D. D., E. D. Gallagher, and D. M. Gould. 1994. Three stages of seasonal succession on the Savin Hill Cove mudflat, Boston Harbor. Limnol. Oceanogr. *39*: 1440-1454. [**13**, **43**]

Whittaker, R. H. 1953. A consideration of climax theory: the climax as a population and pattern. Ecol. Monogr. *23*: 41-78. [**13**]

Whittaker, R. H. 1960. Vegetation of the Siskiyou Mountains, Oregon and California. Ecological Monographs *30*: 279-338.[**18**]

Whittaker, R. H. 1967. Gradient analysis of vegetation. Biological Reviews *42*: 207-264. [**18**, **19**]

Whittaker, R. H. 1975. Communities and ecosystems. MacMillan Press, New York. 387 pp.[**28**, **45**]

Williams, P. J. LeB., K. R. Heinemann, J. Marra, and D. A. Purdie. 1983. Comparison of ^{14}C and O_2 measurements of phytoplankton production in oligotrophic waters. Nature *305*: 49-50. [**44**]

Wimbush, M. 1976. The physics of the benthic boundary layer. Pp. 3-10 in I. N. McCave, ed., The Benthic Boundary Layer. Plenum Press, New York [**7**]

Woodin, S. A. and J. B. C. Jackson. 1979. Interphyletic competition among marine benthos. Amer. Zool. *19*: 1029-1043. [**29**]

Woods, J. D. and R. Onken. 1982. Diurnal variation and primary production in the ocean-preliminary results of a Lagrangian ensemble model. Journal of Plankton Research *4*: 735-756. [**33**]

Web Resources

Oceanographic & ecological glossaries

Table 4. Oceanographic & ecological terms on the web.

Title	URL	Description
Allopatric speciation & genetic drift	**http://www.evotutor.org/Speciation/Sp1A.html**	A wonderful java applet showing the effects of genetic drift on gene frequecines
Biodiversity glossary of terms	**http://pubs.wri.org/pubs_content_text.cfm?ContentID=487**	1992. Global Biodiversity Strategy: Guidelines for action to save, study and use Earth's biotic wealth sustainably and equitably. World Resources Institute ...
The echinoid directory	**http://www.nhm.ac.uk/palaeontology/echinoids/**	The echinoid directory Designed and created by Dr. Andrew B. Smith, The Natural History Museum, London
FAO Fishery glossary	**http://www.fao.org/fi/glossary/default.asp**	Terms compiled by food and agriculture organization of the united nations
Glossary of ecological terms	**http://www.blackwellpublishing.com/townsend/Glossary.asp**	A glossary to accompany Townsend et al.'s Ecology text
Glossary of Marine Biology	**http://life.bio.sunysb.edu/marinebio/glossary.html**	Jeff Levinton's glossary
Glossary of Physical Oceanography and Related Disciplines	**http://stommel.tamu.edu/~baum/paleo/ocean/ocean.html**	Steven Baum's Glossary of oceanographic terms
UCMP Glossary of	**http://www.ucmp.berkeley.edu/glossary/gl**	Glossary of

Title	URL	Description
The Northern Right Whale	**http://www.ncseonline.org/NLE/CRSreports/Biodiversity/biodv-12.cfm?&CFID=17649102&CFTOKEN=2676329**	A Report to Congress by M. Lynne Corn (1995)

STATISTICAL TERMS & CONCEPTS

Table 5. Statistics on the web.

URL	Description	Site
http://www.bmj.com/collections/statsbk/index.shtml	Statistics at Square One Ninth Edition T D V Swinscow Revised by M J Campbell, University of Southampton. *[An overview of some statistical methods]*	British Medical Journal collections
http://members.aol.com/jeff570/mathword.html	Earliest Known Uses of Some of the Words of Mathematics	
http://members.aol.com/jeff570/stat.html	Earliest Uses of Symbols in Probability and Statistics	
http://name.math.univ-rennes1.fr/bernard.delyon/textbook/stathome.html or **http://www.statsoft.com/textbook/stathome.html**	Electronic Statistics Textbook (online)	
http://www.itl.nist.gov/div898/handbook/index.htm	**Engineering Statistics Handbook** - Includes a nice section on exploratory data analysis including the Anscombe quartet.	National Institute of Standards & Technology
http://physics.nist.gov/Pubs/guidelines/contents.html or the pdf **http://physics.nist.gov/Pubs/guidelines/TN1297/tn1297s.pdf**	Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results by Barry N. Taylor and Chris E. Kuyatt	National Institute of Standards & Technology

Table 5. Statistics on the web.

URL	Description	Site
http://davidmlane.com/hyperstat/	Hyperstat online statistics journal	
http://www.stat.uiowa.edu/~rlenth/Power/	Java applets for power & sample size	Russ Lenth University of Iowa
http://www.amstat.org/publications/jse/	Journal of Statistics Education (free on web)	
http://mathworld.wolfram.com/topics/ProbabilityandStatistics.html	Mathworld's Probability & Statistics	
http://www.pitt.edu/~wpilib/statfaq2.html	Rich Ulrich's FAQ. A collection of his posts from the statistical educator's user's group.	
http://www.id.unizh.ch/software/unix/statmath/sas/sasdoc/stat/index.htm	SAS/STAT user's guide, including many references on methods	
http://www.ats.ucla.edu/stat/SPSS/	SPSS Resources from UCLA	
http://www.ats.ucla.edu/stat/spss/examples/default.htm	SPSS Textbook examples & data from UCLA	
http://www.ats.ucla.edu/stat/spss/webbooks/reg/default.htm	SPSS Web Books: Regression with SPSS (from UCLA)	
http://support.spss.com/default.htm	SPSS Support page, incuding white papers (log on as guest/pw guest if you don't want to register)	
http://ourworld.compuserve.com/homepages/jsuebersax/agree.htm#basics	Statistical methods for rater agreement	
http://www.bmj.com/collections/statsbk/index.shtml	Statistics at Square One Ninth Edition T D V Swinscow Revised by M J Campbell, University of Southampton. *[An overview of some statistical methods]*	British Medical Journal collections

Table 5. Statistics on the web.

URL	Description	Site
http://www2.chass.ncsu.edu/garson/PA765/statnote.htm	Statnotes: Topics in Multivariate Analysis, by G. David Garson	
http://www.statsoft.com/textbook/stathome.html	Statsoft electronic statistics textbook	
http://www.cmh.edu/stats/index.asp	Steve's attempt to teach statistics, including many definitions	
http://davidakenny.net/cm/causalm.htm	Structural equation modeling	
http://www.amstat.org/sections/SRMS/whatsurvey.html	Surveys (from the ASA)	
http://www.stat.ucla.edu/history/	UCLA's History of statistics	UCLA
http://www.ats.ucla.edu/stat/spss/library/spssmixed/mixed.htm	UCLA Mixed models (an SPSS html slideshow, available from SPSS, posted at UCLA)	UCLA
http://www.stat.ucla.edu/history/people/	UCLA Portraits of statisticians	UCLA
http://trochim.human.cornell.edu/kb/	William Trochim's Research Methods database	

Index