Chapter 1. Ecological Principles

Although this teaching package is designed for students of non-science background, some basic ecological principles are delivered here in order to strengthen their scientific knowledge. These basic concepts may help them to have a better understanding of the preceding chapters as well as a critical perspective on the principles to be taught.

← Nature © Frank Lee

Life first appeared on Earth about 4 billion years ago. It started with a small living cell that fixes and uses energy in order to grow and reproduce. Eventually life involved many systems of energy management (or metabolism), together with repeated replications, and subsequently evolved into more and more complex forms.

But how do we define life? Generally speaking, we may distinguish living from non-living things based on these characteristics (Beeby and Brennan, 1997; Jones, 1997):

- having a complex, organized structure based on organic (carbon) compounds;
- acquiring material and energy from their environment and converting these into different forms;
- actively maintaining their complex structure;
- responding to environmental stimuli;
- growing and reproducing using a molecular blueprint (DNA); and
- having the capacity to evolve.

I. Basic Principles

Laws, Theories & Principles

A **law** is a hypothesis that has survived repeated examination by many investigators over a long time and has central importance to an area of science, e.g. the biogenetic law. A **theory** *is a broadly written statement that covers large bodies of scientific knowledge. It is well-*thought out and has lots of evidence for its support, e.g. theory of evolution. **Principles** are generally true statements, can be referred to as or base on laws or theories (Bunce, 1993).

Scientific laws with ecological relevance:

Example 1: The first & second law of thermodynamics (Jones, 1997)

1st law	energy can neither be created nor destroyed; it can only be changed from one form into another
2nd law	there is no loss of total energy, but there is a loss of useful energy

Example 2: Limiting Factor Principle (Hanks, 1996)

- Too much or too little of any abiotic factor can limit or prevent growth of a population, even if all other factors are at or near the optimum range of tolerance.

In Greek, the term "Ecology" means "house" or "place to live". **Ecology** is the study of how organisms interact with one another and with their physical and chemical environment (Reiss and Chapman, 2000; Dickinson and Murphy, 1998). It is concerned with the biology of groups of organisms and with functional processes on the land, in the oceans and freshwater, and in the air (Buell and Girard, 1994).

Realms of Ecology (Townsend, Begon and Harper, 2003):

Ecosphere (Biosphere)	- all of the Earth's ecosystems together
↑	
Ecosystems	- community of different species interacting with one another and with their nonliving environment of matter and energy
↑	
Communities	- populations of all the different species occupying a particular place
↑	
Populations	- group of individuals of the same species occupying a given area at the same time
↑	
Organisms	- any form of life

Species is a group of organisms that resemble one another in appearance, behavior, chemistry, and genetic structure (Townsend, Begon and Harper, 2003). Each species can breed with one another to produce fertile offspring under natural conditions. Scientists estimate that between 5,000,000 and 100,000,000 species exist (1,400,000 have been identified). A **habitat** is the place where an organism or population lives (Jones, 1997).

Ecosystem – woodland
© Frank Lee

The word '**ecosystem**' was introduced in 1935 by a British ecologist, Sir Arthur Tansley, referring to the whole community of organisms and their environment taken as a single functioning unit (Reiss and Chapman, 2000).

Today, the term means the basic functional unit in ecology. It contains organisms, populations, and communities, each having unique properties and influence on each other.

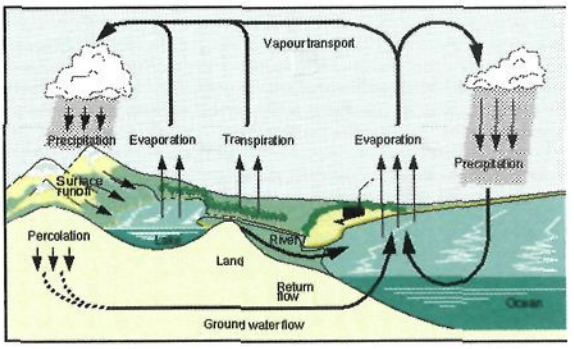
Ecosystem also represents an order of systems below the so-called biosphere, and that a collection of similar ecosystems makes up the conceptual notion of a biome (see illustration of "Realms of Ecology" above).

The **environment** of an organism relates to the features (including physical, chemical and biological) that are significant to its existence. They are (Dickinson and Murphy, 1998):

- abiotic characteristics such as atmospheric gases, temperature, fire and wind, and components such as mineral nutrients and water;
- food, or nutrients required for the organism;
- living habitat to rest, sleep, hide and reproduce;
- or even other organisms of the same species and of other species.

A **Cycle** deals with matters that circulate, transform and re-circulate in the biosphere from the environment to organisms and back to the environment. It applies to chemical elements: water, carbon, nitrogen, sulphur, phosphorous, etc.

Just as the living world depends on water, so too does it influence how water moves through the **Water Cycle.** ➔



(modified from Dickinson and Murphy, 1998)

Community, Competition and Symbiosis

A community is any assemblage of populations living in a prescribed area (Reiss and Chapman, 2000). In a community, organisms compete for limited resources. Symbiosis means "living together". It is defined as a close interaction between organisms of different species for an extended time.

← Corals and coral fish: example of mutualism
© Frank Lee

Interactions among organisms (Jeffries, 1997; Beeby and Brennan, 1997):

Type of interaction	***Effect on organism A***	***Effect on organism B***
Competition between A & B	Harms	Harms
Predation by A on B	Benefits	Harms
Symbiosis *a. Parasitism by A on B* b. Commensalism of A with B c. Mutualism between A & B	 *Benefits* Benefits Benefits	 *Harms* No effect Benefits

Carrying capacity

Every ecosystem has limits in terms of the size of various populations that it can support. Every species has certain needs that the community must provide in order for it to survive *and continue to exist (Reiss and Chapman, 2000).*

Total demand on resources = population x average demand per individual

The term **"ecological niche"** refers to the organism's functional role in the community. It could be the species' status in terms of its activities, its rate of metabolism and growth, its effect on other organisms with which it has contact, or its ability to modify important operations in the ecosystem (Hanks, 1996).

Limiting Factors
In the natural world, limiting factors (i.e. the availability of food, water, shelter and space) can affect the populations of animals and plants (Hanks, 1996). In fact, a species may have a wide range of tolerance for one factor but a narrow range of tolerance for another. For example, species of:

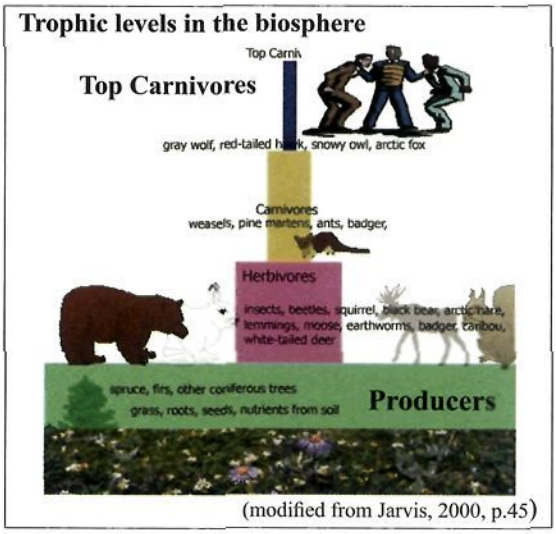
- Terrestrial Ecosystems– limiting factors are temperature, water, light, nutrients, etc.
- Aquatic Ecosystems – limiting factors are salinity, temperature, sunlight, dissolved oxygen, nutrients, etc.

Energy Flow in Ecosystems (Townsend, Begon and Harper, 2003)
The **Food Chain** is the transfer of food energy from its source in plants through a series of organisms where eating and being eaten is repeated a number of times. **Food Web** refers to a network of feeding relationships in an ecosystem. **Trophic Level** basically means "feeding level". The exact level depends on whether an organism is a producer or a consumer and what it eats or decomposes.

- 1st Level = producers
- 2nd Level = primary consumers
- 3rd Level = secondary consumers
- 4th Level = tertiary consumers
- detritivores process detritus from all levels

Ecological Pyramid

- Pyramid of Numbers is the number of organisms at each trophic level.
- Pyramid of Biomass is biomass (weight) of all organic matter contained in the organisms at each trophic level. The biomass is transferred from one level to another in the form of chemical energy.



(modified from Jarvis, 2000, p.45)

Pyramid of Energy Flow is the percent of usable energy transferred from one level to another (Hanks, 1996). Only about 5% to 20% of the energy is transferred (depends on the type of organisms in the ecosystem). This explains why food webs rarely have more than 4 trophic levels.

Productivity
Gross Primary Productivity (GPP) is the rate at which an ecosystem's producers capture and store chemical energy as biomass. Net Primary Productivity (NPP) is GPP minus the rate at which producers use stored chemical energy in their biomass. This is the basic food source for all consumers. It is estimated that humans waste 27% of the world's NPP (Jones, 1997).

II. Living Organisms

Types of organisms based on cell type (Beeby and Brennan, 1997):

- **Prokaryotic** organisms lack a distinct nucleus. They also lack internal parts surrounded by a membrane. They all belong to the Kingdom Monera.
- **Eukaryotic** organisms contain a nucleus surrounded by a membrane. They also have other internal parts surrounded by a membrane.

Kingdoms of Organisms:

Monera
- single celled and microscopic
- all are prokaryotic
- e.g. bacteria

Protista
- most primitive of eukaryotic species
- mainly single celled, some are colonial
- basically a catch-all group
- e.g. algae, protozoa

Fungi
- are mainly multicellular.
- are all non-photosynthetic autotrophs.
- obtain energy by decomposing dead and dying organisms and absorbing their nutrients from those organisms

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Plantae
- are mainly multicellular.
- are all photosynthetic autotrophs.
- are important sources of oxygen, food, and clothing/construction materials, as well as pigments, spices, dyes, and drugs

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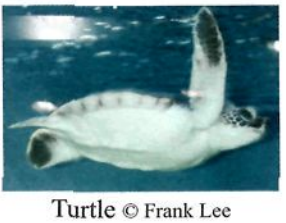
Animalia
- are mainly multicellular
- are all heterotrophic by ingestion
- provide food, clothing, fats, scents and labour

Birds © Zoe Lee

Butterfly © Zoe Lee

Fish © Frank Lee



Turtle © Frank Lee

Monkey © Frank Lee

Types of organisms based on function (Townsend, Begon and Harper, 2003):
Producers/Autotrophs can make the nutrients they need to survive from compounds in their environment. Photosynthesis is the biological process using sunlight to make complex nutrient compounds.

$$CO_2 + H_2O + \text{solar energy} \rightarrow C_6H_{12}O_6 + O_2$$

Chemosynthesis is the conversion of simple compounds from their environment into more complex nutrient compounds without sunlight. **Consumers/Heterotrophs** get their organic nutrients by feeding on the tissues of producers and other consumers.

As primary consumers, **herbivores** feed directly on producers. Feeding only on other consumers, **carnivores** are secondary, tertiary, and quartinary consumers. **Omnivores** eat both plant and animal tissues. **Detritivores** live off detritus (part of dead organisms and cast-off fragments and wastes of living organisms). **Decomposers** digest complex organic molecules in detritus into simpler inorganic compounds and absorb the soluble nutrients. **Detritus feeders** extract nutrients from partly decomposed organic matter.

Aerobic Respiration is the process by which energy is released to sustain life processes of producers and consumers.

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + \text{solar energy}$$

Survival of any individual organism depends on the flow of matter and energy through its body. The community of organisms in an ecosystem survives because of a combination of matter recycling and one-way energy flow.

Conclusion

This chapter introduces some of the basic ecological principles, from knowing the definitions of law, theory and principles, realms of ecology, interactions among species, ecological pyramid, to classifications of living organisms. The important message is that there are different interactions among plants, animals and microorganisms – all being applied by the principles mentioned above.

Questions for Further Thinking

1. It was mentioned that every species has its niches in the ecosystem. Name one species and its niche for the following habitats:

Ecosystem	*Species*	*Niche*
- River/stream		
- Rocky shore		
- Forest		

2. Besides the Water Cycle, name one more natural cycle that is essential in the ecosystem.

第一章　生態學原理

雖然這個教材套是為非修讀理科的學生而設計，不過這裡提供一些基本生態學原理，以加強他們的科學知識。這些基本概念也許幫助他們理解以下的章節及一些重要的原則。

大約四十億年前，**生命**首次在地球上出現。它以一個細胞開始，攝取及利用能量來增長和繁殖。最終，生命包括了很多能量管理系統(或新陳代謝)，配合複製，而演變較複雜的形態。

但我們怎樣定義生命？一般而言，我們可以根據以下特徵去區分生命與非生命 (Beeby and Brennan, 1997; Jones, 1997)：

- 由有機物質組成的複雜及有組織的結構；
- 從外界攝取材料和能量，轉換成不同的形式；
- 維持固定的型態；
- 對外界刺激作出反應；
- 利用DNA生長和複製；及
- 有進化的能力。

I. 基礎原理

定律、學說和定理

定律是很多研究者經過長時間反覆驗證假設，並對科學的一個範疇十分重要，例如：生物遺傳定律。學說是涵蓋廣泛的科學知識，而且是一個很好的意念和有許多證據作為支持，例如進化學說。原理是一般事實的陳述，可被稱為定律或學說的基礎 (Bunce, 1993)。

與生態學相關的科學定律：

例子一：熱力學第一及第二定律 (Jones, 1997)

第一定律	能量不能被創造及消滅；能量只可以由一個型態轉變成另一個。
第二定律	總能量是沒有減少的，減少的是有用的能量。

例子二：限制因子定理（Hanks, 1996）

- 儘管其他因子接近或達到可容忍範圍的最高值，其中一個非生物因子過多或過少可能限制或防礙族群的生長。

在希臘文，「生態學」是指「房子」或「居住的地方」。**生態學**是研究生物與其物理和化學環境的關係（Reiss and Chapman, 2000; Dickinson and Murphy, 1998）。它與在陸地，海洋，淡水和空氣的生物體和功能過程有關（Buell and Girard 1994）。

生態學的範疇 (Townsend, Begon and Harper, 2003):

生物圈	- 所有地球的生態系
↑	
生態系	- 不同物種的群落與環境和群落之間的相互作用
↑	
群落	- 一個地區不同種的放群
↑	
族群	- 一個地區同種的個體
↑	
生物	- 任何生命的形式

物種是一群有類似的形態、行為、化學和基因結構的生物 (Townsend, Begon and Harper, 2003)。在自然的環境下，物種可互相交配產生可育的下一代。科學家估計有5,000,000 至 100,000,000 個物種存在 (有1,400,000個物種被確認)。生境是指生物或族群居住的地方 (Jones, 1997)。

「**生態系**」一詞是由英國生態學家，Sir Arthur Tansley 提出，指整個群落與其環境被視為一個功能單位 (Reiss and Chapman, 2000)。現在，「生態系」一詞是指生態學的基本功能單位。它包括生物、族群和群落，彼此皆有獨特的特徵及互相影響。生態系是生物圈的下一層，而相似的生態系構成生物群落 (參見以上的「生態學的範疇」)。

環境對生物的生存有重大關係，包括物理性，化學性和生物性，包括 (Dickinson and Murphy, 1998):

- 非生物的特徵，例如大氣氣體、溫度、火、風、礦物質和水;
- 生物需要的食物,或營養;
- 休息、睡覺、躲藏和繁殖的棲息地;
- 同種和其他物動的生物。

循環是指物質從環境到生物和歸還環境之間的流動和轉換的過程。循環的化學元素有：水、碳、氮氣、硫磺、磷等。

群落、競爭和共生

群落是一個地區的族群 (Reiss and Chapman, 2000)。在群落裏，生物爭取有限的資源。共生是指「一起生活」。它的定義是在一段持續的時間，不同物種之間的相互作用。

生物間的相互作用 (Jeffries, 1997; Beeby and Brennan, 1997):

相互作用的種類	對生物***A***的影響	對生物***B***的影響
競爭	受害	受害
捕食	獲益	受害
共生		
a. 寄生	獲益	受害
b. 片利共生	獲益	沒有影響
c. 互利共生	獲益	獲益

容納量
每個生態系皆有極限，可支持不同大小的族群。每個物種必須從環境得到其所需，讓它繼續生存 (Reiss and Chapman, 2000)。

資源的總需求量 = 族群 × 個體的平均需求量

「**生態區位**」是指生物在生態系的功能。這是根據物種的活動、代謝和生長速率，對其他物種的影響，或改善生態系的能力 (Hanks, 1996)。

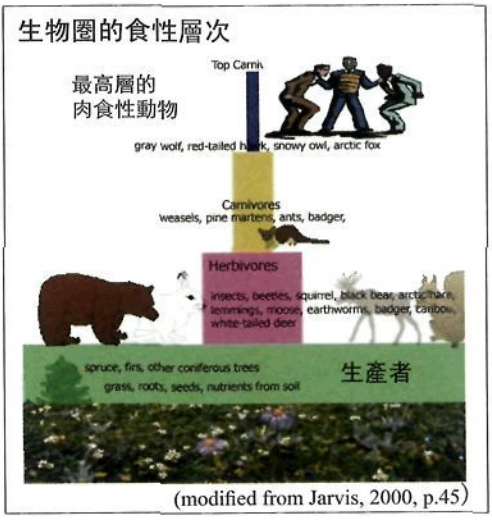
限制因子
在自然界，限制因子(即是食物、水、庇護所和空間)能影響動物和植物的族群 (Hanks, 1996)。實際上，物種也許對一個因素的容忍度較大，但對另一個因素的容忍度較低。例如：

- 陸地生態系 — 限制因素是溫度、水、光、養份等
- 水生生態系 — 限制因素是鹽分、溫度、陽光、溶解氧、養份等

生態系的能量流 (Townsend, Begon and Harper, 2003)
食物鏈是食物能量由植物傳至進食和被攝食的動物的途徑。食物網是指生態系中的進食關係網。食性層次基本上是「進食的層次」。食性層次取決於生物是生產者或消費者，並且它吃什麼或分解什麼。

- 第一層次 = 生產者
- 第二層次 = 初級消費者
- 第三層次 = 次級消費者
- 第四層次 = 三級消費者
- 食碎屑動物處理所有層次的腐屑

生態金字塔
- 數目金字塔是一個食性層次的生物數目。
- 生物量金字塔是一個食性層次的全部有機物質的生物量 (重量)。生物量以化學能量的形式從一個層次轉移到另一個層次。



(modified from Jarvis, 2000, p.45)

能量流程金字塔是從一個層次轉移到另一個層次的可用能量的百分比 (Hanks, 1996)。只有約5% 到20% 能量可被轉移 (取決於生物的種類)。這解釋為什麼食物網很少有超過四個食性層次。

生產力
初級總生產量 (GPP) 是生產者吸取和儲存化學能為生物量的速率。
淨初級生產量 (NPP) 是 GPP 減去生產者儲存化學能為生物量的速率。這是所有消費者的基本食物來源。現估計人類浪費整個世界的NPP百份之二十七 (Jones, 1997)。

II. 生物

以細胞類型劃分的生物種類 (Beeby and Brennan, 1997)：

- 原核生物沒有細胞核。它們沒有由膜包圍著的細胞器。它們全都屬於原核生物界
- 真核生物有由膜包圍的細胞核和細胞器。

生物界：

原核生物界	原生生物界	真菌界
- 單細胞和微小 - 屬於原核生物 - 例子：細菌	- 原始的真核生物 - 主要是單細胞，有些是菌落 - 例子：藻類，原生動物	- 主要是多細胞 - 自營生物，不能作光合作用. - 分解已死和垂危的生物，攝取和吸收能量和營養

動物界	植物界
- 主要是多細胞 - 靠攝取食物的異養生物 - 提供食物、衣物、油脂、香水和勞動	- 主要是多細胞 - 自營生物，可作光合作用 - 是氧氣、食物、衣物 / 建築材料、顏料、香料、染料和藥物的重要來源

以功能劃分的生物種類 (Townsend, Begon and Harper, 2003)：

生產者 / 自營生物可以從環境取得材料，製造它們需要的養份。光合作用是指生物吸收陽光，製造複雜養份的過程。

$$CO_2 + H_2O + \text{太陽能} \rightarrow C_6H_{12}O_6 + O_2$$

化學合成是指在沒有陽光的情況下，生物從環境中取得簡單的化合物，轉換成複雜的化合物。**消費者 / 異養生物**透過進食生產者和其它消費者，獲得有機養份。

作為初級消費者，**草食性動物**直接進食生產者。因為進食其它消費者，**食肉性動物**是次級，三級和四級消費者。**雜食性動物**進食植物和動物組織。**食腐質動物**進食腐質(屍體，被遺棄和浪費的生物碎片)。**分解者**把複雜有機分子消化為簡單的無機化合物，以吸收溶解的營養。**食腐質生物**從部分被分解的有機物質攝取營養。

需氧呼吸是能量釋放的過程，以維持生產者和消費者的生命。

$$C_6H_{12}O_6 + O_2 \rightarrow CO_2 + H_2O + \text{太陽能}$$

任何一個生物個體的生存取決於體內的物質和能量流動。由於物質和能量的循環，生態系的群落才得以生存。

結論

這章節介紹一些基本的生態學原理，如：定律、學說和定理，生態的範疇，物種間的相互作用，生態學金字塔，生物的分類。重要訊息是以上的原則可被應用到植物、動物和微生物之間的相互作用。

思考問題

1. 每個物種在生態系有其生庇區位。在以下生境中，明名一個物種和其生態區位：

生態系	物種	生態區位
- 河流 / 溪流		
- 岩岸		
- 森林		

2. 除水循環外，試列舉另一個對生態系重要的循環。

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