這個課程是為了定義生物多樣性，但是因為應當是實驗課，所以今天的上課方式如下：

1. 投影片全部是英文的，所以我會講得很慢。
2. 上課的方式是30-40分鐘的講解，10分鐘操作，10分鐘下課。
3. 這樣會進行6小時，每節會有一個小作業，共6個。
4. 這些作業請放在一個Word 檔，封面請依序列上課程名稱、學生姓名、上課日期。
5. 這個Word檔請以「學生姓名_上課日期」命名，如「詠超_20210807.doc」
6. 請於2021年8月16日(星期一)下午5點以前寄到ycsu527@gmail.com. 信件標題：中山高中資優課程_xxx作業。

CHAPTER 17
Species Diversity

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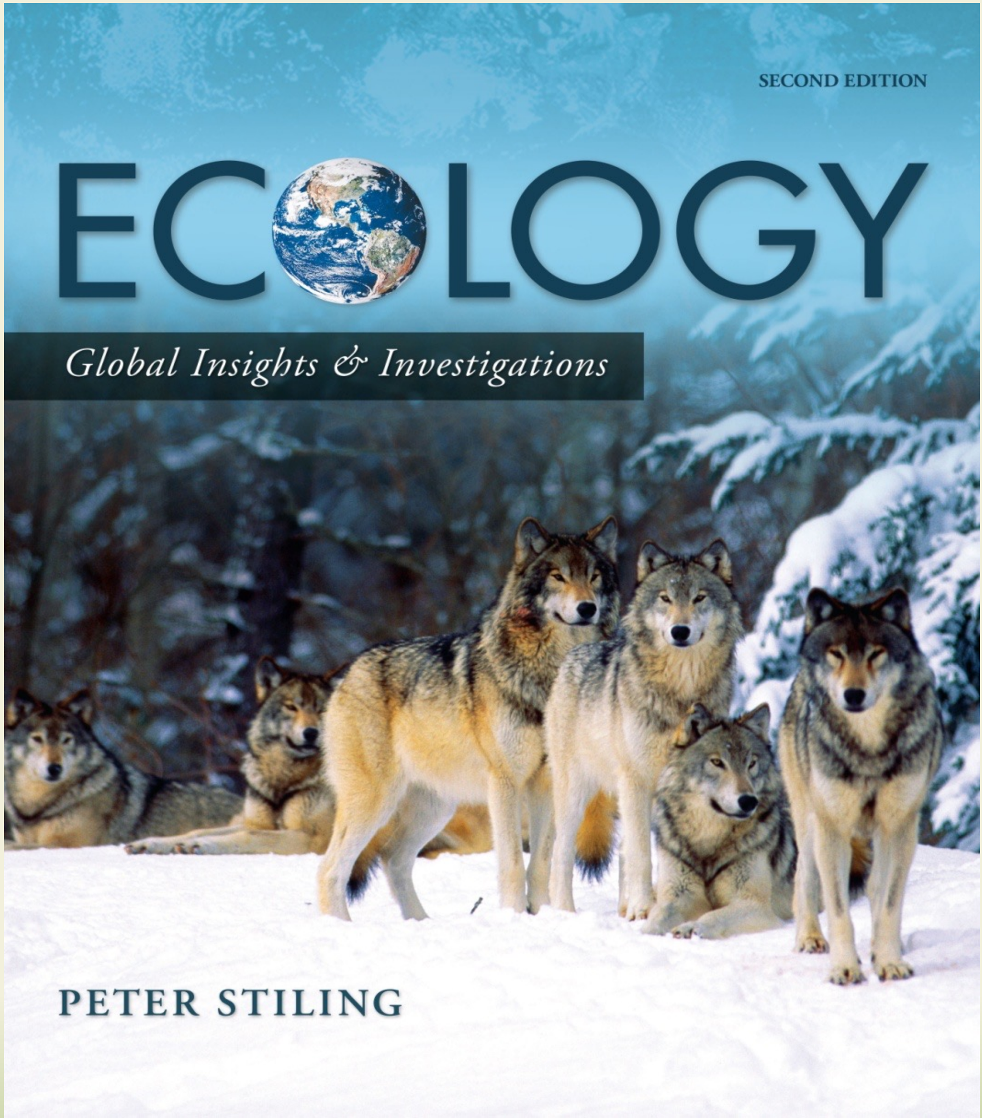

CHAPTER 17

Species Diversity

Outline

17.1 The nature of communities has been debated by ecologists.

17.2 A variety of indices have been used to estimate species biodiversity.

17.3 Rank abundance diagrams visually describe the distribution of individuals among species in communities.

17.4 Community similarity is a measure of how many species are common between communities.

We will be covering:

- The nature of communities and how to quantify the diversity they contain.
- The various techniques used to measure species diversity, including diversity indices, rank abundance diagrams, and similarity coefficients.

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A waterhole community at Etosha National Park, Namibia, Africa. Species include greater kudu, giraffe, zebra, and various birds.

Biodiversity

- Biodiversity can be considered on several levels including:
- Genetic diversity (the genetic variation within species).
- Community diversity (the variation among communities).
- Species diversity (the diversity among species).

Biodiversity Measures

Each of these biodiversity measures can be important in different circumstances, depending on the question of interest.

Indices	Description
Diversity indices	A measure of the number of species in an area and the relative distribution of individuals among these species.
Rank abundance diagrams	Graphical plots of numbers of individuals per species against rank of species commonness in the community.
Similarity indices	Indices which measure how areas may be similar in biodiversity, in terms of the numbers of species they hold in common.

17.1 The nature of communities

Has been debated by ecologists.

- Ecologists have long held differing views on the nature of communities and how they are structured and function.
  - **Organismic model**
  - **Individualist model**

The Nature of Communities

- **Organismic model:** a community is a tight knit collection of species considered to be equivalent to a superorganism, in the same way that the body of an animal is more than just a collection of organs (Frederic Clements, 1905).
- **Individualistic model:** a community is a loose assemblage of species coexisting primarily because of similarities in their physiological requirements and tolerances (Henry Gleason,1926)

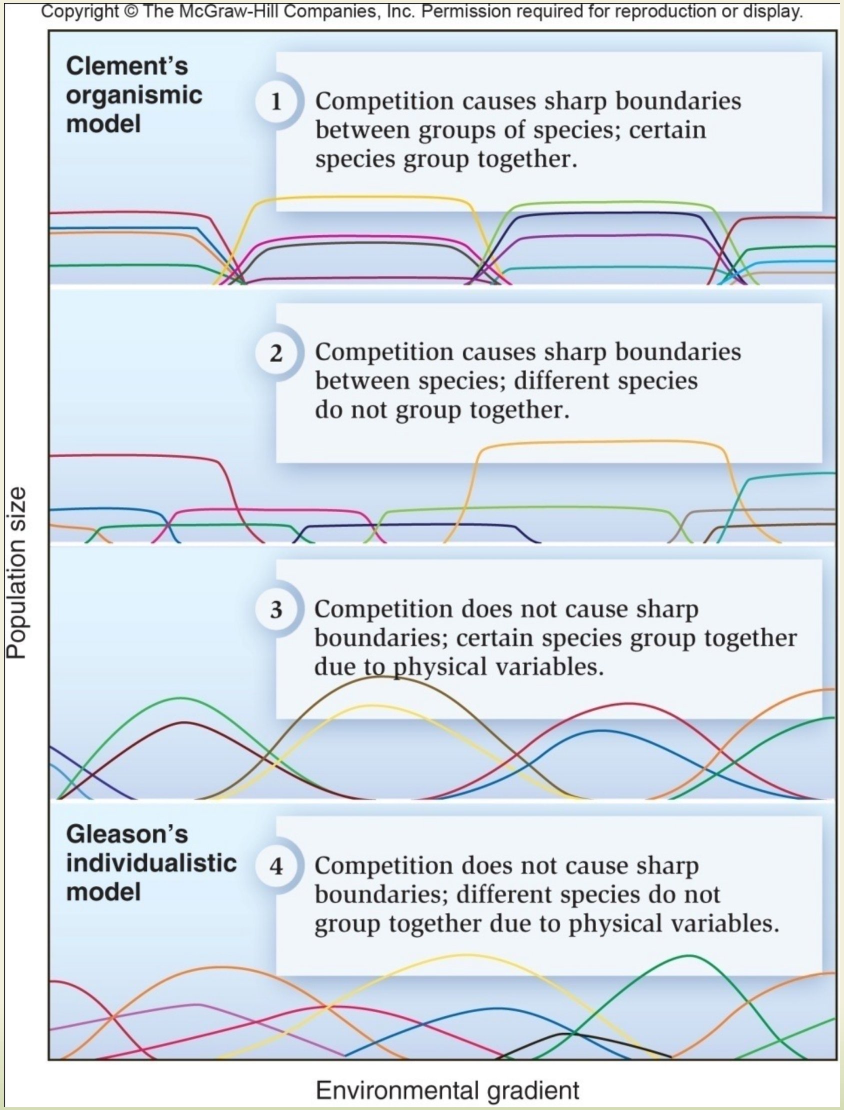
The Nature of Communities

- In an environmental gradient such as a moisture gradient on an uninterrupted slope of a mountain, Robert Whittaker proposed that hypotheses could explain the distribution patterns of plants and animals on the gradient.
- Clement's and Gleason's hypotheses made up the two extremes.

The Nature of Communities

Figure 17.1 Four hypotheses on how populations might relate to one another along an environmental gradient.

Each curve in each part of the figure represents one species and the way its population might be distributed along an environmental gradient such as a mountain slope.



The Nature of Communities

	Hypothesis	Details
1	**Organismic Model** Frederic Clements	• Competing species, including dominant plants, exclude one another along sharp boundaries. • Other species evolve toward a close, perhaps mutually beneficial, association with the dominant species. • Communities develop along the gradient, each zone containing its own group of interacting species giving way at a sharp boundary to another assemblage of species.
2		• Competing species exclude one another along sharp boundaries but do not become organized into groups of species with parallel distributions.
3		• Competition does not usually result in sharp boundaries between species. • The adaptation of species to similar physical variables will result in the appearance of groups of species with similar distributions.
4	**Individualistic Model** Henry Gleason	• Competition does not usually produce sharp boundaries between species. • The adaptation of species to similar physical variables does not produce well-defined groups of species with similar distributions. • The centers and boundaries of species populations are scattered along the environmental gradient.

The Nature of Communities

- To test these possibilities, Whittaker (1970) examined the vegetation on various mountain ranges in the western U.S.
  - The results supported the fourth hypothesis, that competition does not produce sharp boundaries between species and that adaptation to physical variables does not result in defined groups of species.

The Nature of Communities

- Whittaker concluded that his observations supported Gleason's predictions that:
  1. Each species is distributed in its own way, according to its genetic, physiological, and life cycle characteristics; and
  2. The broad overlap and scattered centers of species populations along a gradient implies that most communities grade into each other continuously rather than form distinct, clearly separated groups.

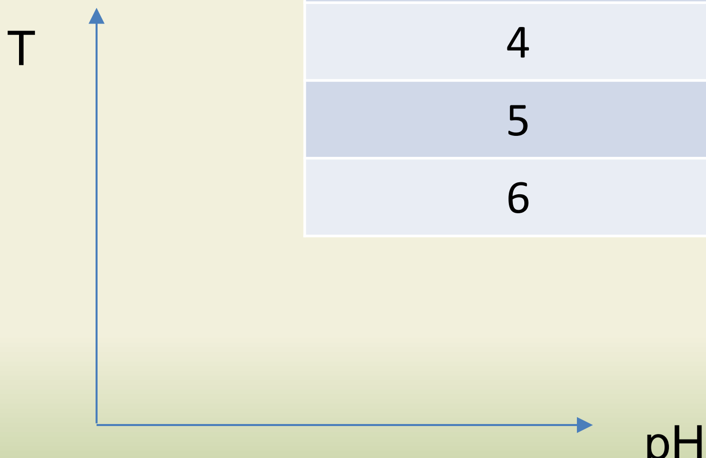
The Nature of Communities

- Whittaker's observations showed that the composition of species at any one point in an environmental gradient was largely determined by factors such as:
  - Temperature
  - Water
  - Light
  - pH

Homework I: Illustrate the concept of individualistic model of species diversity

Given 6 species have their own range of pH ranges and temperature ranges as listed below, give an illustration of how they could distribute on a 2D plot. Do you observe any "share of distribution"?

Species	pH range	T range
1	3-4	32-36
2	3-6	27-38
3	5-8	30-32
4	6-7	24-28
5	7-10	20-26
6	8-11	21-24



CHAPTER 17

Species Diversity

Outline

17.1 The nature of communities has been debated by ecologists.

17.2 A variety of indices have been used to estimate species biodiversity.

17.3 Rank abundance diagrams visually describe the distribution of individuals among species in communities.

17.4 Community similarity is a measure of how many species are common between communities.

Species Diversity

17.2 A Variety of Indices

Have been used to estimate species biodiversity.

- The simplest measure of biodiversity is species richness, which is a count of the number species.
  - This approach does not take species frequency of occurrence or relative abundance into account.

A Variety of Indices

	Community A	Community B
Number of individuals of species 1	99	50
Number of individuals of species 2	1	50

- Species richness of **Community B** equals that of **Community A** because they both contain two species.
- **Community B** is considered more diverse because the distribution of individuals between species is more even (more likely to encounter both species in **Community B** than in **Community A**, where one species dominates).

A Variety of Indices

- Species richness is very susceptible to sample size.
- The greater the number of individuals sampled the higher the number of species recorded.

A Variety of Indices

In two hypothetical communities, 1 and 2.

- The total number of species is called the species richness, and
- The total number of individuals is called species abundance.
- Species richness and abundance in both communities are identical – both have 10 species and 100 individuals.
- Individuals are more evenly distributed in community 1, so we say that community 1 is more diverse.

The Variety of Indices

Table 17.1 Species richness and species abundance.

Species	Individuals per species	
	Community 1	Community 2
a	10	5
b	10	5
c	10	5
d	10	5
e	10	5
f	10	5
g	10	5
h	10	5
i	10	5
j	10	55
Total individuals	100	100
Total number of species	10	10

A Variety of Indices

17.2.1 Dominance Indices

Are more influenced by the numbers of common species.

- Dominance indices are weighted toward the abundance of the commonest, or dominant, species.

The Variety of Indices

Dominance Indices

- Simpson's diversity index (1949) gives the probability of any two individuals drawn at random from a community belonging to different species.
  - If two trees are picked at random from a tropical forest, the chances are low that they will be the same species because there are many different tree species in any given tropical forest.
  - In a boreal forest in Canada, where there are only one or two species of tree in the forest, the chances of both individuals being of the same species would be relatively high.

The Variety of Indices

Dominance Indices

- Simpson's diversity index , D_S is calculated as follows:

$$D_S = \sum_{i=1}^{s} p_i^2$$

Perform this calculation for each species, from species 1 through species S, and sum all the values for all species.

Proportion of individuals in each species.

- where *pi* is the proportion of individuals in the *i*th species.

The Variety of Indices

Dominance Indices

- Imagine a community of five tree species and 200 individuals trees.

Tree species	Number of Individuals in Community A	P_i	p_i^2	Number of Individuals in Community B	P_i	p_i^2
1	100	0.5	0.25	100	0.5	0.25
2	50	0.25	0.0625	100	0.5	0.25
3	30	0.15	0.0225	0	0	0
4	19	0.095	0.009025	0	0	0
5	1	0.005	0.000025	0	0	0
Total	200					
D_s	10		0.34405			0.50

- In community A, for Species 1: the number of individuals = 100,
- The proportion of Species 1 in the community is then 0.5 and P_i^2 = 0.25.
- We repeat these calculations for all five species and sum the values.

The Variety of Indices

Dominance Indices

- The problem is that D_s and species diversity are negatively related so larger values of D_s mean lower diversity.
- However, Simpson's Index may be expressed as a complement index, $1 - D$, so that increasing values mean increasing diversity.
- This value is called the Gini-Simpson index (D_{GS}), where $D_{GS} = 1 - D_s$.
- Values range from 0 to 1.

The Variety of Indices

Dominance Indices

- Species diversity is often greatest at undisturbed sites and declines with increased disturbance.

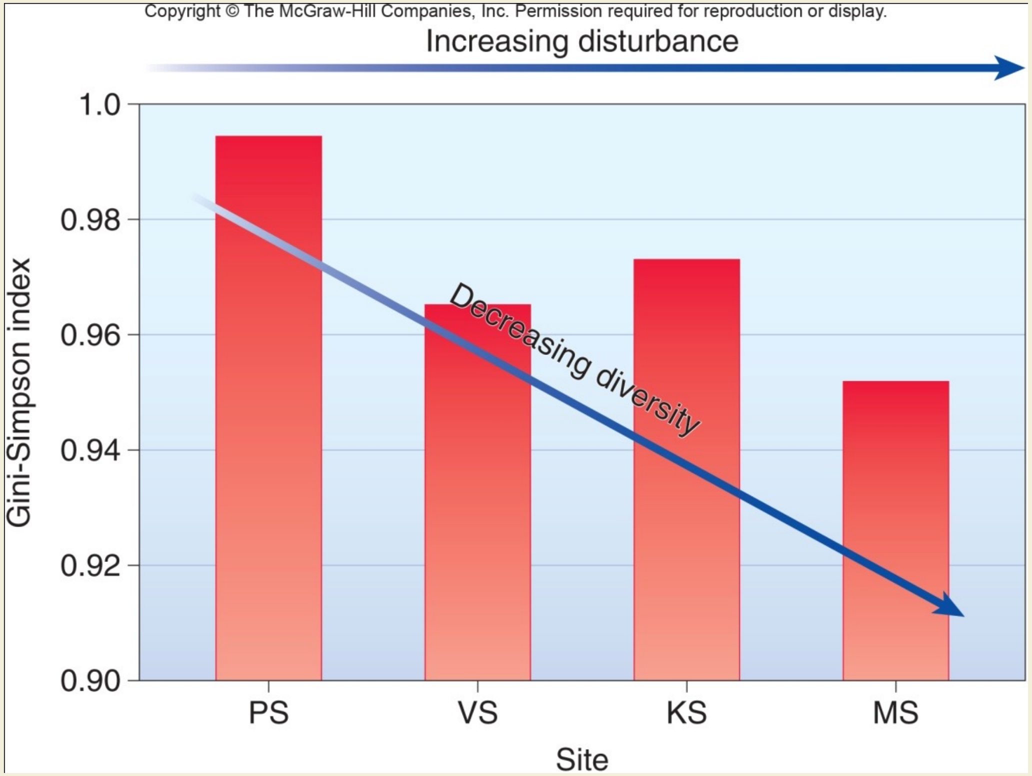


Figure 17.2 Effects of disturbance on diversity of tree species in an Indian tropical forest, as measured by the Gini-Simpson index.

(After data in Chittibabu and Parthasarathy, 2000)

The Variety of Indices

Dominance Indices

- The <u>disadvantage</u> of the Gini-Simpson index is that it is heavily weighted toward the most abundant species.
  - The addition of many rare species of trees with one individual will scarcely change the index.
  - The Gini-Simpson index is of limited value in conservation biology if there are many rare species.

A Variety of Indices

17.2.2 Information Statistic Indices

Are more influenced by the numbers of rare species.

- Information statistic indices are based on the rationale that diversity in a natural system can be measured in a way that is similar to measuring the information in a code.

The Variety of Indices

Information Statistic Indices

Example:

- The sequence bbbbb has a *low uncertainty* because the next letter is virtually certain to be a b.
- The sequence Bhwzj has a *high uncertainty* and hence a high index value.
- The higher the index value, the higher the uncertainly of being able to tell the next letter in the sequence or the next species in a community.
- This means the community is diverse.

Information Statistic Indices

The Shannon Index

Sum or values from species 1 to species S

H_S is given by

$$H_S = - \sum_{t=1}^{s} p_i \ln p_i$$

Proportion of individuals in each species

Where p_i is the proportion of individuals found in the *i*th species, ln is the natural logarithm, and ∑ is a summation sign.

The Shannon Index

For a species in which there are 50 individuals out of a total of 100 in a community,

p_i is 50/100, or 0.5.

The natural log of 0.5 is -0.693

For this species, p_i ln p_i is then,

$$0.5 \times -0.693 = -0.347.$$

The Variety of Indices

Information Statistic Indices

The Shannon Index

- The negative sign in front of the summation changes the summed value to a positive number.
- A positive number is more appealing than an index with a negative number.
- Values of the Shannon diversity index for real communities often fall between 0.5 and 3.5, with the higher the value, the greater the diversity.
- The Shannon diversity index is very valuable to conservation biologists, who often study rare species and their importance to the community. Since rare species contribute value to this index.

The Variety of Indices

Information Statistic Indices

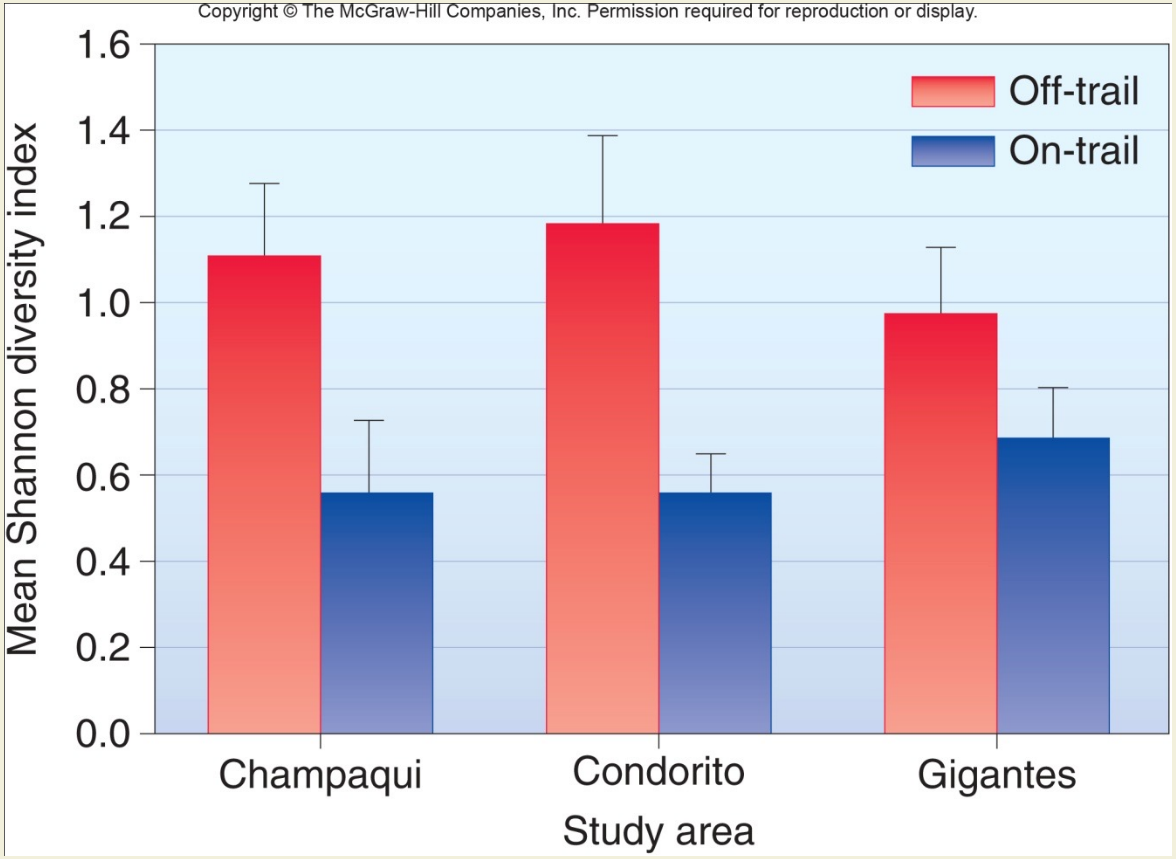


Figure 17.3 Bird diversity in the Andes as measured by the Shannon diversity index in two habitat types: undisturbed (off trail, no humans) and disturbed (on trail, with humans).

(After Heil, et al., 2007)

A Variety of Indices

17.2.3 The Effective Number of Species

Is a conceptually appealing measure of diversity.

- The effective number of species is a species equivalent that allows quick, intuitive comparisons between areas.

The Varity of Indices

The Effective Number of Species

Community A		Community B	
Species	Species Abundance	Species	Species Abundance
A	20	A	20
B	20	B	20
C	20	C	20
D	20	D	20
E	20	E	20
Species richness	5	F	20
H_S	1.609	G	20
D_{GS}	0.8	H	20
		I	20
		J	20
		Species richness	10
		H_S	2.305
		D_{GS}	0.9

Consider the following communities:

- **Community B** is effectively twice as rich as **Community A.** The species richness would reflect this but the Shannon index, of 2.305, and the Gini-Simpson of 0.9 would not.
- The Shannon index of the 10 species community is 43.2% larger than 1.609 and the Gini-Simpson index is only 12.5% larger than 0.8.
- Each index discriminates between these communities and species richness has the greatest discriminant ability.
- The Shannon index has the second greatest while the Gini-Simpson is a distant third.

The Variety of Indices

The Effective Number of Species

- Each index can be converted to an effective number of species using a different formula.
  - For the Shannon index we take the exponential.
  - For the Gini-Simpson index we subtract it from unity and invert it.
  - For our model community A, in both cases we get a value of 5.0, which is the exact number of species, but it is not always so.
  - Consider the following table.

The Variety of Indices

The Effective Number of Species

Table 17.2 Effective number of species using the Shannon and Gini-Simpson indices.

Table 17.2 Effective numbers of species using the Shannon and Gini-Simpson indices.

In communities 1 and 2 there are only two species present.

	Relative abundance of species				Diversity index		Effective number of species	
Community	Species 1	Species 2	Species 3	Species richness	H_S	D_{GS}	H_S	D_{GS}
1	90	10	–	2	0.325	0.180	1.384	1.219
2	50	50	–	2	0.693	0.50	2.000	2.000
3	80	10	10	3	0.638	0.340	1.893	1.515
4	33.3	33.3	33.3	3	1.099	0.667	3.000	3.000

Here, we see that community 3 is 36.8% more diverse that community 1 when using the Shannon effective number of species.

The Variety of Indices

The Effective Number of Species

In conclusion:

1. Species richness has good discriminant ability but is susceptible to sample size.
2. Gini-Simpson focuses on dominant species and effective numbers of species calculations do not have such good discriminant ability.
3. The Shannon index effective number of species has a greater discriminant ability than the Gini-Simpson and is more widely used.

17.2.4 Evenness is a Measure

Of how diverse a community is relative to the maximum possible diversity.

- For any information statistic index, the maximum diversity of a community, H_{max} is found when all species are equally abundant. We can compute evenness, E, which compares the actual diversity to the maximum possible.

For example, using the Shannon index:

$$E = H_S/H_{max}$$

- E varies between 0 and 1.0.

Homework II: Calculate the Simpson and Shannon indices of the data

10am	Temp	27	H%	54	PM2.5	16	softball		
Group	species1	species2	species3	species4	species5	species6	species7	species8	total
1	3	4	1						8
2	11	1	2	2		1			17
3	17			1	1				19
4	17		1						18

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17.3 Rank Abundance Diagrams

Visually describe the distribution of individuals among species in communities.

- A more complete picture of a community is gained by plotting the proportional abundance of species, on a log scale, against rank of abundance.

Rank Abundance Diagrams

17.3.1 The Lognormal Distribution

Is based on statistical properties of data.

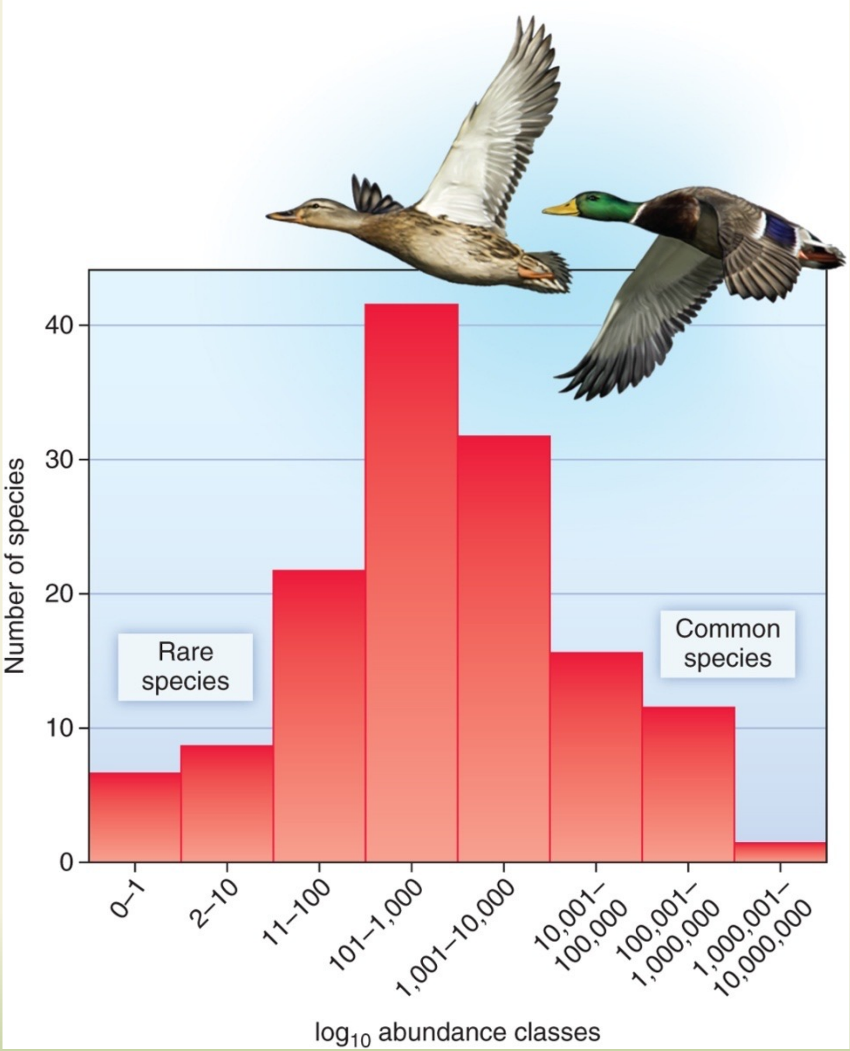
- The lognormal distribution (對數常態分布) results in a bell-shaped curve when plotting numbers of species against log species abundance, often when species are group into abundance classes.

Rank Abundance Diagrams

Figure 17.4 The lognormal distribution.

Species abundance plotted against log $_{10}$ abundance classes for British birds.
(Data from Williams 1964)

The biological meaning of this distribution is that there are a few species that are very common, or very rare, and a lot of species that have an intermediate number of individuals.



Rank Abundance Diagrams

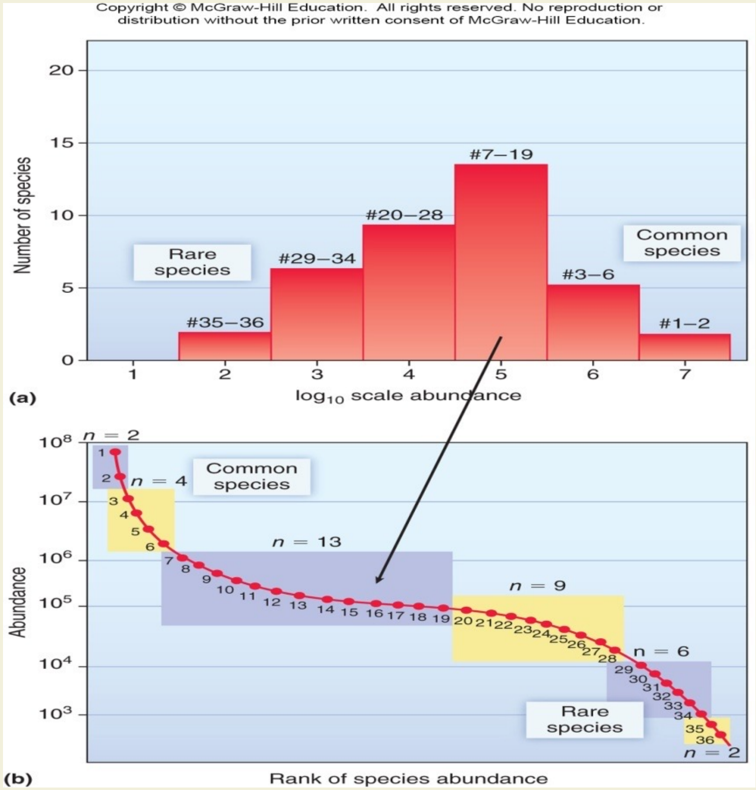


Figure 17.5 The lognormal rank abundance plot.

(a) Each species is given a number. We then group the species in abundance classes of $\log_{10}$. The result is a normal distribution: some species with few individuals (#29-36), some species with many individuals (#1-6), but most with an intermediate number of species (#7-28). **(b)** In the rank abundance plot, the abundance of each species is plotted on a logarithmic scale against the species rank, in order from the most abundant to the least abundant species.

Rank Abundance Diagrams

- Failure to sample all species in a community may result in a truncated lognormal distribution. This may be illustrated with reference to moth samples taken at light traps in England.

Rank Abundance Diagrams

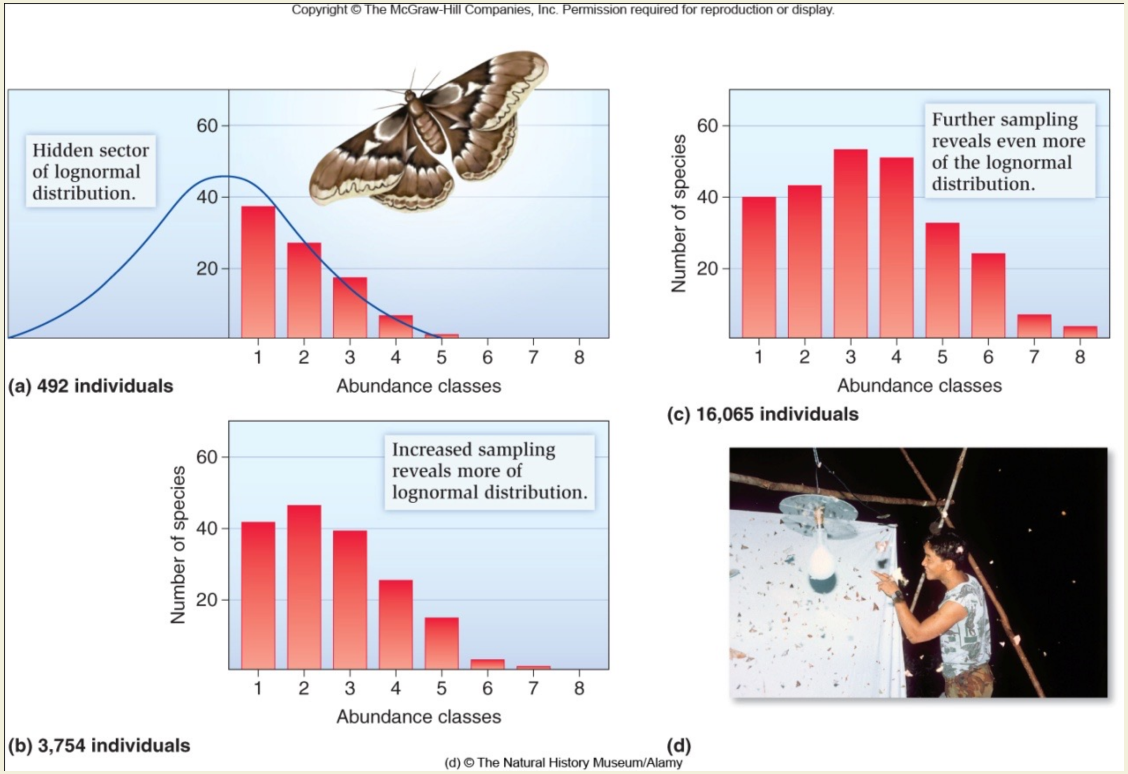


Figure 17.6 The truncated lognormal distribution.

The distribution of abundance of moths captured by light traps in England varies with the number of samples taken. In the top figure **(a)** the true distribution of abundance is hidden by the y-axis. **(b,c)** As the number of samples becomes larger, the distribution pattern moves to the right to reveal the distribution of rarer species. **(d)** Adult moths are drawn to an ultra-violet or black light at night, and rest on a nearby sheet, where researchers can collect or identify them. (Reproduced from Williams, 1964)

17.3.2 Tokeshi's Niche Apportionment

Models provide biological explanations for rank abundance plots.

- We will consider three of Tokeschi's rank abundance plots:
  - The dominance preemption model
  - The random fraction model
  - The MacArthur fraction model

Rank Abundance Diagrams

Tokeshi's Niche Apportionment Models

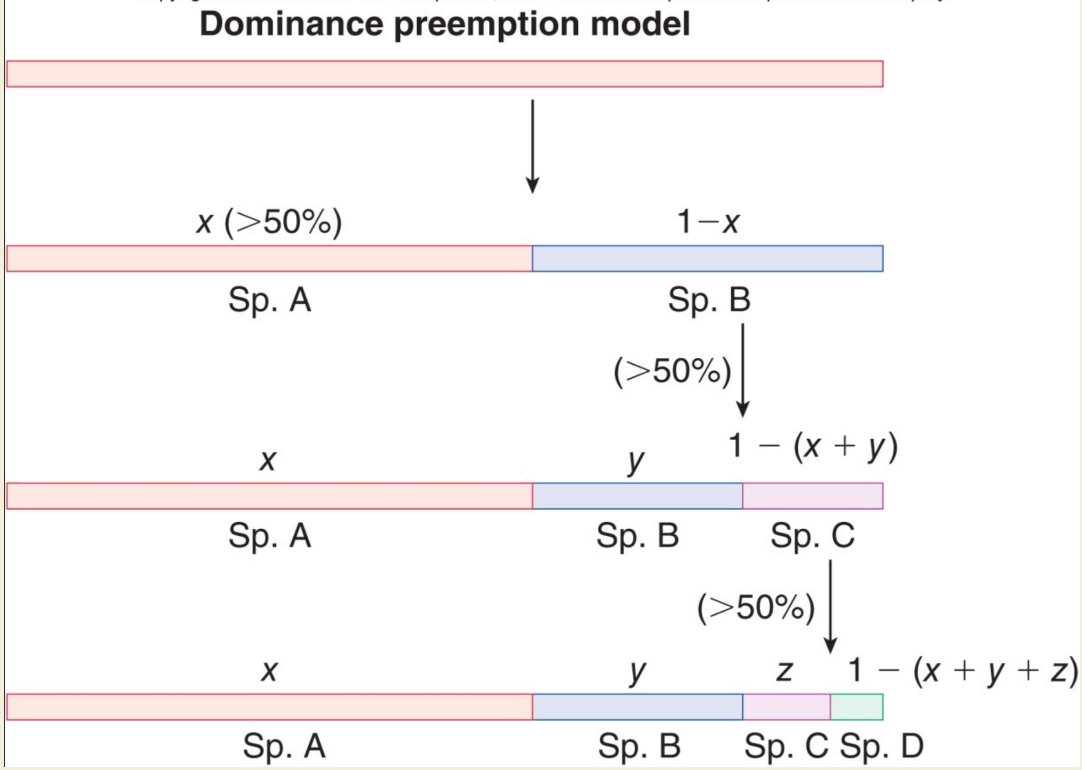


Figure 17.7 The dominance preemption model.

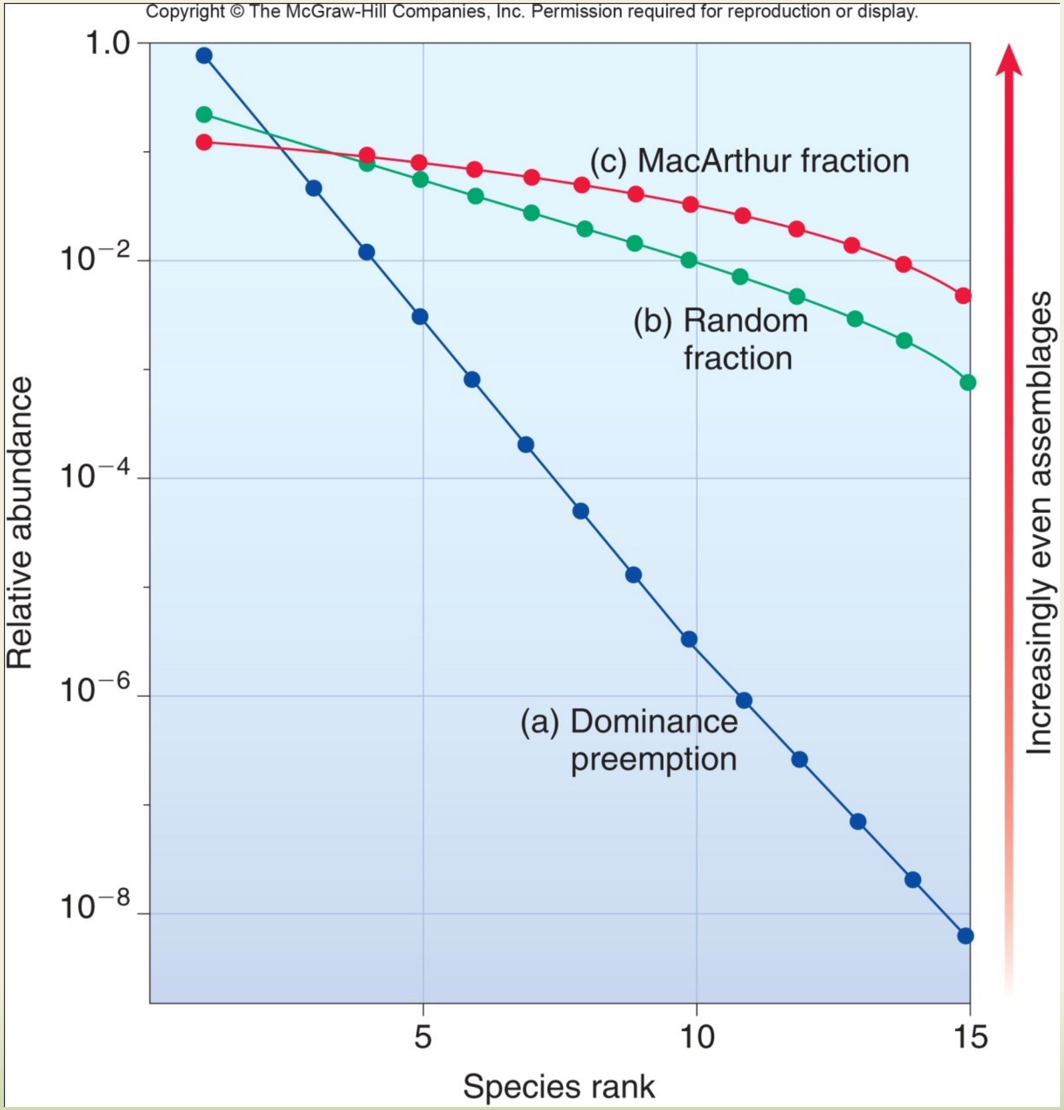
This model assumes the same large fraction, 50% or more, of unused resources is taken by each successive species.

Rank Abundance Diagrams

Tokeshi's Niche Apportionment Models

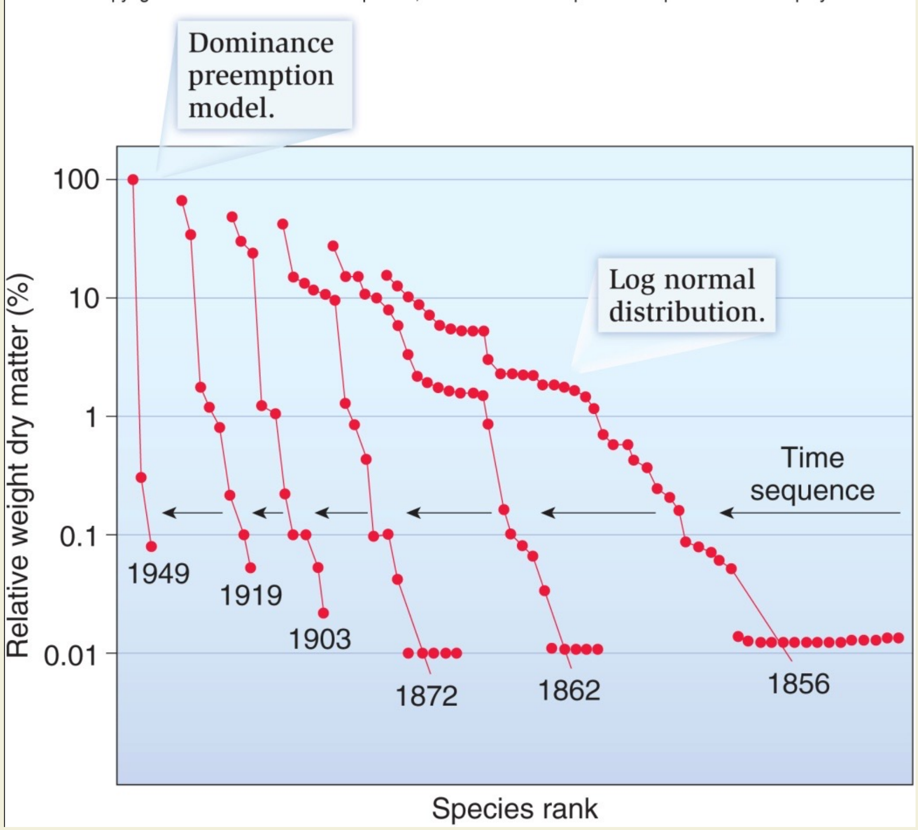
Figure 17.8 Rank abundance plots based on Tokeshi's niche apportionment models.

(From Tokeshi, 1999)



Rank Abundance Diagrams

Tokeshi's Niche Apportionment Models



Chronic fertilization can also result in a dominance preemption rank abundance.

Figure 17.9 Changes in relative abundances of grassland species at Rothamsted Experimental Station, UK, 1856-1949.

Nitrogen fertilization has been added continuously since 1856. (After Kempton, 1979)

17.4 Community Similarity

Is a measure of how many species are common between communities.

- Similarity indices compare diversity of sites directly.
- Consider the following matrix of presence/absence for communities A and B.

Community Similarity

		Community A	Community A
		No. of species present	No. of species absent
Community B	No. of species present	a	b
	No. of species absent	c	d

Where
a = the number of species common to both communities.
b = the number of species in community B, but not A.
c = the number of species in community A, but not B.
d = the number of species absent in both communities.

d is only biologically meaningful if the potential number of species that could be present in both communities is well known, i.e., we have a complete list of species in the area.

Community Similarity

- The Jaccard index is calculated using the equation $C_J = a/(a + b + c)$
- For the data given in Table 17.B between the logged and unlogged sites:

$$C_J = 14/(14 + 1 + 2) = 0.82$$

- The Sorenson index is calculated using the equation $C_S = 2a/(2a + b + c)$
- For the data given in Table 17.B between the logged and unlogged sites:

$$C_S = 28/(28 + 1 + 2) = 0.90$$

Community Similarity

- The simple matching index, C_M makes use of the number of species absent in both areas, *d*

$$C_{SM} = a + d / a + b + c + d$$

- For the data given in Table 17.B between the logged and unlogged sites, and knowing *d* = 2:

$$C_{SM} = 14 + 2 / 14 + 1 + 2 + 2 = 0.84$$

Homework III: Calculate the Simpson and Shannon indices of the data and plot the data using time against diversity indices. Did you observe the changes through a day?

10 am	Temp	27	H%	54	PM2.5	16	softball	
Group	species1	species2	species3	species4	species5	species6	species7	species8
1	3	4	1					
2	11	1	2	2		1		
3	17			1	1			
4	17		1					

12 pm	Temp	26	H%	63	PM2.5	22	soccer	
Group	species1	species2	species3	species4	species5	species6	species7	species8
1	5	9				2		
2	14	1	3	1	1	1		2
3		56	1					
4	24	1						

2pm	Temp	29	H%	64	PM2.5	25	baseball	
Group	species1	species2	species3	species4	species5	species6	species7	species8
1	13	10	7	0	0	2	0	0
2	17	1	7	1	0	0	0	2
3	28			1		1		
4	12	3						