Measuring and Interpreting the Ecosystem Service of Forest Biodiversity

Bill Romme
Colorado State University
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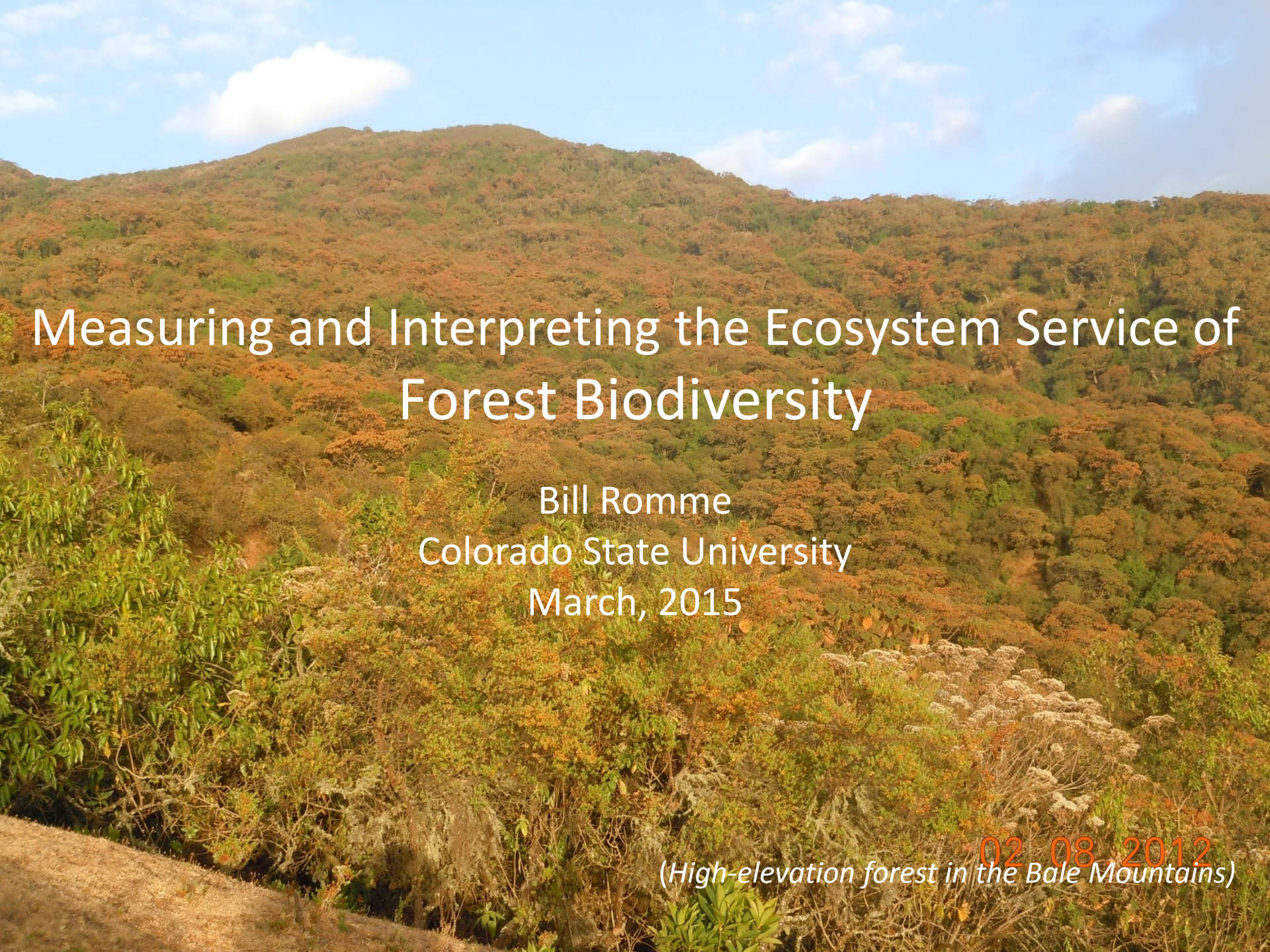

(*High-elevation forest in the Bale Mountains*)

Outline:

- What are ecosystem services
- Elements of forest biodiversity
- Biodiversity at three different scales
- How to sample biodiversity
- How the size of an area affects biodiversity
- How to measure and quantify biodiversity
- Conserving forest biodiversity

What are ecosystem services?

Ecosystem services are the benefits people obtain from ecosystems

Millenial Ecosystem Assessment in 2005:

-- called for by the United Nations Secretary General
-- authorized by governments around the world
-- prepared by 1360 experts from 95 countries

Ecosystems provide a great number and variety of services to people:

Provisioning Services
-- food
-- fresh water
-- wood & fiber
-- fuel

Supporting Services
-- biodiversity
-- nutrient cycling
-- soil formation
-- primary production

Regulating Services
-- moderation of climate
-- flood prevention
-- reduction in disease
-- water purification

Cultural Services
-- beauty & aesthetics
-- spiritual
-- education
-- recreation

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Elements of Forest Biodiversity

Trees & Shrubs

Herbs

Large Animals

Insects & Other Invertebrates

Soil Microbes

**** Species Diversity ****

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**** Species Diversity ****

**** Functional Diversity ****

Deciduous vs. Evergreen Species

Shade-Tolerant vs. Shade-Intolerant Species

Fleshy Fruits vs. Dry Fruits

Herbivores, Carnivores, Omnivores

Active in Day vs. Active at Night

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**** Species Diversity ****

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Active in Day vs. Active at Night

**** Structural Diversity ****

Standing Dead Trees

Large Dead Logs

Dead Leaves & Branches on Forest Floor

Greater tree diversity means greater wildlife diversity

Native forest at Wondo Genet with many species having many different functional traits

Eucalyptus plantation with one or two species, all with about the same functional characteristics

Biodiversity at Three Different Scales

Alpha Diversity … The variety of species in a single forest stand (1-100 hectares) … the 1-hectare stand surrounding the large *Afrocarpus* (*Podocarpus*) tree in Wondo Genet forest

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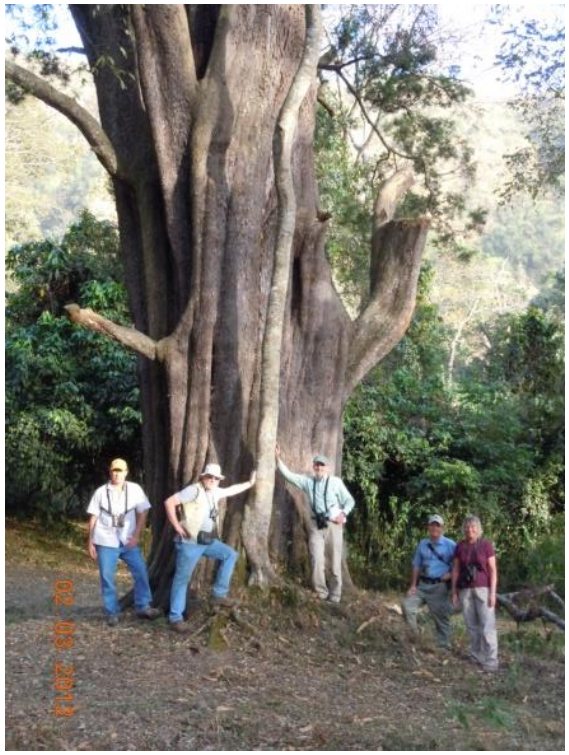

Beta Diversity … a measure of how different one forest stand is from another

Gamma Diversity … the variety of species among all forest stands combined (1,000 hectares or more) … the entire native forest at Wondo Genet, including many different habitats

←

Measuring Species Diversity in a Forest

Two ways to measure species diversity of a forest:

(1) **Census** = tally every individual tree in the forest
… practical only if the forest is small or you have lots of time

(2) **Sample** = tally trees within a large number of plots
… the plots must be representative of the forest as a whole, and must be scattered randomly throughout the forest

How the Size of an Area Affects Biodiversity

A larger tract of forest usually contains more species than a smaller tract of forest

Why is this?

- A bigger area can contain more of the rare species … those that exist at low density with individuals widely scattered … these kinds of species need a larger area to support a viable population
- A bigger area usually contains a greater variety of habitats … e.g., steep slopes and gentle slopes, drier soils and wetter soils, more fertile soils and less fertile soils … and different kinds of habitats can support different kinds of species

It is important to remember this "size of area" effect when sampling species diversity in a forest

The more you sample, the more species you will add to your list …
You will pick up the common or dominant species quickly, but it will require much sampling to encounter all of the rare species within your sample plots

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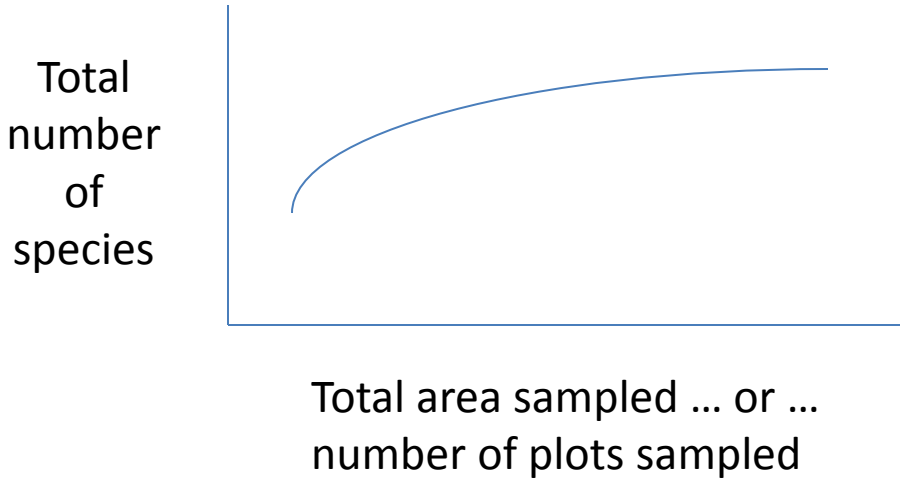

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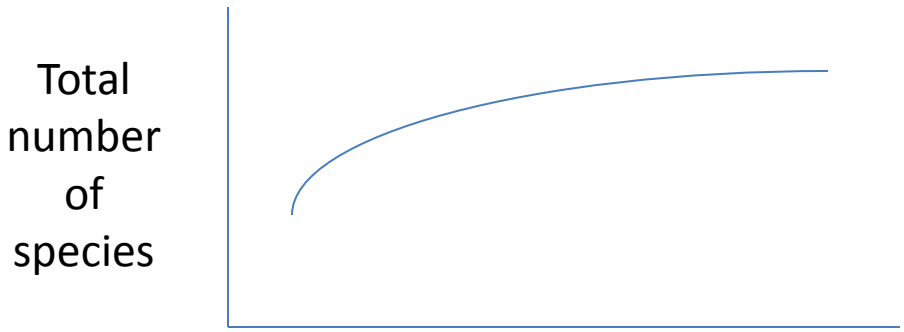

-- The species-area curve rises quickly at first, as we tally the common or dominant species
-- But then it continues to rise more slowly as we add rare species to our list
-- The curve usually does not become perfectly flat, because we usually do not encounter every last rare species

Example of a Species-Area Curve: the High-Elevation Portion of the Harenna Forest:

-- sampled by Nick Young
-- too big an area for a census, so Nick conducted a sample of the diversity of tree species in this 1,000-hectare forest
-- he distributed 1-hectare plots randomly through the area, and tallied the tree species that he found in each plot

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Species Found in Plot Rira10			
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Species Found in Plot Rira10			**Cumulative Species Found in all Plots Combined**
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Species Found in Plot Rira10	Species Found in Plot Rira11		Cumulative Species Found in all Plots Combined
Bersama abyssinica	Erica arborea		Bersama abyssinica
Canthium oligocarpum	Hypericum revolutum		Canthium oligocarpum
Dombeya torrida	Scheflera volenskii		Dombeya torrida
Prunus africana	Hagenia abyssinica		Prunus africana

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Prunus africana	Hagenia abyssinica		Prunus africana
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Canthium oligocarpum	Hypericum revolutum	Scheflera volenskii	Canthium oligocarpum
Dombeya torrida	Scheflera volenskii	Hypericum revolutum	Dombeya torrida
Prunus africana	Hagenia abyssinica		Prunus africana
			Erica arborea
			Hypericum revolutum
			Scheflera volenskii
			Hagenia abyssinica

Here is a table showing the total number of species found among all 24 sample plots in the forest near Rira

Number of Sample Plots	Total Number of Species Found
Number of Sample Plots	Cumulative Number of Species Found
1	4
2	8
3	8
4	9
5	9
6	9
7	10
8	10
9	10
10	10
11	10
12	10
13	10
14	10
15	10
16	10
17	11
18	11
19	12
20	12
21	12
22	12
23	12
24	12

Here is a table showing the total number of species found among all 24 sample plots in the forest near Rira

Notice that he added new species very quickly at first, but then he added them more slowly, because the later plots contain the same species that he found in the earlier plots

Yet, he is still adding a few new species when he gets to 17 plots and then again at 19 plots … these are rare species in this forest

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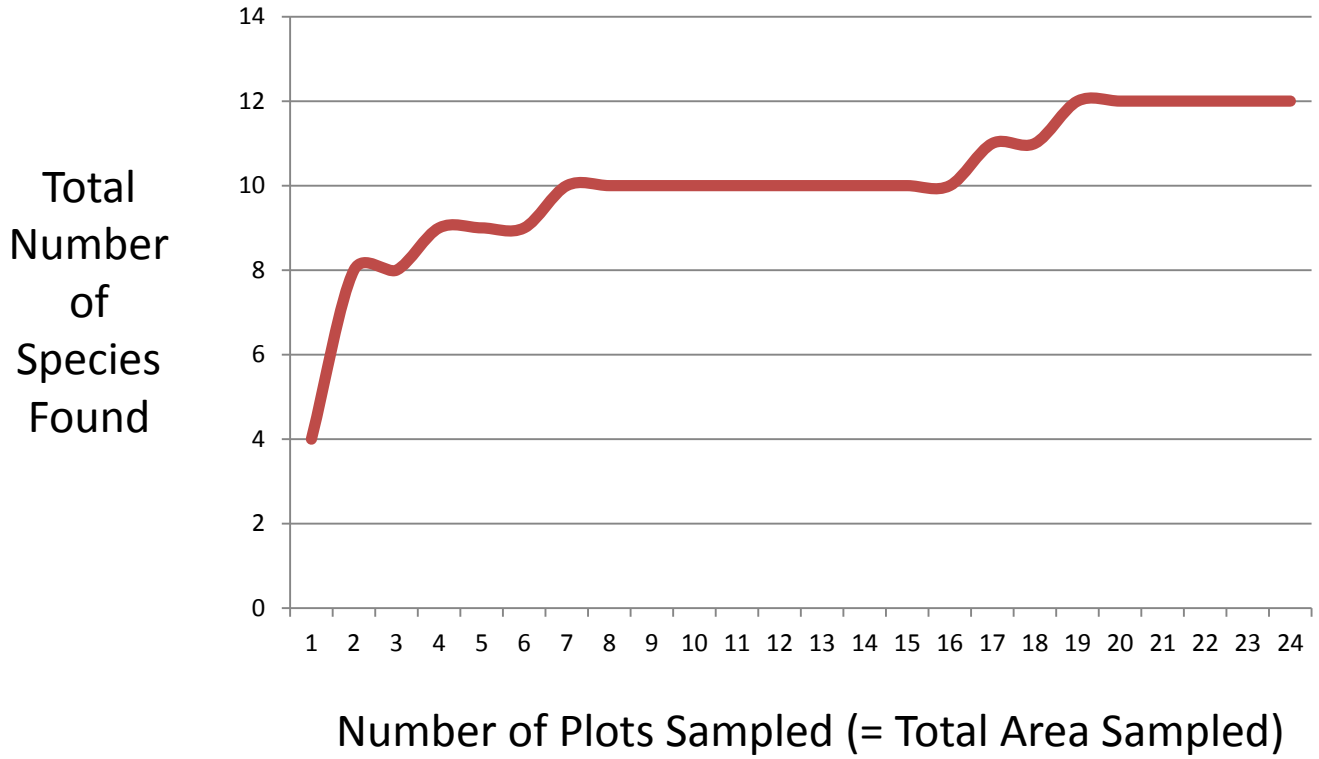
13	10
14	10
15	10
16	10
17	11
18	11
19	12
20	12
21	12
22	12
23	12
24	12

Now, let's make a graph out of the data in this table:



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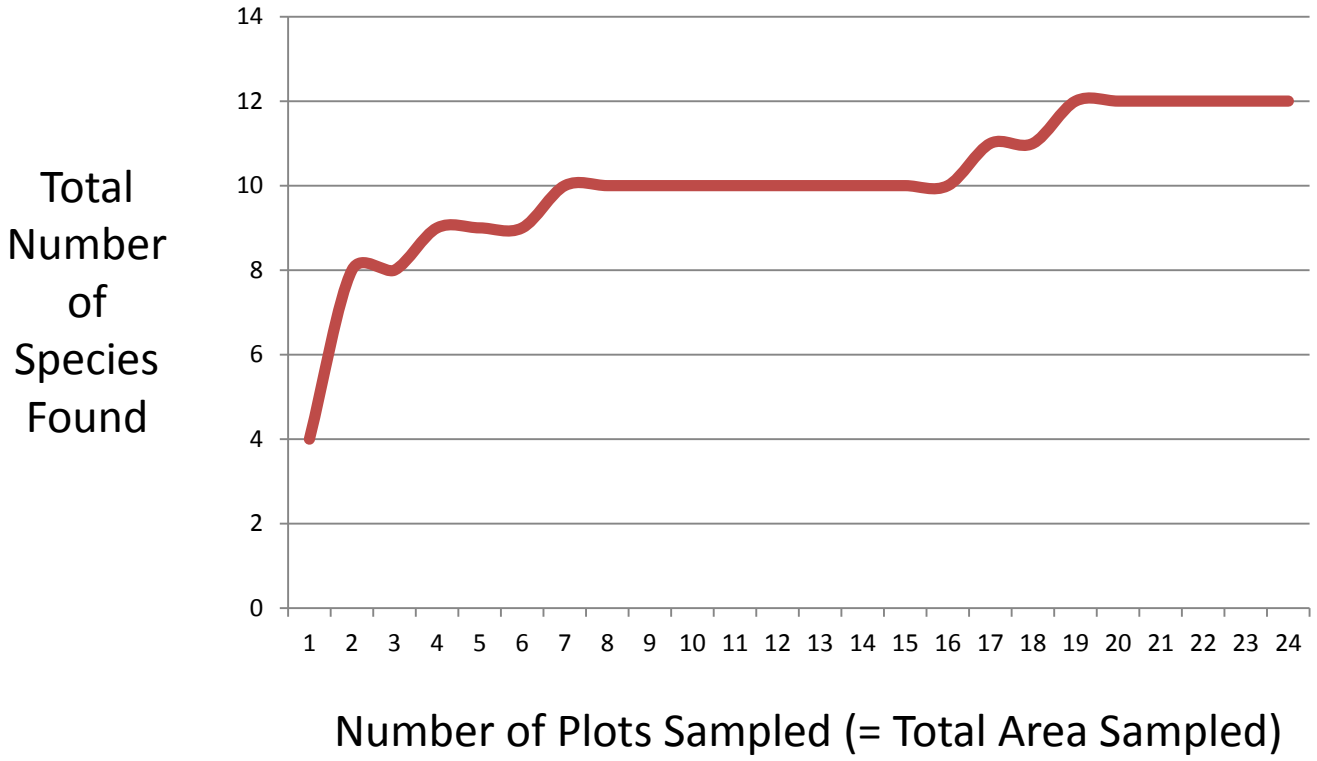

-- Notice that the curve rises quickly, then levels off. Nick had found most of the species in this forest after sampling only 7 plots.

-- However, these 7 plots missed 2 rare species that he didn't find until after 19 plots

-- He stopped after 24 plots. Would he find additional rare species if he continued sampling additional plots?

Practical Considerations:

Suppose that we want to know how many tree species exist in the native forest of Wondo Genet …

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Instead, we could sample tree species in a number of plots … how many plots do we need?

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Don't know …

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Instead, we could sample tree species in a number of plots … how many plots do we need?

Don't know …

So, sample 10 plots, then make a species-area curve … if the curve is still rising at 10 plots, sample 10 more … keep adding plots until the curve levels off

Practical Considerations:

Suppose that we want to know how many tree species exist in the native forest of Wondo Genet …

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Instead, we could sample tree species in a number of plots … how many plots do we need?

Don't know …

So, sample 10 plots, then make species-area curve … if the curve is still rising at 10 plots, sample 10 more … keep adding plots until the curve levels off

Even at this point, there probably are additional rare species in this forest that we have missed … but if the species-area curve has leveled off, then we can be confident that we have found most of the species

How to Quantify and Report Biodiversity

Two Principal Ways:

(1) **Richness**

-- Richness is simply the total number species in an area

-- Important to state the size of the area, especially if we want to compare two areas … a bigger area will have more species simply because it is bigger

-- It is meaningful to compare the richness of two areas ***only*** if those two areas are about the same size

-- Note that richness does not give any information about the abundance of any of the species … a rare species counts the same as a common one

(2) **Shannon Index of Diversity**:

-- Provides information about the relative abundance of the species in addition to the total number of species

-- Requires a modification of the sampling method … in addition to listing all of the species found in a plot, we need to measure the abundance of each species … e.g., record how many individuals of each species are present in each plot

-- Again, it is most meaningful to compare Shannon's Index in two areas, if those two areas are about the same size

Richness is easy to calculate: just add up the total number of species that we have found in our sample plots

Shannon's diversity index is more complicated … requires some math

What is important is not the details of the math, but how we interpret the results of the calculation

Let's make up an example to see how the calculation works …

Example: suppose that 0.01 hectare of forest has three species:
Hagenia abyssinica … 17 trees
Hypericum revolutum… 17 trees
Erica arborea … 16 trees
Total = 50 trees

Let's make up an example to see how the calculation works …

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Total = 50 trees

Richness = 3 species

So now let's also calculate the Shannon diversity index which includes information on the relative abundance of each species.

Notice that these three species have almost exactly equal abundance …

Let's make up an example to see how the calculation works …

Shannon Index: H = - sum[Pi*log(Pi)]

Pi = proportion of all trees in a forest that are of a particular species

Example: suppose that 0.01 hectare of forest has three species:
Hagenia abyssinica … 17 trees
Hypericum revolutum… 17 trees
Erica arborea … 16 trees
Total = 50 trees

Pi for Hagenia abyssinica = 17/50 = 0.34
Pi for Hypericum revolutum = 17/50 = 0.34
Pi for Erica arborea = 16/50 = 0.32
Total = 1.00

log (Pi) for Hagenia abyssinica = log(0.34) = -0.46852
log (Pi) for Hypericum revolutum = log(0.34) = -0.46852
log (Pi) for Erica arborea = log(0.32) = -0.49485

H = -[(0.34)x(- 0.46852)+(0.34)x(- 0.46852) + (0.32) x (- 0.49485)]
= -[(-0.159) + (-0.159) + (-0.158)]
= -[-0.476]
= 0.476

So the Shannon Index for this imaginary forest is 0.476 …

What does that mean?

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Really, nothing by itself.
The Shannon Index is useful when ***comparing*** two or more forests

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So, let's compare this imaginary forest with another imaginary forest …

Suppose that this second imaginary forest also has 3 trees … but the numbers are not even in this forest; one species dominates

Shannon Index: H = - sum[Pi*log(Pi)]

Pi = proportion of all trees in a forest that are of a particular species

Example: this second 0.01 hectare of forest also has three species:
Hagenia abyssinica … 48 trees
Hypericum revolutum … 1 tree
Erica arborea … 1 tree
Total = 50 trees

Pi for Hagenia abyssinica = 48/50 = 0.96
Pi for Hypericum revolutum = 1/50 = 0.02
Pi for Erica arborea = 1/50 = 0.02
Total = 1.00

log (Pi) for Hagenia abyssinica = log(0.96) = -0.01773
log (Pi) for Hypericum revolutum= log(0.02) = -1.69897
log (Pi) for Erica arborea = log(0.2) = -1.69897

H = -[(0.96)x(-0.01773)+(0.02) x (-1.69897) + (0.02)x(-1.69897)]
= -[(-0.017) + (-0.033) + (-0.033)]
= -[-0.083]
= 0.083

Enough numbers and arithmetic!!

Let's see how the numbers compare between these two imaginary forests …

Forest #1: 3 species, each about equally abundant

Hagenia abyssinica … 17 trees
Hypericum revolutum … 17 trees
Erica arborea … 16 trees
Total = 50 trees

Richness = 3 species
Shannon H = 0.476

Forest #2: 3 species, but one species strongly dominates the forest

Hagenia abyssinica … 48 trees
Hypericum revolutum … 1 tree
Erica arborea … 1 tree
Total = 50 trees

Richness = 3 species
Shannon H = 0.083

Enough numbers and arithmetic!!

Let's see how the numbers compare between these two imaginary forests …

Forest #1: 3 species, each about equally abundant

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Hypericum revolutum … 17 trees — ***Richness = 3 species***
Erica arborea … 16 trees — ***Shannon H = 0.476***
Total = 50 trees

Forest #2: 3 species, but one species strongly dominates the forest

Hagenia abyssinica … 48 trees
Hypericum revolutum … 1 tree — ***Richness = 3 species***
Erica arborea … 1 tree — ***Shannon H = 0.083***
Total = 50 trees

** If we walk through forest #1, we continually encounter individuals of all three species that are present … but if we walk through forest #2, we may go for a long time before we see anything other than Hagenia abyssinica*

Forest #1 has more equal distribution of individuals among species, and it feels more diverse … forest #2 has a very unequal distribution of individuals among species, and it does not feel very diverse at all

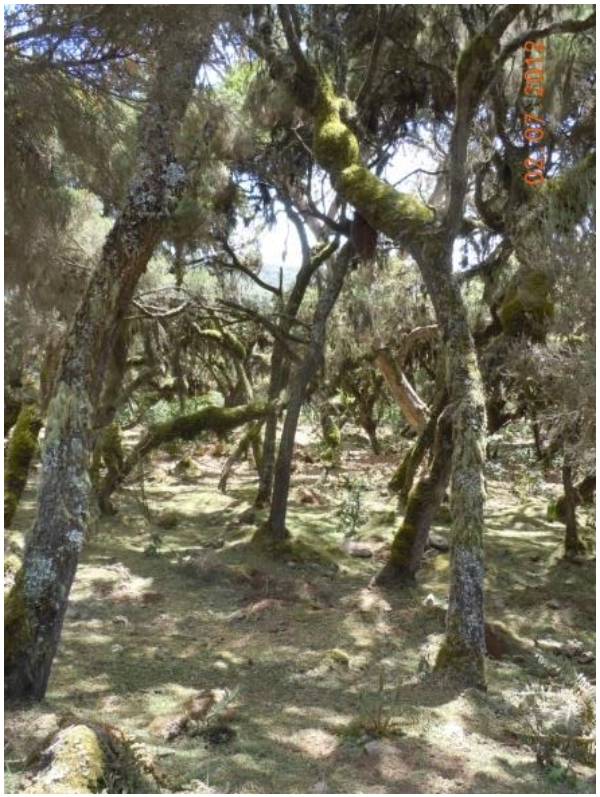
Wildlife will have a similar experience, and will be more diverse in forest #1

So, richness and the Shannon Index give very different pictures of the diversity of the forest … but these different pictures are very complementary.

Remember that the Shannon Index is most useful when ***comparing*** two or more forests …

These might be two forests on different kinds of sites …

Or comparing a forest of unknown diversity with a set of forests that we know are healthy and diverse.



So, now let's look at a real example:

Dr. Tefera measured the density of all tree species INSIDE and OUTSIDE two enclosures in central Ethiopia.

The area inside the enclosures was 88 hectares, so he sampled an area of comparable size outside the enclosures.

From his data, we can compare the diversity of the forests inside and outside the enclosure, to see the effect of protecting a forest from browsing animals … for this purpose, we will calculate both richness and the Shannon Index

(Dr. Tefera published this study in the Journal of Arid Environments in 2005 … I have copied the data in his paper.)

Species	Density INSIDE enclosure	Density OUTSIDE enclosure
A. abyssinica	171	42
A. seyal	141	1
A.etbaica	122	53
A. tortilis	103	1
Clerodendrum myricoides	77	3
Croton macrostachyus	64	32
Eucalyptus camaldulensis	36	8
Buddleja polystachia	19	0
A. sieberiana	15	0
Combretum collinum	13	0
Euphorbia candelabrum	7	0
Withania somnifera	2	43
Ehretia cymosa	1	3
Ficus sycomorus	1	0
A. albida	1	1
Celtis africana	1	0
Olea europaea	0.5	1

Tree Species inside and outside an enclosure in central Ethiopia

Sampled by Dr. Tefera

Data published in Journal of Arid Environments in 2005

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Withania somnifera	2	43
Ehretia cymosa	1	3
Ficus sycomorus	1	0
A. albida	1	1
Celtis africana	1	0
Olea europaea	0.5	1

Tree Species inside and outside an enclosure in central Ethiopia

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Richness INSIDE = 17 species
Richness OUTSIDE = 11 species

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Shannon Diversity Index (H) INSIDE
H = 0.92
Shannon Diversity Index (H) OUTSIDE
H = 0.74

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Euphorbia candelabrum	7	0
Withania somnifera	2	43
Ehretia cymosa	1	3
Ficus sycomorus	1	0
A. albida	1	1
Celtis africana	1	0
Olea europaea	0.5	1

Tree Species inside and outside an enclosure in central Ethiopia

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Richness INSIDE = 17 species
Richness OUTSIDE = 11 species

Shannon Diversity Index (H) INSIDE
H = 0.92
Shannon Diversity Index (H) OUTSIDE
H = 0.74

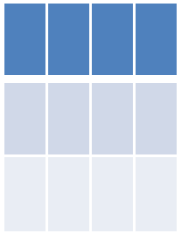
** There are more species of trees inside the enclosure …*
and the individual trees are more evenly distributed among those species

Here is another example of how to measure and interpret forest diversity using richness and the Shannon Index …

A group of researchers, headed by Abrham Abiyu, measured forest diversity inside an exclosure and in two plantations in northern Ethiopia.

The exclosure contained a native forest; one plantation was of *Eucalyptus globulus*; the other was of *Cupressus lusitanica*.

The study was published in the journal Mountain Research and Development in 2011, and the article was kindly provided to me by Dr. Demel Teketay, who is one of the co-authors.



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What they found …

Diversity Index	Native Forest	Cupressus Plantation	Eucalyptus Plantation
Richness	9	1	2
Shannon Index (H)	1.13	0.12	0.39

-- The native forest is more diverse than the plantations, by both measures

-- Of the two plantations, the one with *Eucalyptus* is a bit more diverse than the one with *Cupressus*

Other ecological characteristics also were very different in the native forest compared with the two plantations …

-- Greater soil organic carbon in the native forest
-- Greater soil nitrogen in the native forest
-- Lower soil bulk density in the native forest

But some ecological characteristics were not much different in the native forest compared with the two plantations …

-- Soil potassium
-- soil phosphorus
-- soil clay content
-- soil sand content

Other ecological characteristics also were very different in the native forest compared with the two plantations …

-- Greater soil organic carbon in the native forest
-- Greater soil nitrogen in the native forest
-- Lower soil bulk density in the native forest

But some ecological characteristics were not much different in the native forest compared with the two plantations …

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-- soil phosphorus
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-- soil sand content

We need more studies of this kind to better understand the ecosystem services provided by forests having greater biodiversity …

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Some General Guidelines

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But … we also need single species plantations, because these may more efficient than native forests in producing wood for harvest, and can reduce the pressure on native forests for wood products … but don't convert native forests to plantations, because healthy native forests are rare and hard to re-create.

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-- Monitor the condition of the protected forest on a regular basis (e.g., once each year) … correct any problems that are detected

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- Elements of forest biodiversity
- Biodiversity at three different scales
- How to sample biodiversity
- How the size of an area affects biodiversity
- How to measure and quantify biodiversity
- Conserving forest biodiversity

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***Question for you**: Is this useful information for your job of protecting and improving the condition of forests in Ethiopia?*