Biodiversity monitoring

The task is big

- We are in a “biodiversity crisis”
  - Rate of extinction is similar to mass extinction events in the past
- Tracking individual species is expensive
- We need to conserve not only species, but the ecosystems on which they depend
- Need methods of assessing and tracking biological diversity at a coarser scale than individual species

Biological diversity

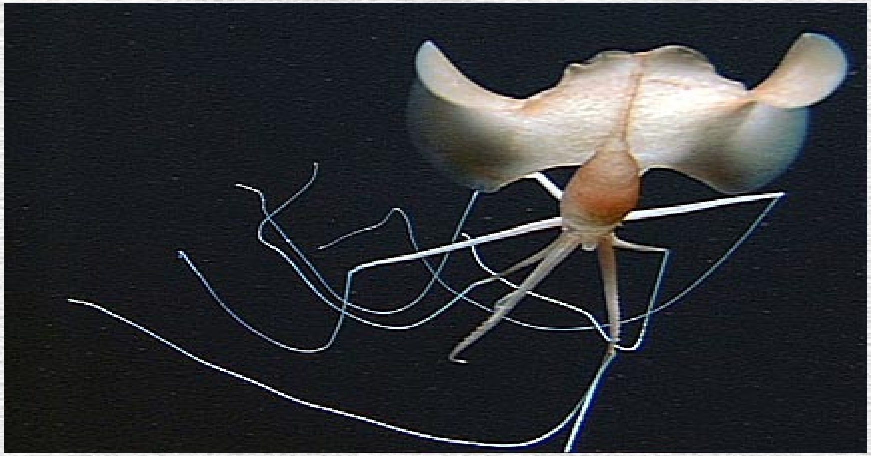
- Estimates of the number of species on earth vary, but credible estimates tend to fall between 5 and 10 million – could be much higher depending on microbial diversity
- We have cataloged about 1.9 million species
- Big species in accessible areas are well known
- Species that are small, cryptic, or inaccessible are less well known

http://www.top10species.org/

Pearl River map turtle, US

Callicebus caquetensis, Columbia

Scaly eyed gecko, Ecuador



Grimalditheuthis bonplandi, Pacific Ocean

The Yeti crab, 2006

Biodiversity is never fully measured

- We only ever measure a subset of it
  - Only what is known
  - Only what is practical
- We only ever estimate that which we attempt to measure
  - Biased estimates
  - Temporal/spatial variability

Inventory and monitoring

- Inventory = status
  - Assessment of the species present in an area
- Monitoring = trend
  - Assessment of change in biodiversity over time

Inventory broadly, but not deeply

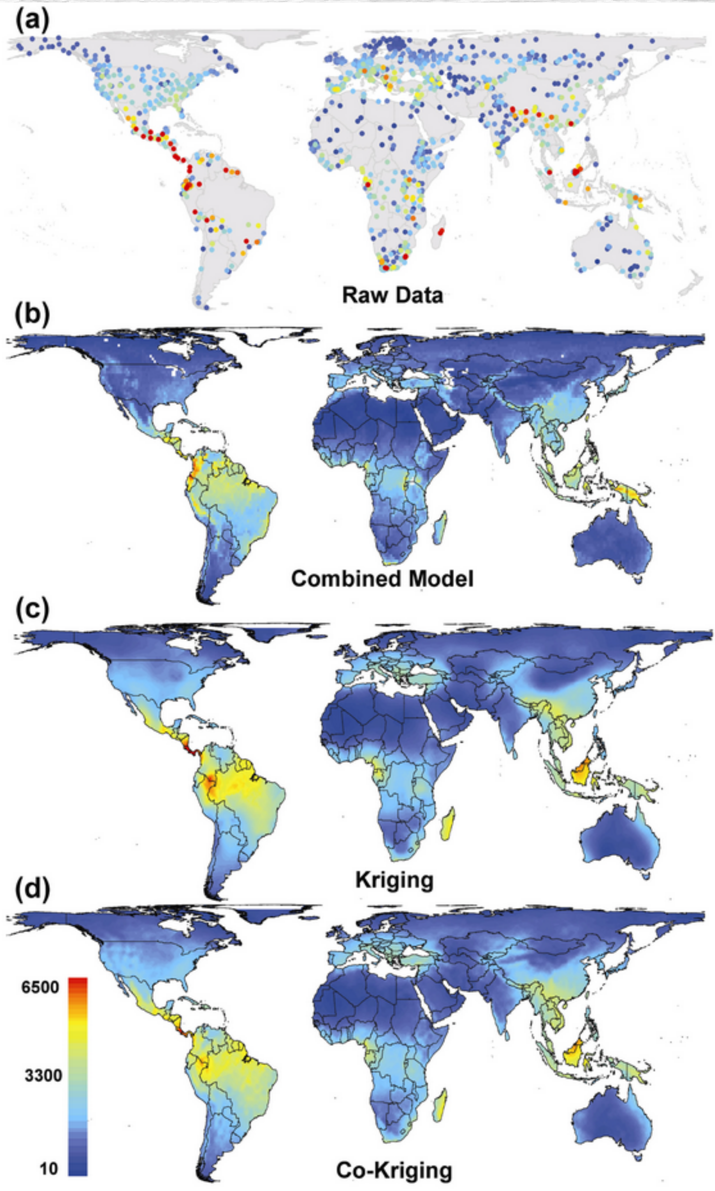
- One solution to getting the job done is to work at a coarse scale of resolution, but sample as broadly as possible
  - Presence/absence of species
  - Document as many species as you can
- Advantages
  - Know where the diverse areas are
  - Can document whether you're including all the species you wish to conserve
- Disadvantages
  - You don't know if you're meeting the needs of any single species
  - You don't have detailed information about any single species

Species richness

- Simple measure of biodiversity = count the species present
- Depends on taxonomic representativeness of the sampling
  - Are all species detected? NO! So, which are not?
  - Detectability will vary by species
  - Rare species are less likely to be detected
  - If detectability differs among areas, then differences in apparent diversity could result
- Doesn't account for compositional differences

San Elijo Lagoon

Spatial projections



From Kreft and Jetz, 2007

Diversity indices

- Species richness doesn’t include information on relative abundance
- Example of two sites:
  - Sp 1 = 100, Sp 2 = 10, Sp 3 = 10
  - Sp 1 = 40, Sp 2 = 40, Sp 3 = 40

  ...which is more diverse?
- Diversity indices incorporate species richness and species “evenness” into a single value
- The Shannon-Wiener index is common

The Shannon-Wiener index

$$H' = -\sum p_i \ln p_i$$

- Increases with increasing richness
- Increases with increasing evenness
- Can calculate evenness (E) as:

$$E = \frac{H'}{\ln S}$$

- Ln S is the maximum possible diversity (H_{max})

Species composition

- Composition = the species that make up the community
- Richness, evenness, diversity don’t account for species composition
- Two sites can have the same diversities and have completely different lists of species
- An invasive exotic species that replaces a native species may not reduce diversity
- Need to account for species composition as well
  - Focus on native diversity
  - Use a composition metric

Composition metrics

- Simplest is a list of species
  - Hard to assess uncertainty – can’t calculate a standard error for a list
  - Quantitative measures of composition are preferable
- Can use similarity measures
  - There are many
  - Some just based on lists (presence/absence)
  - Some based on abundance
- Multivariate methods can be used to obtain composition measures
- If you use these to compare time points you have a measure of change in composition over time

Species	Burned	Unburned
Baccharis sp	0.003	
Black Sage		0.007
Buckwheat	0.104	0.199
California Sagebrush	0.007	0.207
Coyote Brush	0.008	
Herb	0.863	0.303
Lichen		0.003
Unknown	0.015	0.257
White sage		0.023

Jaccard: proportion shared = 4/(4+2+3) = 0.444

Bray-Curtis:

$$\frac{\sum min(n_{i1}, n_{i2})}{\sum n_{i1} + \sum n_{i2}} = 0.398$$

Use of range maps to assess change in diversity

- Range maps of individual species are very coarse, general depictions of distribution
- But, some species have undergone changes in their ranges at geographic scales
- If range changes have been consistent across species, an overall change in diversity will be evident
- Not useful for fine-scale assessment, only appropriate for continental scale

Changes in historic ranges

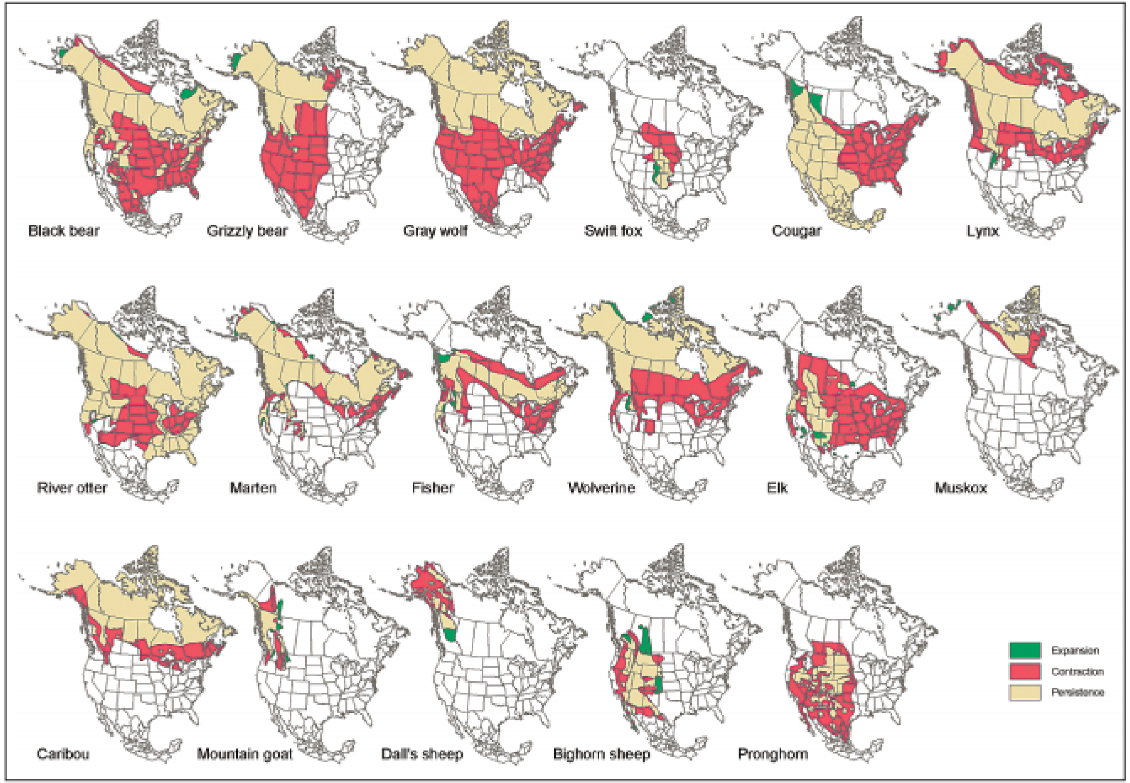


Figure 2. Areas of expansion, contraction, and persistence, based on historic and current species ranges for 17 species that experienced range contractions over more than 20% of their historic range.

From Laliberte and Ripple 2004

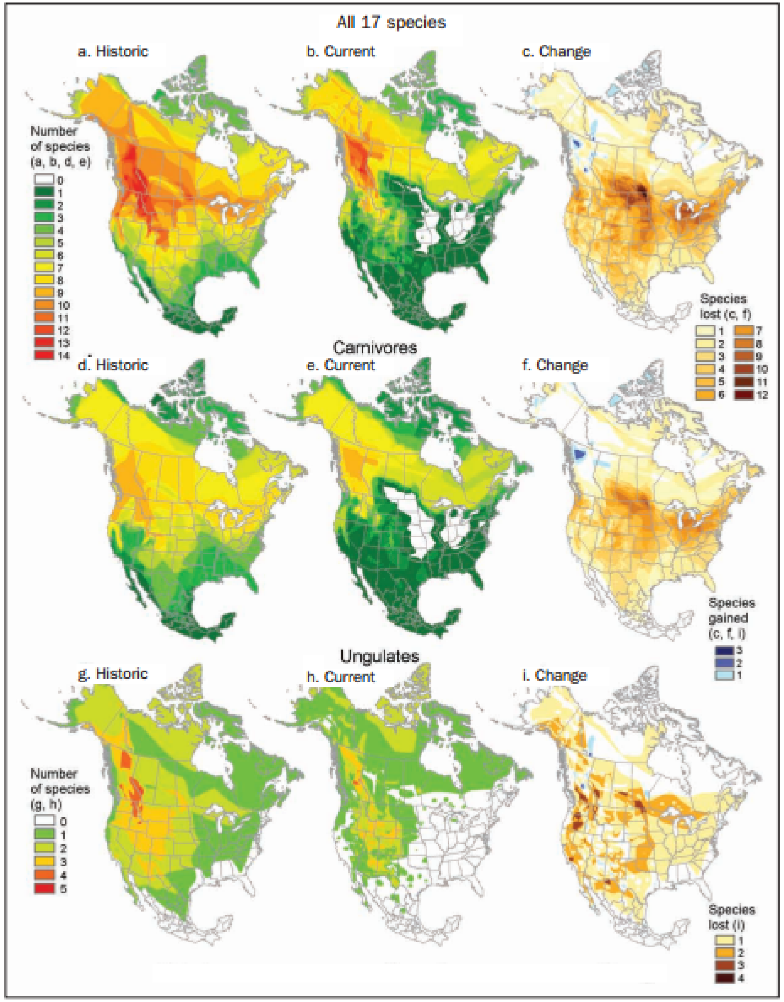


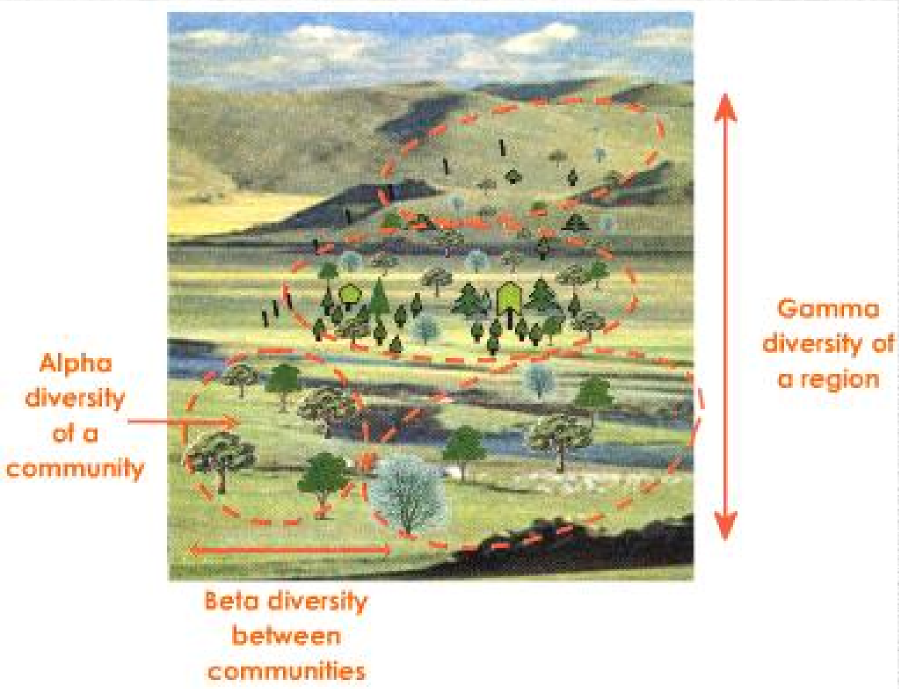
Figure 4. Historic and current species richness and number of species lost over time for 17 species that experienced range contractions over more than 20% of their historic range (a, b, c), for 10 carnivores (d, e, f), and for 7 ungulates (g, h, i). The maps for historic and current species richness were created by combining the historic or current range maps for the species. The maps showing the number of species lost or gained over time were created by subtracting the current from the historic maps.

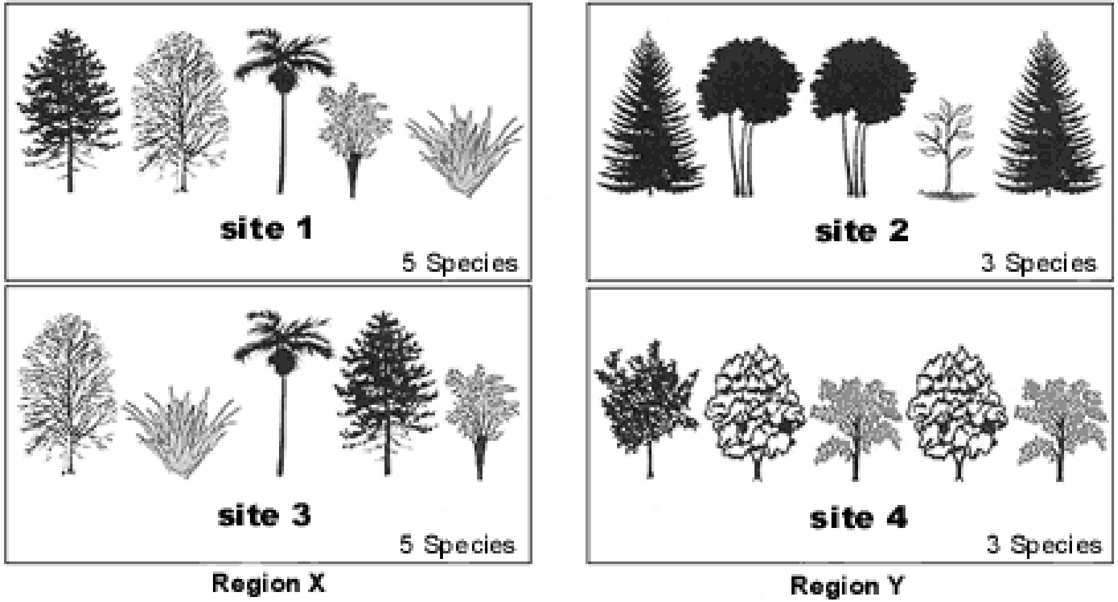
What causes high diversity?

- We may want to protect diverse areas to get more “bang” for our conservation “buck” = look for biodiversity “hotspots”
- What causes high species diversity?
  - Habitat/niche diversity
  - Landscape heterogeneity
- Because of this, we can often substitute measures of habitat/landscape diversity for actual data on species

Scale dependence of diversity

- Traditionally, we define diversity at different scales of resolution
  - α = alpha diversity, diversity at a point
  - β = change in species composition among points in a region
  - γ = gamma diversity, diversity within a region
- Sites may be high in one of these, but not the others





ALPHA-, BETA- AND GAMMA-DIVERSITY.
Alpha diversity is measured locally, at a single site,
as at sites 1 and 2. Site 1 has higher alpha-diversity than site 2.

Beta-diversity measures the amount of change betwen two sites or along a gradient, as in regions X and Y. Region Y has higher beta-diversity than region X, as there is a higher turnover of species among the sites in region Y.

Gamma-diversity is similar to alpha-diversity, only measured over a large scale. Both alpha- and beta-diversity contribute to gamma-diversity. Region X has high alpha-diversity at its sites, but they are all fairly similar; the region thus has low beta-diversity and only moderate gamma-diversity. Region Y has low alpha-diversity at its sites, but the sites differ from each other; the region therefore has high beta-diversity, and higher gamma-diversity than region X.

Using proxies of species diversity

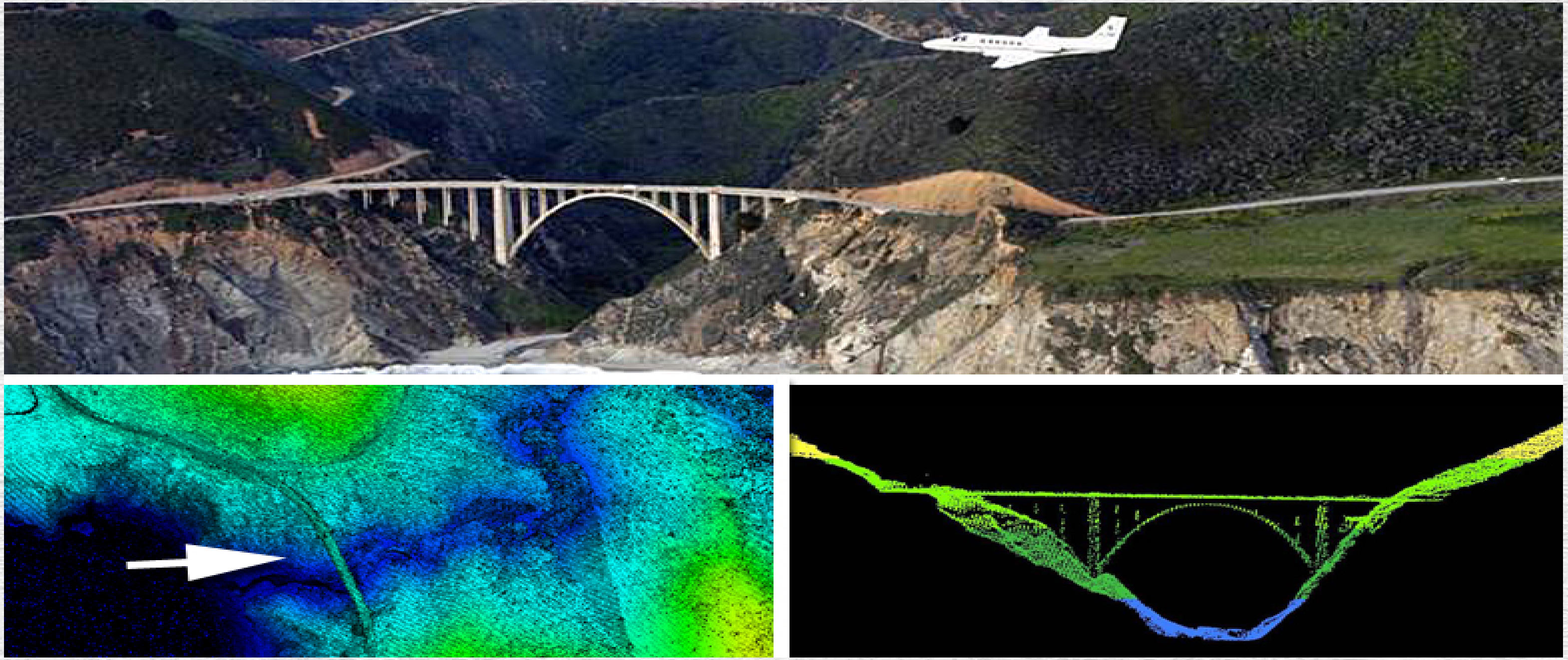
- Sometimes it isn't practical to obtain species diversity information
  - Remote areas
  - Limited time/budget constraints
- Can instead use a “proxy”, or index, of biodiversity
- Proxies are selected that are easier to measure, and that have a functional relationship with diversity

Soundscapes, structural diversity

- Use recordings of sound at a site as an index of biodiversity (diversity of vocalizing species)
- Use LIDAR to measure structural diversity
- Relate diversity in the soundscape to structural diversity
- To the extent they are related, structural diversity is a good proxy for biological diversity

LIDAR

- Light Detection and Ranging
- Remote sensing technique, collected from aircraft
- Uses pulsed laser to measure distances to features on the ground
- Given known location of the aircraft, can be used to derive accurate 3D representations of features
- Can then be used to measure structure of vegetation



Limitations of proxy measures

- How do you know that diversity in the proxy equates to diversity in species?
- Will the proxy change over time as the species distributions and abundances change?

Measuring changes in diversity over time

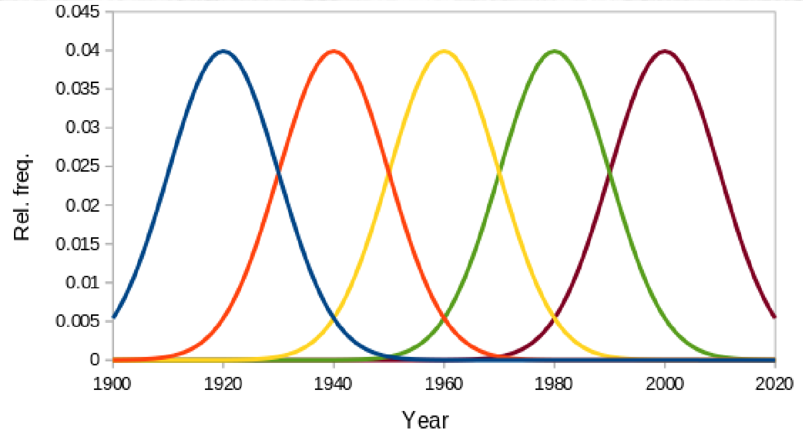
- Can measure diversity each year, use regression to measure change
- For species composition, can use a method like Canonical Correspondence Analysis, with year as a predictor

Example: change in bird species at the San Dieguito River estuary

- Surveys have been conducted at the SDR estuary for 12 years
- 11 full years of data available
- We can ask, is composition changing over time?
  - Use a matrix of samples (rows, years of sampling) by species (columns, one for each species)
  - Ask if there is a change in relative distribution of the species over time

The basic idea of CCA...

- Species respond to environmental gradients
- As you move along the gradient, the species composition is changing



- Canonical correspondence analysis finds the pattern of change in composition that best aligns with the predictor variable(s) you use
- If we use year as a predictor, it will find the pattern of change in composition most associated with time

CCA finds scores for samples and species

- Scores for years are numerical representations of species composition
  - Years with similar scores had similar species composition
- Scores for species are numerical representation of the years the species was observed
  - Species with similar scores were present in the same years

Year	Species 1	Species 2	Species 3	Species 4	Species 5	Sample score
1900	0	0	0	1	0	-0.75
1920	1	0	0	2	0	-0.5
1940	2	0	1	1	0	-0.25
1960	1	0	2	0	1	0
1980	0	1	1	0	2	0.25
2000	0	2	0	0	1	0.5
2020	0	1	0	0	0	0.75
	-0.25	0.5	0	-0.5	0.25	

Year	Species 4	Species 1	Species 3	Species 5	Species 2	Sample score
1900	1	0	0	0	0	-0.75
1920	2	1	0	0	0	-0.5
1940	1	2	1	0	0	-0.25
1960	0	1	2	1	0	0
1980	0	0	1	2	1	0.25
2000	0	0	0	1	2	0.5
2020	0	0	0	0	1	0.75
	-0.5	-0.25	0	0.25	0.5	

Statistical significance, interpretation

- There is not a known sampling distribution for CCA
- Instead of using a distribution, p-values obtained by randomization testing
  - Data are randomly shuffled
  - Analysis performed on randomized data
  - Strength of relationship measured each time
  - Size of the observed relationship compared to randomized – proportion of random outcomes as strong as observed is the p-value
- To interpret which species are changing over time can correlated species abundances with year scores

Limitations of biodiversity monitoring

- Is presence an indication of viability?
- Will a change in abundance be detectable, or only a change in distribution?
- Will a change in one species out of a community be detectable?
- Will the causes of change be evident?