Assessing brachiopod diversity in the Glass Mountains of West Texas and implications for closure of the Delaware Basin*

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*Activity originally developed by Tom Olszewski, Texas A&M University

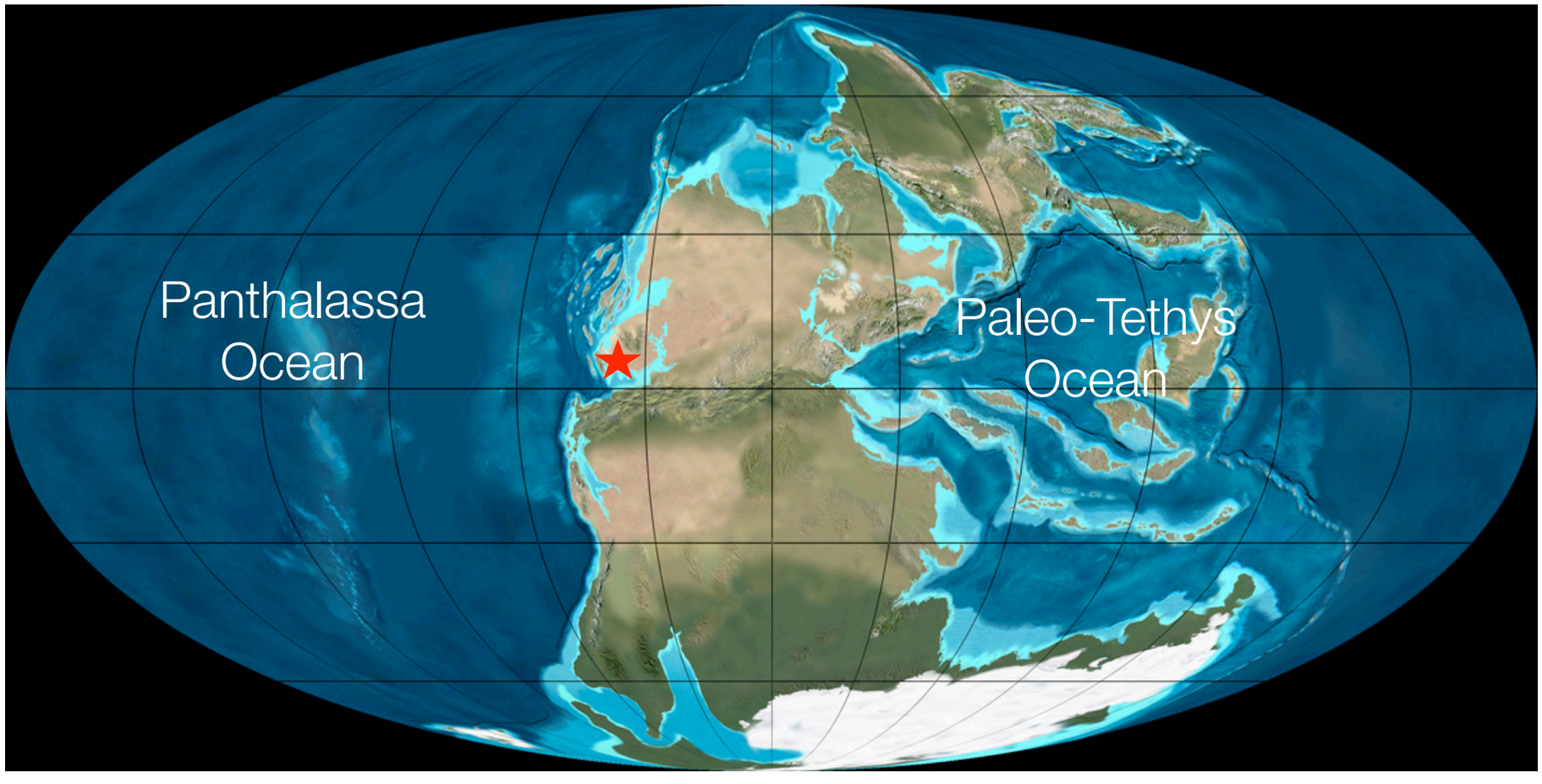
Goals

- Students create and analyze brachiopod diversity plots based on raw data
- Students apply bootstrap resampling method to normalize diversity
- Students evaluate the research question with raw data and the sampling-corrected diversity

  - *Did the diversity of brachiopods in this ecosystem change significantly through time as environmental conditions changed?*

Geologic background

- Late Permian (260 Ma) paleogeographic map



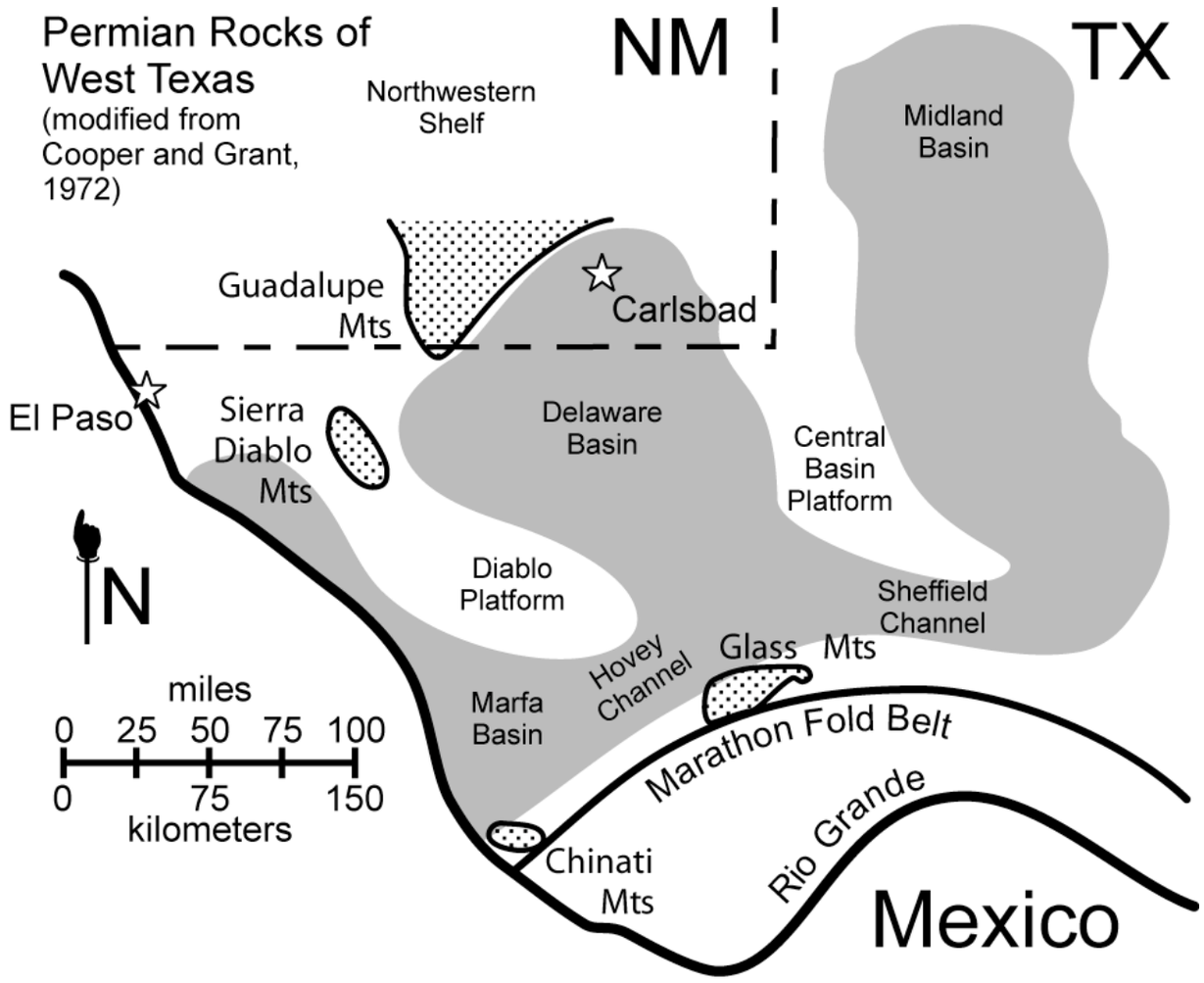
Geologic background

- Delaware Basin

- Glass Mountains and Guadalupe Mountains expose part of an ancient reef ecosystem that rimmed the basin

- Delaware Basin received normal marine waters by Hovey Channel

- By end of Middle Permian, basin become isolated, indicated by extensive accumulation of evaporites



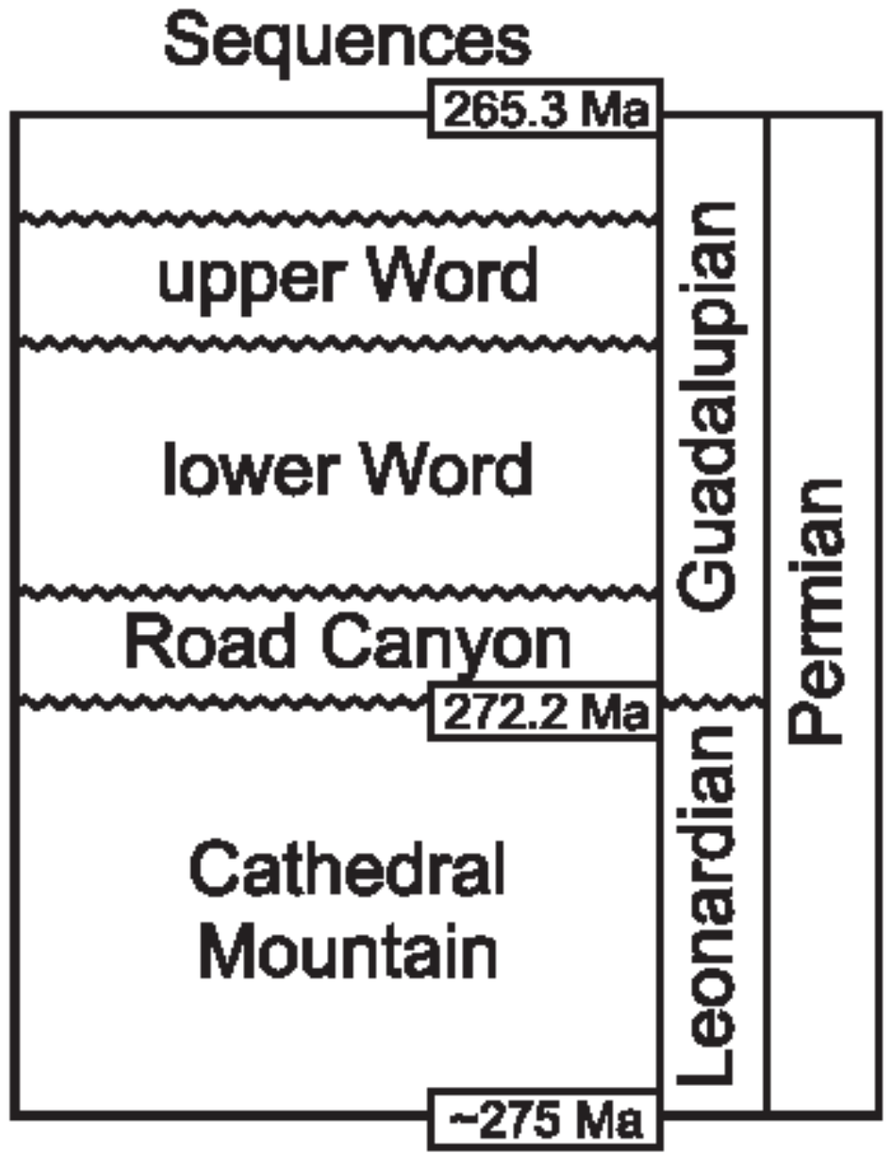
Reef composed of sponges, bryozoans, algae, brachiopods, rugose corals, crinoids

El Capitan, Guadalupe Mountains, Williams Ranch Road

Permian Reef Complex

Geologic background

- Glass Mountains stratigraphy
- Second-order flooding event at base of Guadalupian; termination of normal marine deposition just above base of Lopingian
- Sequences separated by unconformities
    - They provide distinct, non-overlapping intervals of time (these can be thought as repeated natural experiments)
- Analyses will be conducted at the sequence level: Cathedral Mountain, Road Canyon, lower Word, and upper Word



Research question

- *Did the diversity of brachiopods in this ecosystem change significantly through time as environmental conditions changed?*

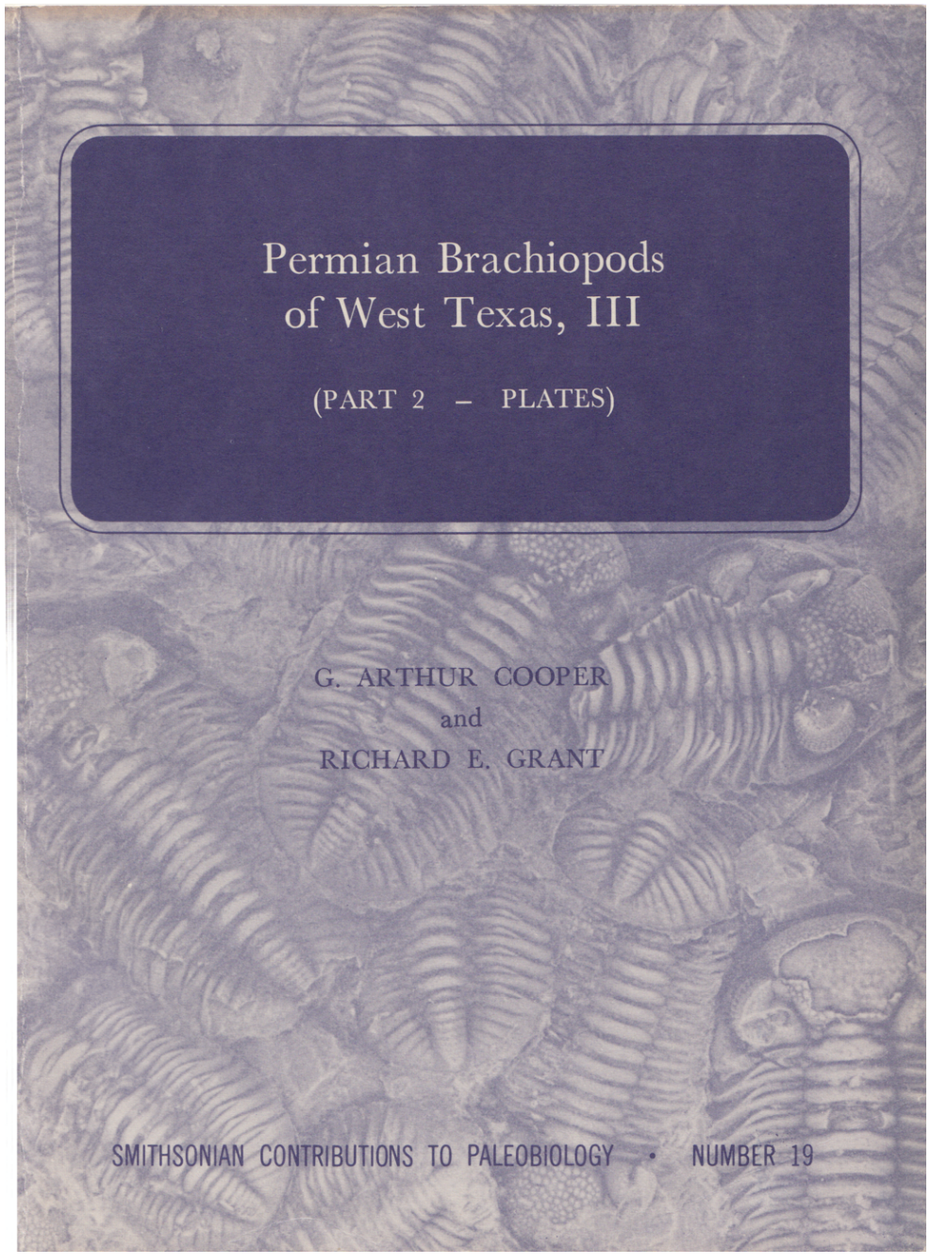
- Hypersaline conditions are physiological stressful to most multicellular animals

- Stressful conditions generally reduce viability of rare taxa and can lead to lower diversity

Data

- Brachiopod genera – presence/absence
- Collections made by G. A. Cooper and R. E. Grant between the late 1930's and late 1960's
- Another possible data set – J. G. Johnson (1990) Journal of Paleontology 64:902–941

Sequence	Richness	Number of Collections
upper Word	71	17
lower Word	75	24
Road Canyon	107	69
Cathedral Mountain	104	81



lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0
Cenorhynchia	5		0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Cleiothyridina	1		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collemataria	15		1	1	0	1	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	1	1	1
Composita	15		1	1	0	1	0	1	1	0	1	0	0	0	1	1	1	1	1	0	1	0	1	0	1	1
Compressoproductus	3		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
Cooperina	12		1	1	0	1	0	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	0
Costispinifera	13		0	1	0	1	0	1	1	0	1	1	0	0	0	1	1	1	0	0	1	0	1	1	1	0
Crenispirifer	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crurithyris	8		0	0	0	1	0	1	1	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0
Ctenalosia	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyclacantharia	18		1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	1	0	1	1	0	1	1	1	1
Derbyia	15		1	1	0	1	0	1	1	0	1	1	0	0	1	1	1	1	0	0	0	1	0	1	1	1
Dielasma	18		1	1	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	1
Dyoros (Dyoros)	14		1	1	0	1	0	1	1	1	1	0	0	1	1	0	1	0	0	0	1	0	1	1	0	1
Dyoros (Lissosia)	13		1	0	0	1	0	1	1	0	0	1	0	0	1	1	1	1	1	0	0	0	0	1	1	1
Dyoros (Tetragonetes)	4		0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Echinauris	17		1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	1	0	1	1	1
Echinosteges	13		1	1	0	1	0	1	1	0	1	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1
Ectoposia	4		0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Edriosteges	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enteletes	15		0	1	0	1	1	1	0	0	1	1	0	0	0	1	1	1	1	0	1	1	1	1	1	0
Glossothyropsis	6		1	0	0	1	0	0	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Grandaurispina	13		1	1	0	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1
Heteralosia	15		1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	1	1	0
Heterelasma	7		0	1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Holosia	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hustedia	20		1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1
Leiorhynchoidea	4		0	0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lepidocrania	4		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leurosina	6		0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0
Liosotella	17		1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	1	0	1	1	1	1
Lirellaria	1		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meekella	21		1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1
Megousia	16		1	1	0	1	1	1	1	0	1	1	0	0	0	1	0	1	1	0	1	0	1	1	1	1
Metriolepis	9		0	1	0	1	0	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
Neochonetes	1		0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neophricadothyris	5		0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Neospirifer	10		0	1	0	1	0	1	1	0	1	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0
Notothyris	3		0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Paranorella	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paraspiriferina	16		1	1	0	1	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	1
Paucispinifera	17		1	1	0	1	0	1	1	1	1	0	0	0	1	1	1	1	1	0	1	0	1	1	1	1
Petasmatherus	7		0	0	0	1	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1
Petrocrania	2		0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phrenophoria	5		1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polymorpharia	2		0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pontisia	1		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pseudodielasma	7		0	0	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1
Pseudoleptodus	3		0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptygmactrum	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reticulariina	9		0	0	0	1	0	1	1	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	1	0
Rhamnaria	18		1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1
Rhynchopora	15		1	1	0	1	0	1	1	1	1	0	0	0	1	1	1	1	1	0	0	0	1	0	1	1
Spiriferella	10		1	0	0	1	0	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	1	1
Spiriferellina	14		1	1	0	1	0	1	1	0	1	1	0	0	1	0	1	1	1	0	0	0	0	1	1	1
Spiriferinaella	6		0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	0
Stenoscisma	7		0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0
Tautosia	4		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Texarina	6		0	0	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Thamnosia	2		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Thedusia	11		1	1	0	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
Tropidelasma	8		0	1	0	1	0	1	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0
Undulella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Waagenoconcha	7		1	0	0	1	0	1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0
Wellerella	10		1	0	1	1	0	1	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1	1
Xenosteges	10		1	1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	1	0
Yakovlevia	10		1	0	0	1	0	1	1	1	1	0	0	0	1	0	1	0	0	0	1	0	0	0	0	1
	Richness =>		34	30	9	63	7	66	59	21	37	15	1	4	35	30	42	38	15	1	14	7	18	24	36	32

Example of data set given to students

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0
Cenorhynchia	5		0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Cleiothyridina	1		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Collemataria	15		1	1	0	1	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	0	1	1	1
Composita	15		1	1	0	1	0	1	1	0	1	0	0	0	1	1	1	1	1	0	1	0	1	0	1	1
Compressoproductus	3		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Cooperina	12		1	1	0	1	0	1	1	1	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1	0
Costispirifer	13		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	1	0	0	0	0	0	1	1	0
Crenispirifer	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crurithyris	8		0	0	0	1	0	1	1	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0
Ctenalosia	1		0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Cyclacantharia	18		1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1
Derbyia	6		0	1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	1	1
Dielasma	18		1	1	1	0	1	1	1	0	1	1	0	0	1	0	1	0	1	0	1	0	1	1	1	1
Dyoros (Dyoros)	14		1	1	0	0	0	1	1	1	0	1	0	0	1	0	1	0	0	0	1	0	1	1	1	1
Dyoros (Lissosia)	9		0	0	0	0	0	1	1	0	0	1	0	0	1	0	1	0	1	0	0	0	0	0	1	1
Dyoros (Tetragonetes)	4		0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1
Echinauris	5		0	0	0	1	0	1	1	1	0	1	0	0	1	0	1	0	1	0	0	0	0	1	0	1
Echinosteges	13		1	1	0	1	0	1	1	0	1	0	1	0	1	0	1	1	1	0	0	1	0	1	0	1
Ectoposia	4		0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Edriosteges	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Enteletes	7		0	0	0	1	0	1	1	0	1	1	0	0	0	0	1	1	1	0	1	1	1	0	1	0
Glossothyropsis	6		1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Grandaurispina	13		1	1	0	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	1	1
Heteralosia	15		1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	0	1	1	0
Heterelasma	7		0	1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Holosia	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hustedia	20		1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	1	1	1	1	1
Leiorhynchoidea	4		0	0	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lepidocrania	4		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leurosina	6		0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0
Liosotella	17		1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	1	0	1	1	1	1
Lirellaria	1		0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Meekella	21		1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1
Megousia	16		1	1	0	1	1	1	1	0	1	1	0	0	0	1	1	1	1	0	1	0	1	1	1	1
Metriolepis	9		0	1	0	1	0	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
Neochonetes	1		0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Neophricadothyris	5		0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1
Neospirifer	10		0	1	0	1	0	1	1	0	1	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0
Notothyris	3		0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Paranorella	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Paraspiriferina	16		1	1	0	1	0	1	1	1	1	1	0	0	1	1	1	1	0	0	0	0	1	1	1	1
Paucispinifera	17		1	1	0	1	0	1	1	1	1	0	0	0	1	1	1	1	1	0	1	0	1	1	1	1
Petasmatherus	7		0	0	0	1	0	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1
Petrocrania	2		0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Phrenophoria	5		1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Polymorpharia	2		0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Pontisia	1		0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pseudodielasma	7		0	0	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1
Pseudoleptodus	3		0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ptygmactrum	1		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reticulariina	9		0	0	0	1	0	1	1	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	1	0
Rhamnaria	18		1	1	1	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	1	1	1	1	1	1
Rhynchopora	15		1	1	0	1	0	1	1	1	1	0	0	0	1	1	1	1	0	0	0	0	1	0	1	1
Spiriferella	10		1	0	0	1	0	1	1	1	0	0	0	0	1	0	1	0	1	0	0	0	0	0	1	1
Spiriferellina	14		1	1	0	1	0	1	1	0	1	1	0	0	1	0	1	1	1	0	0	0	0	1	1	1
Spiriferinaella	6		0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	0
Stenoscisma	7		0	0	0	1	0	1	1	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0
Tautosia	4		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Texarina	6		0	0	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Thamnosia	2		0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Thedusia	11		1	1	0	1	0	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0	1	1
Tropidelasma	8		0	1	0	1	0	1	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0
Undulella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Waagenoconcha	7		1	0	0	1	0	1	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0
Wellerella	10		1	0	1	1	0	1	1	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1	1
Xenosteges	10		1	1	0	1	0	1	1	0	1	0	0	0	1	0	1	0	0	0	0	0	0	1	1	0
Yakovlevia	10		1	0	0	1	0	1	1	1	1	0	0	0	1	0	1	0	0	0	1	0	0	0	0	1
	Richness =>		34	30	9	63	7	66	59	21	37	15	1	4	35	30	42	38	15	1	14	7	18	24	36	32

Example of data set given to students

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0

Example of data set given to students

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0

Brachiopods

Example of data set given to students

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0

Brachiopods

Collections

Example of data set given to students

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0

Brachiopods

Collections

Collections assigned a number

Example of data set given to students

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0

Brachiopods

Collections

Collections assigned a number

Presence/absence

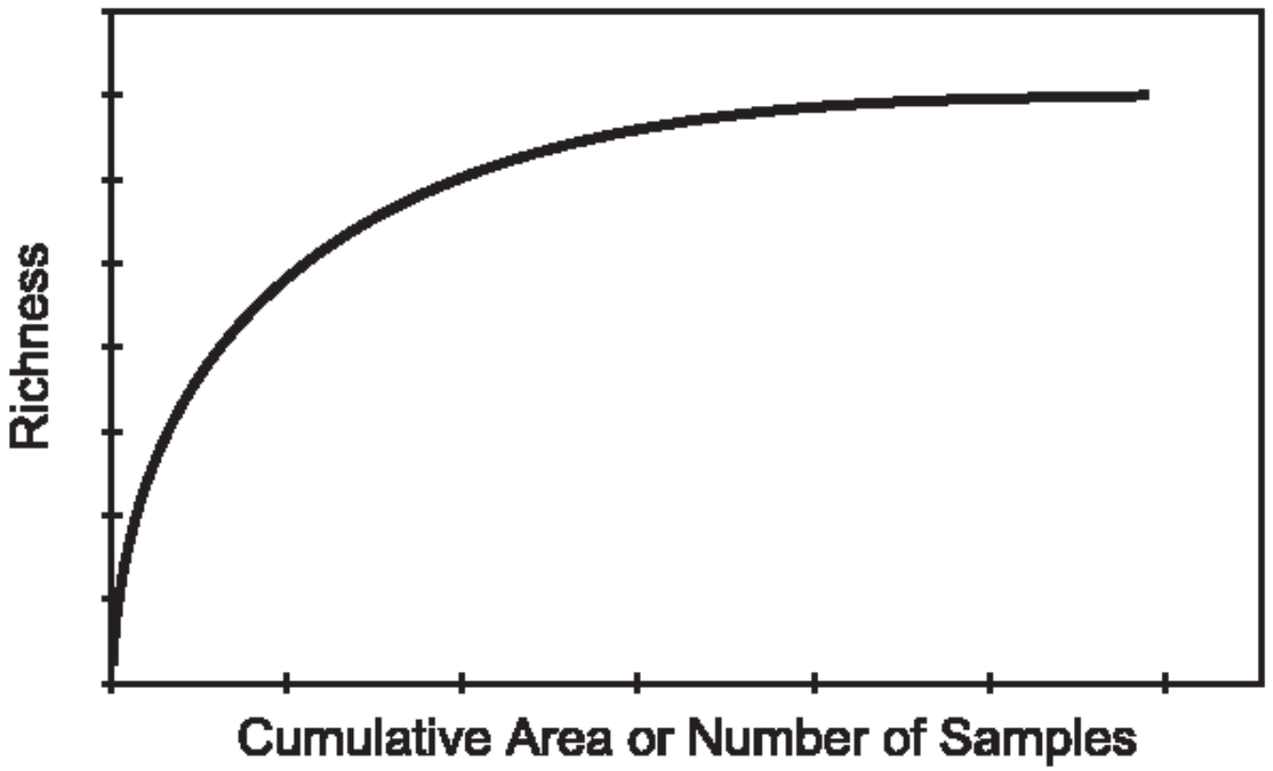
Example of data set given to students

Species-area relationship

- Theory of island biogeography (MacArthur and Wilson 1967)
    - Larger islands contain more species than smaller ones – determined by extinction and immigration

- As you increase area or number of samples, the species richness (i.e., number of species) also increases

- Abundant, cosmopolitan found quickly, while increasing sampling effort is needed to find rare taxa



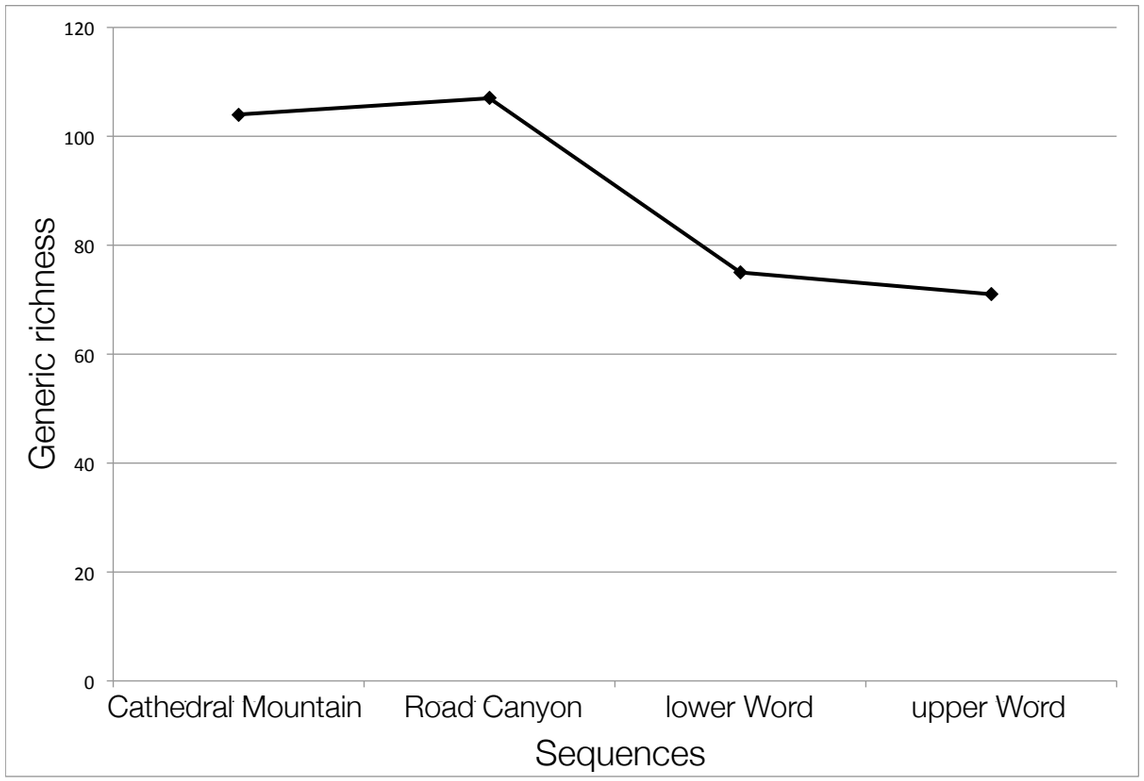
Analysis

- Bootstrapping – a resampling method
  - Draw repeated samples a large number (1000) of times from a population
  - Calculate the mean on the bootstrap population
  - Construct confidence intervals – maximum and minimum values of the bootstrap population
- Fairly easy for students to compute by hand (but not 1000 times!)
  - For our purposes, number of repeated samples depends on the number of collections we are resampling to

Plots of data

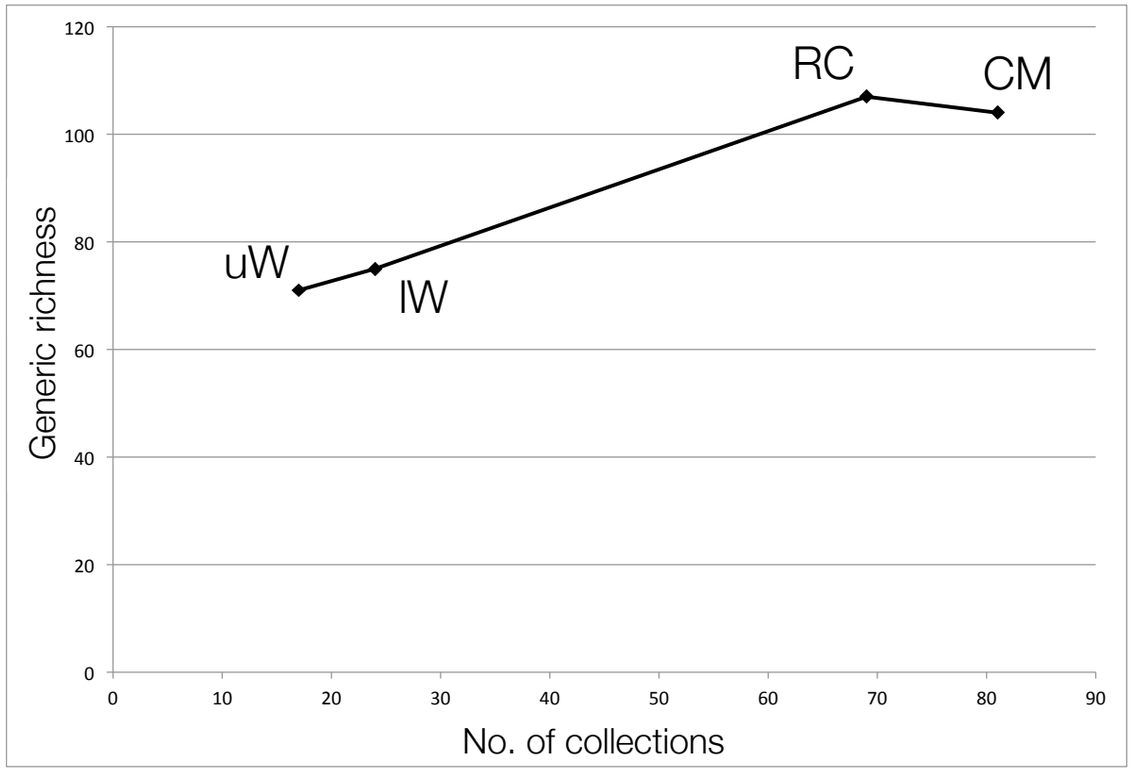
Data obtained from table

Brachiopod generic richness by sequence



The raw data shows that diversity declines over time.

Number of collections vs. generic richness



Number of collections influences richness.

Does the same pattern emerge if the Road Canyon and Cathedral Mountain are resampled to the Word Formation?

Running the analysis

- Each student is given a set of random numbers – one set of 17 and one set of 24

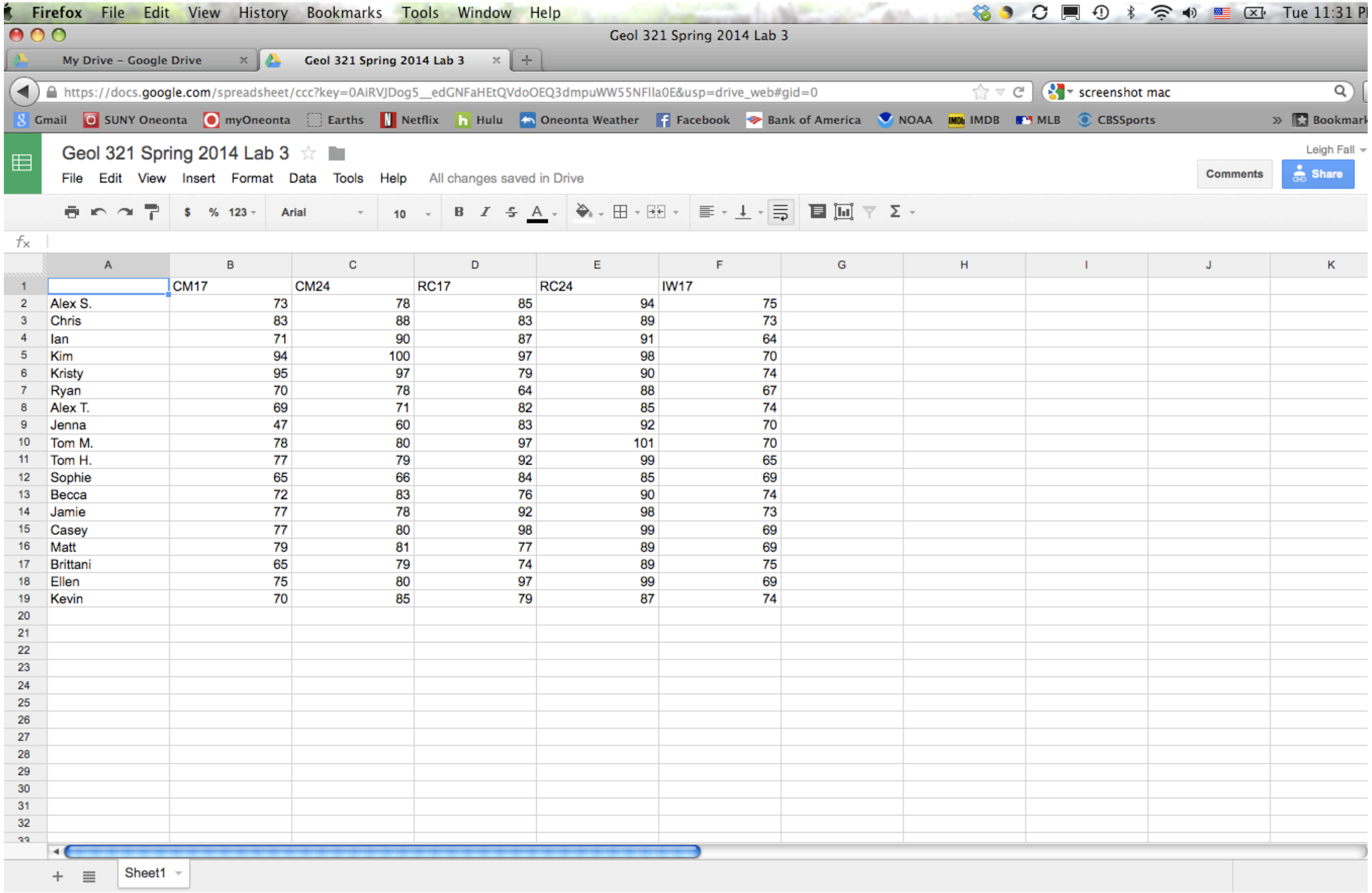
    - expected diversity of Cathedral Mountain at 17 and 24 collections
      expected diversity of Road Canyon at 17 and 24 collections, and
      expected diversity of lower Word at 17 collections.

Sequence	Number of Collections	Resample to uW	Resample to lW
upper Word	17	NA	NA
lower Word	24	17	NA
Road Canyon	69	17	24
Cathedral Mountain	81	17	24

Running the analysis

lower Word Fm			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
(24 collections, 75 genera)	Collection =>		505	506	703E	706	706A	706C	706E	706Z	713	718D	719E	721P	723T	723W	724U	726R	726S	731H	731M	731P	731U	732S	733Q	735C
Genus	Occurrences																									
Acanthocrania	7		0	1	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0
Acolosia	2		0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Allorhynchus	16		1	0	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	0	1	1	1	1	1	1
Arionthia	3		0	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bothrionia	5		0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Cactosteges	13		1	1	0	1	0	1	1	0	1	1	0	1	0	1	1	1	0	0	0	0	0	1	1	0
Cancrinella	5		1	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Cartorhium	7		0	0	0	1	0	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0

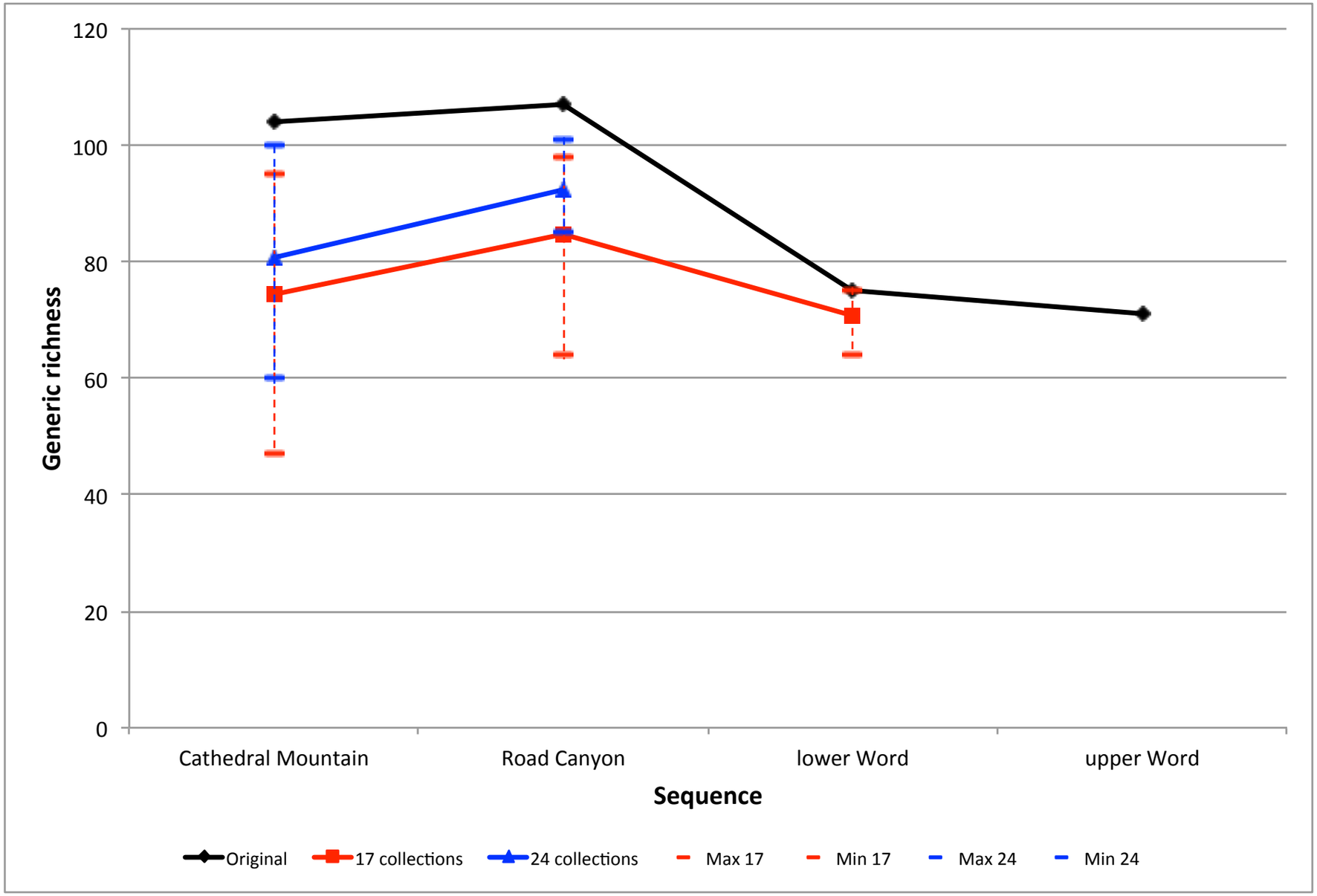
CM	8 77 10 73 27 33 81 63 19 67 58 55 6 80 48 56 2 34 35 28 62 16 15 4
RC	46 66 8 2 12 38 21 26 30 35 32 28 15 67 61 60 43 5 6 40 62 57 56 1
IW	9 1 6 4 11 8 12 10 21 3 7 16 13 18 2 14 15



	A	B	C	D	E	F
1		CM17	CM24	RC17	RC24	IW17
2	Alex S.	73	78	85	94	75
3	Chris	83	88	83	89	73
4	Ian	71	90	87	91	64
5	Kim	94	100	97	98	70
6	Kristy	95	97	79	90	74
7	Ryan	70	78	64	88	67
8	Alex T.	69	71	82	85	74
9	Jenna	47	60	83	92	70
10	Tom M.	78	80	97	101	70
11	Tom H.	77	79	92	99	65
12	Sophie	65	66	84	85	69
13	Becca	72	83	76	90	74
14	Jamie	77	78	92	98	73
15	Casey	77	80	98	99	69
16	Matt	79	81	77	89	69
17	Brittani	65	79	74	89	75
18	Ellen	75	80	97	99	69
19	Kevin	70	85	79	87	74

Students share data on Google Drive. They do not resample 1000 times! Download as Excel spreadsheet and calculate mean, maximum value, and minimum value.

Plot of sampling-corrected data



Students can evaluate the question – What is the sampling-corrected diversity history? What might this suggest about environmental conditions during this time interval? Related to closure of basin?

Final thoughts

- Students learn how number of samples can change interpretations

- Students have a difficult time answering question because the outcome is not clear cut

- Students have a difficult time understanding confidence intervals

- Important concepts covered – sampling, species-area curve, use of confidence intervals, sequence stratigraphy, presence/absence data, diversity, common/rare taxa

- Activity provides opportunity to incorporate sequence stratigraphic concepts