

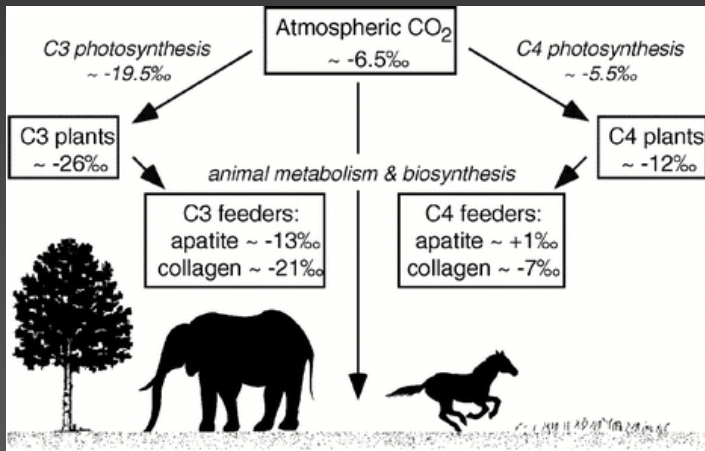
# Increasing the research potential of digitized fossils: A pilot study using Specify to attach stable isotope data to vouchered museum specimens

Sean M. Moran, Richard C. Hulbert, Warren H. Brown, Bruce J. MacFadden  
Florida Museum of Natural History, University of Florida



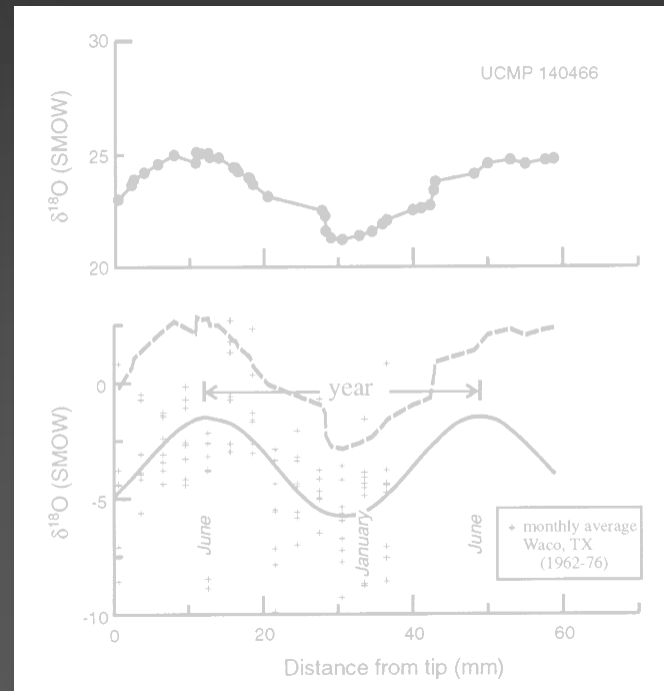
# Stable Isotopes in Vertebrate Paleontology

## Paleodiet ( $\delta^{13}\text{C}$ )



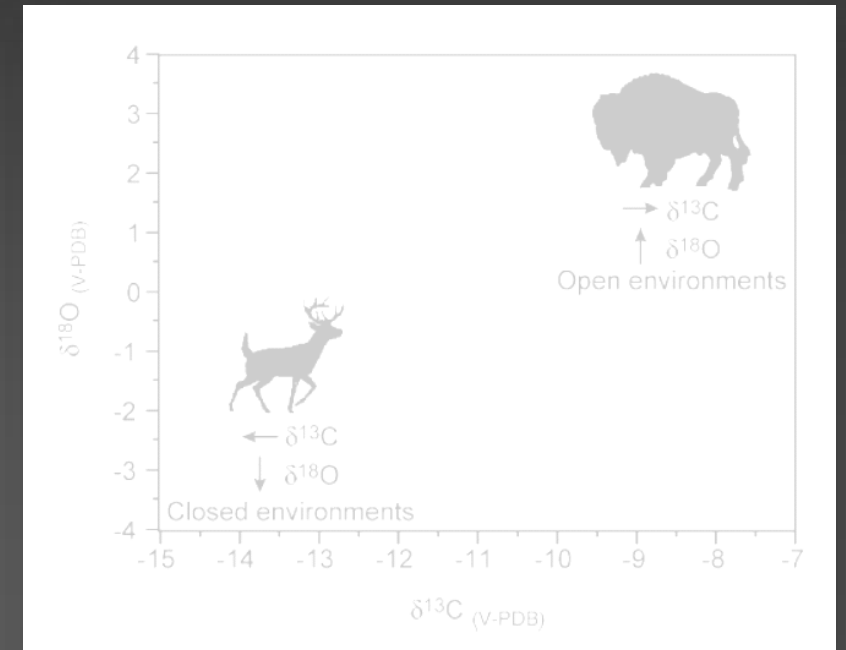
Koch, 1998

## Paleoclimate ( $\delta^{18}\text{O}$ )



Sharp and Cerling, 1998

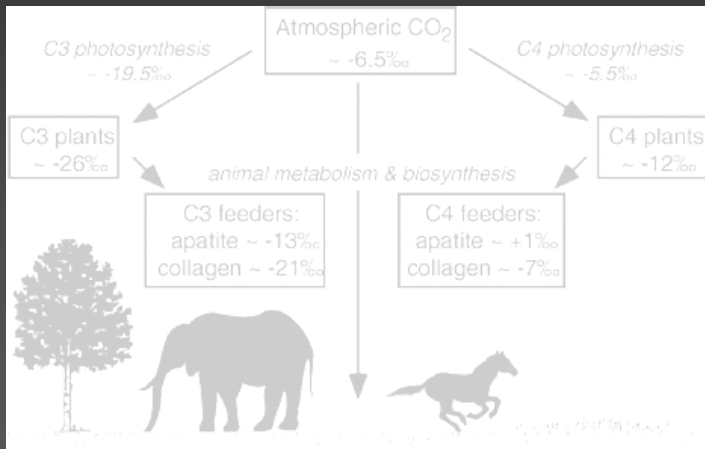
## Paleoenvironmental Reconstruction ( $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ )



Feranec and MacFadden, 2006

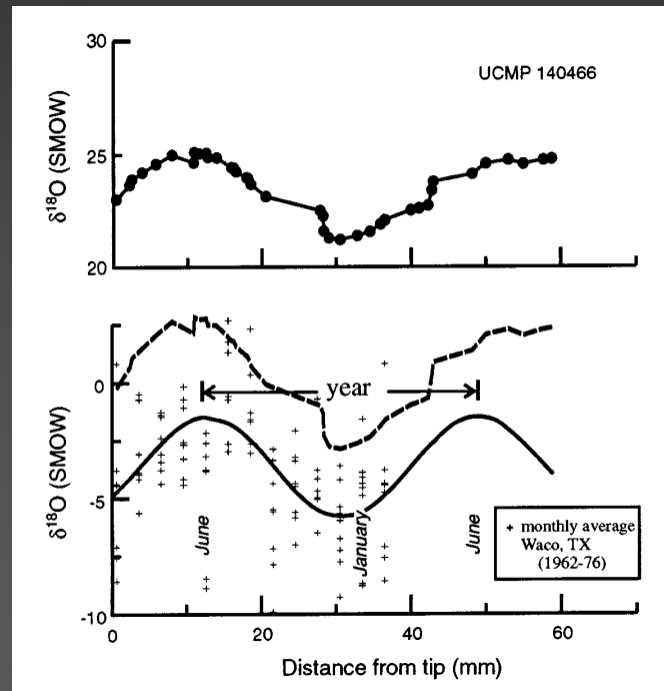
# Stable Isotopes in Vertebrate Paleontology

## Paleodiet ( $\delta^{13}\text{C}$ )



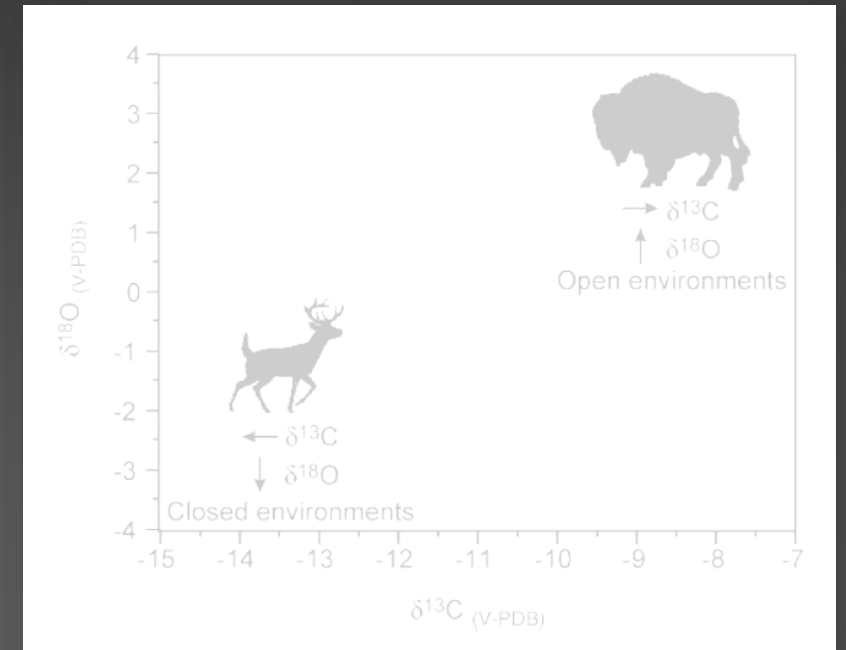
Koch, 1998

## Paleoclimate ( $\delta^{18}\text{O}$ )



Sharp and Cerling, 1998

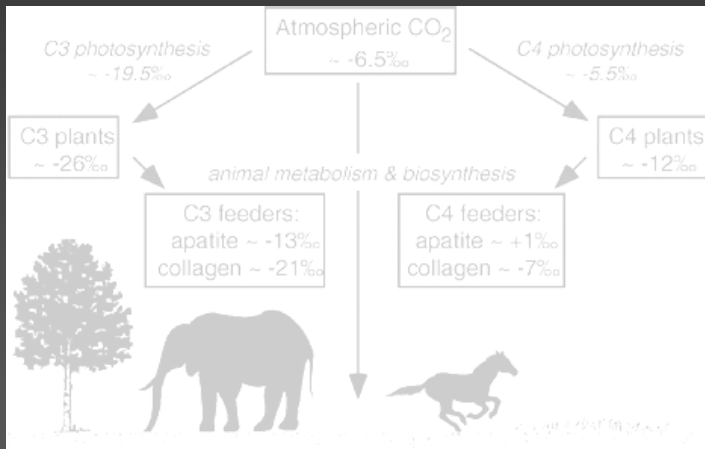
## Paleoenvironmental Reconstruction ( $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ )



Feranec and MacFadden, 2006

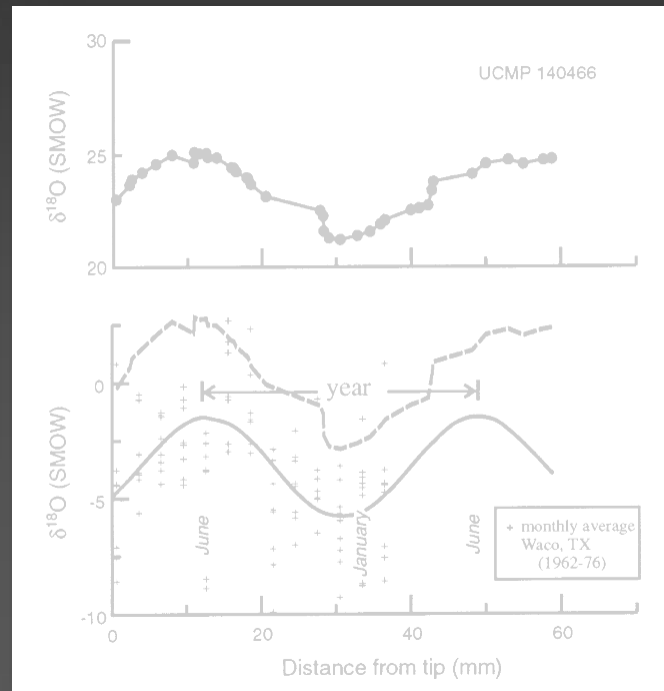
# Stable Isotopes in Vertebrate Paleontology

## Paleodiet ( $\delta^{13}\text{C}$ )



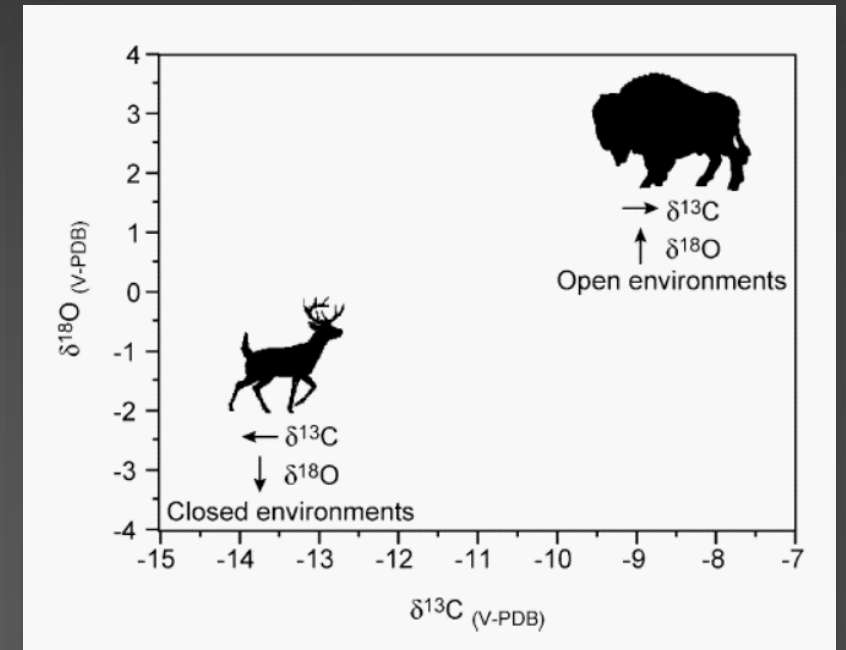
Koch, 1998

## Paleoclimate ( $\delta^{18}\text{O}$ )



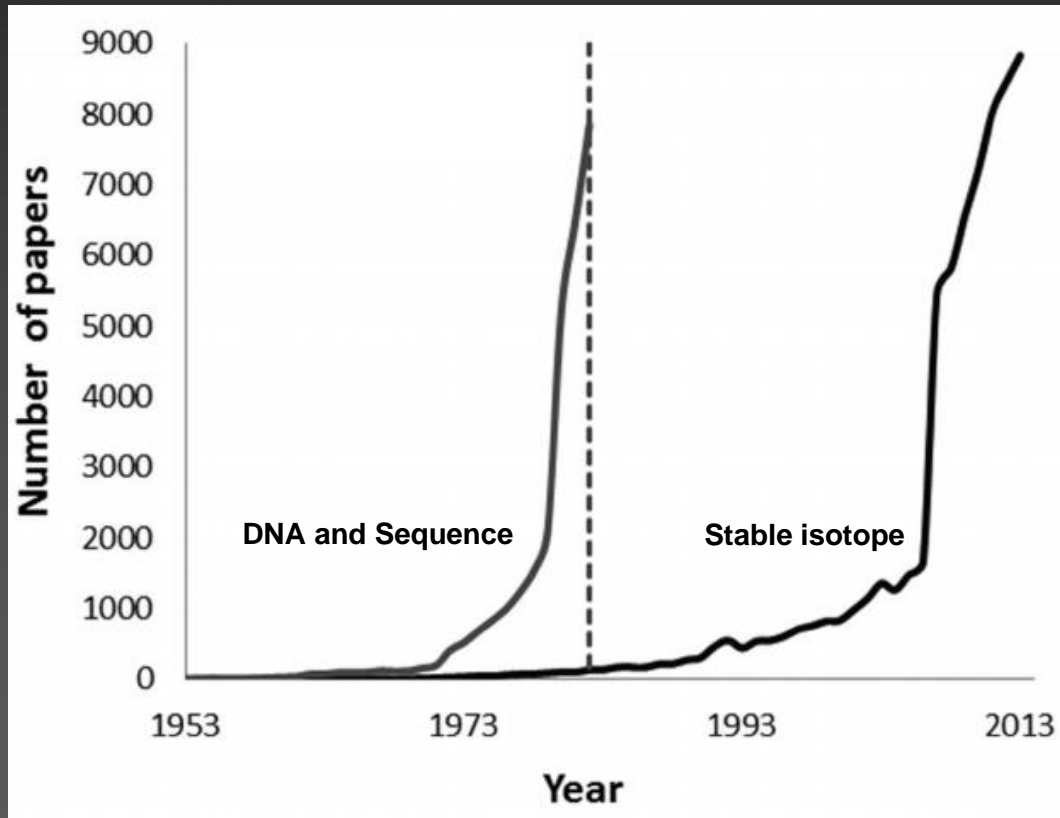
Sharp and Cerling, 1998

## Paleoenvironmental Reconstruction ( $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ )



Feranec and MacFadden, 2006

# The Need for a Global Stable Isotope Database



Pauli et al., 2015



# Glut of Stable Isotope Data

Appendix Continued.

Sample no.	Museum no.	Taxon	Locality	Tooth	$\delta^{13}C$	$\delta^{18}O$
RSF04118	UF 68840	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04119	UF 68843	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04120	UF 92963	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04121	UF 92969	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04122	UF 96521	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04123	UF 68824	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04124	UF 68828	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04125	UF 68830	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04126	UF 68834	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04127	UF 68835	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04128	UF 68837	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04129	UF 68838	Pseudhipparion skinneri	LBB	M3	-11.0	-2.5
RSF04130	UF 50634	Nannippus	LBB	M3	-11.0	-2.5
RSF04131	UF 64504	Nannippus	LBB	M3	-11.0	-2.5
RSF04132	UF 63909	Nannippus	LBB	M3	-11.0	-2.5
RSF04133	UF 96239	Nannippus	LBB	M3	-11.0	-2.5
RSF04134	UF 92975	Nannippus	LBB	M3	-11.0	-2.5
RSF04135	UF 92990	Nannippus	LBB	M3	-11.0	-2.5
RSF04136	UF 96240	Nannippus	LBB	M3	-11.0	-2.5
RSF04137						

**Supplementary Table 2 Oxygen isotope composition of Meshippus teeth from Toadstool Park (NE).**

Sample <sup>a</sup>	Distance <sup>b</sup> $\delta^{18}O$ (‰ SMOW)	Sample <sup>a</sup>	Distance <sup>b</sup> $\delta^{18}O$ (‰ SMOW)
Late Eocene	23.96	Early Oligocene	23.33
UF 209600 M3 A	23.16	UF 209563 M3 A	23.11
B		B	
C		C	
D		D	
E		E	
F		F	
G		G	
H		H	
I		I	
J		J	
K		K	
L		L	
M		M	
N		N	
O		O	
P		P	
Q		Q	
R		R	
S		S	
T		T	
U		U	
V		V	
W		W	
X		X	
Y		Y	
Z		Z	

**Appendix A. Isotopic data and percent C<sub>1</sub> plants in diets for Pleistocene mammals from Florida**

Taxon	UF no. <sup>a</sup>	Part <sup>b</sup>	$\delta^{13}C$	Percent C <sub>1</sub>
Page Lagoon				
Mammuthus	14779*	M7	-0.2	87
Mammuthus	14780*	M3	0.5	92
Mammuthus	103505*	M12	-10.0	17
Mammuthus	103570			
Mammuthus	148668			
Mammuthus	148669*			
Mammuthus	148670*			
Mammuthus	92513			
Mammuthus	92568			
Mammuthus	92522			
Mammuthus	92563			
Rock Springs				
Mammuthus	4383			
Mammuthus	4473			
Mammuthus	48987			
Mammuthus	119828			
Mammuthus	4385*			
Mammuthus	48986			
Mammuthus	119827*			
Mammuthus	48974*			
Mammuthus	48975*			
Mammuthus	48970			
Mammuthus	148673*			
Horridy Springs				
Mammuthus	987*			

**Table 1. Mean values and univariate statistics for  $\delta^{13}C$  and  $\delta^{18}O$  values for Pleistocene Equus from the different latitudes analysed in this study. Also see Appendix 1 for individual sample data.**

Lat. (°)	N	$\bar{x}$ (‰)	s (‰)	Obs. Range (‰)
68 N	2	-10.0		
65 N	1	-9.5		
64 N	2	-11.5		
51 N	1	-11.1		
48 N	2	-10.9		
44 N	1	-7.0		
43 N	2	-8.3		
40 N	1	-9.3		
36 N	2	-8.4		
35 N	1	-3.0		
34 N	3	-5.5		
33 N	14	-5.1		
32 N	6	-4.7		
30 N	5	-1.6		
28 N	5	-2.4		
27 N	1			

**Table 1. Summary statistics of the carbon and oxygen isotope compositions of the Cypress Hills Eocene teeth analysed in this study.**

Tooth ID	Taxon	Site	n subsamples	Mean $\delta^{13}C$ (‰ V-PDB)	SD (‰)	Mean $\delta^{18}O$ (‰ V-SMOW)	SD (‰)
P2787.1	Trigonias robustus	Bud	8	-8.6	0.2	18.2	1.1
P2551.29	Rhino	ISW	2	-8.7	0.0	20.8	0.8
CH 71-1	Rhino	Inch Springs	13	-9.1	0.1	18.2	0.6
P2363.3	Mesolippus	Parter Ranch/Alexander Ranch	14	-8.8	0.1	20.5	1.0
P 2595.8	Mesolippus	Bud	3	-9.2	0.0	20.5	0.3
P 2549.5	Mesolippus	Conglomerate Creek	7	-9.2	0.1	20.5	1.9
P2754.4	Mesolippus propinquus	Call Creek	2	-9.2	0.1	20.5	1.2
P1585.1542	Mesolippus propinquus	Call Creek	3	-8.6	0.2	18.6	1.9
P1585.1546	Mesolippus propinquus	Call Creek	3	-8.4	0.1	24.4	0.6

were sub-sampled perpendicular to the growth axis at intervals of 1.25 mm and the outer layer of enamel and adhering dentin were removed under a binocular microscope with a dental drill and a razor blade, respectively. Because of differences in tooth size and crown height, the number of analyzable subsamples varied among the analyzed teeth from 1 to 20. For the analyses of the carbonate component of enamel, powdered samples were treated with H<sub>2</sub>O<sub>2</sub> to remove organic contaminants and with an acetic acid-calcium acetate buffer to remove diagenetic carbonates (Koch et al. 1997). A recent study conducted by Zanazzi et al. (2015) analysed the carbon and oxygen isotope compositions of the Cypress Hills Eocene teeth analysed in this study. (p = 0.001 t-test; p = 0.002 Mann-Whitney test) and rhinos (p = 0.04 t-test; p = 0.01 Mann-Whitney test) separately. However, when horse and rhino data are pooled into perissodactyl datasets, average Eocene (-8.8 ± 0.3‰) and Oligocene (-9.0 ± 0.5‰)  $\delta^{13}C$  values are not statistically different (p = 0.15 t-test; p = 0.76 Mann-Whitney test). With respect to variability, intra-tooth isotope profiles generally show a very small  $\delta^{13}C$  range in both the Eocene and Oligocene (Figs. 3 and 4). However, variance in perissodactyl  $\delta^{13}C$  is probably higher in the Oligocene than in the Eocene (p < 0.001 F-test; p = 0.082 Levene test).



## Typical Specify data record

**Collection Object**

Specify Number: 60976      Catalog No: 27101      Old Cat No:   
Field Number:       Source: UF      Accession:  *i*  
Nature of Spec: P2, left upper      Nat of Spec Abb:   
Status of Spec: IN COLLECTION      Specimen Type: FIGURED  
Cataloger: UNKNOWN *i*      Cataloged Date:   
Remarks: R. C. HULBERT (2005), BULLETIN OF THE FLORIDA MUSEUM OF NATURAL HISTORY 45(4):476, FIG. 71 *i*

**Determinations**

Taxon: Tapirus webbi *i*  Current  
Preferred Taxon: Tapirus webbi  
Qualifier:       Modifier:       Type Status: None  
ID Date:       Identifier:  *i*  
Orig Identifier:

**Collecting Information**

Start Date: 1980      End Date:       Collected Date: 1980  
Locality: LOVE BONE BED, AL001, North America USA Florida Alachua *i* 0  
Collector (verb): FLORIDA STATE MUSEUM CREW

**Collectors** *i*

First Name	Middle Initial	Last Name	Remarks
		Florida State Museum Crew	

**Col Obj Attribute**

Provenience: NFD      Stratigraphy:   
 Sampled     Sampled for Stable Isotopes     Sampled for REE     Sampled for Radiocarbon     Other Sampling  
Scanning:   
Count Amount: 1

**Preparations**

Prep Type: fossil      Count: 1       Is On Loan      Show Loans 0  
Nature of Spec:       Nat of Spec Abb:   
Fossil ID: tooth, upper, premolar *i*  
Fossil ID Agent:  *i*

## Our insertion of isotope data fields

**Preparation Attribute**

Side: left      Serial Number: second  
Completeness: complete      Portion Present: all  
Ontogeny:       Ontogeny Basis:   
Sex: unknown      Sex Determination Basis:   
Pathology: none      Post mortem bone modification: none  
Fossil ID Date: 06/20/2016      delta C-13: -13.1  
carbon isotope ... V-PDB      delta O-18: 2.9  
oxygen isotope ... V-PDB      isotope sampling method: enamel; single  
Remarks:  *i*

**Collection Object Citations**

Reference Work: Isotopic discrimination of resource partitioning among ungulates in C3-dominated communities from the Miocene of Florida and California *i*  
 Is Figured  
Figure Number:   
Table Number:   
Remarks:  *i*



## Typical Specify data record

**Collection Object**

Specify Number: 60976    Catalog No: 27101    Old Cat No:   
Field Number:    Source: UF    Accession:   
Nature of Spec: P2, left upper    Nat of Spec Abb:   
Status of Spec: IN COLLECTION    Specimen Type: FIGURED   
Cataloger: UNKNOWN    Cataloged Date:   
Remarks: R. C. HULBERT (2005), BULLETIN OF THE FLORIDA MUSEUM OF NATURAL HISTORY 45(4):476, FIG. 71

**Determinations**

Taxon: Tapirus webbi     Current   
Preferred Taxon: Tapirus webbi   
Qualifier:    Modifier:    Type Status: None   
ID Date:    Identifier:   
Orig Identifier:   
1 of 1

**Collecting Information**

Start Date: 1980    End Date:    Collected Date: 1980   
Locality: LOVE BONE BED, AL001, North America USA Florida Alachua   
Collector (verb): FLORIDA STATE MUSEUM CREW

**Collectors**

First Name	Middle Initial	Last Name	Remarks
		Florida State Museum Crew	

**Col Obj Attribute**

Provenience: NFD    Stratigraphy:   
 Sampled     Sampled for Stable Isotopes     Sampled for REE     Sampled for Radiocarbon     Other Sampling   
Scanning:   
Count Amount: 1

**Preparations**

Prep Type: fossil    Count: 1     Is On Loan    Show Loans   
Nature of Spec:    Nat of Spec Abb:   
Fossil ID: tooth, upper, premolar   
Fossil ID Agent:

## Our insertion of isotope data fields

**Preparation Attribute**

Side: left    Serial Number: second   
Completeness: complete    Portion Present: all   
Ontogeny:    Ontogeny Basis:   
Sex: unknown    Sex Determination Basis:   
Pathology: none    Post mortem bone modification: none   
Fossil ID Date: 06/20/2016    delta C-13: -13.1   
carbon isotope ... V-PDB    delta O-18: 2.9   
oxygen isotope ... V-PDB    isotope sampling method: enamel; single   
Remarks:   
1 of 1

**Collection Object Citations**

Reference Work: Isotopic discrimination of resource partitioning among ungulates in C3-dominated communities from the Miocene of Florida and California   
 Is Figured   
Figure Number:   
Table Number:   
Remarks:   
1 of 1

- New preparation attributes can be added for each tooth of a given specimen (e.g., m1, m2, and m3 of a dentary) with isotope data attached



# An example: Easily queried records

Collection Object

Taxon

Locality

Chronostratigraphy

Paleo context

Collection object attribute  
Storage

Preparation attribute

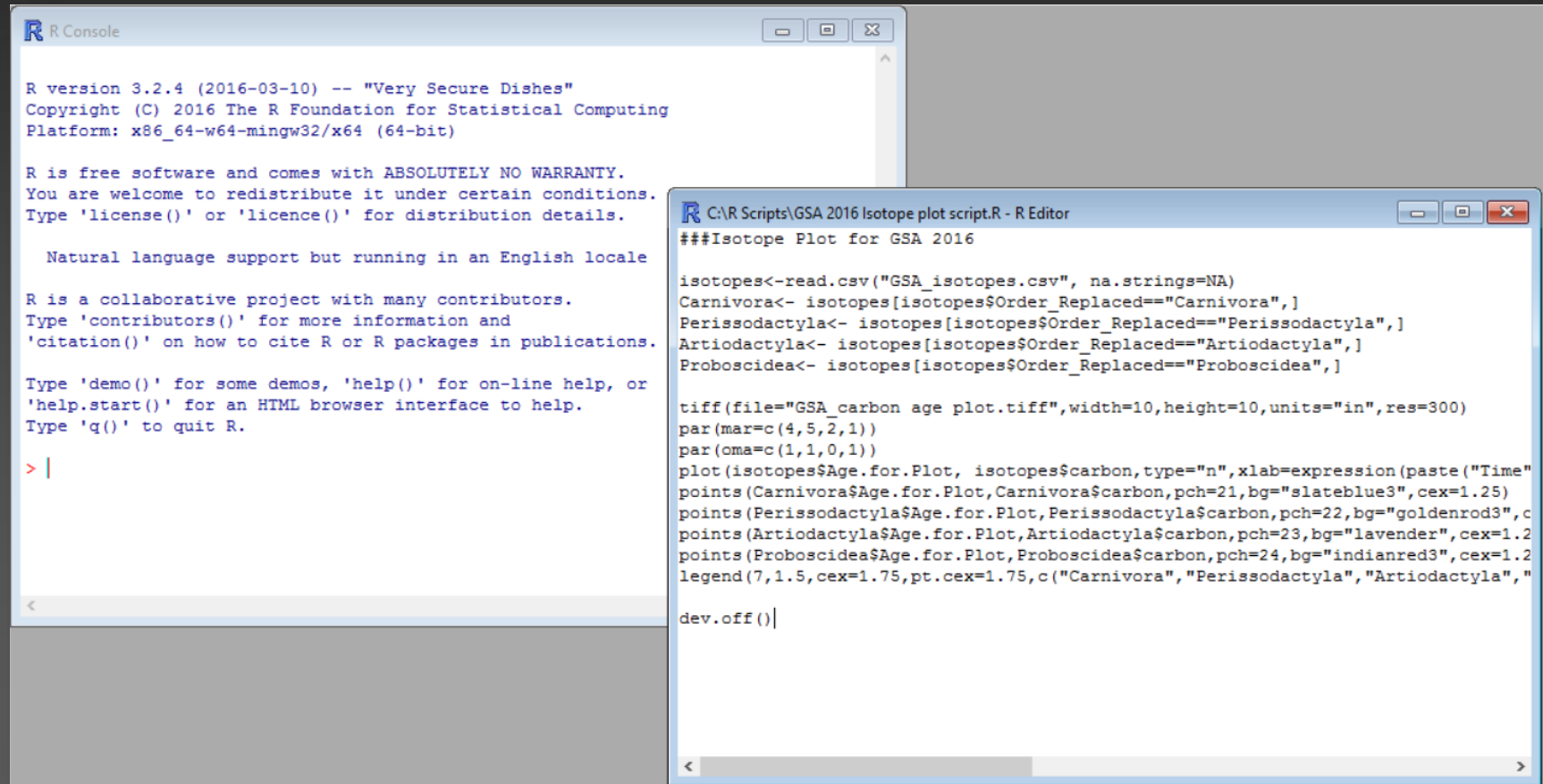
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CO	Catalog No	<input type="checkbox"/>	=	
CO	Specify Number	<input type="checkbox"/>	=	
CO	Collection Object/Remarks	<input type="checkbox"/>	Contains	
CO	Nature of Spec	<input type="checkbox"/>	Contains	
Tax	Class	<input type="checkbox"/>	Contains	
Tax	Order	<input type="checkbox"/>	Contains	
Tax	Family	<input type="checkbox"/>	Contains	
Tax	Genus	<input type="checkbox"/>	Contains	
Tax	Species	<input type="checkbox"/>	Contains	
Loc	Site	<input type="checkbox"/>	Contains	
Loc	Site Key	<input type="checkbox"/>	Contains	
Loc	Datum	<input type="checkbox"/>	Contains	
Loc	Latitude1	<input type="checkbox"/>	=	
Loc	Longitude1	<input type="checkbox"/>	=	
CS	Series/Epoch	<input type="checkbox"/>	Contains	
PC	Land Mammal Age	<input type="checkbox"/>	Contains	
PC	Faunal Zone	<input type="checkbox"/>	Contains	
CoA	Sampled for Stable Isotopes	<input type="checkbox"/>		
Sto	Full Name	<input type="checkbox"/>	Contains	
PrA	Side	<input type="checkbox"/>	=	
PrA	Serial Number	<input type="checkbox"/>	=	
PrA	delta O-18	<input type="checkbox"/>	=	
PrA	oxygen isotope standard	<input type="checkbox"/>	Contains	
PrA	delta C-13	<input type="checkbox"/>	>=	-40
PrA	carbon isotope standard	<input type="checkbox"/>	Contains	
PrA	isotope sampling method	<input type="checkbox"/>	=	
PrA	Preparation Attribute/Remarks	<input type="checkbox"/>	Contains	

# An example: Output to Excel file

	A	B	C	D	E	G	H	I	K	L	N	P	Q	R	S	T	Y	Z	AA	AB	AC	AD	AE	
1	Source	Catalog No	Specify Nu	Class	Order	Family	Genus	Species	Nature of	Site	Site Key	Latitude1	Longitude1	Series/Epo	Land Mam	Faunal Zor	Full Name	Side	Serial Num	delta O-18	oxygen iso	delta C-13	carbon iso	
2	UF/FGS	5107	18682	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	molar, left	SANTA FE	CO071	29.83575	-82.6832	Pleistocen	Blancan or	Racholabr	tooth, upp	left	none/NA				-9.7	V-PDB
3	UF	2855	36643	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	M2, right u	REDDICK 1	MR016	29.36123	-82.1856	Pleistocen	Rancholab	Ra2	tooth, upp	right	second				-14	V-PDB
4	UF	2991	36991	Mammalia	Artiodacty	Camelidae	Palaeolama		dentary, le	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	left	first	29	V-SMOW		-8.4	V-PDB
5	UF	3224	37183	Mammalia	Artiodacty	Tayassuidae	Mylohyus		dentary, le	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	left	third	31.7	V-SMOW		-7.6	V-PDB
6	UF	3264	37223	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	maxilla, wi	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	right	first	29.2	V-SMOW		-10.5	V-PDB
7	UF	3265	37224	Mammalia	Artiodacty	Cervidae	Odocoileus		dentary, ri	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	right	second	30.3	V-SMOW		-13.1	V-PDB
8	UF	3268	37227	Mammalia	Artiodacty	Tayassuidae	Mylohyus	fossilis	dentary, le	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	left	third	29.7	V-SMOW		-11.2	V-PDB
9	UF	3279	37238	Mammalia	Artiodacty	Tayassuidae	Mylohyus	fossilis	skull, parti	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	left	third	29.4	V-SMOW		-11.9	V-PDB
10	UF	4051	38002	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	mandible,	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	right	first	30.2	V-SMOW		-9.2	V-PDB
11	UF	7559	41496	Mammalia	Artiodacty	Bovidae	Bison	latifrons	skull, right	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	right	third	30.5	V-SMOW		-1.1	V-PDB
12	UF	8902	42866	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	maxilla, rig	REDDICK 1	MR055	29.36123	-82.1856	Pleistocen	Rancholab	Ra2	tooth, upp	right	third				-9.2	V-PDB
13	UF	10252	44189	Mammalia	Artiodacty	Cervidae	Odocoileu	virginianus	SKELETON	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	right	third	31.6	V-SMOW		-12.3	V-PDB
14	UF	10253	44190	Mammalia	Artiodacty	Cervidae	Odocoileus		SKELETON	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	right	second	29.9	V-SMOW		-14.2	V-PDB
15	UF	10324	44261	Mammalia	Artiodacty	Tayassuidae	Mylohyus	fossilis	palate witl	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	right	third	29.7	V-SMOW		-11.1	V-PDB
16	UF	10935	44908	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	dentary, ri	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, low	right	first	30.4	V-SMOW		-8.7	V-PDB
17	UF	10938	44911	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	DP4, right	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	right	fourth	31.6	V-SMOW		-9.9	V-PDB
18	UF	11503	45440	Mammalia	Artiodacty	Camelidae	Hemiauchenia		M3, left up	INTRACOA	SA017	27.08221	-82.4303	Pleistocen	Rancholab	Ra2	tooth, upp	left	third				-5	V-PDB
19	UF	11503	45440	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	M3, left up	INTRACOA	SA017	27.08221	-82.4303	Pleistocen	Rancholab	Ra2	tooth, upp	left	third				-5	V-PDB
20	UF	12494	46224	Mammalia	Artiodacty	Tayassuidae	Mylohyus		maxilla, rig	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	right	first	29.1	V-SMOW		-9.1	V-PDB
21	UF	16187	50124	Mammalia	Artiodacty	Bovidae	Bison	latifrons	M1 or M2,	HAILE 8A	AL026	29.69498	-82.5824	Pleistocen	Rancholab	Ra2	tooth, upp	left	first or sec	30.4	V-SMOW		-4.7	V-PDB
22	UF	17518	51483	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	maxilla, le	INGLIS 1A	CI001	29.00743	-82.6893	Pleistocen	Blancan,	le B13	tooth, upp	left	fourth				-10.2	V-PDB
23	UF	17519	51484	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	maxilla, le	INGLIS 1A	CI001	29.00743	-82.6893	Pleistocen	Blancan,	le B13	tooth, upp	left	none/NA				-9.1	V-PDB
24	UF	17522	51487	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	mandible,	INGLIS 1A	CI001	29.00743	-82.6893	Pleistocen	Blancan,	le B13	tooth, low	right	third				-12.4	V-PDB
25	UF	17693	51630	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	m3, left lo	SANTA FE	CO003	29.83699	-82.6996	Pleistocen	Blancan or	Racholabr	tooth, low	left	third				-13.4	V-PDB
26	UF	18027	51964	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	right upper	INGLIS 1A	CI001	29.00743	-82.6893	Pleistocen	Blancan,	le B13	tooth, upp	right	third				-11.3	V-PDB
27	UF	18028	51965	Mammalia	Artiodacty	Camelidae	Hemiauch	macrocepl	M3, right u	WITHLACC	LV041	29.01356	-82.6281	Pleistocen	Rancholab	Ra2	tooth, upp	right	third				-7.9	V-PDB
28	UF	18188	52125	Mammalia	Artiodacty	Tayassuidae	Platygonus	bicalcarat	MANDIBLE	INGLIS 1A	CI001	29.00743	-82.6893	Pleistocen	Blancan,	le B13	tooth, upp	right	third				-11.5	V-PDB
29	UF	18196	52133	Mammalia	Artiodacty	Tayassuidae	Platygonus	bicalcarat	right upper	INGLIS 1A	CI001	29.00743	-82.6893	Pleistocen	Blancan,	le B13	tooth, upp	right	third				-12	V-PDB

# An example: Data manipulation

- Data subset by mammalian class (crocodylians not included)
- Simply plotted specimen age by  $\delta^{13}\text{C}$



```
R Console
R version 3.2.4 (2016-03-10) -- "Very Secure Dishes"
Copyright (C) 2016 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64 (64-bit)

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'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> |

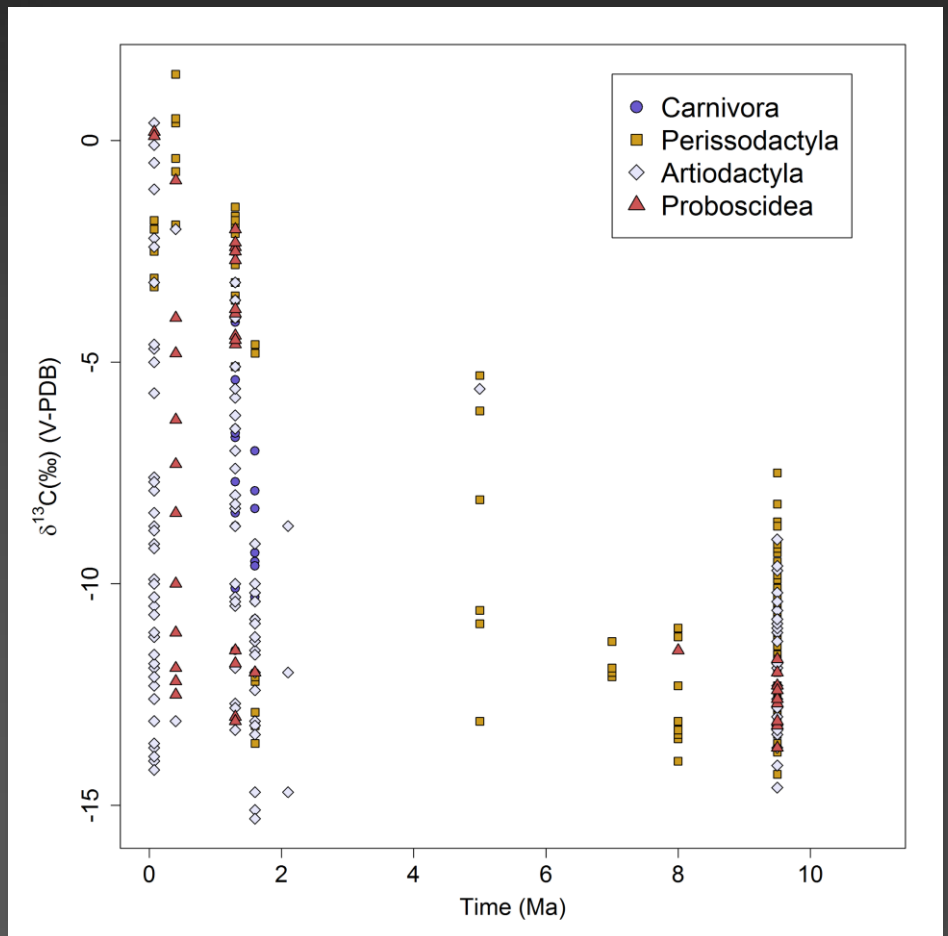
C:\R Scripts\GSA 2016 Isotope plot script.R - R Editor
###Isotope Plot for GSA 2016

isotopes<-read.csv("GSA_isotopes.csv", na.strings=NA)
Carnivora<- isotopes[isotopes$Order_Replaced=="Carnivora",]
Perissodactyla<- isotopes[isotopes$Order_Replaced=="Perissodactyla",]
Artiodactyla<- isotopes[isotopes$Order_Replaced=="Artiodactyla",]
Proboscidea<- isotopes[isotopes$Order_Replaced=="Proboscidea",]

tiff(file="GSA_carbon age plot.tiff",width=10,height=10,units="in",res=300)
par(mar=c(4,5,2,1))
par(oma=c(1,1,0,1))
plot(isotopes$Age.for.Plot, isotopes$carbon,type="n",xlab=expression(paste("Time"
points(Carnivora$Age.for.Plot,Carnivora$carbon,pch=21,bg="slateblue3",cex=1.25)
points(Perissodactyla$Age.for.Plot,Perissodactyla$carbon,pch=22,bg="goldenrod3",c
points(Artiodactyla$Age.for.Plot,Artiodactyla$carbon,pch=23,bg="lavender",cex=1.2
points(Proboscidea$Age.for.Plot,Proboscidea$carbon,pch=24,bg="indianred3",cex=1.2
legend(7,1.5,cex=1.75,pt.cex=1.75,c("Carnivora","Perissodactyla","Artiodactyla",
dev.off()|
```

# An example: Expansion of C4 consumption

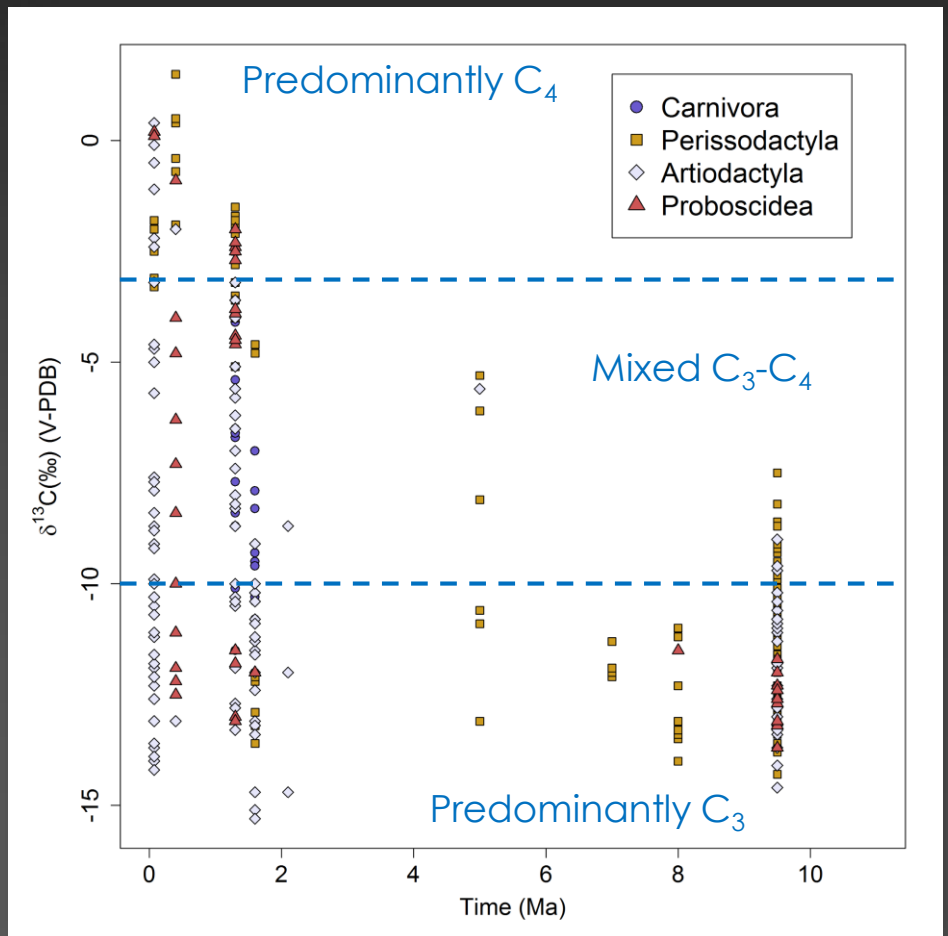
- Increase in tooth enamel carbonate  $\delta^{13}\text{C}$  in Florida over last 10 Ma
- n=369



Data included from Feranec 2003, Feranec and MacFadden 1996, MacFadden 1998, MacFadden and Cerling 1996, Yann and DeSantis 2014

# An example: Expansion of C4 consumption

- Increase in tooth enamel carbonate  $\delta^{13}\text{C}$  in Florida over last 10 Ma
- n=369



Data included from Feranec 2003, Feranec and MacFadden 1996, MacFadden 1998, MacFadden and Cerling 1996, Yann and DeSantis 2014

# Obstacles

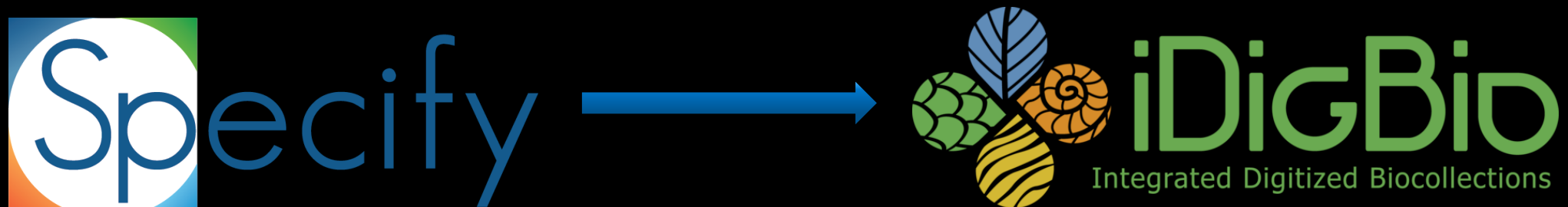
Samp. No. <sup>1</sup>	UF Cat. no.	Family <sup>2</sup>	Taxon <sup>3</sup> (genus)	Material <sup>4</sup>	Locality	$\delta^{13}\text{C}$ (‰)
93	115776	Tap	<i>Tapirus</i>	p3, ml-m $\bar{3}$	Ichetucknee	-10.1
94	19376	Bov	<i>Bison</i>	RP/M	Ichetucknee	-3.9
95	v4703	Cer	<i>Odocoileus</i>	RM2-M3	Ichetucknee	-13.8
97	None	Cam	<i>Hemiauchenia</i>	rp4	Cutler	0.4
98	None	Bov	<i>Bison</i>	LP/M	Cutler	1.5
99	None	Bov	<i>Bison</i>	lp/m	Cutler	-0.5
100	None	Tay	<i>Mylohyus</i>	rm2/m3	Cutler	-8.0
101	None	Tay	<i>Platygonus</i>	lm3	Cutler	-8.3
102A	None	Equ	<i>Equus</i>	incisor	Cutler	0.2
102B	None	Equ	<i>Equus</i>	RP3/P4	Cutler	-0.4
103	None	Equ	<i>Equus</i>	rp2	Cutler	-0.5
104	None	Equ	<i>Equus</i>	rp/m	Cutler	-0.6

MacFadden and Cerling, 1996

- Uncataloged specimens
- Incorrectly labeled specimens
- Lost specimens
- Unreported  $\delta^{18}\text{O}$  data
- Data quality control
- Serially sampled specimens

# Research potential and future directions

- Provides the opportunity for paleontologists to address hypotheses of the past that, until now, could only be addressed by modern ecologists.



- Necessary to develop global standards for isotope metadata (TDWG)