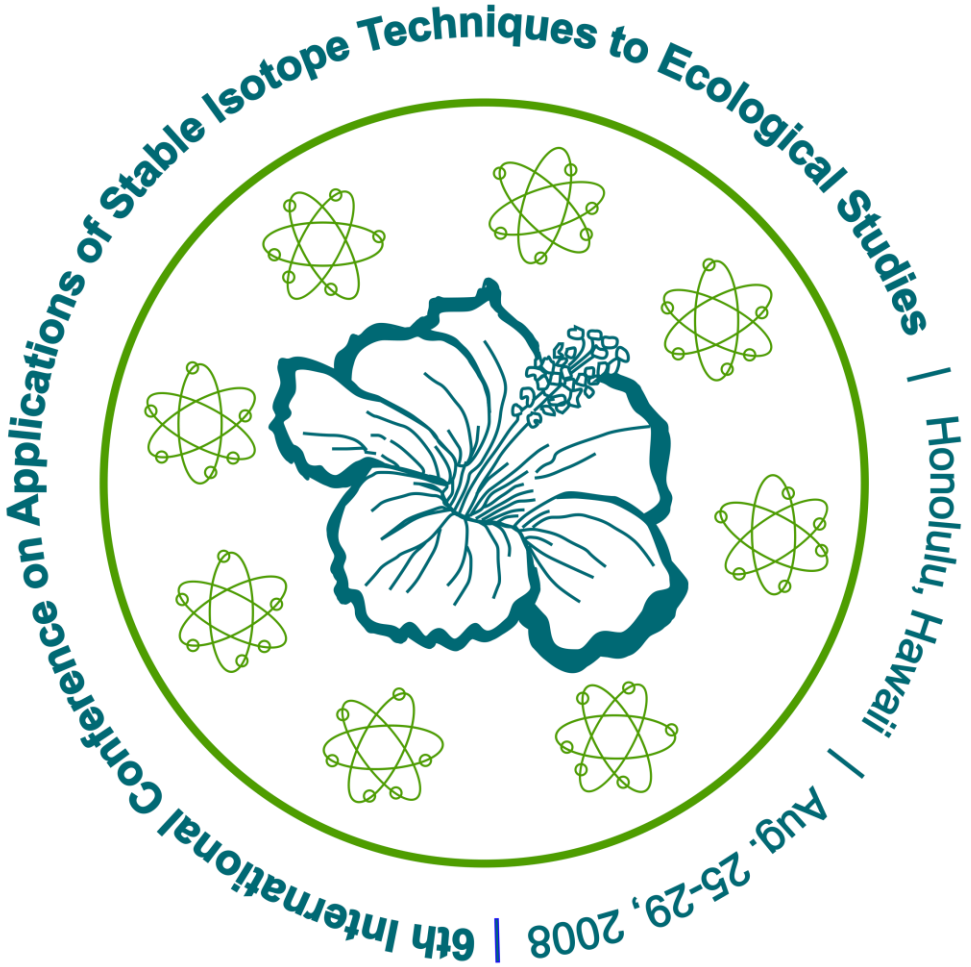
The 6th International Conference on Applications of Stable Isotope Techniques to Ecological Studies



Honolulu, HI, August 25th to 29th 2008

Conference Organizers
Brittany Graham, Carrie Holl, Brian Fry, and Brian Popp

Event Organizer: *UH Conference Center*
Yvonne Yamashita

Aloha & Welcome!

Welcome to Honolulu and to the 6th International Conference on Applications of Stable Isotope Techniques to Ecological Studies. In this, the 10th year of the conference series, we are delighted once again to have that productive blend of researchers and students from universities, governmental institutions and industry that has made this series so successful.

We hope that Honolulu will build on the success of the previous five meetings in Belfast, Wellington, Flagstaff, Braunschweig and Saskatoon, retaining the friendly and collaborative atmosphere that sets IsoEcol apart. The 1st conference in Saskatoon in 1998 had 115 delegates, this has grown steadily over the years and we will have close to 170 attending this meeting. As you can imagine with so many delegates, we had an extremely difficult task selecting oral presentations (we could have included twice the number of talks!). However this has made for a very exciting, diverse and very full program. To build on the success of the Belfast meeting, we have also incorporated a nice blend of social activities that will provide further opportunity to interact with your colleagues in an informal setting. We hope you will participate in the full program.

This year we have selected two plenary speakers, each an international leader in their field. The plenary speakers will lead two broad sessions ("Isoscapes" and "Marine Ecology"), and these sessions will dovetail into 11 additional themes.

We hope that you enjoy your stay in Honolulu, experience the local aloha, and that you take some time out, either before or after the conference, to travel further a-field on Oahu or to the other Hawaiian Islands. This is a special place, full of tropical adventures and beautiful scenery.

Most importantly, we hope that you find this a rewarding and productive week, and that research colloborations are forged and strengthened.

Thank you for participating and helping to make this meeting a success!

Aloha and a hui hou,
Brittany Graham, Carrie Holl, Brian Fry, and Brian Popp

The Scientific Program

ISOECOL VI has 168 papers in total – 70 oral and 98 poster presentations. We wish to extend a mahalo nui loa to all the contributors for making this an incredibly diverse and exciting group of presentations.

PLENARY SPEAKERS

There are two plenary speakers, each a leading researcher in their field.

On Monday morning Dr. Gabriel Bowen, of Purdue University, USA, will present his recent work entitled: *Tracing with isotopes: practices, applications, and opportunities.* Gabe has been at the forefront of examining spatio-temporal variability on a global scale to address an array of ecological questions. Gabe will provide a synthesis of exciting frontiers in ecological isoscapes and a review of the important information generated from the IsoScapes 2008 conference.

On Thursday morning Dr. Simon Jennings, of Environment and Ecosystems division at the Centre for Environment, Fisheries and Aquaculture Science (Cefas), UK, will present his work entitled: *Marine food web ecology: insights from stable isotopes.* Simon has been at the forefront of applying stable isotope analysis to understand the complexity and diversity of marine food webs, with an emphasis on quantifying fishing and environmental effects on marine communities and ecosystems.

ORAL PRESENTATIONS

All oral presentations will be conducted in the IMIN Conference Center, in the Keoni auditorium. Presenters should take their presentation files (PowerPoint) to Scott Carleton the day before they are due to talk (this will be on Tues. for those presenting on Thurs.). Scott Carleton will go through your presentation on a laptop in order to make sure there are no problems with the transfer. In order to maintain our tight schedule (and to allow you to enjoy the evenings!) presentations will be held strictly to 15 minutes in length, with 5 minutes available for questions. The presentations are organized in the following 13 sessions:

Session 1: Isoscapes – spatio-temporal distributions of isotopes
Session 2: Organic $\delta^{18}O$ tracers
Session 3: Transfer of energy/nutrients between disparate ecosystems
Session 4: Methods I – amino acids
Session 5: Mammalian herbivory – C_3 vs. C_4
Session 6: Freshwater ecology
Session 7: Animal migration
Session 8: Marine ecology
Session 9: Human ecology
Session 10: Methods II – isotopic discrimination and models
Session 11: Biogeochemical cycling
Session 12: Retro ecology – isotopes as indicators of past ecological change
Session 13: Anthropogenic forcings on ecosystems

POSTER PRESENTATIONS

Poster presentations will be held in both the Garden level of the IMIN Conference Center and in the rear of the Keoni auditorium on Monday and Tuesday

evenings. The poster sessions will begin ~6:00 pm and continue until 8:00 pm. An assortment of pupus, wine, and soft drinks will be provided in the Garden level conference room. Posters can be put up during Monday morning registration onwards and have to be removed by lunch time on Friday (before 12:50pm). We would like to see all posters remain up on the poster boards all week to give your fellow delegates plenty of time to read and digest the material and discuss it with the author(s) and colleagues.

NAME BADGES

Name badges will be distributed when you register for the conference, along with your tote bags and conference materials. The first chance to pick up your conference materials will occur at the opening night reception (Sun, 24th) from 6-7pm. Please wear your name badge at all times during the meeting. If you lose your badge or another problem arises, please contact the event organizer, Yvonne Yamashita, or one of her staff.

STUDENT AWARDS

We have over 50 students attending the conference and nearly all of them giving oral or poster presentations. Three registration-waiver awards have already been given to Alex Wyatt, Haley Gillespie, and Robin Warne. Congratulations! Two additional awards will be given for the best student oral presentation and best student poster. The presentations will be judged by several attending scientists and the awards will consist of $250. Good luck!

FINANCIAL SUPPORT FOR THE CONFERENCE.

We gratefully acknowledge the support of the following organisations and businesses for their financial support: ThermoFisher Scientific, Los Gatos Research Inc., Isotech Laboratories Inc., IVA Analysentechnik, BASIN, Elementar Analysensysteme, Picarro, Sercon, and Nu Instruments. You will find information on their products and services at the end of this programme booklet. Also, many representatives from these companies will be attending the conference – please contact them regarding their services and products.

ACKNOWLEDGEMENTS

The organisers would like to thank: Jason Newton for the isoecol.org website maintenance; Lawrence So; Marshal Kingsbury, Cathy Hirano, Kathleen Clarke from the IMIN Conference Center; Stuart Bearhop and Jason Newton for passing along IsoEcol V information; Sabrina Dechert for the conference logo (Fox & Clover Glasswork); Scott Carleton and Rebecca Sylvestri for logistical help.

Social Events

Opening Night Reception **6:00 – 9:00 pm** ***Sunday 24th August***

Join us for beer, wine and local style “grinds” at the Waikiki aquarium. This is a charming setting, only feet away from the waves of the Pacific, and a great event to invite your partners and children to. Also, you are free to explore the aquarium exhibits and enjoy a sunset and night on Waikiki Beach. At the reception, we will have the registration desk available for the first hour and you can pick up your conference materials.

CONFERENCE FIELD TRIPS ***Wednesday 27th August***

Field Trip 1: Hanauma Bay Nature Preserve snorkel & Makapu'u Lighthouse hike

Field Trip 2: Tantalus rain forest hike & Makani sail & snorkel

Please remember to register for the field trips at the registration desk by Tuesday 26th at noon. Sorry we are not able to accommodate registrations after this deadline. Details on where and when to meet will be given upon arrival at the conference and will also be provided for you in your conference registration materials. Field trip participants should bring or wear hats and sunscreen. You may also like to have a bottle of water and a snack handy and cameras are a must! If you brought snorkelling equipment with you please feel free to bring that along. If not, snorkelling equipment will be provided for you on Field Trip 2 and available for a nominal fee on Field trip 1. Lunch will be on your own on Field Trip 1 (after the snorkel and before the hike). Lunch is provided for you during the Makani sail on Field Trip 2. If you are taking Field Trip 1, please remember to bring money for snorkel equipment rental (~$5) and for lunch. More details can be found on the conference website, or in your field trip handouts.

CONFERENCE BANQUET **6:30 – 8:30 pm** ***Thursday 28th August***

The conference banquet will be held at Tiki's Grill and Bar. Tiki's is located in the ResortQuest Waikiki Beach Hotel, 2570 Kalakaua Avenue, near the corner of Kalakaua and Kapahulu and provides fabulous views of the sunset (6:50pm) over Waikiki beach. Buses will take you to Tiki's following the final oral presentation on Thursday and all conference hotels are just a short stroll "home" in the warm ocean breeze - you can even walk along the beach home. If you have not yet registered for the dinner please do so before Tuesday at noon.

AT-A-GLANCE SCHEDULE

Time	Mon, 25-Aug	Tues, 26-Aug	Wed, Field Trips	Thurs, 28-Aug	Fri, 29-Aug
8:00, 8:30	Buses depart Kapioloni/Zoo Parking Lot to IMIN Conference Center				
8:45-9:00	Short Intro	Announcements		Announcements	Announcements
9:00	**Plenary 1 Gabe Bowen**	18 Methods 1 **Martinez del Rio**		**Plenary 2 Simon Jennings**	54 Biogeochem Cyc **Lehman**
9:20		19 Methods 1 **Focken**			55 Biogeochem Cyc **Holl**
9:40	1 Isoscapes **Still**	20 Methods 1 **McMahon**		37 Marine Ecology **Mazumder, A**	56 Biogeochem Cyc **Dijkstra**
10:00	2 Isoscapes **Koch**	21 Methods 1 **Tuross**		38 Marine Ecology **Trueman**	57 Biogeochem Cyc **Boeckx**
10:20	3 Isoscapes **West**	22 Methods 1 **Larsen**		39 Marine Ecology **Foley**	58 Biogeochem Cyc **Gebauer**
10:40	Tea/Coffee Break (Garden Level)				
11:10	4 Isoscapes **Graham**	23 C3 vs. C4 **Fox-Dobbs**		40 Marine Ecology **Bury**	59 Retro Ecology **Brooks**
11:30	5 Isoscapes **Carleton**	24 C3 vs. C4 **Warne**		41 Marine Ecology **Oppel**	60 Retro Ecology **Dawson**
11:50	6 Isoscapes **Chesson**	25 C3 vs. C4 **Sponheimer**		42 Marine Ecology **Hirons**	61 Retro Ecology **Johnson**
12:10	7 Isoscapes **Podlesak**	26 C3 vs. C4 **Codron, J.**		43 Marine Ecology **Hill**	62 Retro Ecology **McKenzie**
12:30	8 Isoscapes **Gibbs**	27 C3 vs. C4 **Codron, D**		44 Marine Ecology **Vanderklift**	63 Retro Ecology **Perga**
12:50	Lunch (Garden Level)				
14:10	9 Organic 18O **Fogel**	28 Freshwater Ecol **Grey**		45 Human Ecol **O'Brien**	64 Retro Ecology **Clementz**

14:30	10	Organic 18O **Passey**	29	Freshwater Ecol **Marty**		46	Human Ecol **Nash**	65	Anthropogenic Forcings **Brown**
14:50	11	Organic 18O **Wang**	30	Freshwater Ecol **Church**		47	Human Ecol **Kraft**	66	Anthropogenic Forcings **Kolasinski**
15:10	12	Between Ecosystems **Hungate**	31	Animal Migration **Valenzuela**		48	Human Ecol **Kelly**	67	Anthropogenic Forcings **Hayden**
15:30	Tea/Coffee Break (Garden Level)								
16:00	13	Between Ecosystems **Bearhop**	32	Animal Migration **Huckstadt**		49	Methods II (models) **Caut**	68	Anthropogenic Forcings **Stricker**
16:20	14	Between Ecosystems **Harrod**	33	Animal Migration **Newsome**		50	Methods II **Fisk**	69	Anthropogenic Forcings **Mazumder, D**
16:40	15	Between Ecosystems **Walters**	34	Animal Migration **Reichlin**		51	Methods II **Jahren**	70	Anthropogenic Forcings **Verburg**
17:00	16	Between Ecosystems **Dierking**	35	Animal Migration **Fraser**		52	Methods II **Jackson**		Closing/Student Awards
17:20	17	Between Ecosystems **Wyatt**	36	Animal Migration **Wunder**		53	Methods II **Inger**		
18:00, 18:30						Buses departs IMIN to Waikiki			
18:00	**Poster Session 1**		**Poster Session 2**			**Tiki's Banquet Dinner**			
19:30 20:15	Buses departs IMIN to Waikiki								

OVERVIEW OF EVENTS

Sunday 24th August

1800 - 1900	Registration at the *Waikiki Aquarium*
1800 - 2100	Opening Night Reception at the *Waikiki Aquarium*

Monday 25th August

0800	Bus Pick-up #1, parking lot in front of the Waikiki Zoo
0830	Bus Pick-up #2, parking lot in front of the Waikiki Zoo
0745 - 0845	Registration, in front of the *IMIN Conference Center*
0845 - 0900	Welcome and introductions, *Keoni Auditorium*
0900 - 0940	Plenary I: Dr. Gabe Bowen,
0940 - 1040	Session: Isoscapes
1040 - 1110	**Coffee break***, Garden level of the IMIN CC*
1110 - 1250	Session: Isoscapes
1250 - 1410	**Lunch***, Garden level of the IMIN CC*
1410 – 1530	Session: Organic $\delta^{18}O$ Tracers
1530 – 1600	**Coffee break***, Garden level of the IMIN CC*
1600 – 1740	Session: Transfer of Energy/Nutrients Among Disparate Ecosystems
1800 – 2000	Poster Session 1*, Garden level of the IMIN CC and in the Keoni Auditorium*
1915	Bus Pick-up #1, *in front of IMIN CC*
1930	Bus Pick-up #1, *in front of IMIN CC*
2015	Bus Pick-up #3, *in front of IMIN CC*

Tuesday 26th August

0800	Bus Pick-up #1, parking lot in front of the Waikiki Zoo
0830	Bus Pick-up #2, parking lot in front of the Waikiki Zoo
0800 - 0850	Registration, in front of the *IMIN conference center*
0850 - 0900	Housekeeping, *Keoni Auditorium*
0900 - 1040	Session: Methods I – Amino Acids
1040 - 1110	**Coffee break***, Garden level of the IMIN CC*
1110 - 1250	Session: Animal Herbivory – C_3 vs. C_4
1250 - 1410	**Lunch***, Garden level of the IMIN CC*
1410 – 1530	Session: Freshwater Ecology
1530 – 1600	**Coffee break***, Garden level of the IMIN CC*
1600 – 1740	Session: Animal Migration
1800 – 2000	Poster Session 2*, Garden level of the IMIN CC and in the Keoni Auditorium*
1915	Bus Pick-up #1, *in front of IMIN CC*
1930	Bus Pick-up #1, *in front of IMIN CC*
2015	Bus Pick-up #3, *in front of IMIN CC*

Wednesday 27th August

Field Trips !!

Thursday 28th August

0800	Bus Pick-up #1, parking lot in front of the Waikiki Zoo
0830	Bus Pick-up #2, parking lot in front of the Waikiki Zoo
0830 - 0850	Registration, in front *IMIN conference center*
0850 - 0900	Housekeeping, *Keoni Auditorium*
0900 - 0940	Plenary: Dr. Simon Jennings,
0940 - 1040	Session: Marine Ecology
1040 - 1110	**Coffee break***, Garden level of the IMIN CC*
1110 - 1250	Session: Marine Ecology
1250 - 1410	**Lunch***, Garden level of the IMIN CC*
1410 – 1530	Session: Human Ecology,
1530 – 1600	**Coffee break***, Garden level of the IMIN CC*
1600 – 1740	Session: Methods II - isotopic discrimination & models
1800	Bus Pick-up #1, *in front of IMIN Conference Center*
1830	Bus Pick-up #2, *in front of IMIN Conference Center*
1800 – 2100+	**Conference Banquet at Tiki's**

Friday 29th August

0800	Bus Pick-up #1, parking lot in front of the Waikiki Zoo
0830	Bus Pick-up #2, parking lot in front of the Waikiki Zoo
0830 - 0850	Registration,
0850 - 0900	Housekeeping, *Keoni Auditorium*
0900 - 1040	Session: Biogeochemical Cycling
1040 - 1110	**Coffee break***, Garden level of the IMIN CC*
1110 - 1250	Session: Retro Ecology – Stable Isotopes as Indicators of Past Ecological Change
1250 - 1410	**Lunch***, Garden level of the IMIN CC*
1410 – 1530	Session: Anthropogenic Forcings on Ecosystems
1530 – 1600	**Coffee break***, Garden level of the IMIN CC*
1600 – 1700	Session: Anthropogenic Forcings on Ecosystems
1700 – 1730	Student prizes and conference wind up
1745	Bus Pick-up #1, *in front of IMIN Conference Center*
1815	Bus Pick-up #2, *in front of IMIN Conference Center*

CONFERENCE PROGRAM

Monday 25th August

0745 - 0845 Registration, in front of the *IMIN Conference Center*

0845 - 0900 Welcome and introductions, *Keoni Auditorium*

0900 – 0940 Plenary: ***Dr Gabriel Bowen***
Tracing with isotopes: practices, applications, and opportunities.

ORAL SESSION 1: ISOSCAPES (spatiotemporal distribution of isotopes)
Chair: Jason West

0940 – 1000 Continental-scale distributions of plant stable isotope ratios.
Still, C.J., *West, J.B, Ehleringer, J.R., Powell, R.L.*

1000 – 1020 The distribution and ecology of southern elephant seals and Adélie penguins on the Holocene Ross Sea coast.
Koch, P.L., *Hall, B., Baroni, C., Newsome, S.D., Salvatore, M.C.*

1020 – 1040 Inferring sources of plant materials from stable isotope ratios.
West, J., *Hurley, J., Ehleringer, J., Cerling, T.*

1040 – 1110 **Coffee Break**

ORAL SESSION 1: ISOSCAPES (spatiotemporal distribution of isotopes)
Chair: Jason West

1110 – 1130 Using isoscapes to trace the movements and foraging behavior of predators in oceanic ecosystems.
Graham, B., *Fry, B. Popp, B., Koch, P., Newsome, S., McMahon, K.*

1130 – 1150 Biotic factors override abiotic factors in determining δD of feathers in a migratory bird species.
Carleton, S., *Wunder, M., Martínez del Rio, C.*

1150 – 1210 Isotopic variation in American fast food meals.
Chesson, L.A., *Podlesak, D.W., Thompson, A.H., Cerling, T.E., Ehleringer, J.R.*

1210 – 1230 ^{2}H and ^{18}O of human body water: a GIS model to distinguish residents from nonresidents in the contiguous United States.
Podlesak, D.W., *Bowen, G.J., Cerling, T.E., Ehleringer, J.R.*

1230 – 1250 Interpreting multi-layer, spatially explicit, isotopic data in an estuary.
Gibbs, M.*, Lohrer, D., Safi, K.*

1250 – 1410 **LUNCH**

ORAL SESSION 2: ORGANIC $\delta^{18}O$ TRACERS
Chair: Brian Popp

1410 – 1430 Complexities and rewards in oxygen isotope tracers of ecosystem processes and food webs.
Fogel, M.L., *Newsome, S.D.*

1430 – 1450 Cut-and-dried: leaf water is the primary amplifier of an aridity signal in mammalian body water $\delta^{18}O$.
Passey, B.H., *Robinson, T.F., Cerling, T.E., Singer, J.W.*

1450 – 1510 The influence of diet and water on the stable oxygen and hydrogen isotope composition of aquatic organisms (Chironomidae: Diptera), and paleoecological implications.
CWang, Y., *O'Brien, D., Jenson, J., Francis, D., Wooller, M.J.*

ORAL SESSION 3: TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS
Chair: Seth Newsome

1510 – 1530 What can stable isotopes of hydrogen (δD) tell us about freshwater food-web ecology?
Doucett, R.R., ***Hungate, B.***

1530 – 1600 **Coffee Break**

ORAL SESSION 3: TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS
Chair: Seth Newsome

1600 – 1620 Swallows powered by natural gas – a novel carbon subsidy to terrestrial systems.
Kelly, D., ***Bearhop, S.****, Inger, R., Grey, J.*

1620 – 1640 Oil-fuelled guppies? Trophic subsidies from a previous geological era.
Harrod, C., *Phillip, D., Mallela, J., Mohammed, A., Mohammed, R., Ramsubhag, A., Reimer, P.*

1640 – 1700 $\delta^{13}C$ and $\delta^{15}N$ track contaminant flux from aquatic to terrestrial food webs.
Walters, D.M., *Fritz, K.M., Raikow, D.F., Mills, M., Otter, R.R.*

1700 – 1720 Land and sea connected: stable isotopes revel a role of terrestrial organic matter in nearshore ecosystem functioning in the Gulf of Lions, Mediterranean Sea.
Dierking, J., *Banaru, D., Hermand, R., Fontaine, M.F., Degiovanni C., Letourneur, Y., Nicolas, C., Salen-Picard, C., Harmelin-Vivien, M.*

1720 – 1740 Oceanographic inputs to a fringing coral reef from stable isotope and fatty acid biomarker analysis.
Wyatt, A.*, Waite, A., Humphries, S., Babcock, R.*

1800 – 2000 **POSTER SESSION I**

Tuesday 26th August

0745 - 0845 Registration

0850 – 0900 Housekeeping

ORAL SESSION 4: METHODS IN ISOTOPE ECOLOGY 1 – Amino Acids
Chair: Stuart Bearhop

0900 – 0920 Isotopic routing: field observations, theory, and experimental results. ***Martínez del Rio, C****., Kelly, L., Tibbets, T.*

0920 – 0940 Tracing amino acids from the diet to tissues by LC-IRMS: a feeding trial with rainbow trout, *Oncorhynchus mykiss*, using purified diets partly enriched with ^{13}C-glutamate.
Focken, U.*, McCullagh, J., Gaye-Siessegger, J.*

0940 – 1000 Individual amino acid carbon isotope fractionation patterns between consumer and diet in a model fish species.
McMahon, K.W.*, Elsdon, T., Thorrold, S.R.*

1000 – 1020 Breaking all the rules: when you aren't what you eat.
Tuross, N.*, Warinner, C.*

1020 – 1040 ^{13}C fingerprinting of amino acids: a novel method for tracking the biosynthetic origin of amino acids.
Larsen, T.*, Taylor, D.L., Leigh, M.B., O'Brien, D.M.*

1040 – 1110 **Coffee Break**

ORAL SESSION 5: HERBIVORY: C_3 vs. C_4
Chair: Daryl Codron

1110 – 1130 The relative influences of termites, herbivores, and Acacia trees on nitrogen processes in a savanna ecosystem.
Fox-Dobbs, K.*, Doak, D.F., Brody, A.K., Palmer, T.M.*

1130 – 1150 Linking precipitation and C_3-C_4 plant production to resource dynamics in higher trophic level consumers.
Warne, R.*, Gilman, A.D., Pershall, A.D., Wolf, B.O.*

1150 – 1210 A mammal's-eye view of plant isotopic compositions in the Kruger National Park, South Africa.
Sponheimer, M.*, Codron, J., Codron, D., Lee-Throp, J., de Ruiter, D.*

1210 – 1230 Carbon isotope distributions across dung heaps offer a fresh approach to the African elephant browser/grazer debate.
Codron, J.*, Lee-Thorp, J., Sponheimer, M., Kirkman, K., Duffy, K., Page, B., de Ruiter, D., Codron, D.*

1230 – 1250 Isotopic and functional diversity in herbivore communities: little space for redundancy!
Codron, D.*, Clauss, M., Brink, J., Sponheimer, M.*

1250 – 1410 LUNCH

ORAL SESSION 6: FRESHWATER ECOLOGY
Chair: Bruce Hungate

1410 – 1430 Rehabilitation effects on food webs: a retrospective stable isotope analysis of Roach (*Rutilus rutilus*) scales and zooplankton from Barton Broad, UK.
Grey, J.*, Harrod, C., Graham, C., Britton, J, Bays, J.*

1430 – 1450 Carbon sources supporting aquatic food webs: a δ^{13}C meta-analysis from boreal streams, lakes and reservoirs.
Marty, J.*, Smokorowski, K., Power, M.*

1450 – 1510 Stable isotopes of C and S as indicators of habitat use by fish in small Oregon coast range streams.
Church, R.*, Ebersole, J., Kendall, C., Miller, B., Rensmeyer, K., Wigington, J.*

ORAL SESSION 7: ANIMAL MIGRATION
Chair: Brittany Graham

1510 – 1530 Isotopic and genetic evidence for site fidelity to feeding grounds in Southern Right Whales (*Eubalaena Australis*).
Valenzuela, L.*, Sironi, M., Rowntree, V., Calliari, D., Seger, J.*

1530 – 1600 Coffee Break

ORAL SESSION 7: ANIMAL MIGRATION

Chair: Brittany Graham

1600 – 1620 Seasonal variation in foraging ecology of southern elephant seals along the western Antarctica peninsula.
Hückstädt, L.*, McDonald, B, Koch, P, Goebel, M, Crocker, D, Costa, D.*

1620 – 1640 Stable isotope analysis of Great Grey Owl (*Strix nebulosa*) invasions in North America.
Newsome, S.*, Graves, G., Willard, D., Grosshuesch, D., Fogel, M.*

1640 – 1700 Use of stable isotope signatures (δ^2H, δ^{13}C, and δ^{15}N) to indicate breeding and wintering grounds in a European long-distance migratory bird, *Upupa Epops*.
Reichlin, T.*, Schaub, M., Arlettaz, R., Jenni, L.*

1700 – 1720 Detecting altitudinal migration and molt patterns in neotropical birds using stable hydrogen isotopes.
Fraser, K.*, Cunjak, R., Diamond, A.*

1720 – 1740 Estimating proportional mixtures of hydrogen and oxygen sources in a highly restricted avian system.
Wunder, M.*, Jehl, J., Inger, R., Bearhop, S.*

1800 – 2000 **POSTER SESSION II**

Thursday 28th August

0800, 0830 Bus Pick-ups, parking lot in front of the Waikiki Zoo

0830 – 0850 Registration

0850 – 0900 Housekeeping

0900 – 0940 Plenary II: ***Dr Simon Jennings***
Marine food web ecology: insights from stable isotopes.

ORAL SESSION 8: MARINE ECOLOGY
Chair: Brian Fry

0940 – 1000 Shifting warm-water to cold-water conditions and foodweb dynamics of juvenile Pacific Salmon in the Eastern Bering Sea ecosystem.
Mazumder, A.*, Trudel, M., Mazumder, S., Farley, E., Moss, J., Eisner, L., Murphy, J.*

1000 – 1020 Metabolic rates and life histories in deep water fish.

Trueman, C.

1020 – 1040 Contribution of terrestrial materials to nearshore kelp beds in central California.
Foley, M.

1040 – 1110 **Coffee Break**

ORAL SESSION 8: MARINE ECOLOGY
Chair: Brian Fry

1110 – 1130 Quantifying prey proportions of Antarctic Toothfish (*Dissostichus mawsoni*) in the Ross Sea, Antarctica.
Bury, S.*, Pinkerton, M., Thompson, D., Hanchet, S, Cherel, Y., Brown, J.*

1130 – 1150 Individual variation in nutrient allocation to egg production in an arctic sea duck.
Oppel, S.*, Powell, A., O'Brien, D.*

1150 – 1210 Interdecadal variability of stable isotopes reflected in Bering Sea zooplankton.
Hirons, A.*, Finney, B., Springer, A.*

1210 – 1230 Biogeographic isotope trends in marine intertidal food webs.
Hill, J.*, McQuaid, C., Kaehler, S.*

1230 – 1250 Stable isotopes show consistent consumer-prey relationships across hundreds of kilometers.
Vanderklift, M.*, Wernberg, T.*

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1250 – 1410 **LUNCH**

ORAL SESSION 9: HUMAN ECOLOGY
Chair: Diane O'Brien

1410 – 1430 A quantitative biomarker of fish intake: ^{15}N is highly correlated with red blood cell omega-3 fatty acids (EPA and DHA) in Yup'ik Eskimos.
O'Brien, D.*, Jeannet, M, Wilkinson, M, Bersamin, A, Kristal, A, Luick, B.*

1430 – 1450 Red blood cell $\delta^{15}N$ and $\delta^{13}C$ vary according to age, geography, and intake of specific nutrients; results from over 1000 Yup'ik Eskimos om the CANHR I study.
Nash, S.*, Pasker, R., Wilkinson, M., Bersamin, A., Luick, B., O'Brien, D.*

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1450 – 1510 Clinical-scale investigations of stable isotopes in human blood: $\delta^{13}C$ and $\delta^{15}N$ from 406 patients at the Johns Hopkins medical institutions. ***Kraft, R.,*** *Jahren, A., Saudek, C.*

1510 – 1530 Strontium isotope tracing at a Neandertal site in South-western France.
Kelly, T.*, Grün, R., Mortimer, G., Aubert, M., Woodhead, J., Eggins, S., Thönnessen, M., Radtke, U., Maureille, B.*

1530 – 1600 **Coffee Break**

ORAL SESSION 10: METHODS IN ISOTOPE ECOLOGY II - Isotopic Discrimination & Models
Chair: Carlos Martínez del Rio

1600 – 1620 Fixed discrimination factors in diet reconstruction?
Caut, S.*, Das, K.*

1620 – 1640 Assessing stable isotope turnover upon diet switches in animals under controlled settings.
Fisk, A*, Olin, J., Overmyer, J., Howell, G., Drouillard, K., MacNeil, M.*

1640 – 1700 Prediction of atmospheric $^{13}CO_2$ using plant tissues grown under elevated PCO_2. ***Jahren, A.***

1700 – 1720 Solving isotope mixture models using Bayesian methods: an introduction using the free to download R package "SIAR".
Jackson, A.*, Parnell, A., Inger, R., Bearhop, S.*

1720 – 1740 Testing Bayesian approaches to stable isotope mixing models. ***Inger, R.****, Jackson, A., Parnell, A., Bearhop, S.*

Friday 29th August

0800, 0830 Bus pick-up, parking lot in front of the Waikiki Zoo

0745 – 0845 Registration

0850 – 0900 Housekeeping

ORAL SESSION 11: BIOGEOCHEMICAL CYCLING
Chair: Carolyn Holl

0900 – 0920 Coupled ^{13}C and ^{15}N patterns of individual amino acids in prokaryotic vs. eukaryotic phytoplankton production.
Lehman, J.*, McCarthy, M.*

0920 – 0940 Microbial community nitrogen and carbon cycling in super-intensive shrimp aquaculture systems.
Holl, C.*, Tallamy, C., Moss, S.*

0940 – 1000 Isotope fractionation during N mineralization and the N isotope composition of terrestrial ecosystem N pools.
Dijkstra, P., LaViolette, Coyle, J., Schwartz, E., Hungate, B., Hart, S.

1000 – 1020 Mechanisms for the retention of bio-available nitrogen in volcanic rainforest soils.
*Huygens, D., **Boeckx, P.**, Templer, P., Paulino, L., Van Cleemput, O., Oyarzun, C., Müller, C., Godoy, R.*

1020 – 1040 Stable isotopes as a tool to study nutrient exchange between orchids and fungi. ***Gebauer, G.**, Zimmer, K., Liebel, H., Stöckel, M.*

1040 – 1110 **Coffee Break**

ORAL SESSION 12: RETRO ECOLOGY - Stable Isotopes as Indicators of Past Ecological Change
Chair: Renee Brooks

1110 – 1130 Physiological responses to fertilization recorded in tree rings: isotopic lessons from a long-term fertilization trial.
***Brooks, R.**, Coulombe, R.*

1130 – 1150 Variability and coherence among distant sites in O and C stable isotope ratios from tree ring cellulose of Sequoia Sempervirens, Coast Redwood: links to climate and ecological change. ***Dawson, T.**, Roden, J., Johnstone, J.*

1150 – 1210 Changes in near shore food web dynamics over the last 4500 years, Penobscot Bay, Gulf of Maine.
***Johnson, B.**, Bourgue, B., Steneck, R.*

1210 – 1230 The marine life of Atlantic salmon: isotopic determination.
***MacKenzie, K.**, Trueman, C., Palmer, M., Moore, A.*

1230 – 1250 Using $\delta^{13}C$ and $\delta^{15}N$ of zooplankton fossil exoskeltons for retrospective ecological studies: changes in planktonic food web during 150yrs of human perturbations on Lake Annecy.
***Perga, M.E.**, Reyss, J., Semet, M.*

1250 – 1410 **LUNCH**

ORAL SESSION 12: RETRO ECOLOGY - Stable Isotopes as Indicators of Past Ecological Change
Chair: Renee Brooks

1410 – 1430 From river horses to sea cows: using stable isotopes in tooth enamel to identify semiaquatic mammals in the fossil record.
***Clementz, M.**, Holrody, P.*

ORAL SESSION 13: ANTHROPOGENIC FORCINGS ON ECOSYSTEMS
Chair: Craig Stricker

1430 – 1450 Variations in the foraging ecology of a contentious piscivorous predator.
Brown, S., *Bearhop, S., Newton, J., McDonald, R., Harood, C.*

1450 – 1510 Detecting anthropogenic contamination in coral reefs using stable isotopes of holothurians.
Kolasinski, J.*, Rogers, K., Frouin, P.*

1510 – 1530 Feeding interactins of Cyprinid fishes in Irish lakes.
Hayden, B.*, Mass-Gallucci, A., Mariani, S., Kelly-Quinn, M.*

1530 – 1600 **Coffee Break**

ORAL SESSION 13: ANTHROPOGENIC FORCINGS ON ECOSYSTEMS
Chair: Craig Stricker

1600 – 1620 Sulfur biogeochemistry in agricultural and natural wetlands: linking food webs to sediment and water-column processes.
Sricker, C.*, Ackerman, J., Alpers, C., Eagles-Smith, C., Fleck, J., Marvin-DiPasquale, M., Windham-Myers, L.*

1620 – 1640 The use of stable isotopes as tracers of trophic response to an environmental flow in the regulated lower Gwydir wetlands of NSW, Australia.
Mazumder, D.*, Kelleway, J., Kobayashi, T., Knowles, L., Iles, J., Saintilan, N., Wilson, G.*

1640 – 1700 N cycling in an upland forest stream in Panama before and after the decline of the dominant amphibian community.
Verburg, P.*, Kilham, S., Pringle, C., Whiles, M., Connelly, S., Colon-Gaud, J., Griffith, E., Ross, H., Dodds, W., Hall, R., Huryn, A., Lips, K.*

1700 – 1730 **Student prizes and conference wind up**

Poster Sessions: August 25th & 26th

ISOSCAPES

A1 Carbon, nitrogen, oxygen, and fatty acid hydrogen isotope analyses of polished rice for verifying its geographical origin. ***Nakashita, Rumiko****, Suzuki, Y., Akamatsu, F., Korenaga, T.*

A2 Geographical origin of beef based on bulk carbon, nitrogen, oxygen, and fatty acid hydrogen isotope analyses. ***Suzuki, Yaeko****, Nakashita, R., Akamatsu, F., Korenaga, T.*

TRANSFER OF NUTRIENTS AMONG DISPARATE ECOSYSTEMS

B1 Combined stable carbon isotope and C/N ratios as indicators of source and fate of organic matter in a tropical river estuarty. ***Boonphakdee, Thanomsak,*** *Kasai, A., Fujiwara, T*

B2 The use of stable isotopes $\delta^{13}C$ and $\delta^{15}N$ as tracers of the source and fate of energy in a dynmical coastal area located at the temperate-tropical transitional zone (BCS, México) ***Camalich, Jaime,*** *Aguiñiga, S, Balarat, E., Aurioles-Gamboa, D.*

B3 Tracing terrestrial and aquatic organic matter sources in the Colorado River food web using stable isotopes of hydrogen (δD). ***Caron, Melanie,*** *Doucett, R., Sabo, J., Kennedy, T.*

B4 Gravity matters: how habitat structure influences food-web structure. ***Fox-Dobbs, Kena,*** *Pringle, R., Doak, D.*

B5 Bingeing on bycatch in Baja: anthropogenic marine subsidies and possible trophic cascades. ***Newsome, Seth,*** *Moore, J., Yeakel, J., Wurzel, W., Fogel, M.*

B6 Resource partitioning among insectivorous bats: insights from stable isotope analysis. *Crawford, K., McDonald, Bearhop, S.,* ***Newton, Jason****.*

METHODS IN ISOTOPE ECOLOGY

C1 Seaweed or biofilm? Experimental approaches to examine the diet of *Patella vulgata* using stable isotopes. ***Andrew, Gillian,*** *Burrows, M., Hawkins, S., McGill, R.A.R.*

C2 Effects of temperature and diet quality on carbon and nitrogen stable isotope fractionation in an omnivorous fish ***Bloomfield, Alexandra,*** *Elsdon, T., Walther, B., Gillanders, B.*

C3 A stable isotope approach to improve calculations of consumers-resource nutrient imbalances. ***Bruans, Mario,*** *Gücker, B., Wagner, C., Pusch, M.*

C7 The effect of lipid-extraction on high lipid-content notothenioid (anti-freeze) fish from the Ross Sea, Antarctica. ***Bury, Sarah****, Pinkerton, M., Thompson D., Cherel, Y., Brown J.*

C8 Modeling isotope Incorporation: one- or many compartments and does it matter? ***Carleton, Scott****, Kelly, L., Anderson-Sprecher, R., Martínez del Rio, C.*

C9 Fish mucus as a rapid responding tissue in diet switching studies. ***Church, Robbins****, Ebersole, J., Rensmeyer, K., Couture, R., Noakes, D., Barrows, R., Wigington, J.*

C10 Multi-isotope analysis of animal tissue in lipid-containing and lipid-free material. ***Claymore, Valerie****, Beavan-Athfield, N., Phillips, A., Cooper, J.*

C11 Isotopic turn-over in claw tissue of a long-distance migratory thrush (*Catharus bicknelli*): implications for conservation and studies of migratory connectivity. ***Fraser, Kevin****, Rimmer, C., McFarland, K., Cunjak, R., Diamond, A.*

C12 Shifts in Stomatal Control of Photosynthesis in Response to Regional Climate Change: Evidence from Tree Ring $\delta^{13}C$ and $\delta^{18}O$ of *Callitris columellaris*. ***Grierson, Pauline****, Cullen, L., Anderson, M., Adams M.*

C13 Sharks vs. the rest of the world: lipid extraction and stable isotopes. ***Hussey, Nigel****, McCarthy, I., Dudley, S., Fisk, A.*

C14 Calibrating isotopic methods to study shark ecology. ***Kim, Sora,*** *Casper, D., Koch, P.*

C15 Effects of seasonality and ontogeny on the organic $\delta^{18}O$ and δD of rodent tissue. ***Kirsanow, Karola****, Tuross, N.*

C16 Using isotopes in tropical macrofauna: is sample acidification required? ***Kolasinski, Joanna****, Rogers, K., Frouin, P.*

C17 Using ^{15}N to Track Tissue Catabolism during Hibernation in an Extreme Arctic Hibernator, *Spermophilus parryii* *Lee, T., Buck, C., Barnes, B.,* ***O'Brien, Diane***

C18 Effects of lipid extraction on $d^{13}C$, $d^{15}N$, and $d^{34}S$ in avian egg yolk. ***Oppel, Steffen****, Federer, R., Powell, A., Hollmén, T.*

C19 A study on feeding habit of Asiatic Black Bear by nitrogen isotope analysis of amino acids. ***Nakashita, Rumiko****, Suzuki, Y., Akamatsu, F., Sato, M., Goto, M., Izumiyama, S., Hayashi, H., Yoh, M., Tsubota, T., Korenaga, T.*

C20 Differential isotopic turnover (C and N) detected in Antarctic scavenger amphipods. ***Nyssen, Fabienne****, Michel, L., Dauby. B., Brey, T.*

C21 Modeling $\delta^{13}C$ dynamics in soft tissues and calcified structures of aquatic organisms in the context of the Dynamic Energy Budget (DEB) theory. ***Pecquerie, Laure****, Fablet, R., Lorrain, A., Dufour, E., Nisbet, R., Kooijman, SALM.*

C22 Combining stable isotope analysis and census data correlations to compare metrics of detritus based food webs in different environmental contexts. ***Rossi, Loreto****, Costantini, M., di Lascio, A., Carlino, P., Rossi, D.*

C23 Continuous isotopic CO_2 measurements by wavelength-scanned cavity ring down spectroscopy: studies of exchange processes in terrestrial ecosystems. ***Van Pelt****, Aaron, Rahn, T.*

HERBIVORY: C3 vs. C4

D1 Isotopic modeling of the Hippo ecomorph: identifying aquatic habits of herbivorous mammals through stable isotope analysis. ***Clementz, Mark****, Holroyd, P.*

D2 Carbon isotope distributions in mixed-feeding herbivores: a browser-grazer approach to functional response. ***Codron, Daryl****, Sponheimer, M., Lee-Thorp, J., Codron, J., de Ruiter, D.*

D3 Tiny teeth and the big picture: carbon and oxygen isotope ratios of micromammal teeth from Eastern Africa. ***Levin, Naomi****, Manthi, F, Kaleme, P, Cerling, T*

D4 ^{13}C, ^{2}H, & ^{18}O values of hair reveal seasonal patterns in resource use for American Bison. ***Podlesak, David****, Erkkila,B, Brennan, S, Quigley, B, Ehleringer, J, Cerling, T*

D5 The isotopic ecology of Ring-tailed Lemurs (*Lemur catta*) in Southwest Madagascar. ***Sponheimer, Matt****, Loudon, J., Whitelaw, D., Sauther, M., Cuozzo, F.*

FRESHWATER ECOLOGY

E1 Trophic position of bottom-feeding fish in the Upper Paraná River Floodplain, Brazil. *Lopes, C.,* ***Benedito, Evanilde****, Martinelli, L.*

E2 Temporal and individual diet variation in the Barton Springs Salamander (*Eurycea sosorum*): An application of stable Isotope analysis to the conservation of rare and endangered species. ***Gillespie, Hayley***

E3 Repeated patterns of isotopic variation with depth in lake benthos. ***Harrod, Chris****, Kahilainen, K.*

E4 Using stable isotopes to investigate tree water sources and groundwater-surface water interactions in the Macquarie Marshes, NSW Australia. ***Hollins, Suzanne****, Meredith, K., Twining, J.*

E5 Reducing food miles: an investigation of gardening by a sedentary Caddisfly. *Ings, N., Hildrew, A.,* ***Grey, Jonathan***

E6 Trophic interactions between planktivorous fish and zooplankton in lakes of contrasting DOC concentrations. ***Persaud, Anurani****, Dillon, P., Molot L.*

E7 Food webs of lakes from Iberá Wetlands (Northeastern Argentine): spatial variation in the stable isotope composition. ***Soneira, Paula****, Almirón, A., Casciotta, J., Planas, D., Ruiz Díaz, F., Alabarcez, M, Bechara, J.*

ANIMAL MIGRATION

F1 Patterns of $\delta^{18}O$ in fish tissues in two Oregon coast range streams. ***Church, Robbins****, Ebersole, J., Miller, B., Wigington, J.*

F2 Tracking migratory pathways of Atlantic Bluefin Tuna (*Thunnus thynnus*) to Gulf of Mexico spawning grounds through electronic tagging and stable Isotope analyses. ***Logan, John****, Knapp, J., Lutcavage, M.*

F3 Changing places? Contrary winter movements of small seabirds from both sides of the Drake Passage. ***Quillfeldt, Petra****, McGill, R., Masello, J., Weiss, F., Gladbach, A., Furness, R.*

MARINE ECOLOGY

G1 Trophic Influences on heavy metal patterns in South Georgian Procellariiformes. ***Anderson, Orea****, Phillips, R., Shore, R., McGill, R., Bearhop, S.*

G2 Variability and isotopic fractionation of $\delta^{13}C$ and $\delta^{15}N$ in zooplankton species from upper Paraná River Floodplain, Brazil. *Santana, A., Lansac-Tôha, F.,* ***Benedito, Evanilde****, Ducatti, C.*

G3 Food web structure of deep Mediterranean cold seeps: a multiple stable isotope ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) approach. ***Carlier, Antoine****, Ritt, B., Rodrigues, C., Sarrazin, J., Grall, J., Clavier J.*

G4 Mercury levels in Hawaiian predatory pelagic fishes and their lower trophic level prey as a function of depth and ecology. ***Choy, Anela****, Drazen, J., Popp, B.*

G5 The consumer-diet $\delta^{13}C$ and $\delta^{15}N$ enrichment in the benthic system of a tropical-subtropical continental shelf in the southwestern Atlantic. ***Corbisier, Thais****, Petti, M., Bromberg, S., Valiela, I.*

G6 Spatial variation of the benthic marine food web in Admiralty Bay (King George Island, Antarctica): analysis using stable isotopes. ***Corbisier, Thais****, Petti, M., Bromberg, S., Gheller, P., Valiela, I.*

G7 Multi-source mixing model analysis of diet in the formidable marine predator, Mantis shrimp. ***deVries, Maya***

G8 Coupling stable isotope and metal analysis as ecological tracers to study the feeding ecology of the leatherback turtle. **Guirlet, Elodie**, Caut, S., Das, K., Girondot, M.

G9 $\delta^{13}C$ and $\delta^{15}N$ reveal significant differences in the coastal food webs of the seas surrounding the Islands of Trinidad and Tobago. ***Harrod, Chris****, Mallela, J.*

G10 Characterising marine food webs using combination of C, N, and S stable isotopes, fatty acid biomarkers, and compound-specific C stable isotope analysis: a case study of subtidal sand-bottom community. ***Kiyashko, Sergey****, Rodkina, S., Kharlamenko, V.*

G11 Resource and habitat utilization of Southern Ocean penguins inferred from the $\delta^{13}C$ and $\delta^{15}N$ values of amino acids. ***Lorrain, Anne****, Graham, B., Menard, F., Cherel, Y.*

G12 Trophic connectivity of estuarine biota elucidated by stable isotope signatures of carbon & nitrogen. ***Mazumder, Debashish****, Saintilan, N, Williams, R, Szymczak, R, Cairns, J.*

G13 Marine food webs. ***McMeans, Bailey****, Svavarsson, J., Fisk, A.*

G14 Body size and $\delta^{15}N$ relationship of marine fish on the coastal waters off Southeastern Brazil. ***Muto, Elizabeti*** *,* ***Soares, Lucy****, Corbisier, T.*

G15 Spatial and temporal variation of stable isotopes signatures of marine fishes in the coastal waters of southeastern Brazil. ***Muto, Elizabeti****, Soares, L.,* ***Corbisier, Thais****.*

G16 Trophic ecology of the medio-littoral rocky shore in the Bay of Banyuls-sur-mer (northwest Mediterranean, France). ***Nahon, Sarah****, Pruski, A, Nozais, C, Charles, F*

G17 Evolution of the trophic structure of a coastal Antarctic food web during pack Ice break-up. ***Paulet, Yves-Marie****, Amice, E., Chauvaud, L., Leynaert, A., Richard J.*

G18 Diet and nutrition of western rock lobsters, *Panulirus cygnus*, in shallow coastal waters: the role of habitat. *MacArthur, L, Hyndes, G, Hanson, C,* ***Phillips, Donald, Vanderklift, Mat****, Babcock, R.*

G19 A novel approach to monitoring changes in the diet of lactating mothers through isotopic analysis of young Steller sea lions vibrissae. ***Rea, Lorrie****, Farley, S., Stricker, C., Stegall, V., Eischens, C.*

G20 Nutritional status of San Francisco Bay harbor seals by assessing $\delta^{13}C$ and $\delta^{15}N$ amino acid patterns. ***Roland, Leslie****, McCarthy, M., Koch, P., Harvey, J.*

G21 Stable isotope analysis of some representative fish and squids of a subtropical continental shelf food web, southwestern Atlantic. ***Soares, Lucy****, Muto E., Vera G., Lopez J., Valiela, I.*

G22 Trophic relationships and carbon flow in the Scotia Sea food web. *Stowasser, G., **McGill, Rona**, Pond, D., Collins, M, Phillips, R, Atkinson, A*

G23 Using stable Isotopes of carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) to differentiate winter flounder nursery areas. ***Taplin, Bryan**, Pruell, R., Karr, J.*

G24 Comparing patterns of stable nitrogen isotopes and mercury in diet and stable isotope analysis of the fish *Raneya brasiliensis* on continental shelf off southeastern Brazil. *Vera, G., Soares, L.*

BIOGEOCHEMICAL CYCLING

H1 Soil and plant $\delta^{15}N$ as indicator for wildfire effects in a Nothofagus – Araucaria ecosystem in southern Chile. ***Boeckx, Pascal**, Paulino, L., Matus, F., Rivas, Y., Huygens, D., Godoy, R.*

H2 New isotopic evidence of fungal networking in the plant tribe Pyroleae (Ericaceae). ***Hynson, Nicole**, Zimmer, K., Gebauer, G., Bruns, T.*

H3 The oxygen isotopic signature of biogenic nitrous oxide is determined by H_2O through oxygen exchange. ***Kool, Dorien**, Wrage, N., Oenema, O., Harris, D., Van Groenigen, J.*

H4 Net N mineralization affects ^{15}N natural abundance of the soil microbial biomass. ***LaViolette, Corinne**, Dijkstra, P, Hart, S, Schwartz, E, Hungate, B.*

H5 Multiproxy isotope analysis shows anaerobic oxidation of methane in high alpine lake sediments. ***Schubert, Carsten**, Loesekann, T., Knittel, K., Boetius, A.*

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

I1 Applying stable isotope analyses of extant tapirs to constrain paleoecological hypotheses. ***DeSantis, Larisa***

I2 Geochemical records of geoduck shells (*Panopea abrupta*) and the low dissolved oxygen conditions in Hood Canal. ***Gao, Yongwen**, Palzer, T., Sizemore, B., Brand, U.*

I3 The utility of paleoecology and sedimentary $\delta^{15}N$ as indicators of past salmon abundance in Coastal British Columbia, Canada. ***Pellatt, Marlow***

I4 The sulfur stable isotope composition of peat-forming plants – a possible record of environmental conditions? ***Skrzypek, Grzegorz**, Drzewicki, W., Jedrysek, M.*

I5 Stable isotope analyses of stratified sediments collected from an elephant seal wallow in Antarctica shows late-Holocene changes in diet and foraging location. ***van den Hoff, John***

I6 Development of $\delta^{13}C$ in chironomid cuticles as a new palaeolimnological proxy. *van Hardenbroek, M, Heiri, O, Verbruggen, F., **Grey, Jonathan**, Bodelier, P., Lotter A.*

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

J1 Carbon and oxygen stable isotopes of rice as proxy parameters for changes in rice production with climate warming. ***Akamatsu, Fumikazu**, Suzuki, Y., Nakashita, R., Korenaga, T.*

J2 Effects of an invasive N-fixing tree on a Hawaiian stream food web. ***Atwood, Trisha**, Wiegner, T., Turner, J., MacKenzie, R.*

J3 Impact of mountaintop mining/valley fill on the stable carbon isotopic composition and concentration of dissolved organic carbon and dissolved inorganic carbon in headwater streams. ***Burke, Roger**, Fritz, K., Johnson, B., Fulton, S., Barton, C.*

J4 Comparative Study of the Food Webs of two Northwestern Mediterranean lagoons under varying degree of anthropogenic influences: a $\delta^{13}C$ and $\delta^{15}N$ assessment. ***Carlier, Antoine**, Riera, P, Amouroux, J, Bodiou, J, Desmalades, M, Grémare, A*

J5 Using $\delta^{15}N$ values of three red algal species to examine nutrients sources in intertidal and shallow subtidal habitats at Ewa Beach: is storm-drain water a possible nutrient source? ***Cox, Erin**, Smith, C.*

J6 Recovery of salt marsh trophic structure in restored marshes of Venice Lagoon, Italy. ***Demopoulos, Amanda**, McMillan, P., Gonzalez, J., Levin, L.*

J7 Soil respiration and plants isotopic composition in a Cerrado sensu stricto area. ***Dias, Jadson**, Ometto, J., Camargo, P.*

J8 Dietary investigations of Yellowstripe Goatfish (*Mulloidichtys flavolineatus*) using stable isotopes. ***Frouin, Patrick**, Kolasinski, J, Potier, M., Rogers, K., Sallon, A.*

J9 Chemical markers of niche space for Hawaiian red mangroves. ***Fry, Brian**, Cormier, N.*

J10 N_2O sink function in a forest soil as indicated by concentration and stable Isotope profiles. ***Gebauer, Gerhard**, Goldberg, S.*

J11 Dietary shifts on human-impacted coastlines: consequences of subtidal habitat change. ***Gorman, Daniel**, Connell S., Carlson I.*

J12 Stable isotopes as tools helping to understand benthic community responses to coastal eutrophication. ***Grall, Jacques**, Le Loc'h, F., Guyonnet, B.*

J13 Conduits of contamination to contemporary food webs of the Norfolk Broads (UK) from an organotin legacy. *Laws, J, Heppell, C., Sheahan, D.,* ***Grey, Jonathan***

J14 Stable isotopic studies on ecological consequences of the Three Gorges Dam, China. ***Lin, Guanghui****, Jianzhu, Wang, Shuanfeng Sun, Jianhui Huang[1], Jianguo Wu, Xingguo, Han*

J15 Stable isotopes indicate the effects of river regulation on invertebrate food webs in tributaries of the Hunter River, NSW. ***Maxwell, Sally****, Boulton, A., Growns, I.*

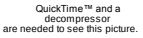
J16 Using stable isotopes and other chemical tracers to quantify the influence of anthropogenic alteration of hydrologic regimes in estuarine food webs. ***Olin, Jill****, Heupel, M., Simpfendorfer, C., Poulakis, G., Fisk, A.*

J17 Implications of drought Induced changes to the primary energy sources supporting the food web of a subtropical reservoir. ***Roberts, David****, Burford, M, Bunn,S*

J18 Food web relationships of Hamilton Harbour using $\delta^{13}C$ and $\delta^{15}N$ analysis. ***Ryman, Jennie****, Koops, M., Power, M.*

J19 Soil respiration source partition and net wheat-soil ecosystem productivity under elevated atmospheric pCO_2. ***Xie, Zubin****, Taiji Kou, Jianguo Zhu, Ganliu*

ORAL PRESENTATIONS



PLENARY I

TRACING WITH ISOTOPES: PRACTICES, APPLICATIONS AND OPPORTUNITIES

Bowen, Gabriel J.

Earth & Atmospheric Sciences Dept. and Purdue Climate Change Research Center, Purdue Univ., West Lafayette, IN, USA

Stable isotopes represent inherent mass tracers, and provided the mechanisms that underlie isotopic partitioning can be adequately represented stable isotopes can be helpful in quantifying biogeochemical fluxes, reconstructing movement of organisms or products, and establishing connectivity in all manner of systems. Isotopes are particularly well suited to addressing problems the deal with tracing and connectivity at relatively large spatial scales, but at these scales the quantification of isotope partitioning in the environment can be difficult. "Isoscapes," models of the spatiotemporal distribution of isotopes, represent the solution to this problem through the integration of isotopic data and theory with geographic information systems modelling. Recent improvements in isoscapes have been driven by availability of new data, introduction of new models or novel model parameterizations, and recognition of new applications for isotope tracing.

Applications of isotope tracing at intermediate to large spatial scales have seen significant recent advances. In ecology, tracing of animals and plant products on land is positioned to benefit from improved mechanistic understanding of biological partitioning of H and O isotopes, and early efforts at tracing marine organisms have expanded as new and refined isoscapes have developed for aquatic systems. In biogeochemistry a long legacy of learning from isotope tracing of atmospheric trace gases continues, but innovative ground-based approaches to large-scale problems have been slow to develop. Exciting new isotope-based approaches to assessing large-scale fluxes in the water cycle continue to develop, and applications to anthropogenic systems have 'exploded'. Within the coming decade, several emerging opportunities promise to offer new spatially distributed isotope data at unprecedented scales. The history of isotope tracer research suggests that advances have occurred where innovative questions and applications have intersected with innovation in technology, suggesting that the ecological community will have an important role to play in, and is positioned to benefit from, advancing isotope tracer research.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

CONTINENTAL-SCALE DISTRIBUTIONS OF PLANT STABLE ISOTOPE RATIOS

Still, Chris J.[1], West, J.B.[2], Ehleringer, J.R.[2], Powell, R.L.[3]

[1] Dept of Geography, University of California, Santa Barbara, CA, USA
[2] Dept of Biology, University of Utah, UT, USA
[3] Dept of Geography, University of Denver, CO, USA

The stable isotope composition of terrestrial vegetation is important for a variety of scientific applications in fields ranging from biogeochemistry to zoology to paleoclimatology. Plant stable isotope ratios are the consequence of "source" isotope ratios (e.g., CO_2 or soil water) combined with biological and chemical fractionations during photosynthesis and other biophysical, metabolic and biosynthetic reactions. Although gaps in understanding exist for all isotope systems, modeling large-scale spatial patterns in plant stable isotope ratios has been approached successfully through a variety of methods. We discuss here three increasingly sophisticated approaches, provide an initial evaluation of these products, and identify important gaps in understanding or data necessary for improved descriptions. Three primary approaches are discussed: (1) a regression approach to model $\delta^{15}N$ using climate drivers, (2) a mechanistic approach to model leaf water $\delta^{18}O$ using climate drivers and modeled precipitation $\delta^{18}O$, and (3) an approach that combines mechanistic modeling and continuous fields derived from remote sensing products to model leaf $\delta^{13}C$. The global $\delta^{15}N$ plant isoscape (Amundson et al.) compared favorably with distributed observations of Ricinus communis $\delta^{15}N$ data. However, observations fell far from the 1:1 line and had different relationships with the primary model drivers (precipitation and temperature). Caution is warranted in applying these isoscapes when the regressions do not adequately capture the underlying mechanisms. The global $\delta^{18}O$ leaf water isoscape also compares favorably with distributed observations of a va*f*riety of species. Here a better understanding of the drivers (source water and climate experienced by plants) and the mechanisms of fractionation (e.g., non-steady state and species-specific Péclet effects) will improve future efforts. To a large degree, landscape-to-regional-scale spatial patterns in plant $\delta^{13}C$ in many areas are imparted by variations in the C_3/C_4 composition of vegetation. We present results from a project to predict the $\delta^{13}C$ of terrestrial vegetation using a combination of MODIS Vegetation Continuous Fields (VCF) satellite data, climate data, and crop type maps. Our approach relies on the strong ecological sorting of C_3 and C_4 grasses along temperature gradients, as well as the near-universal restriction of C_4 photosynthesis to the herbaceous growth form. By combining these products, we can predict the C_4 fraction of vegetation at continental to global scales, and also its contribution to productivity. We will present continental-scale mapping and modeling of C_3 and C_4 biogeography and productivity in Africa and South America. The $\delta^{13}C$ of vegetation on these continents is estimated from their C_3/C_4 composition, assuming constant values for C_3 and C_4 leaf material. The values for C_3 plants can vary several per mil in space and time due to differences in isotope fractionation, whereas the values for C_4 plants are more constant. Future efforts will include variable C_3 and C_4 isotopic fractionation values predicted by global biosphere models, as well as seasonal variations in C_3 and C_4 photosynthetic activity.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

THE DISTRIBUTION AND ECOLOGY OF SOUTHERN ELEPHANT SEALS AND ADÉLIE PENGUINS ON THE HOLOCENE ROSS SEA COAST

Koch, Paul L.,[1] Hall, B.[2], Baroni, C.[3], Newsome, S.D.[4], Salvatore, M.C.[5]

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Radiocarbon dates on skin, hair and mummified carcasses show that during the Holocene, southern elephant seals (SES; Mirounga leonina) occurred along the western coast of the Ross Sea (Victoria Land Coast, VLC) from at least Edmonson Point (74°20' S) to Explorer's Cove (77°30' S). The most recent occupation ended only 500 years ago. The closest breeding site to the region today is Macquarie Island (54°30' S), 2500 km to the north. Today, most Macquarie SES feed further north, in the productive waters of the Subantarctic Front and Antarctic Circumpolar Current (60-70° S), or along the Antarctic continental shelf outside the Ross Sea. SES feed in open, ice-free water and they haul-out on ice-free beaches to moult and breed. Their absence from the VLC today is presumably a result of abundant pack ice and land fast-ice in the Ross Sea, even in summer months. Thus the presence of abundant SES along the VLC suggests substantially less pack ice and fast-ice in the Ross Sea at intervals from the middle to late Holocene. This interpretation is supported by the distributions of relict Adélie penguin rookeries. These penguins nest on land but forage in pack ice. Adélie rookeries are widespread along the VLC today. From 3800-2300 yr BP penguins occur without SES (suggesting conditions similar to today), whereas from 2300-500 yr BP, SES occur but Adélie rookeries are uncommon (indicating less ice than today). From 6200-3800 yr BP, SES and Adélie penguins co-occur at a number of sites along the VLC, suggesting intermediate conditions, with little fast-ice, but with nearby pack ice.

Carbon and nitrogen isotope data from seals and Adélie penguins support the interpretation that Holocene conditions in the Ross Sea were different than today. Today, there are strong carbon and nitrogen isotope gradients at the base of the food web in the region. Values are higher at lower latitudes, in the southern Pacific Ocean and frontal zone with Antarctic water, and drop by several per mil in Antarctic waters. While we currently lack data from modern Macquaire SES, comparisons to data from other modern and fossil seals and penguins suggest that ancient SES foraged within the Ross Sea ecosystem. Isotopic values suggest SES foraged within the Ross Sea for much of the Holocene, with little evidence for secular variation in either seal behavior or marine conditions, at least when SES are present. In contrast to the recent results of Emslie & Patterson (2007), who studied Adélie penguin eggshell fragments, our study of collagen from fossil Adélie penguin bones found no evidence for a drop in penguin trophic level in the past few 100 years. Overall, our study of suggests that Ross Sea ecosystems of the recent past were different than those at present, and perhaps that the VLC supported a substantial southern elephant seal breeding colony, an idea we are investigating through further studies of fossils and ancient DNA.

Reference:
Emslie SD, Patterson WP (2007) PNAS 104: 11666-11669

ISOSCAPES: Spatiotemporal Distribution of Isotopes

INFERRING SOURCES OF PLANT MATERIALS FROM STABLE ISOTOPE RATIOS

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The stable isotope ratios of plants record the isotope ratios of the water, atmospheric gases, and soil-derived elements necessary for growth, as well as the biophysical and metabolic processes that occur during plant growth. This record can therefore yield a variety of insights about the conditions and geography of plant growth. As in other areas of ecology, there is strong potential for interactions between what might be called stable isotope ecology and fields related to human activities such as in agriculture, commerce or forensics. We present case studies from our work on the interactions between ecological theory, empirical observations, and applications to targeted questions. We demonstrate progress in understanding isotopic “signals” in the environment, as well as the utility of these cross-disciplinary interactions, both in terms of advances in developing forensic or commercial tools and in terms of improving mechanistic understanding. We focus here on the stable isotopes of marijuana (an illicit drug) and wine (a legal though highly-regulated beverage). Marijuana stable isotopes have been explored by a few groups interested in their potential for providing source information. We have developed a framework for interpreting carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios in terms of growth conditions (e.g., indoor versus outdoor-growth) and hydrogen ($\delta^{2}H$) and strontium ($^{87/86}Sr$) isotope ratios in terms of geographic origin. Clear signals of indoor growth are found in depleted carbon isotope ratios of marijuana, supported by theoretical expectations and Drug Enforcement Administration information. In addition, there is evidence of geographic origins recorded in the $\delta^{2}H$ and $^{87/86}Sr$ of marijuana. This is relevant in a forensic context and provides “forensic intelligence” where other sources of information are lacking. Especially for the outdoor-grown samples, these results also provide a unique opportunity to test and develop models of spatial variation in plant stable isotopes for the generation of isoscapes, advancing basic understanding for application to a wide array of questions. Ecologists have long sought archives of past climate and have found a rich array of information in tree rings, pollen records, etc. Since wine is often stored for many years, it has also been explored as a potential archive of climate. By sampling small vineyard wineries and analyzing the $\delta^{18}O$ of these wines we find that wine $\delta^{18}O$ records aspects of both source water $\delta^{18}O$ and climate. Our results suggest that better mechanistic models of wine $\delta^{18}O$ will yield a useful authentication tool, as well as a better way to infer past climate from wine records. Our results make clear that continued interaction between ecologists familiar with the dynamics of stable isotope ratios in natural systems and researchers in a wide variety of fields can lead to productive insights and bridges across disciplines.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

USING ISOSCAPES TO TRACE THE MOVEMENTS AND FORAGING BEHAVIOR OF PREDATORS IN OCEANIC ECOSYSTEMS

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The stable isotope composition of animal tissues can provide intrinsic tags to study the foraging and movements of elusive or highly mobile species. By comparing the isotope value of the animal to the isotope value of the base of the food web, information can be gained on their residency and movements. Developing isoscapes for marine predators can be a first step towards understanding their basin-level movements. Given several assumptions, if a predator has a similar isotope value as the local isotopic baseline, then the animal is a resident, whereas if the animal and baseline values are distinctly different, the animal is an immigrant from another, isotopically-distinct region.

We will broadly review a case study of marine isoscapes developed for tropical tunas in the equatorial Pacific (eqPac). Tuna isoscapes and compound-specific stable isotope analysis demonstrated that the bulk isotope values of tuna are driven mainly by variations in the isotopic baseline in the eqPac. Thus, the geographic isotope variation in tuna relates more to their movements than differences in their resource utilization. More importantly, tuna isoscapes and additional isotope datasets indicated a high degree of residency by tunas in the eqPac, which has important implications for tuna fisheries management and conservation. To conclude, the limitations of applying marine isosocapes to examine predators' movements and future research directions will be discussed.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

BIOTIC FACTORS OVERRIDE ABIOTIC FACTORS IN DETERMINING δD OF FEATHERS IN A MIGRATORY BIRD SPECIES

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Understanding the movements of migratory species has been the subject of much attention by ecologists. Recent advances in stable isotope analysis (SIA) and novel modelling techniques allow us to characterize feather hydrogen isotope values of breeding bird populations across the landscape and then link wintering populations back to their breeding origins. We applied stable isotopes to characterize the feather hydrogen isotope values of white-winged doves (*Zenaida asiatica*) across their breeding range. The ultimate goal of our study is to describe the breeding distribution of doves from samples collected during winter in southern Mexico. White-winged doves that breed in the United States had a strong longitudinal gradient in δD values across their range (-35 to -125‰; east to west). In the western portion of their range, white-winged doves use two different habitats. In Arizona, doves occupy either Sonoran desert or agricultural habitats during the breeding season. SIA of feather tissues revealed that populations of white-winged doves in Arizona can be differentiated based on breeding season habitat use. The feather δD values differed greatly from those expected from precipitation based models. The difference between observed and expected δ D values is due to ecological factors, such as the dominance of CAM producers, in desert ecosystems and anthropogenic effects, such as the use of irrigation, in agricultural fields. Our findings highlight the importance of understanding the factors that determine local variation in feather δD values in the study of bird migration.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

ISOTOPIC VARIATION IN AMERICAN FAST FOOD MEALS

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The stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) can trace the flow of organic matter in food webs and provide insights into a consumer's diet and trophic position. Hydrogen ($\delta^{2}H$) and oxygen ($\delta^{18}O$) provide information on the geographic origin of both the consumer and food items within the consumer's diet. The source of carbon and nitrogen to a consumer is solely diet, but hydrogen and oxygen can be provided by diet, water contained within dietary items, and drinking water. The contribution of food $\delta^{2}H$ and $\delta^{18}O$ values to the consumer will change for animals eating varied diets, i.e. humans. Thus, different dietary choices can potentially affect the average isotopic signal integrated by a consumer. Historically, researchers have assumed that most modern Americans consume a fairly homogeneous "supermarket" diet but regional differences may exist in both the choices made and the isotopic composition of the food eaten. Here we examine that hypothesis.

We present isotopic survey results for one portion of the average American diet: fast food meals. Hamburger (beef) patties, hamburger buns, and French fries from national chain restaurants across the United States and from local restaurants in two isotopically distinct regions, Salt Lake City, UT and Charleston, SC, were analyzed for $\delta^{2}H$, $\delta^{13}C$, $\delta^{15}N$, and $\delta^{18}O$ values. The $\delta^{13}C$ values for patties ranged from -23 to -11‰, with the majority of patties reflecting a distinct C_4 component. However, some meat used in the fast food industry was harvested from cattle with a significant fraction of C_3 plants in their diet. Thus, we propose that variation in the $\delta^{13}C$ values of hamburger patties is indicative of differences in cattle-rearing practices (i.e. the dietary composition of feed). While dietary inputs of carbon varied for cattle, the trophic level at which the cattle ate did not, with almost all hamburger patty $\delta^{15}N$ values within a ~1‰ range.

All three components (patty, bun, and fry) of the fast food meals we collected displayed significant linear $\delta^{2}H$ versus $\delta^{18}O$ relationships. The large variation in the $\delta^{2}H$ and $\delta^{18}O$ values of all meal components is evidence that significant geographic variation exists in the region-of-origin for food. The isotopic (i.e. geographic) range was greatest for hamburger patties, supplying a potentially regional component in a "continental" supermarket diet. Potatoes used for French fries also came from a distinct region, yet potatoes from that single region may supply the entire nation, erasing any truly regional differences in that dietary component.

Although some of the patterns we observe in fast food meals support the concept of a "continental" supermarket diet, there appears to be a strong regional component as well.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

^{2}H AND ^{18}O OF HUMAN BODY WATER: A GIS MODEL TO DISTINGUISH RESIDENTS FROM NONRESIDENTS IN THE CONTIGUOUS UNITED STATES

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The isotopic composition of body water influences the isotopic composition of tissues such as hair that are used to reconstruct movement patterns of humans. Predictive models of these tissues are based on the isotopic composition of the body water and these models will be enhanced by accurate spatial models of the $\delta^{2}H$ and $\delta^{18}O$ values of body water ($\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$). We combined spatial climate layers and estimated $\delta^{2}H$ and $\delta^{18}O$ values of drinking water ($\delta^{2}H_{dw}$ and $\delta^{18}O_{dw}$) with a mechanistic body water model to produce spatial projections of $\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$ values for the contiguous United States. We created 4 parameterizations to investigate the influence of gender, climate, food source, and drinking water source on predicted values. Predicted values were compared with published $\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$ values. Differences in gender, and food source had limited influences on predicted body water values. This model predicted that higher evaporation across the skin and lungs in arid regions causes greater differences between $\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$ values and $\delta^{2}H_{dw}$ and $\delta^{18}O_{dw}$ values than regions of higher humidity. The strongest influence on $\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$ values was related to the source layer used for $\delta^{2}H_{dw}$ and $\delta^{18}O_{dw}$ values. Using predicted tap water values as the source layer for drinking water more accurately reproduced observed $\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$ values than using predicted precipitation values as the source layer for drinking water. Accurate predictions of $\delta^{2}H_{bw}$ and $\delta^{18}O_{bw}$ values require accurate estimates of the isotopic composition of drinking water. We then combined the model with the rate of body water turnover to produce estimates for the length of time required for a transported nonresident to reach isotopic equilibrium with a resident population.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

INTERPRETING MULTI-LAYER, SPATIALLY EXPLICIT, ISOTOPIC DATA IN AN ESTUARY

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Transects of surface sediment samples down the main channel of an estuary are expected to show isotopic gradients between the terrestrial and marine endmember signatures. Spatially explicit isotopic data, however, suggested a more complex mixing pattern between these two endmembers in the Mahurangi estuary, New Zealand. Adding multiple layers of spatially explicit isotopic data from compound-specific isotopic analyses (CSIA) revealed further complexity, suggesting the influence of another organic sediment source within the estuary. A primary contender for this additional source was aquaculture, with intensive rack-farming of Pacific oysters, Crassostrea gigas, on the intertidal zones.

In this study, CSIA of fatty acid methyl esters (FAME) extracted from the surface sediment samples, together with sediment bulk $\delta^{13}C$ values, were used as discrete isotopes in the mixing model, IsoSource (Phillips & Gregg 2003), to interpret the data. Sediment from beneath the largest oyster farm was used as a third endmember in the mixing model. Contrary to expectation, plotting the mean proportional contribution output data from IsoSource for each endmember across the estuary produced two coherent spatial patterns that were independent of the oyster farming areas and the terrestrial input at the head of the estuary.

Algal enumeration of spatial sediment samples identified a broad and variable assemblage of benthic diatoms down the estuary. Using the most dominant species (estimated from biovolume), these data showed that there were distinct differences in the major algal species composition in the two areas identified by the isotopic data. The correlation of the algal data differences with the distribution patterns produced from IsoSource model output data suggests that multi-layer, spatially explicit, isotopic data may be used to provide distribution maps of different benthic microphyte communities within an estuary.

Phillips, D. L., and J. W. Gregg. 2003. Source partitioning using stable isotopes: coping with too many sources. Oecologia 136:261–269.

ORGANIC $\delta^{18}O$ TRACERS

COMPLEXITIES AND REWARDS IN OXYGEN ISOTOPE TRACERS OF ECOSYSTEM PROCESSES AND FOOD WEBS

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Hydrogen isotope dynamics are critical components for defining certain aspects of food webs, movement patterns, and biosynthetic routes in terrestrial and marine ecosystems, because hydrogen only has two principal sources in plants and animals: water and organically bonded hydrogen in food. The sources, pathways, and isotopic fractionation of oxygen in living organisms are more complex. In plants, equilibrium isotope fractionations between intracellular water and organic oxygen groups are principal determinants of $\delta^{18}O$ in organic molecules. In animals, intracellular water pools are determined by three sources of oxygen: (I) drinking water or liquid H_2O in food, (II) molecular O_2 from respiration that enters the body water pool via enzymatic reactions (i.e., oxygenase and electron transport), and (III) metabolic water from the catabolism of organic compounds (e.g. carbohydrates). Enrichment of $\delta^{18}O$ of body water can result from losses of ^{16}O in respiratory H_2O (IV). These sources and sinks, in various proportions and with various isotopic fractionations, determine the $\delta^{18}O$ compositions of an animal's body water from which it synthesizes tissues. How the various pools of water influence the oxygen isotopic composition of organic matter in terrestrial and marine food webs will be discussed.

In aquatic environments, the oxygen isotopic compositions of organic matter in invertebrates are depleted in ^{18}O with respect to their diet (e.g. marine algae) by 5 to 10‰. Vertebrates are further depleted from their invertebrate prey by an additional 5‰, which we explain by oxygen isotope fractionations during respiration of molecular O_2. It is clear from our results that animals' body water isotopic compositions are strongly influenced by respired O_2. We will also present data from heterotrophic microbial cultures grown on various substrates and water with varying $\delta^{18}O$ compositions to determine metabolic fractionations.

In terrestrial ecosystems, oxygen isotopic compositions of organic matter of animal tissue are only occasionally related to their δD values, demonstrating that the simple precipitation-plant-animal model does not always apply. For example, animals in simple, straight food chains are about 5‰ more depleted in $\delta^{18}O$ predicted from equilibrium values based on precipitation alone. In these situations, the δD and $\delta^{18}O$ of the animals is linearly related. This simple relationship breaks down with larger vertebrates, where δD and $\delta^{18}O$ trends are no longer linked. We propose that metabolic rate, which influences H_2O sources II and III, and respiratory water (IV) losses become more important factors in determining $\delta^{18}O$ of organic oxygen of large animals.

ORGANIC $\delta^{18}O$ TRACERS

CUT-AND-DRIED: LEAF WATER IS THE PRIMARY AMPLIFIER OF AN ARIDITY SIGNAL IN MAMMALIAN BODY WATER $\delta^{18}O$

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Field observations and isotopic mass balance models suggest that evaporation has a strong influence on mammalian body water $\delta^{18}O$, especially in taxa that are relatively independent of drinking water and that obtain a large proportion of water from leaves. This is particularly important in climates with low relative humidities where leaf waters can be enriched in ^{18}O by 5 – 15‰ relative to meteoric waters, and an evaporation effect recorded in fossil mammalian bioapatite has been proposed as a basis for estimating paleoaridity. At present, there are no experimental data relevant to the effect of plant water on mammalian $\delta^{18}O$, and our understanding of oxygen isotopes in mammals largely relies on field- and model-based approaches, and on experimental studies utilizing dried feeds. We evaluated the leaf water effect by switching four goats (*Capra aegagrus hircus*) between diets consisting of cut-and-dried feed (corn or alfalfa) and fresh live plants. Body water $\delta^{18}O$ of animals in near-equilibrium with live plant diets growing in relative humidities of ~25 – 50% was 7 – 10‰ higher than that of the same animals when eating dry feed, regardless of whether the live feed consisted of weedy dicots and grasses, or pasture grasses. This magnitude of enrichment is consistent with model predictions for water-efficient mammals living in low humidity environments, and the results of this study demonstrate that leaf water is the dominant mechanism by which an aridity signal is recorded mammalian body water $\delta^{18}O$. In addition, we suggest that in arid environments, a large proportion of seasonal change in body water $\delta^{18}O$—such as that recorded as intratooth isotopic variation—may be due to seasonality in the availability of fresh green vegetation, rather than seasonal changes in meteoric water $\delta^{18}O$, as is usually presumed. The half-life of body water turnover was 3 to 6 days, meaning that on seasonal timescales, the body water of large mammals is in near-equilibrium with the instantaneous diet.

ORGANIC $\delta^{18}O$ TRACERS

THE INFLUENCE OF DIET AND WATER ON THE STABLE OXYGEN AND HYDROGEN ISOTOPE COMPOSITION OF AQUATIC ORGANISMS (CHIRONOMIDAE: DIPTERA), AND PALEOECOLOGICAL IMPLICATIONS

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Stable oxygen and hydrogen isotope analyses of fossil aquatic organisms (e.g. the chitinous headcapsules of chironomid larvae) are promising proxies for inferring paleoecological conditions. We cultured chironomid larvae (Chironomideae: Diptera) in two isotopically distinct waters (nature abundance water $\delta^{18}O$=-15.1±1.2‰, $\delta^{2}H$= -123.9±7.9‰ and enriched water $\delta^{18}O$=6.5±0.7‰, $\delta^{2}H$=35.9±16.0‰) under controlled, replicated laboratory conditions. Chironomids were fed on identical diets, to examine the degree to which water and diet influence the $\delta^{18}O$ and $\delta^{2}H$ of these organisms. We used a two-end member mixing model to determine the proportional contributions of oxygen and hydrogen from water and diet to the oxygen and hydrogen of chironomids larvae. Our experiment demonstrated that 69.0±0.4% of oxygen and 30.8±2.6% of hydrogen in chironomid larvae are derived from habitat water. Our results show that oxygen isotopes from chironomid remains can better constrain past habitat water isotopic changes compared to hydrogen, due to 70% of the chironomid oxygen being influenced by habitat water. Our data also add to a growing suite of comparative data derived from analyses of the proportional contribution of oxygen and hydrogen from diet and water to the organic composition of organisms.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

WHAT CAN STABLE ISOTOPES OF HYDROGEN (DD) TELL US ABOUT FRESHWATER FOOD-WEB ECOLOGY?

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After initial interest, some 30 years ago, in the use of stable isotopes of hydrogen (δD) to identify food sources, organic δD values in animal ecology quickly disappeared until the late 90s when technological advances made measurements easier to make, equilibration procedures made data more reliable, and avian ecologists (via migration studies) brought organic δD back to the forefront of the ecological literature. In this talk, we will examine how organic δD is now being used to understand food-web relationships in freshwater ecosystems. Current research has shown that terrestrial (allochthonous) inputs are much more enriched than aquatic (autochthonous) inputs, and that δD has potential to be a better tracer of food-source importance than δ^{13}C. Examples will be given from a variety of freshwater systems across North America and Europe. Results from laboratory feeding-studies will show that one must consider the incorporation of drinking water (i.e., body water) when using organic δD to interpret diet. Future direction for organic δD research in freshwater ecology will be discussed.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

SWALLOWS POWERED BY NATURAL GAS – A NOVEL CARBON SUBSIDY TO TERRESTRIAL SYSTEMS.

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In recent years it has become apparent that the microbial loop and chemosynthetic production are much more widespread than was first thought. As such, it is now recognised that the microbial loop can play a significant role in both marine and freshwater systems. It is also clear that there can be substantial nutrient transport across what were previously regarded as ecosystem boundaries and these subsidies can be critical for recipient communities. Seasonally clumped carbon subsides for terrestrial systems occur in the form of mass emergences of aquatic insects from freshwater bodies, and there is growing evidence that this can exert a significant influence on surrounding riparian communities. However, the importance of mass emergences to terrestrial consumers and the extent to which they are exported into the surrounding habitat is largely unquantified. Here we use the unique stable carbon isotope signatures (associated with microbial loop production) combined with novel Bayesian methodologies to quantify the importance of this subsidy to avian insectivores and show that it can form a substantial proportion of the diet of swallow chicks, even when nests are several km from the source. We also demonstrate that this subsidy is exploited by a range of terrestrial consumers.

OIL-FUELLED GUPPIES? TROPHIC SUBSIDIES FROM A PREVIOUS GEOLOGICAL ERA

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The guppy, Poecilia reticulata has long been of interest to biologists. This reflects the guppy's value to experimental ecologists, but also demonstrates the hardiness of this small but resilient fish, which thrive in aquaria and other non-natural habitats. Wild guppies have largely been studied in semi-pristine habitats in the north of Trinidad, but they also inhabit hydrocarbon-polluted rivers draining the oil-producing areas of southern Trinidad. Invertebrate prey suitable for guppies are typically depauparate in these systems, raising a question regarding what foods support the abundant guppy populations found in these rivers. Here we use a multiple isotope approach to examine the trophic ecology of guppies in oil-contaminated rivers.

We sampled guppies from 10 similar river sites located in the southwest of Trinidad. The sites were selected to represent a gradient of hydrocarbon pollution from low to high. Subsequent analyses showed that total petroleum hydrocarbon concentrations in river sediments ranged between 1.6 to 128.7 ppm. There were significant differences in mean guppy size along this contamination gradient, and guppies of both sexes were larger from more polluted sites (dry mass: male $P = 0.01$; female $P < 0.001$). We examined variation in $\delta^{13}C$ and $\delta^{15}N$ in guppies, their putative food (invertebrates, biofilm, and algae) and sediments along the pollution gradient. Guppies $\delta^{15}N$ was negatively correlated with sediment oil concentrations ($r = -0.32$, $P<0.001$), indicating that guppies from less contaminated sites fed at a higher trophic position. Guppy $\delta^{13}C$ (range -34.5 to -14.6‰) tracked oil contamination ($r = -0.4$, $P < 0.001$, with guppies from the most contaminated sites displaying the most ^{13}C depleted values.

We hypothesised that this pattern might reflect the indirect assimilation of energy from oil via microbial degradation. We undertook $\delta^{34}S$ and ^{14}C analysis of guppies in order to examine evidence of microbial activity ($\delta^{34}S$) and the assimilation of fossil carbon originating from oil (^{14}C). $\delta^{34}S$ values (range -9.8 to 13.5‰) tracked variation in oil contamination and were closely associated with $\delta^{13}C$ values ($r = -0.65$, $P < 0.001$). Most striking were the results from the ^{14}C analyses: guppies from oil polluted sites had ^{14}C age estimates ranging between 357 (SD ±32) and 4469 (± 32) years BP indicating assimilation of fossil carbon, whilst guppies from sites showing low-levels of oil pollution displayed contemporary ^{14}C ages (0±0 yBP).

The results provide evidence for the assimilation of fossil carbon from waste oil in a higher vertebrate, but raise the question of the biological consequences of inhabiting what is typically considered a toxic environment. The water surface, sediments and riparian vegetation were all clearly degraded with oil at polluted sites, whilst benthic macroinvertebrates (putative prey) and fish predators were almost completely absent. As guppies from these sites were on average larger than individuals from less-polluted sites, we hypothesise that the beneficial effects of living in these impacted environments may outweigh the toxic effects normally associated with crude oil.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

$\delta^{13}C$ AND $\delta^{15}N$ TRACK CONTAMINANT FLUX FROM AQUATIC TO TERRESTRIAL FOOD WEBS

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Aquatic insects provide a critical energy subsidy to riparian food webs, yet their role as vectors of contaminants to terrestrial ecosystems is poorly understood. We investigated aquatic resource utilization and contaminant exposure among riparian invertivores (spiders and herptiles) along a stream and reservoir contaminated with polychlorinated biphenyls (PCBs). $\delta^{13}C$ and $\delta^{15}N$ values indicated that aquatic insect utilization varied among stream riparian predators, with progressive enrichment of $\delta^{13}C$ and depletion of $\delta^{15}N$ as predators shifted from aquatic to terrestrial prey. PCB concentrations significantly increased along these isotopic gradients; $\delta^{13}C$ and $\delta^{15}N$ explained 65% and 15% of the variance in predator ΣPCBs, respectively.

We sampled spiders and insects at various distances (0-30m) from the reservoir shore to quantify the lateral extent of contaminant flux. Aquatic insects flux was limited to the first ~5 m of the shore. Riparian spiders preyed heavily on aquatic insects along the shore (as inferred from $\delta^{13}C$ and $\delta^{15}N$), but switched to terrestrial prey beyond 5-10 m of the shore. PCB concentrations tracked these patterns in aquatic insect utilization and declined rapidly beyond 5 m from the shore.

Persistent contaminants (e.g., PCBs) are underutilized for addressing landscape-level questions in subsidy research, but our results demonstrate that they are an ideal in situ tracer of aquatic-derived energy because they label aquatic insects over large distances. Likewise, riparian predators such as spiders have great potential as biological monitors of ecosystem condition and as assessment tools for risk management of contaminated aquatic sediments.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

LAND AND SEA CONNECTED: STABLE ISOTOPES REVEAL A ROLE OF TERRESTRIAL ORGANIC MATTER IN NEARSHORE ECOSYSTEM FUNCTIONING IN THE GULF OF LIONS, MEDITERRANEAN SEA

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Deltas and estuaries belong to the most productive aquatic systems worldwide, due to the ample supply of inorganic (DOM) and particulate organic matter (POM) of terrestrial origin that is carried by rivers. While the role of DOM in primary productivity of nearshore communities has received much attention, interest in terrestrial POM has been more recent. Considering the knowledgegap regarding this potentially important parameter, a main goal of our group is to elucidate the role of terrestrial POM carried by the Rhone river (the biggest river flowing into the Mediterranean Sea) for ecosystems in the Gulf of Lions, which is the origin of almost 90% of total fishery catches in the French Mediterranean.

The use of stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) as tracers, coupled with conventional dietary analysis, has proven highly useful in this endeavor. In particular, as signatures of POM carried by the Rhone differed significantly from that of marine POM ($\delta^{13}C$ = -27.8‰ versus -23.5‰, $\delta^{15}N$ = 6.7‰ versus 3.4‰), we were able to determine the respective role of POM from the two sources on the growth and productivity of the fish species common sole (Solea solea), hake (Merluccius merluccius), and two species of goatfishes (Mullus barbatus and M. surmuletus), with each species serving as a model for a different component of the nearshore trophic net. We found that terrestrial POM played a very important role for the growth of the common sole, whereas the effect on hake and goatfishes, though present, was weaker. After placing these results in a framework including data on stomach contents of the species above, and on isotope signatures of their prey, we concluded that two distinct pathways of energy flow occur in parallel in the Gulf of Lions: The first takes place in the benthos, and directly depends on terrestrial POM supplied by the Rhone, which fuels the growth of polychaetes that in turn constitute food for certain benthic fish predators such as the sole. Secondly, a parallel foodchain is fueled by DOM of terrestrial and marine origin, and leads from phyto- and zooplankton via planktivorous fishes to pelagic fish predators such as the hake.

We were subsequently able to show that effects of terrestrial POM on the productivity of the sole are reflected in a highly significant correlation of the annual discharge of the Rhone with sole landings, time delayed by 5 years. For goatfishes and hake, correlations were weaker, but elevated catch per area as well as relative fitness for these species near the mouth of the Rhone compared to the Western Gulf of Lions nonetheless suggested that a positive effect of the Rhone existed.

Our findings are of particular interest in the context of fishery management, as they may allow better modeling of population fluctuations of commercial species. In addition, better understanding of terrestrial POM in nearshore systems is important to assess the consequences of ongoing alterations of discharge patterns and material load of rivers due to dam construction and climate change.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

OCEANOGRAPHIC INPUTS TO A FRINGING CORAL REEF FROM STABLE ISOTOPE AND FATTY ACID BIOMARKER ANALYSIS

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Rapid recycling of sparse nutrients as a means of sustaining productivity is a paradigm that suggests that coral reefs are largely independent of the surrounding ocean, being neither a net source nor sink of nutrients. Recently studies have begun to suggest that reefs may be closely linked to the ocean, and perhaps more dependent on its variability, than previously considered. Our recent work at Ningaloo Reef, Western Australia suggests that uptake of phytoplankton alone represents a particulate nitrogen flux to the reef that may be up to an order of magnitude higher than typically reported for dissolved nitrogen, confirming particulate feeding as a missing link in reef nitrogen budgets. To determine which components of the reef biotope utilise ocean-derived particles, and are therefore closely coupled to offshore oceanographic processes, we examine a combination of stable isotope and fatty acid biomarkers in benthic and pelagic organisms. Stable isotopes studies of coral reefs raise several technical complications, particularly in terms of sample sizes and the need for sample acidification due to shallow-water sand resuspension and resultant carbonate contamination of samples. Techniques for accurate determination of $\delta^{13}C$ in the presence of carbonate, with no effect on $\delta^{15}N$, have been developed for a variety of coral reef samples, including suspended particulate matter, corals (tissue, zooxanthellae and mucus), and fishes. Stable isotope analysis has potential application in the study of impacts on coral reefs from human- and climatically-induced changes in the surrounding ocean, particularly for those organisms most dependent on oceanic supply, but requires rigorous testing of sampling methodology and assumptions.

METHODS IN ISOTOPE ECOLOGY I: Amino Acids

ISOTOPIC ROUTING: FIELD OBSERVATIONS, THEORY, AND EXPERIMENTAL RESULTS

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Mixing models in all their guises assume that assimilated nutrients are disassembled into their elemental components and that these elements are then reassembled into the molecules that make up tissues. Van der Merwe (1982. Am. Sci. 70: 459-465) called this assumption the “scrambled egg” premise. Anthropologists and paleontologists have observed that the bone collagen and bone apatite of omnivores sometimes have contrasting carbon isotopic signatures. The explanation that they give to this difference is that collagen represents the protein component of diet whereas apatite represents the carbohydrates and lipids ingested and used to fuel metabolism. Schwarcz (1991. J. Archaeol. Sci. 18: 261-275) christened the differential allocation of isotopically distinct dietary components to different tissues “isotopic routing”. The isotopic routing conjecture poses a quandary to field isotopic ecologists that work with omnivores that often ingest diets in which carbohydrates (and sometimes lipids) are derived from one dietary source and protein is derived from another. They may find that using different tissues for isotopic analyses to reconstruct an animal’s diet might give different answers. Worse, using a single type of tissue might give the wrong answer. We present a modification to mixing models that accounts for routing. Our model predicts that mixing models overestimate the contribution of proteins to the animal’s diet in a predictable fashion. We tested the model in controlled feeding studies on fish (*Oreochromis niloticus*) and crayfish (*Orconectes virilis*). We suggest the use of compound specific isotopic analyses as a straightforward, albeit expensive, approach to test the assumptions of our routing model.

METHODS IN ISOTOPE ECOLOGY I: Amino Acids

TRACING AMINO ACIDS FROM THE DIET TO TISSUES BY LC-IRMS: A FEEDING TRIAL WITH RAINBOW TROUT, ONCORHYNCHUS MYKISS, USING PURIFIED DIETS PARTLY ENRICHED WITH ^{13}C-GLUTAMATE

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Isotopic signatures of individual amino acids (AA) have attracted interest by ecologists as well as by archaeologists and nutritionists. They offer the potential to trace the food of free-ranging animals or pre-historic human populations with much higher resolution than bulk analysis, and in the case of known diets, allow insights into the different utilization of protein sources from mixed diets, allowing more efficient use of high-price protein sources. The application of this method was however limited in the past, as isotopic signatures of amino acids cannot be directly be determined by GC-C-IRMS, the common method for compound-specific analysis. In order to allow separation of AAs by gas chromatography, they have to be derivatized, which dilutes the original signal and may cause isotopic fractionation difficult to control. The relatively new coupling of liquid chromatography and IRMS via IsoLink® allows to overcome this problem[1] and has been applied to a controlled feeding experiment with rainbow trout, Oncorhynchus mykiss.

In a preceding trial[2, 3], we have studied the effect of substituting some non-essential/ conditionally essential amino acids by their biochemical precursors and finally by only glutamate. For this purpose, a set of semi-purified, iso-nitrogenous, diets was made, which did not contain any protein but only synthetic AAs. The first diet resembled exactly the AAs of fish meal, in the second, cysteine, proline and tyrosine were replaced, the third diet contained only glutamate as non-essential AA. While there was some effect on growth and protein productive value (PPV), both decreasing with reducing the spectrum of non-essential AAs, there were no significant effects on the δ^{13}C values of individual AAs except for tyrosine[3]. In order to answer the question whether the non-essential amino acids in fish tissues, not provided in the diet, were derived from glutamate or from essential AAs, in this experiment, three additional treatments with the same composition but glutamate enriched by 22.5‰, were used.

Growth performance was best in fish receiving the diet with the full spectrum of non-essential amino acids. δ^{13}C of AAs from fish fed the full spectrum of non-essential AAs were -14.4‰ for Glu, -14.4‰ for Gly -13.3‰ for Pro and -9.1‰ for Ser; in fish fed only Glu (-12.9‰) as non-essential AA, the respective values were -12.6‰, -10.2‰, -14.1‰ and -6.5‰; in fish fed enriched Glu (δ^{13}C = 11.8‰) -7.4‰, -10.0‰, -10.5‰ and -6.3‰, indicating a low contribution of dietary Glu to the build-up of these amino acids. This explains the lower growth performance of fish reared on a reduced spectrum of non-essential AAs. In conclusion, by adjusting also the non-essential amino acids in the diet to the requirements of the fish, the utilization of essential amino acids can be improved.

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METHODS IN ISOTOPE ECOLOGY I: Amino Acids

INDIVIDUAL AMINO ACID CARBON ISOTOPE FRACTIONATION PATTERNS BETWEEN CONSUMER AND DIET IN A MODEL FISH SPECIES.

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Stable isotope analysis (SIA) in fish ecology has provided a wealth of information regarding stock identification, diet and trophic dynamics, and movement over a range of spatial and temporal scales. However, the stable isotope ratio of any consumer is primarily a function of the trophic level of that consumer scaled to the stable isotope ratio of the primary producers at the base of the food web. In the marine environment, bulk tissue SIA can be difficult to interpret in light of shifting isotopic baselines over short spatial and temporal scales, especially with regards to highly migratory species. Compound specific-stable isotope analysis (CS-SIA) of individual biological compounds (e.g. amino acids) has the potential to provide a more powerful tool to examine diet and ultimately movement patterns than conventional bulk SIA. Hare et al. (1991) and Howland et al. (2003) showed that many individual amino acids exhibited significantly different trophic enrichments in carbon ($\delta^{13}C$) between diet and consumer (Pigs) compared to typical bulk muscle trophic enrichments 0-1‰). Non-essential amino acids (Glutamic Acid, Aspartic Acid, Serine), which undergo significant reprocessing during synthesis, typically exhibited large trophic enrichments (> 7‰), suggesting that these amino acids may provide a better trophic position indicator than conventional bulk SIA. Conversely, because essential amino acids (Leucine, Isoleucine, Phenylalanine) cannot be synthesized in vivo and must come from dietary sources, there is little to no trophic enrichment between diet and consumer. Therefore, the $\delta^{13}C$ values of these amino acids should reflect those at the base of the food web and could serve as natural tracers for residence in locations with isotopically distinct food web signatures. In addition, the difference in isotopic value between essential and non-essential amino acids from a single sample may provide an internal index of trophic position that normalizes for differences in baseline food web isotope composition. Despite the clear utility of compound-specific isotope analyses, the $\delta^{13}C$ values for individual amino acids between fish and their diet are currently unknown. In this study, I conducted a controlled laboratory feeding experiment with Fundulus heteroclitus juveniles reared on three isotopically distinct diets (Vegi-Pro: a vegetable based-diet, Bio-Vita: a fish-based diet, and Squid). Individual amino acid $\delta^{13}C$ values were determined for diet and consumer via GC-C-irm-MS and their $\delta^{13}C$ values were compared to conventional bulk tissue $\delta^{13}C$. The ability to tease apart metabolic and trophic-level relationships in a food web from changes in baseline food web isotopic signatures will be highly valuable for tracking fish movement between isotopically distinct habitats.

METHODS IN ISOTOPE ECOLOGY I: Amino Acids

BREAKING ALL THE RULES: WHEN YOU AREN'T WHAT YOU EAT

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Adequate nutrient intake, absorption, and metabolism are known to be required for the healthy growth of an organism. In humans, a well documented condition known as "failure to thrive" has been shown to have multiple etiologies including lack of adequate nutrition, endocrine abnormalities and gastrointestinal disorders. We report the isotopic compositions ($\delta^{13}C$, $\delta^{15}N$, δD and $\delta^{18}O$) from multiple tissues in a group of pigs fed a constant, controlled diet compared to one "failure to thrive" sibling. This small sibling appeared in other external characteristics (e.g. color, activity level, vocalizations) to be normal, and, as with the entire cohort, was under the care of a veterinarian for the duration of the study. Significant deviations in isotopic composition are observed in the sibling that experienced retardation in growth, and preliminary observations on compound specific nitrogen and carbon isotopic shifts are reported.

METHODS IN ISOTOPE ECOLOGY I: Amino Acids

^{13}C FINGERPRINTING OF AMINO ACIDS: A NOVEL METHOD FOR TRACKING THE BIOSYNTHETIC ORIGIN OF AMINO ACIDS

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Understanding nutrient flow is a central goal of both organismal biology and ecosystem ecology. Amino acids play an important role in many biological systems, as a source of organic nitrogen, as building blocks of proteins, and as intermediates in metabolism. While primary producers can synthesize all the 20 amino acids used in protein synthesis, the genes coding for almost half of them have been lost in animals. For this reason, animals depend on the diet or microbial endosymbionts to provide these essential amino acids, and requirements for these compounds help determine foraging ecology. In arctic ecosystems, amino acids are a key source of nitrogen for boreal plant communities, but how they are supplied to soil is unclear. Nutritional associations between plants and root-fungi (mycorrhizae) are common, whether these partners exchange amino acids is not known. In all these cases, progress is limited by the available tools for tracing amino acid exchange.

The biosynthetic pathways for a number of amino acids and their precursors differ between bacteria, fungi and plants. These different pathways have the potential to differentially fractionate ^{13}C, thus imparting an isotopic "fingerprint" of amino acid δ^{13}C that could be diagnostic of the organism that synthesized them. We tested this hypothesis by measuring amino acid δ^{13}C on 10 plants, 13 fungi, and 10 bacteria, and evaluating whether amino acid ^{13}C fingerprints could be used to identify taxonomic affiliation. Fungi and bacteria samples were primarily isolated from the soil of a boreal forest in interior Alaska, and were cultured on amino acid free media to prohibit incorporation of exogenous amino acids. We collected plant samples from the same boreal forest site and also included plants grown on inorganic nitrogen sources in the greenhouse. Fungi and bacteria were identified to genus or species using PCR and DNA sequencing. The fungal samples included representatives of both Ascomycota, Basidiomycota and Zygomycota, and the bacterial samples included Proteobacteria, Actinobacteria and Bacteroidetes. Amino acid ^{13}C analysis was performed using GC-C-IRMS.

We found that bacteria, fungi and plants generated ^{13}C fingerprints that were distinctly different, and clearly diagnostic of taxonomic affiliation. The essential amino acids (EAA) were more informative than the non-essential amino acids (NEAA). Using linear discriminant analysis we obtained the clearest separation of the 3 lineages with all 7 measured EAA. However, the δ^{13}C signatures of the 3 most informative EAA, lysine, leucine and isoleucine, were sufficient to identify a sample's taxonomic affiliation. With the 6 NEAA we could separate plants from fungi and bacteria, but not fungi from bacteria. Wild and cultured plants clustered similarly indicating that availability of external amino acid sources for wild plants did not significantly affect their ^{13}C fingerprints. We tested whether the δ^{13}C of 7 EAA could be used to correctly match previously measured samples of animal consumers to their known diets, whether plant or fungal, and found that the assignation was correct in 27 out of 29 samples. Our results indicate that ^{13}C fingerprints of amino acids can provide a powerful in-situ assay of amino acid sources, whether for symbiotic associations between animals and microorganisms, plants and fungi, or simply in attributing the primary contributors of amino acids to soil organic matter or sediments.

HERBIVORY: C_3 vs. C_4

THE RELATIVE INFLUENCES OF TERMITES, HERBIVORES, AND ACACIA TREES ON NITROGEN PROCESSES IN A SAVANNA ECOSYSTEM

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In semi-arid landscapes within Africa termites are one of the most ubiquitous modifiers of habitats, and have been described as both ecosystem engineers and keystone species. Despite this, few hard data exist on the magnitude and mechanisms for community-wide effects of termites in these landscapes that are threatened by various forms of human over-use. Within our study system, the black cotton savanna of East Africa, termites mounds may be responsible for a large fraction of ecosystem-level spatial heterogeneity; they differ in soil composition, support a unique flora, have higher invertebrate densities, and experience elevated levels of grazing by wild and domestic herbivores. Matrix soils are clay-rich vertisols, with low plant-available N, and support two dominant plant types; an Acacia tree species, and C_4 grasses. Due to their small-scale physical and chemical influences on soils termite mounds may essentially be islands of fertility ('hotspots') that have large-scale effects, such as enhancement of biodiversity and food web structure.

Away from termite mound 'hotspots' N_2-fixation by Acacia trees is an important input of N into black cotton savanna ecosystems. We investigated how termite mounds, and the preferential use of mounds by herbivores, generate spatial heterogeneity in N processes in a forested savanna. We used the $\delta^{15}N$ values of dominant plant types to determine; 1) if patterns of Acacia N_2-fixation are dictated by proximity to termite mounds, and 2) to what extent herbivore use enhances these patterns. We sampled Acacia, C_4 grass and Aspelia sp. (non-fixing herb) foliage on and off (>35m away) termite mounds inside and outside large herbivore exclosures at the Mpala Research Center in Kenya. We also sampled Acacia trees along 40m transects away from termite mounds outside the exclosures. The abundance of ^{15}N in Acacia foliage, and therefore the amount of N not derived from N_2-fixation, was significantly higher near termite mounds, and herbivore presence had no effect. Likewise, C_4 grasses and Aspelia had higher $\delta^{15}N$ values on vs. off mounds (again no herbivore effect), indicating that Acacia trees are a source of biologically fixed N_2 away from termite 'hotspots'. We determined from the Acacia transects that gradients of Acacia N_2-fixation away from termite mounds were sensitive to topo-edaphic variables (eg. linear vs. exponential decline), but ~30m was the average distance at which Acacia trees relied solely upon atmospheric N (assuming no isotopic fractionation during N_2-fixation and assimilation).

Our results show that termite mounds exert strong spatial controls on landscape-scale N cycling in forested savannas. Herbivore use of mound 'hotspots' did not enhance these patterns, indicating that termites independently generate ecosystem-level heterogeneity.

HERBIVORY: C_3 vs. C_4

LINKING PRECIPITATION AND C_3 - C_4 PLANT PRODUCTION TO RESOURCE DYNAMICS IN HIGHER TROPHIC LEVEL CONSUMERS

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In this study we examine how the interplay between pulsed precipitation and primary production by plants using C_4 and C_3 photosynthesis influence the seasonal and inter-annual resource dynamics in a Chihuahuan desert food web. Although plants using C_4 and C_3 photosynthesis differ in their seasonal availability, abundance and nutritional quality, we know little about their importance as sources of nutrients and energy for consumers at any level of a food web. This paucity of data and understanding of the importance of these plants to ecological communities is surprising considering that C_4 plants account for more than one-fifth of global annual primary production, largely as a result of highly productive grasses in semi-arid ecosystems.

Through carbon isotope analysis of a lizard community, we show that pulsed production by C_4 and C_3 plants result in a seasonally shifting resource landscape for arthropods and lizards in the Chihuahuan desert. In the desert grassland of the Sevilleta Long Term Ecological Research site in New Mexico, a bimodal precipitation pattern drives a spring pulse of C_3 production with carbon isotope values ($\delta^{13}C$ = -27‰ VPDB) that are distinct from a summer pulse of C_4 production ($\delta^{13}C$ = -14‰ VPDB). Because the carbon isotope values of animal consumers reflect those of their diet, we show that with an increased summer abundance of C_4 plants, the resources assimilated by insectivorous lizard consumer's shift from 27% C_4 derived plant sources in June 2005 to 42% by August 2005. These results demonstrate that lizards reflect resource assimilation in the bulk of the food web through integrating variation in resource use by basal consumers.

The following 2006 season in contrast, was characterized by precipitation extremes with the driest winter and the wettest monsoon on state record; which resulted in a failure of spring C_3 primary productivity and a doubling of summer C_4 primary productivity. As a result, throughout the spring and summer, C_4 derived resources accounted for over 40% of the carbon incorporated into the lizard community in 2006. Because the nutritional quality of C_3 and C_4 plants differ significantly, this increased use and incorporation of C_4 resources during the spring and early summer could affect the life cycles and population dynamics of arthropod and lizard consumers alike. Over the long term such climatically driven alterations in C_3 and C_4 plant productivity will fundamentally alter the structure and function of grassland ecosystems. In the face of predicted climate change, research such as this can provide insight into the importance of resources derived from C_3 and C_4 plants and how alterations to their seasonal production patterns may impact the flow of energy and nutrients within individuals and across entire communities.

HERBIVORY: C_3 vs. C_4

A MAMMAL'S-EYE VIEW OF PLANT ISOTOPIC COMPOSITIONS IN THE KRUGER NATIONAL PARK, SOUTH AFRICA.

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It is well known that plant $\delta^{13}C$ and $\delta^{15}N$ values vary across rainfall gradients and between habitat types. However, few studies have investigated how whole plant communities vary in their carbon and nitrogen isotope compositions across rainfall gradients and microhabitats in African savanna biomes. Fewer still have examined how such variability influences mammal stable isotope abundances and distributions, particularly the numerous large herbivores that inhabit savanna biomes and which can consume dozens if not hundreds of plant species. In order to understand how savanna plant isotopic compositions vary at temporal and spatial scales relevant to mammalian dietary ecology, we analyzed ~3200 plant specimens comprising at least 100 species from the Kruger National Park (KNP) in South Africa. Plant samples were obtained from sampling sites throughout KNP during both dry and rainy seasons over a three-year period, including monthly intervals during the third year. Sampling sites were chosen so as to capture variations associated with differences in geology, habitat, and rainfall. In general, the $\delta^{13}C$ and $\delta^{15}N$ values of trees, forbs, and grasses varied minimally across a small but biologically significant rainfall gradient (about 300 mm to 500 mm). For instance, mean tree leaf $\delta^{13}C$ values were -26.8‰ in the moister southern portion of KNP and -26.7‰ in the drier northern regions. There were, however, small but significant differences ($P<0.01$) in the $\delta^{13}C$ values of grasses in the far north (-13.2‰) and the south (-12.6‰). There were also significant differences in the $\delta^{13}C$ and $\delta^{15}N$ values of trees, forbs, and grasses related to microhabitat (e.g., riparian forest, open savanna), basement geology (e.g., granite, basalt), season (wet vs. dry), plant part (e.g., fruit, leaves, bark), and species (e.g., *Ziziphus mucronata, Diospyros mespiliformis*), all of which explained more of the observed variability in vegetation $\delta^{13}C$ and $\delta^{15}N$ values than mean annual precipitation. Yet, tree, forb, and grass $\delta^{13}C$ values for each sampling site varied by less than 2‰ (and usually by less than 1‰) across this large national park (~20 000 km^2). Site $\delta^{15}N$ values, in contrast, were far more variable across microhabitats (up to 4‰). This variability has important implications for isotopic studies of mammalian dietary ecology, and we show how region- and habitat-specific plant data greatly increased our ability to interpret stable isotope data from over 4500 mammalian faecal samples.

HERBIVORY: C_3 vs. C_4

CARBON ISOTOPE DISTRIBUTIONS ACROSS DUNG HEAPS OFFER A FRESH APPROACH TO THE AFRICAN ELEPHANT BROWSER/GRAZER DEBATE

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African elephants (*Loxodonta africana*) are thought to have substantial impacts on their environments, mainly by consuming large amounts of woody vegetation. However, elephants are mixed-feeders that switch almost entirely along the browser-grazer continuum. While much research has been done on elephant diet composition, little is known about diet variations that occur over scales at which impacts on vegetation are manifest. Stable carbon isotope studies have provided illuminating insights into elephant dietary trends at intra-individual, regional and continental scales. A preliminary study using faeces from the Kruger National Park, South Africa, revealed geographic differences in diet, with elephants in the northern regions eating more C_4 grass than those in south. To better understand these variations, and the processes that drive them, we analyzed isotope compositions of faeces collected from eight habitats within Kruger Park during each month of the seasonal cycle.

Results confirmed the north-south geographical change in diet, as well as our previous hypothesis that seasonal switches are less pronounced in the north compared with the south. However, relationships between diet and habitat were more complex than this distinction implies. Multivariate analysis accounting for monthly changes in diet per habitat revealed 4 distinct components: a southern component where elephants switch from grass-based to browse-based diets between wet and dry seasons; a less variable component in the southwestern central region; a variable, yet grass-rich component in the southeastern and northern central regions; and a uniform grass-rich diet in the far north. Using optimal foraging approaches to food selection, we tested whether patterns underlying dietary complexity across Kruger Park could be ascribed to changes in C_4 grass availability and nutritional value, or whether selection and avoidance of available C_3 browse is a more important determinant of diet. We found a better fit for models predicting increased C_4 grass intake in response to increases in grass availability, as opposed to models predicting these changes as a response to switching when browse availability declines. But changes in grass intake in response to grass availability asymptote when diet is between ~60 and 70%. With mixed-feeder models fitted to our data, we found that increases in grass consumption above this threshold are explained by further declines in browse availability, particularly when homogeneity of woody landscapes is accounted for. Moreover, grazing models do not fit data well at low levels (<20%) of grass intake, but browser models perform well. We found that this distinction is related to dry versus wet season differences, and we suggest that elephants might in fact show behavioural and/or physiological adaptations to switch from being selective browsers to selective grazers between seasons, and that such modifications occur even prior to environmental shifts.

HERBIVORY: C_3 vs. C_4

ISOTOPIC AND FUNCTIONAL DIVERSITY IN HERBIVORE COMMUNITIES: LITTLE SPACE FOR REDUNDANCY!

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In the debate over whether neutrality or niche differentiation regulates biodiversity, little emphasis has been placed on explicitly relating niche with species diversity. Niche theorists can tackle this problem by addressing hypotheses about ecological redundancy, and its partner functional equivalence, but data to do so are seldom accessible. We aimed to determine whether functional diversity or ecological redundancy prevails in African mammal herbivore communities, where redundancy could be expected to be prevalent in the form of multiple browsing and multiple grazing species. To investigate relationships between niche, functional, and species diversity, we compared $\delta^{13}C$ and $\delta^{15}N$ distributions in 25 South African grassland taxa, as proxies for feeding style (C_3 browsing vs C_4 grazing) and diet quality respectively, with 4 craniodental traits predicted to correlate with diet. We tested three hypotheses: i) the trophic niche axis is best described as the interaction between feeding style and diet quality; ii) morphological diversity reflects differentiation along this axis; and iii) the number of species comprising a herbivore metacommunity is dependent on the diversity of trophic niches therein.

Results showed that only 2 out of the 4 craniodental variables were related to differentiation along the diet type ($\delta^{13}C$) axis, while the other 2 were related to ^{15}N-distributions across species. The strongest relationships for all variables were found along the niche axis that describes the interaction between the two models ($\delta^{13}C.\delta\ ^{15}N$ axis). Further support for trophic differentiation was found when all craniodental variables were averaged, i.e. accounting for compensation in adaptation and a wider range of possibilities for morphological diversity; here, the trophic niche axis explained >80% of the variation in craniodental morphology. In a sample that includes taxa as diverse as bovids, giraffe, suids, perissodactyls, and hyrax, this relationship had an almost 100% likelihood of persistence, regardless of phylogenetic affiliations, species composition, and number of species included in the model. Other models showed a distinct tendency to vary in strength depending on the number and combination of species. Finally, we found a strong dependence of species diversity on niche diversity. However, whereas most models we employed suggested communities comprising 12 to 15 species, the model based on the $\delta\ ^{13}C.\delta\ ^{15}N$ niche axis required the addition of 18 to 19 species before all available niche space was occupied. Thus, at least 72% of species diversity in this metacommunity can be accounted for by the $\delta^{13}C.\delta^{15}N$ niche axis alone. We expect that this figure will increase rapidly with additions of further niche variables, and with investigation into intraspecific niche variation. Stable isotope diversity clearly indicates that functional diversity, rather than redundancy, prevails in these communities.

FRESHWATER ECOLOGY

REHABILITATION EFFECTS ON FOOD WEBS: A RETROSPECTIVE STABLE ISOTOPE ANALYSIS OF ROACH (RUTILUS RUTILUS) SCALES AND ZOOPLANKTON FROM BARTON BROAD, UK

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There is increasing interest in using stable isotope analyses of archived samples to retrospectively examine temporal change in ecosystems ('hindcasting'). For example, analysis of preserved zooplankton samples pre and post invasion of a lake by zebra mussels revealed increasing reliance upon allochthonous resources by the zooplankton post invasion (Maguire & Grey 2006). An obvious choice of material for use in hindcasting studies of aquatic ecosystems has been fish scale archives, for several reasons. A reliable relationship can usually be drawn between scale material and muscle tissue which is typically the isotope ecologist's tissue of choice. Moreover, archives of scales have often been collected and stored without preservation for decades by fisheries biologists as a standard protocol for determining age and growth structure.

Recently, Perga & Gerdeaux (2003) demonstrated that whitefish scales could be used as a proxy for the nutrient loading of Lake Geneva; changes in isotope values of whitefish scales reflected the changing isotopic baseline transmitted throughout the food chain because whitefish were purely planktivorous in that lake. However, whitefish are typically restricted to large, deep, more nutrient poor lakes in colder temperate areas, so we sought to broaden the scope of their study using a well studied shallow, eutrophic lake system that had undergone major nutrient loading manipulations (Barton Broad, UK) and which had recorded a marked change in zooplankton community composition as a result. We chose a common cyprinid fish, the roach (*Rutilus rutilus*) which can be considered ubiquitous in Eurasia. We used scales from 1+ fish archived pre & post manipulations based on the assumption that at this age, they would be reliant upon zooplankton for prey although roach can undergo ontogenetic dietary shift at this young age. To account for any potential dietary shift, we analysed preserved zooplankton samples from similar time periods.

Roach and zooplankton isotope values responded to lake manipulations in a similar manner, suggesting that despite a reduction in preferred zooplankton prey, the significant positive relationships between roach scale $\delta^{13}C$ and total phosphorus and chlorophyll a were nutrient related and not a result of dietary shift.

References

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FRESHWATER ECOLOGY

CARBON SOURCES SUPPORTING AQUATIC FOOD WEBS: A $\delta^{13}C$ META-ANALYSIS FROM BOREAL STREAMS, LAKES AND RESERVOIRS.

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In boreal waters, terrestrial carbon dominates the carbon pool and, therefore, has an important role in the functioning of ecosystems. In humic waters, respiration generally exceeds production, suggesting that terrestrial organic carbon could represent a significant subsidy for the food web. Such trends may be amplified in regulated rivers and reservoirs in which connectivity with the terrestrial biome is increased by flooding and variations in water level.

Based on data from 13 lakes, 6 reservoirs and 2 rivers situated in the boreal region, this meta-analysis aims to assess the relative contribution of autochthonous versus allochthonous carbon sources for several trophic levels of the food web. Autochthonous $\delta^{13}C$ signatures were obtained based on the signature of particulate organic matter corrected for algal biomass (lakes/reservoirs), periphyton, macro algae and macrophytes (rivers) and compared to $\delta^{13}C$ signatures of several taxa of zooplankton (7), macro-invertebrates (11) and fish (14). Variance analysis indicated that the main source of carbon for organisms remained homogeneous in these systems, despite high variation in the loading of allochthonous material. In lakes and reservoirs, zooplankton carbon signatures were strongly related to that of algae, with a relationship that did not differ from the 1:1 line. In rivers, similar relationships were observed between autochthonous $\delta^{13}C$ signatures (algal and herbivorous taxa) and $\delta^{13}C$ values of invertebrate predators. The slope of the relationship between invertebrate and fish taxa $\delta^{13}C$ was not significantly different than 1 but had an intercept value higher than zero, likely as a result of trophic fractionation.

Results from this study demonstrate that even in ecosystems where allochthonous carbon pools dominate, autochthonous production remains the main food web carbon source.

FRESHWATER ECOLOGY

STABLE ISOTOPES OF C AND S AS INDICATORS OF HABITAT USE BY FISH IN SMALL OREGON COAST RANGE STREAMS

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We are using stable isotopes of C, N, O and S (H planned) to study the ecology of coho salmon in streams of the Oregon Coast Range. We have found isotopes of C and, surprisingly, S to be very useful in discriminating rearing habitats in our small streams.

We found $\delta^{13}C$ values of coho salmon juveniles at dietary equilibrium in late summer in tributaries of a highly shaded, low-order stream system in the Oregon Coast Range to vary spatially as much as 6‰. Values of $\delta^{13}C$ in sculpin and trout closely parallel those for coho. Values show a linear relationship to available light (i.e., possible autochthony vs. allochthony) only for sites with shading less than 90%. In contrast, $\delta^{13}C$ values were linearly related to temperature at all sites – and especially strong for sites with shading between 90% and 100%. We hypothesize that these patterns are dominated by out-gassing of ^{13}C-depleted CO_2 as a function of increasing heterotrophic stream metabolism driven by temperature and cumulative downstream effects.

In a parallel study, we found low $\delta^{34}S$ values of muscle tissue of coho salmon smolts from a low-gradient stream system with wetland areas. We also found sculpin (which remain more locally resident than coho) of that system to show clustering of $\delta^{34}S$ values by locations sampled, with fish more proximate to wetland areas being lower (relative to fish from free-flowing habitats) in $\delta^{34}S$ by up to 12‰. These results indicate significant incorporation of reduced sulfur into aquatic food webs, most likely via incorporation of bacteria with reduced and ^{34}S-depleted sulfur by chironomids at the food web base. The $\delta^{34}S$ values reflect lengthy occupation by fish of habitats with reducing environments (e.g., beaver ponds) during stream rearing. We propose that $\delta^{34}S$ might serve as a useful indicator of habitat use patterns in mixed-environment systems, especially ones with a range of red/ox conditions.

These findings have interesting implications for food web dynamics in such systems, contrasting a relatively closed nutrient cycling (sulfur example) with a more open system (carbon example) in these specific cases.

ANIMAL MIGRATION

ISOTOPIC AND GENETIC EVIDENCE FOR SITE FIDELITY TO FEEDING GROUNDS IN SOUTHERN RIGHT WHALES (*EUBALAENA AUSTRALIS*)

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Ocean warming will certainly affect the migratory patterns of many marine species, but specific changes can be predicted only where behavioural mechanisms guiding migration are understood. Southern right whales show maternally inherited site fidelity to near-shore winter nursery grounds, but exactly where they go to feed in summer remains mysterious. They consume huge quantities of copepods and krill, and their reproductive rates respond to fluctuations in krill abundance linked to El Niño-Southern Oscillation (Leaper et al., 2006, Biol. Lett. 2:289–292). Here we show that genetic and isotopic data, analysed together, indicate maternally directed site fidelity to diverse summer feeding grounds for female right whales calving at Península Valdés, Argentina. Isotope values from 131 skin samples span a broad range ($\delta^{13}C$ = -23.1 to -17.2‰, $\delta^{15}N$ = 6.0 to 13.8‰) and overlap with isotope values (from the literature and unpublished) of krill and copepods from a large geographic range; from waters north of the Polar Front, to the southern Patagonian shelf, to offshore Uruguay. The isotope values of skin samples are more similar than expected among individuals sharing the same mitochondrial haplotype, indicating that whales learn summer feeding locations from their mothers, and that the time scale of culturally inherited site fidelity to feeding grounds is at least several generations. Such fidelity would be expected to limit the exploration of new feeding opportunities, and might explain why this population shows increased rates of reproductive failure in years following sea surface temperature anomalies in the south-western South Atlantic, the richest known feeding ground for baleen whales.

ANIMAL MIGRATION

SEASONAL VARIATION IN FORAGING ECOLOGY OF SOUTHERN ELEPHANT SEALS ALONG THE WESTERN ANTARCTICA PENINSULA

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The southern elephant seal (*Mirounga leonina*) is an abundant, wide-ranging, deep-diving predator of squid and fish within the Southern Ocean, where they play an important role in the dynamics of the ecosystem. We examined the seasonal variation in the foraging habits of 42 female southern elephant seals foraging in the Western Antarctic Peninsula (WAP) by analyzing the $\delta^{13}C$ and $\delta^{15}N$ values along whiskers. Whiskers were collected between 2005 and 2008 during the annual molt in January-February at Cape Shirreff, Livingston Island (62º28'S, 60º46'W). Additionally, CTD-Satellite Relay Data Loggers were attached to the seals to measure individual patterns of habitat utilization and diving behavior. Whiskers were sub-sampled every 1 cm from the base to the tip of the whisker, allowing us to reconstruct the variation in isotopic values of elephant seals in a time period of > 1 year. The mean $\delta^{13}C$ and $\delta^{15}N$ values were -21.1 ± 1.0‰ (± 1 SD), and 10.4 ± 0.9‰ respectively. All sampled animals showed the highest $\delta^{15}N$ values at the base of the whisker (i.e. the most recent data) with a maximum of 14.3‰, coinciding with the molting (fasting) period. A secondary peak in $\delta^{15}N$ values was observed at 3 - 4 cm from the base of the whisker. This secondary peak corresponded to the breeding season (October-November), when the animals undergo another fasting period on land. The isotopic results showed partitioning in foraging strategies and habitat utilization for southern elephant seals. Most of the animals analyzed fed in southern waters (Antarctic shelf) as indicated by their lower $\delta^{13}C$ (<-20‰) and $\delta^{15}N$ (<11‰) values, and corroborated by tracking data. However, some animals had higher $\delta^{13}C$ (>-19‰) and $\delta^{15}N$ (>12‰) values, which suggest foraging zones north of the Antarctic Circumpolar Current Front (~ 50°S). Our results suggest that elephant seals from the WAP display different strategies in resource utilization and feed on different prey. It is therefore necessary to assess their role on the different food webs in the Southern Ocean.

ANIMAL MIGRATION

STABLE ISOTOPE ANALYSIS OF GREAT GRAY OWL (*STRIX NEBULOSA*) INVASIONS IN NORTH AMERICA

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The Great Gray Owl (GGO; *Strix nebulosa*), one of the world's largest owls, makes periodic winter invasions into regions well south of its core breeding range in the northern boreal forests of North America and Eurasia. Little is known, however, about the underlying causes of irruptive movements, the geographic origin of the immigrants, or the fate of individual owls. The most spectacular invasion in the past 150 years occurred during the winter of 2004-2005 in Minnesota, where 5200+ owls were observed or banded. This number surpassed the total observed in all previous winter invasions combined.

We are using δ^2H, $\delta^{18}O$, $\delta^{15}N$, $\delta^{13}C$ values of feather, liver, and pectoral muscle tissue from 300+ salvaged specimens to (i) determine the geographic origin of immigrant owls and (ii) to investigate the degree to which owls experience nutritional stress and starvation during the course of the winter. $\delta^{15}N$ and $\delta^{13}C$ values from bulk liver and pectoral muscle provide integrated isotope signals over short to intermediate time frames, while δ^2H and $\delta^{18}O$ values of metabolically inert feathers record ecological information from the summer prior to the invasion. Analyses to date show several intriguing patterns, including: (i) Liver and muscle $\delta^{15}N$ values range from 4‰ to 12‰, while liver $\delta^{15}N$ values are, on average, ~2‰ higher than associated muscle $\delta^{15}N$ values. $\Delta^{15}N_{liver\text{-}muscle}$ significantly increases throughout the winter for males, while females show no trend through time; (ii) δ^2H values range from –10‰ to –120‰, and high-latitude individuals ($\delta^2H < -100$‰) do not arrive in Minnesota until mid-winter; (iii) Feather $\delta^{18}O$ and δ^2H values show no significant relationship. Future analyses will continue to shed light on the geographic origins of GGO invasions and the nutritional stress experienced by owls during invasion winters. The resulting data will provide much needed data for modeling local and regional population dynamics of GGO as well as critical information for raptor conservation programs.

ANIMAL MIGRATION

USE OF STABLE ISOTOPE SIGNATURES (δ^2H, $\delta^{13}C$ AND $\delta^{15}N$) TO INDICATE BREEDING AND WINTERING GROUNDS IN A EUROPEAN LONG-DISTANCE MIGRATORY BIRD UPUPA EPOPS

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Tracking migratory animals and linking breeding and wintering areas has important consequences on the conservation of species. While for birds traditionally ring-banding has been used to explore migratory connectivity, analyses of stable isotopes in feathers are now widely applied to track small passerine birds. Stable isotopes in feathers reflect the isotopic composition of the place where feathers were grown. Hence, if a species is molting incompletely at two different places, thus has two generations of feathers from two different places, stable isotope analysis have the advantage, that we can obtain feathers of different origins at only one capture event. In many cases, some feathers bear the isotopic signatures of the wintering area while others are indicative of the breeding grounds.

We analyzed δ^2H, $\delta^{15}N$ and $\delta^{13}C$ signatures of feathers in the European hoopoe, Upupa epops, at two breeding sites in Europe over two years. Our goal was to detect isotopic differences in summer and winter molted feathers of Swiss hoopoes related to year, sex and age. Furthermore, we were interested in inter-annual variations of isotopic signatures on an individual basis. Lastly, we tried to predicted wintering areas based on feather isotopic signatures. For this we used data on isoscapes (isotopic landscapes) in combination with published isotopic signatures of birds in Africa.

Isotopic signatures were distinct between summer and winter molted feathers. We found a year effect in all three isotopes in winter molted feathers, whereas the year effect was only evident in δ^2H for summer molted feathers. Comparing individuals captured in both years, age had a significant effect on δ^2H and $\delta^{15}N$, which could be due to a later winter-molt in yearling birds. We hypothesize that differences in isotopic composition of winter molted feathers between the two populations are due to different wintering locations. We assume that Swiss birds almost exclusively winter on the African continent south of the Sahara, more to the east compared to Spanish hoopoes, which either migrate more to West-Africa or stay in Spain during winter.

We conclude that stable isotopes are a useful tool to separate breeding and wintering areas on the continental scale, but for small-scale predictions of wintering areas in the Palaearctic migration system further refinement of isotopic basemaps are needed to make accurate predictions about the wintering areas, and to better understand the migratory connectivity in hoopoes.

ANIMAL MIGRATION

DETECTING ALTITUDINAL MIGRATION AND MOLT PATTERNS IN NEOTROPICAL BIRDS USING STABLE HYDROGEN ISOTOPES.

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Short-term or seasonal movement of passerine birds over an elevational gradient, termed 'altitudinal migration', is thought to occur regularly in many tropical regions. Such movements can influence seasonal distributions of many species and may have been the precursor for the evolution of long-distance migration out of the tropics. However, altitudinal migration patterns remain poorly described for most Neotropical passerine species due to the limitations of mark-recapture techniques. Stable hydrogen isotopes (δ D) in meteoric water are known to covary with elevation and may be a valuable tool for the detection of migration events.

We collected tissues that represent short- (feathers) and longer-term (claws) integration of δD values from a high-elevation, cloud-forest bird community in Nicaragua between 2006 and 2008. We compared the δD values in feathers and claws to those in vegetation, insects and rainwater collected monthly in the study area. We looked for mismatches between expected values for the study site and bird tissues to infer which species or individuals migrated altitudinally. We compared monthly patterns of δD in rainfall with feather values to infer the timing of molt for species that are known to breed at the study site. These methods may provide an effective means for researchers to detect previously unrecognized movement and molt patterns in tropical montane environments.

ANIMAL MIGRATION

ESTIMATING PROPORTIONAL MIXTURES OF HYDROGEN AND OXYGEN SOURCES IN A HIGHLY RESTRICTED AVIAN SYSTEM

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Stable isotope ratio measurements have long been used in studies of trophic ecology and researchers are increasingly using them to infer seasonal linkages in studies of migratory animals. Most of these studies have relied on assumptions that have not been adequately tested under field conditions. For example, most studies of migratory birds assume little or no variation in δ-values associated with feathers grown at the same location, yet very few such studies measure values for feathers of known origin (e.g. freshly moulted) to anchor their inferences. Although much more work has been done to probe the assumptions associated with studies of trophic ecology, many empirical studies likewise assume little or no variation in the values of the dietary items (or trophic levels) used for tissue synthesis.

We took advantage of a unique moult-migration scenario to explore the variation present in isotope values for hydrogen and oxygen measured in feathers and food items of a migratory bird under non-manipulated conditions. Eared grebes (*Podiceps nigricollis*) migrate to the Great Salt Lake in Utah, USA each fall where they moult flight feathers and add needed fat before flying further south to spend the winter. During this non-sequential moult, the birds are flightless, using the lake as protection against predation. The birds generally consume two prey items, brine shrimp (*Artemia spp*) or brine flies (*Ephydra riparia*), during this period. Most of the water used by grebes during this period is thought to be metabolized from food, although they may infrequently drink fresh water from local sources also. We measured stable hydrogen and oxygen isotope ratios in grebe feathers, brine flies, brine shrimp and surface waters for incorporating into Bayesian mixture models to estimate the proportional contributions of each source in the development of new feathers. Our findings contain important implications for both food web and migration studies that use natural variations in isotope compositions.

PLENARY II

MARINE FOOD WEB ECOLOGY: INSIGHTS FROM STABLE ISOTOPES

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Marine food webs are complex and diverse, but methods to understand and predict their general properties must be developed to describe human and environmental impacts on structures and processes at regional and global scales. Stable isotope data have provided valuable insights into food web properties; insights that are difficult, and in some cases impossible, to obtain in other ways. Thus stable isotope data have been used to estimate intra- and inter-specific variation in trophic level, predator-prey size ratios, transfer efficiency, food chain length, relationships between predator and prey species diversity and the dynamics of energy use. As food web science continues to mature, such estimates are increasingly used to parameterise models for predicting human and environmental impacts. These models are likely to play an increasing role in marine environmental management; a consequence of the widespread adoption of an ‘ecosystem approach’.

MARINE ECOLOGY

SHIFTING WARM-WATER TO COLD-WATER CONDITIONS AND FOODWEB DYNAMICS OF JUVENILE PACIFIC SALMON IN THE EASTERN BERING SEA ECOSYSTEM

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Pacific salmon are an important fisheries resource for several Pacific Rim countries, with significant links to both regional and national economies, and social and cultural heritage of costal communities. In recent decades the productivity of Pacific salmon has been declining, with several stocks all but disappearing. Although the underlying mechanisms are still unclear, there is a growing sense that such declines may be linked to large-scale changes in ocean conditions and the resultant variability in temperature, nutrients, the quantity and quality of zooplankton, forage fish and predator assemblages. We hypothesize that changing ocean conditions through shifts in the quality and quantity of prey may affect foodweb dynamics and ontogeny of salmon as a function size within species, and significant diet overlaps among species, and ultimately the growth and survival of salmon.

The Eastern Bering Sea (EBS) ecosystem is one of the important feeding grounds for juvenile Pacific salmon. Shifts in the relative strength of Pacific Decadal Oscillation (PDO) and Arctic Oscillation (AO), and associated shifts in thermal regimes in the EBS have been suggested to have major implications for energy flow along foodweb and trophic interactions among forage fish and juvenile salmon. The EBS shifted from a warm-water condition during 2002-2005 to a relatively cold-water condition during 2006-2007. This shift seems to be linked to dramatic shifts in the abundance of the major forage fish species, the most common diet of juvenile Pacific salmon species. We evaluate if the reversal of ocean thermal regimes caused significant shifts in foodweb dynamics and trophic interactions among the juveniles of salmon species, ontogenetic niche shifts as a function of size within species, and diet overlaps among species. To test our objectives, we used N and C stable isotope signatures of over 10,000 samples of juvenile salmon, forage fish and zooplankton collected during six years along the north-south and east-west transects of the EBS. We present results showing how the change from warm to cold years are associated with significant contrasts in diet overlaps and trophic interactions among salmon species, and onshore-offshore variability in trophic shifts within Pacific salmon species as a function of body size, and discuss the implications of the observed variability for growth, survival and productivity of Pacific salmon.

MARINE ECOLOGY

METABOLIC RATES AND LIFE HISTORIES IN DEEP WATER FISH

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Deepwater fish communities are adapted to low light, low nutrient availability, low temperature high pressure environments. The physiological adaptations to these conditions are diverse, but difficult to study as animals cannot be raised experimentally. Metabolic rates in deep water fish are particularly interesting, as many fish (such as the orange roughy, Hoplostethus atlanticus) have extreme longevity but apparently relatively high metabolic rates. This apparently contradicts metabolic ecological theory where longevity is expected to scale inversely with metabolic rate. Unfortunately direct determination of realistic metabolic rates is extremely difficult in these inaccessible environments.

The carbon in carbonate biominerals of marine organisms is derived from dietary (isotopically light) carbon and dissolved inorganic carbon. The isotopic composition of carbon in biominerals is therefore controlled in part by the proportion of metabolically derived carbon within the blood, and consequently metabolic rate. Simple mass balance models demonstrate that fish derive a relatively large proportion of carbon from metabolic pools, ranging from <10 to >40% of total carbon in the otolith. Large variations in the proportion of metabolically derived carbon in otoliths are seen both between species and ontogenetically within individuals, and δ^{13}Coto values can consequently be used as a proxy for relative (field) metabolic rates.

Here I present preliminary comparisons of relative metabolic rates of a range of fish living between 500 and 1500m on the NE Atlantic slope, together with ontogenetic records of depth and metabolic rate derived from subsampled otoliths. Slope fish exhibit a range of metabolic rates, suggesting a diversity of metabolic strategies. Active fish such as the orange roughy reveal surprisingly low proportions of metabolic carbon in blood, contrasting with expectations based on muscle composition and metabolic enzymes, but potentially more consistent with the metabolic explanations for extreme longevity.

MARINE ECOLOGY

CONTRIBUTION OF TERRESTRIAL MATERIALS TO NEARSHORE KELP BEDS IN CENTRAL CALIFORNIA

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Cross-habitat connections have recently become an important area of ecological study as new scientific tools become available and human activities continue to affect species composition and community functioning in natural systems on a global scale. Along the central California coast, I am investigating the connectivity of habitats at the land-sea interface. In two relatively pristine watersheds along the Big Sur coast, I am investigating the delivery of terrestrial subsidies to nearshore kelp communities by comparing sites close-to and far-from river inputs. Rivers are important sources of dissolved and particulate fluxes to the world's oceans and may significantly influence dynamics in nearshore marine communities. These effects can be especially important in short, steep watersheds (e.g. Big Sur) where little filtering occurs before rivers meet the ocean. Using the stable isotopes of carbon and nitrogen, I am able to measure the relative contributions of marine vs. terrestrial materials into this system throughout the year. Tissue samples were collected year-round from 2005 to 2008 from a suite of marine organisms with different nutrient uptake and foraging strategies. With these samples, I am able to determine the extent to which terrestrial material is incorporated within the kelp community, as well as measure the variability between seasons. My results show significant differences in both $\delta^{13}C$ and $\delta^{15}N$ values in organisms collected close-to versus far-from river inputs. These differences are especially pronounced in organisms that have relatively short tissue turnover times. There are also significant seasonal differences in the $\delta^{13}C$ and $\delta^{15}N$ values of multiple organisms at close-to river sites that are most likely driven by the changing contributions of terrestrial versus marine subsidies throughout the year.

MARINE ECOLOGY

QUANTIFYING PREY PROPORTIONS OF ANTARCTIC TOOTHFISH (DISSOSTICHUS MAWSONI) IN THE ROSS SEA, ANTARCTICA

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The Antarctic toothfish (*Dissostichus mawsoni*) is endemic to the Antarctic continental shelf and supports a commercially important and valuable longline fishery in the Ross Sea. The fishery is managed by the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR), which has called for an improved understanding of how this fishery is affecting Ross Sea ecosystem form and function. To date, dietary information has been derived from a relatively small number of studies of stomach content analyses, which only give insight into the latest prey catch, and provide no information on long-term integrated diet. Current understanding of trophic connections in the Ross Sea is therefore limited. Such information is critical to developing Ross Sea trophic models and to assessing the impact of the Antarctic toothfish fishery on associated species. We present data from over 600 isotope analyses of Antarctic toothfish and potential prey species from the Ross Sea CCAMLR Subarea 88.1 and show that there is a large range in isotope values for Antarctic toothfish: 7‰ $\delta^{15}N$ (equating to two trophic levels) and 3.5‰ $\delta^{13}C$ (suggesting multiple primary sources of organic matter). We show that the diet of the Antarctic toothfish varies with location and with fish length and that some Antarctic toothfish occupy a trophic position in the Ross Sea food web equivalent to orca (*Orcinus orca*), sperm whales (*Physeter macrocephalus*) and Weddell seals (*Leptonychotes weddellii*). We assess the relative proportions of different food sources ingested by Antarctic toothfish using the IsoSource multi-source mixing model and discuss the implications of these data to the management of the fishery.

MARINE ECOLOGY

INDIVIDUAL VARIATION IN NUTRIENT ALLOCATION TO EGG PRODUCTION IN AN ARCTIC SEA DUCK

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Many arctic bird species produce eggs at a time when food abundance is low. This energetic challenge can be overcome by using endogenous body stores for egg production. We quantified the proportion of endogenous nutrients invested into eggs of a large arctic nesting sea duck, the King Eider (*Somateria spectabilis*), at two sites in northern Alaska. We employed a novel approach to account for individually varying diet on breeding grounds by using eggshell membranes as a nest-specific dietary endpoint in a simple linear $\delta^{13}C$ mixing model. For the second endpoint, we chose red blood cell $\delta^{13}C$ to reflect endogenous nutrients. We used published values for diet-egg discrimination, and contrast results from those estimates with unpublished experimental data of diet-egg discrimination of a related eider species. We found large isotopic variation (>10‰) in lipid-free yolk, albumen, and eggshell membranes. On average, both lipid-free yolk and albumen nutrients were mostly derived from food consumed on breeding grounds, with a higher proportion of endogenous nutrients in lipid-free yolk (mean ± SD 52±25%) than in albumen (84±15%). However, there was considerable variation in resource allocation among individuals, with the contribution of endogenous nutrients ranging from 0-100% in lipid-free yolk, and from 0-70% in albumen. Our conclusions were sensitive to the discrimination factor we selected: Different discrimination factors yielded endogenous source contributions differing by 31% for lipid-free yolk and 14% for albumen. Our study demonstrates that nutrient allocation to eggs is individually variable, but that King Eiders rely mainly on food obtained on the breeding grounds to produce eggs.

MARINE ECOLOGY

INTERDECADAL VARIABILITY OF STABLE ISOTOPES REFLECTED IN BERING SEA ZOOPLANKTON

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Zooplankton samples from the eastern side of the Bering Sea were collected from 365 stations during the years 1999, 2001 and 2002-2006. The dominant zooplankton taxonomic groups, including calanoid copepods and euphausiids, as well as bulk zooplankton samples, were analyzed for stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios. The sampling locations were separated into distinct domains based on their bathymetric and oceanographic features. Euphausiids and chaetognaths were more enriched in $\delta^{13}C$ than the calanoid copepods (average □ ~ 1.5‰) but showed no significant difference in $\delta^{15}N$. Geographic domains appeared to exert the greatest variability in both isotope ratios. The most enriched values for both $\delta^{13}C$ and $\delta^{15}N$ were found along the western coast of Alaska in the inner domain, seemingly regardless of any latitudinal gradient. A trend of onshore enrichment to offshore depletion towards the Bering Sea shelf break was exhibited in all the major zooplankton taxonomic groups studied. This is in sharp contrast to the findings of Schell et. al. (1998) who analyzed the stable isotope ratios of copepods, euphausiids and chaetognaths from samples collected in the Bering Sea. Our isotopic values from these same taxonomic groups were compared from the same season (August-September) and regions with Schell's samples collected in 1993 and 1995. Schell et. al. consistently found the most enriched values for both carbon and nitrogen isotopes along the Bering Sea shelf break and more depleted values along the western Alaskan coast and in the southern basin. Not only is there a significant difference in geographic distribution of the isotope ratios during the past decade, but an overall depletion in both $\delta^{13}C$ and $\delta^{15}N$ exists in our recent data. All three taxonomic groups, regardless of location, showed an average decline of nearly 2‰ in $\delta^{13}C$ (copepods: -22.7 to -24.5‰) and an approximately 3‰ decline in $\delta^{15}N$ (copepods: 9.8 to 7.4‰). As these isotopic differences are found consistently throughout the eastern Bering Sea basin, these differences can represent a decrease of primary production to the region and a resulting increase in the number of trophic levels necessary to support the pelagic community. Environmental changes, e.g sea ice extent and coccolithophore blooms, during the past decade may harken to further changes in the trophic structure and production in one of the most productive fisheries in the world.

Schell DM, Barnett BA, Vinette KA (1998) Carbon and nitrogen isotope ratios in zooplankton of the Bering, Chukchi and Beaufort seas. Mar Ecol Progr Ser 162:11-23

MARINE ECOLOGY

BIOGEOGRAPHIC ISOTOPE TRENDS IN MARINE INTERTIDAL FOOD WEBS

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Broad differences in coastal hydrography and primary production are likely to result not only in differences in species composition, but also in substantial differences in trophic pathways. Although stable isotopes of carbon and nitrogen provide important information on trophic relationships, there has been limited research on geographic variation in isotopic composition of marine consumers and their food. $\delta^{13}C$ and $\delta^{15}N$ isotopic ratios of suspended particulate matter (SPM), common macroalgae, mussels and other filter feeders were explored using stable isotope analysis to investigate biogeographic and temporal variability of isotopic signatures of marine intertidal consumers and their food sources around the coast of South Africa.

SPM exhibited overall trends of carbon depletion when moving from west to east along the coastline and from nearshore to offshore water, in both cases suggesting a shift from macrophyte detritus to a phytoplankton signature. $\delta^{13}C$ signatures of SPM also revealed temporal and biogeographic variation that had strong ties to local oceanography, being closely correlated to regional hydrographic features and tidal influences.

Although intertidal macroalgae showed no consistent biogeographic or temporal trends, IsoSource models suggested that they accounted for upwards of 60% of the organic carbon and nitrogen in nearshore SPM. Subsequent linear mixing models indicated that the diets of both mussels and other filter feeders were heavily dependent on nearshore SPM and discriminant analyses categorized both mussel and other filter feeder populations into four geographic groups on the basis of both carbon and nitrogen ratios. These results indicate a deeply penetrating effect of coastal hydrography on intertidal food webs.

MARINE ECOLOGY

STABLE ISOTOPES SHOW CONSISTENT CONSUMER-PREY RELATIONSHIPS ACROSS HUNDREDS OF KILOMETRES

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Studies of trophic relationships using stable isotopes typically resolve the nature of trophic interactions across small spatial extents. We investigated trophic interactions between key taxa (herbivorous invertebrates and their macroalgal prey) in shallow marine ecosystems across hundreds of kilometres along the west coast of Australia. We used a hierarchical nested survey design, and used partial regression analysis to determine the extent to which spatial patterns in stable isotopes of consumers could be attributed to spatial variation in stable isotopes of prey. $\delta^{15}N$ of herbivores and algae varied among locations separated by hundreds of kilometres, mainly due to high values from biota collected near a metropolitan area. In contrast $\delta^{13}C$ of herbivores and algae varied considerably among individual reefs separated by a few kilometres, suggesting high spatial variability in sources of carbon. Stable isotope values of herbivores were strongly correlated with those of macroalgal prey. However the amount of spatial variation that could be explained by prey was inconsistent among consumers. For one sea urchin, most of the spatial variation in stable isotopes could be explained by spatial variation in a single kelp species known to be a key prey item. This suggests that some consumer-prey relationships are highly consistent across biogeographical spatial scales.

HUMAN ECOLOGY

A QUANTITATIVE BIOMARKER OF FISH INTAKE: ^{15}N IS HIGHLY CORRELATED WITH RED BLOOD CELL OMEGA3 FATTY ACIDS (EPA AND DHA) IN YUP'IK ESKIMOS

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It is well known to stable isotope ecologists that δ^{15}N reflects intake of marine foods in animals. However, linking a single isotope ratio to a specific food type in modern humans can be less straightforward given the great diversity of isotopically variable diet items consumed. Using stable isotope signatures as biomarkers of specific dietary components is attracting interest from the nutritional community, as questionnaire-based instruments for human diet assessment can be problematic: they are not sensitive to individual difference in intake, they are prone to bias, and they can be burdensome to administer and complete. Thus, validated, accurate biomarkers of intake are highly desirable for detecting associations between diet and disease.

Fish and other marine foods are rich in the "omega-3" polyunsaturated fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). EPA and DHA have been shown to be anti-inflammatory, cardioprotective, and to promote insulin sensitivity. High intake of EPA and DHA in marine subsistence foods are thought to account for low rates of chronic obesity-related disease in Alaska Natives, particularly Yup'ik Eskimos. EPA and DHA levels in both plasma and red blood cells (RBC) are a well-validated biomarker for intake of these fatty acids and fish, however, measuring these fatty acids directly in blood samples is expensive, time-consuming, and requires invasive sampling. We propose that δ^{15}N could serve as an alternative biomarker for EPA and DHA intake via marine foods, which could ultimately be measured in hair rather than blood. If so, δ^{15}N would provide a biomarker, which is inexpensive, straightforward to measure, sensitive and highly accurate.

Here we examine the relationship between the RBC δ^{15}N and RBC membrane EPA and DHA in 500 Yup'ik Eskimo participants in the Center for Alaska Native Health Research I study. These participants come from 8 small communities in the Yukon-Kuskokwim region of Southwest Alaska, and range in age from 14-92 years old. They are an ideal population for testing whether δ^{15}N reflects fish intake because intake of marine foods is highly variable; from > 60% of all calories in some elders to neglible amounts in some teens. RBC δ^{15}N was measured using continuous-flow isotope ratio mass spectrometry, and RBC EPA and DHA were measured using gas chromatography.

RBC δ^{15}N is strongly and positively correlated with RBC membrane EPA ($\square$=0.83) and DHA ($\square$=0.82). RBC δ^{15}N also correlates strongly with total RBC membrane omega-3 ($\square$=0.85) and omega-6 ($\square$=-0.80) fatty acids, as well as the omega-6/omega-3 ratio (indicator of dietary fatty acid imbalance). We also tested the association between δ^{15}N and EPA and DHA intake, as assessed through 4 days of diet records administered to 244 of the 500 participants, and found the association to be weaker: ($\square$=0.5-0.6). Thus, we propose that δ^{15}N provides a low-cost, highly accurate biomarker for EPA and DHA intake in this population that outperforms dietary questionnaires against validated intake biomarkers. Furthermore, we suggest that this relationship should occur in any population in which people derive most of their dietary EPA and DHA from fish.

HUMAN ECOLOGY

RED BLOOD CELL δ ^{15}N AND δ ^{13}C VARY ACCORDING TO AGE, GEOGRAPHY, AND INTAKE OF SPECIFIC NUTRIENTS; RESULTS FROM OVER 1000 YUP'IK ESKIMO PARTICIPANTS IN THE CANHR I STUDY.

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Naturally occurring stable isotope variation may provide a way to accurately assess dietary intake on a larger scale than is currently possible for human populations. Our research aims to develop multiple stable isotope signatures as accurate diet proxies for Yup'ik Eskimos, particularly with reference to subsistence and non-subsistence intake. Ultimately we wish to use these proxies in long-term large scale studies of diet and disease risk in this population.

The Center for Alaska Native Health Research (CANHR) is partnered with 10 Yup'ik Eskimo communities in Southwest Alaska in a study of the determinants of obesity and related disease. This population provides an ideal opportunity to evaluate the suitability of stable isotopes as dietary biomarkers, as diets include significant consumption of marine foods (salmon, seal, shellfish, walrus), terrestrial foods (moose, reindeer, muskox, caribou, berries), as well as market foods grown outside Alaska, all of which are expected to vary in their C,N, O/H and S signatures. Diets vary by village, through the year, and have been argued to be changing over a timeframe of years to decades. Ongoing research into the genetic, biological and environmental causes of obesity and chronic disease in this population would benefit from intake biomarkers that would be tracked seasonally and over time.

We measured red blood cell δ^{13}C and δ^{15}N from 1005 participants in the CANHR I study; these participants were nearly all Yup'ik Eskimo living in 10 coastal and riverine communities in the Yukon-Kuskokwim Delta region of Southwest Alaska. RBC δ^{15}N and δ^{13}C varied strikingly with age, with older participants highly enriched in ^{15}N and depleted in ^{13}C relative to younger participants. These patterns accord with what has been learned using diet surveys; for example, in one coastal community dietary surveys suggested that marine subsistence foods contributed over half of total calorific intake in participants over 60 years of age, whereas in participants aged 14-20, this figure reduced to less than 10%. Accordingly, the range of variation in RBC δ^{15}N was huge: from 7 to 15‰. The highest contributor of calories in the latter age bracket was high fructose corn syrup and refined sugar (soda). Variation in RBC δ^{13}C was more moderate (-21.5 to -19‰), with younger participants being significantly more enriched relative to elder participants, suggesting greater consumption of C-4 based foods such as chicken or beef in addition to their increased soda consumption. Interestingly, however, there appeared to be no significant correlation between high fructose corn syrup intake (as assessed by dietary recalls) and δ^{13}C values. Mean δ^{13}C and δ^{15}N also varied among communities, with coastal communities exhibiting the greatest age related variation, in comparison to riverine communities. Thus, isotopes do exhibit sufficiently wide range of values to detect regional dietary differences.

These preliminary results suggest that there is indeed potential to exploit stable isotope methodologies for accessing diets of Southwest Alaskan communities, and potentially further afield. This means that there is possibility to be able to expand studies

based on a knowledge of what people are eating without the labour intensive and probable inconvenience of dietary questionnaires.

HUMAN ECOLOGY

CLINICAL-SCALE INVESTIGATION OF STABLE ISOTOPES IN HUMAN BLOOD: δ ^{13}C AND δ ^{15}N FROM 406 PATIENTS AT THE JOHNS HOPKINS MEDICAL INSTITUTIONS

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Five of the leading 10 causes of death in the United States are related to obesity(1). Objective chemical biomarkers are needed in clinical studies of diet-related diseases to supplement subjective self-reporting methods. Researchers have pointed to recent increases in refined carbohydrate(2) and meat(3) consumption as important factors in the diabetes/obesity epidemic. C4 plants sugar cane corn, and their derivatives (such as high fructose corn syrup) have conspicuously high $\delta^{13}C$ values and may represent a biomarker for human consumption(4). As for $\delta^{15}N$, it has long been shown that with elevation of trophic level, ^{15}N is concentrated in biological tissues(5).

Here we report on several critical experiments designed to inform the development of clinically-legitimate dietary isotope biomarkers. We chose blood because it represents a universally collected and archived clinical substrate. Our examination of human blood has revealed the following: 1. We quantified $\delta^{13}C$ and $\delta^{15}N$ values in blood serum and clot from 406 anonymous donors (201 males, 205 females). Within the total sample (n=406) $\delta^{13}C$ means are -19.1‰± 0.8‰ (SD) for serum, -19.3‰ ± 0.8‰ (SD) for clot, with a range of −15.8‰ to −23.4‰. Mean $\delta^{13}C$ values are virtually identical for males, females, blood clot, and serum. Blood $\delta^{15}N$ values (n=206) show mean values of +8.8 ± 0.5‰ (SD) for serum, +7.4‰ ± 0.4‰ (SD) for clot, and have a range of +6.3‰ to +10.5‰. Means for δ ^{15}N are virtually identical for males and females. Blood serum is enriched in ^{15}N relative to blood clot by a mean value of +1.4‰, potentially explained by the difference in protein amino acid content. 2. We compared the isotopic composition of capillary and venous blood from 24 individuals. Capillary blood is enriched in ^{13}C by 0.1‰ and depleted in ^{15}N by 0.1‰ relative to clot (on average). Similarly, clot is enriched in ^{13}C by 0.1‰ and depleted in ^{15}N by 1.5‰ relative to serum (on average). Capillary blood appears to accurately reflect the $\delta^{15}N$ signature of venous blood clot (predominantly red blood cells) rather than serum (primarily water, proteins, glucose, etc.). 3. We assessed the effect of blood additives (sodium fluoride and polymerized acrylamide resin) and laboratory process (autoclaving, freeze drying) commonly used to preserve or prepare venous blood. Mean change in $\delta^{13}C$ is 0.2‰ when compared to unadulterated blood from the same individual. 4. Storage of blood with and without the additives described above for a period of up to 115 days does not affect the $\delta^{13}C$ or $\delta^{15}N$ isotopic composition of the blood. This is particularly important in the application of a stable isotope biomarker to blood archived for epidemiological studies (Atherosclerosis Risk in Communities, Magnetic Resonance Imaging, blood archive 1987 to 1998) with these experiments, we gain a much needed clinical context for future development of a stable isotope based dietary biomarker.

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HUMAN ECOLOGY

STRONTIUM ISOTOPE TRACING AT A NEANDERTAL SITE IN SOUTH-WESTERN FRANCE

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Strontium isotope ratios ($^{87}Sr/^{86}Sr$) can be utilised in reconstructing the migration and mobility of ancient animal and human populations. Strontium isotopes in fossil tooth enamel are compared to a geological, bio-available strontium isotope map, to determine whether teeth are from local or migrant individuals. This study was carried out on the Upper Pleistocene site of Les Pradelles (Marillac-le-Franc, Charente, France), which has yielded numerous faunal remains including an important collection of Neandertal pieces (Homo neanderthalensis or Homo sapiens neanderthalensis). The surrounding area consists of two main rock regions, the Jurassic and Cretaceous limestones of the Dordogne and the Devonian metamorphic and granitoid rocks of the Massif Central, which yield differing average strontium isotope ratios.

ICP-MS analysis was used to measure bio-available $^{87}Sr/^{86}Sr$ in soil and plant samples from 40 locations across both rock regions. Despite some variation in $^{87}Sr/^{86}Sr$ within each rock region, the two main regions are successfully differentiated on the basis of Sr isotopes and a Sr isotope map of the area has been produced. The fossil faunal samples from Les Pradelles consisted of 23 teeth from seven species including both herbivores and carnivores. Sr isotopes in the tooth enamel were measured via laser ablation ICP-MS, resulting in high resolution records along the growth axis of the enamel. The strontium isotope ratios do not vary significantly within samples, potentially indicating a lack of migration across the rock provinces while the teeth were forming. However, the lack of seasonality may alternatively be explained by reservoir effects and complexities in tooth mineralisation.

Animals with small feeding ranges are successfully linked to particular rock regions according to Sr isotope ratio and indicate that the Neanderthals may have travelled over at least 5 km while hunting. Intermediate $^{87}Sr/^{86}Sr$ values in migrating animals suggest an averaging of values from both units. As such, lifetime migration could be determined in some animals, though seasonal migration could not. This study forms the basis for an ongoing study into Neandertal migration.

METHODS IN ISOTOPE ECOLOGY II: Isotopic Discrimination & Models

FIXED DISCRIMINATION FACTORS IN DIET RECONSTRUCTION?

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Stable isotope analyses are frequently used to determine the relative contributions of different food sources to an animal's diet. Recently, a number of studies have used geometric procedures to reconstruct such diets. These isotopic models typically use the mean $\delta^{13}C$ and $\delta^{15}N$ values for each type of diet corrected for the discrimination factor of the consumer (the increase in consumer isotopic ratio compared with that of the consumer's diet, δ). Since the 1950s, when the first isotopic models were used, an increasing number of studies have employed these models to quantify the contribution of multiple sources in a mixture, such as the proportions of different types of food sources in an animal's diet. As is the case with traditional methods of estimating consumer diet, isotopic models are not exact and provide estimations only. Previous studies on isotopic models have highlighted this problem and called for laboratory studies to assess the extent of inaccuracies and to ascertain the reasons why the errors occur. Laboratory studies offer opportunities to obtain accurate isotopic values for both a consumer and the consumer's resources, allowing tests of model performance. In addition, the use of a fixed discrimination factor has been suggested as a possible source of error in the determination of mixed diet composition. Whereas it is difficult to design field studies to demonstrate this assertion, several studies continue to use fixed discrimination factors without taking into account the taxon under study, the tissue examined, or the type of diet. For example, in some cases the fixed discrimination factor used in the model has been earlier associated with a different species or, even if the selected factor was earlier used with the same species, the factor is now used for work with different tissues or different diets.

With the synergy of different approaches (laboratory, review, isotopic model and application in field studies), we draw attention on the high variability of discrimination factors and highlight the relationship between diet isotopic values and discrimination factors in most animal groups. These relationships allow us to propose a framework to estimate discrimination factors from diet isotopic ratios by means of regression models. This trend has an important impact in the outcomes of mixing-models and estimates of trophic positions. Future studies should be focused on understanding why discrimination factors vary as a function of the isotopic value of the diet. Ecologists and zoologists working with species in the wild need to know the accuracies of isotopic models in diet reconstruction, and the implications of choosing given discrimination factors.

METHODS IN ISOTOPE ECOLOGY II: Isotopic Discrimination & Models

ASSESSING STABLE ISOTOPE TURNOVER UPON DIET SWITCHES IN ANIMALS UNDER CONTROLLED SETTINGS

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Over the past five years we have carried out a number of controlled laboratory studies to assess the turnover of carbon and nitrogen stable isotopes in invertebrates, fishes and snakes. The strategy in these experiments was to use food that varied widely in stable isotope signature (in some cases by more than 500‰) so that slow and small changes in stable isotope concentration would be magnified above variation in the methodology. These extreme stable isotope signatures permitted isolation of uptake and elimination of nitrogen and carbon isotopes and allowed us to model the rate of isotope turnover dependent only on the stable isotope concentration of the food. This food was created by exposing worms to soil that varied widely in ^{15}N and ^{13}C content, thus converting inorganic sources of carbon and nitrogen to organic sources. Results from multiple studies indicate that: 1) in growing vertebrates, growth dominates stable isotope turnover; 2) in some rapidly growing invertebrates metabolic turnover of stable isotopes is greater than turnover due to growth; 3) the diet tissue fractionation factor is dependent on the concentration of heavy isotopes in the food source; 4) and metabolic turnover of stable isotopes varies across tissue type. These results may have significance when interpreting stable isotope values in the environment and have potential to provide a temporal aspect to mixing models. However, a few reviewers have questioned these experimental protocols and these concerns will be discussed.

METHODS IN ISOTOPE ECOLOGY II: Isotopic Discrimination & Models

PREDICTION OF ATMOSPHERIC $^{13}CO_2$ USING PLANT TISSUES GROWN UNDER ELEVATED PCO_2

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Reconstruction of the carbon isotope composition of atmospheric CO_2 is critical to the understanding of long-term global carbon cycling. I have suggested that the $\delta^{13}C$ value of land plant carbon ($\delta^{13}C_p$) preserved in the geologic record should reflect the $\delta^{13}CO_2$ at the time during which the plants grew ($\delta^{13}C_a$), based on a meta-analysis of modern plant data. Here I present the results of laboratory experiments designed to quantify the relationship between plant tissue $\delta^{13}C$ and $\delta^{13}CO_2$ values under varying environmental conditions, including differential pCO_2 ranging from 1 to 3 times today's levels. As predicted, plants grown under elevated pCO_2 showed increased average biomass compared to controls grown at the same temperature. Across a very large range in $\delta^{13}C_a$ (≈ 24 ‰) and pCO_2 (≈ 740 ppmv) I observed a consistent correlation between $\delta^{13}C_a$ and $\delta^{13}C_p$ ($p<0.001$). There was an average isotopic depletion of -25.4 ‰ for above-ground tissue and -23.2 ‰ for below-ground tissue of Raphanus sativus L. relative to the composition of the atmosphere under which it formed. For both above- and below-ground tissue, grown at both ~23 ˚C and ~29 ˚C, correlation was strong and significant ($r^2 \geq 0.98$, $p<0.001$); variation in pCO_2 level had little or no effect on this relationship. These results validate the initial conclusion that—in the absence of environmental stress—plant $\delta^{13}C$ primarily reflects atmospheric $\delta^{13}CO_2$ linearly across pCO_2 levels; the demonstrated excellent correlation in $\delta^{13}C_a$ and $\delta^{13}C_p$ suggests a high level of predictive power across varying environmental conditions.

METHODS IN ISOTOPE ECOLOGY II: Isotopic Discrimination & Models

SOLVING ISOTOPE MIXTURE MODELS USING BAYESIAN METHODS: AN INTRODUCTION USING THE FREE TO DOWNLOAD R PACKAGE "SIAR".

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The ability to infer the proportions of food sources in the diets of consumers is central to much isotope research in ecology. Methods to date, such as ISOSOURCE (Phillips et al. 2005), have proved popular with researchers but have suffered from an inability to allow robust statistical comparison between estimates of diet between consumers. The fundamental problem being that a true probability distribution of the parameter estimates cannot be generated under the exhaustive parameter space search method. Bayesian statistical inference provides an appropriate framework for analysing this system. The Bayesian method has several advantages over traditional mixing models in that all sources of error around any observed measurements (e.g. uncertainty in isotopic discrimination factors) can be explicitly incorporated and the output is a fully defined statistical distribution of diet proportion estimates.

Here we introduce the Bayesian framework for analysing isotope mixture models for those not familiar with the method, and outline its key advantages over the current set of models with particular reference to ISOSOURCE (Phillips et al. 2005). We also provide an introductory guide to our recently developed, and free to download, SIAR (Stable Isotope Analysis in R) package for the R statistical computing environment. We show how multiple groups of consumers can be compared with respect to their diet in a single and easy to implement analysis. SIAR can be run from an interactive menu system, or through a set of customisable functions for more competent users.

The Bayesian approach opens up a whole new range of potential applications and offers to address much more detailed ecological questions than previously possible.

Phillips D.L., Newsome S.D. & Gregg J.W. (2005) Combining sources in stable isotope mixing models: alternative methods. Oecologia, 144, 520-527

METHODS IN ISOTOPE ECOLOGY II: Isotopic Discrimination & Models

TESTING BAYESIAN APPROACHES TO STABLE ISOTOPE MIXING MODELS

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In recent years stable isotope analysis has become a crucial tool in quantifying the diets of consumers, and has enabled researchers to answer increasing complex and wide-ranging questions. Key to this is the ability to generate estimates of the proportions of different food sources within the diet. By measuring the stable isotope ratios of both consumer tissues and putative food sources the combination of sources required to match the isotopic value of the consumer can be determined, and hence dietary proportions estimated. At the heart of these approaches lie the mixing models used to determine the source proportions, and the development of Isosource by Phillips & Gregg (2003) brought with it a renewed interest in the approach and removed many of the restrictions of earlier models. Isosource however is limited in its ability to incorporate variability in both source proportions and trophic discrimination factors, both parameters which are inherently variable and can severely bias model outputs. In addition the output from Isosource is particularly resistant to further analysis making the resultant data rather qualitative.

These problems are overcome by recently developed Bayesian approaches to Isotopic mixing models, which naturally incorporate these variabilities within the model and produce most-likely source proportions with associated probabilities facilitating further quantitative analysis.

Here we test these novel methods with multiple large isotopic data sets, and highlight some of the dangers of ignoring sources of variability within mixing models and the benefits of producing single metrics for further analysis. Furthermore we demonstrate how difficult datasets from which robust models cannot be created using previous approaches can be analysed within the Bayesian framework. In conclusion we propose exciting areas of potential research made accessible by these methods, and outline the roadmap for future developments.

Phillips, D. L. & Gregg, J. W. 2003. Source partitioning using stable isotopes: coping with too many sources. Oecologia 136: 261-269.

BIOGEOCHEMICAL CYCLING

COUPLED ^{13}C AND ^{15}N PATTERNS OF INDIVIDUAL AMINO ACIDS IN PROKARYOTIC VS. EUKARYOTIC PHYTOPLANKTON PRODUCTION

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Traditional $\delta^{13}C$ and $\delta^{15}N$ bulk isotopic measurements have long been used to evaluate source and transformation of marine organic matter (OM). Compound specific amino acid (AA) ^{13}C and ^{15}N measurements are a relatively new tool, which may be able to elucidate source, metabolic transformation, and extent of microbial degradation affecting marine OM. Here we present coupled $\delta^{13}C$-AA and $\delta^{15}N$-AA metabolic patterns in prokaryotic vs. eukaryotic phytoplankton biomass and excreted DOM, from a series of organisms grown in large batch culture. We also measured the AA-isotopic signatures of whole cells, cell walls and cytosol fractions, to examine whether particular cellular components have diagnostic signatures. We compare these patterns to the AA stable isotopic patterns of natural ultrafiltered-POM (UPOM) from central North Pacific and coastal California waters. We propose that changes in bulk parameters, as well as AA isotopic patterns, can be used as a proxy for the degree of degradation and trophic transfer the OM has undergone, and that comparison of specific metabolic patterns can track changes in source organisms between the coastal and oceanic ecosystems.

BIOGEOCHEMICAL CYCLING

MICROBIAL COMMUNITY NITROGEN AND CARBON CYCLING IN SUPER-INTENSIVE SHRIMP AQUACULTURE SYSTEMS

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In super-intensive, recirculating shrimp aquaculture systems (RAS) without external filtration, the microbial community is solely responsible for the removal and subsequent detoxification of nitrogenous compounds which concentrate via feed dissolution and shrimp excretion. Consequently, uptake and sequestration of ammonium by phytoplankton and heterotrophic bacteria and bacterial nitrification and denitrification are vital to shrimp health in RAS. In addition, previous studies have shown that microbial-detrital aggregates are used by the shrimp as a source of supplemental nutrition. We have conducted time-course measurements of C and N isotopes in whole and size-fractioned suspended particles, dissolved pools, and in the shrimp themselves throughout several RAS design trials to elucidate microbial N and C cycling in replicated, large scale shrimp production experiments.

Analysis of natural abundance C isotopes in size fractioned particles shows characteristically distinct signatures for bicarbonate uptake by photosynthetic and nitrifying microorganisms and for organic (feed) C use by heterotrophic microorganisms. Our results support the hypothesis that there is size-based niche partitioning for C usage in RAS exposed to ambient sunlight regardless of RAS management protocol (feeding regime, filtration method, shrimp density, etc.) Interestingly, particles in the dark treatment also showed the distinct C signatures of heterotrophic and chemoautotrophic nitrifying microorganisms but the heterotrophic signal was enriched over that of the ambient light treatment, likely resulting from C reuse and recycling in support of a highly productive bacterial community.

In all experiments, $\delta^{15}N$ of whole and size fractioned particles increased with time regardless of treatment, consistent with the uptake and incorporation of N from a pool that had also increased with time. In these RAS, nitrate is always present at concentrations several orders of magnitude greater than ammonium. However, our $\delta^{15}N$-nitrate results suggest that only in systems where bacterial denitrification was coupled to nitrification is an increase in $\delta^{15}N$ with time possible in the nitrate pool. The ammonium pool, often the preferred source of N, undergoes significant isotopic fractionation during uptake, volatilization and nitrification. Our measurements of $\delta^{15}N$-ammonium reflect this fractionation as an increase in $\delta^{15}N$-ammonium with time. There is always a concurrent decrease in the $\delta^{15}N$-nitrate with time, in fully oxygenated RAS where denitrification is not a significant process.

The use of natural abundance isotopes in these closed systems offers a time-integrated perspective on the myriad, simultaneous microbial community N and C transformations of dissolved and suspended pools and allows for the determination of the onset of important N cycle processes in RAS.

BIOGEOCHEMICAL CYCLING

ISOTOPE FRACTIONATION DURING N MINERALIZATION AND THE N ISOTOPE COMPOSITION OF TERRESTRIAL ECOSYSTEM N POOLS

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It has been an open question for several decades whether N mineralization is a fractionating process. This question is important for N cycling in terrestrial ecosystems because even a small fractionation during N mineralization could potentially have a large influence on the N isotope composition of other ecosystem N pools, since it represents the largest N flux in ecosystems. Fractionation during N mineralization should result in a difference between the N isotope composition of the soil microorganisms and that of its substrates.

We analyzed the N isotope composition of the soil microbial biomass in a variety of ecosystems, and found that it was ^{15}N enriched compared to that of other soil N pools, such as soil soluble, organic and inorganic N (Dijkstra et al. 2006a,b). We observed a negative correlation between the ^{15}N enrichment of the microorganisms and the relative C and N availability for soil from ecosystems in Hawaii and Arizona, across a broad range of climates, grasslands and forests, and more than four million years of ecosystem development. This result suggests that during N dissimilation (and associated transaminations) and N export, the lighter ^{14}N isotope is preferentially removed in a manner similar to that proposed for animals and ectomycorrhizae. This was further confirmed by the positive correlation between microbial ^{15}N enrichment and net N mineralization rate (Dijkstra et al. 2008, Ecology Letters 11: 389-397) and by culture experiments with Escherichia coli (Collins et al 2008).

Since mineralization is the largest flux of N in ecosystems, fractionation during N mineralization has the potential to influence and even determine the N isotope composition of other N pools, such as inorganic N, plant N and soil organic matter N. We will show that the N isotope composition of these ecosystem N pools exhibit differences that are consistent with fractionation during N mineralization.

Collins JG, Dijkstra P, Hart SC, Hungate BA, Flood NM, Schwartz E (2008) Nitrogen source influences natural abundance ^{15}N of Escherichia coli. FEMS Microbiol Lett 282: 246-250

Dijkstra, P, Ishizu A, Doucett RR, Hart SC, Schwartz E, Menyailo OV, Hungate BA (2006a) ^{13}C and ^{15}N natural abundances of soil microbial biomass. Soil Biol Biochem 38:3257-3266

Dijkstra, P, Menyailo OV, Doucett RR, Hart SC, Schwartz E, Hungate BA (2006b) C and N availability affects the ^{15}N natural abundance of the soil microbial biomass across a cattle manure gradient. Eur J Soil Sci 57:468-475

Dijkstra P, LaViolette CM, Coyle JS, Doucett RR, Schwartz E, Hart SC, Hungate BA (2008) ^{15}N enrichment as an integrator of the effects of C and N on microbial metabolism and ecosystem function. Ecol Lett 11: 389-397

BIOGEOCHEMICAL CYCLING

MECHANISMS FOR THE RETENTION OF BIO-AVAILABLE NITROGEN IN VOLCANIC RAINFOREST SOILS

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Old-growth forests ecosystems in southern Chile represent the largest reserve of pristine temperate rainforest in the world. These forest ecosystems maintain a high productivity of bio-available N, while simultaneously minimizing N-losses. To understand biogeochemical functioning of these ecosystems a process based insight into the responsible mechanisms is required. Moreover, this will also allow predicting potential susceptibility to changing environmental conditions.

A ^{15}N tracing study, including six labelling treatments (combinations of ^{15}N labelled NO_3^-, NH_4^+ and NO_2^-), was performed under controlled laboratory conditions. Gross N transformation rates were quantified with a ^{15}N tracing model in combination with a Markov Chain Monte Carlo optimization algorithm. In a second experimental step, the modelled N transformations were validated in the field via a ^{15}N pulse chase experiment over a one year time period. These experiments were carried out in an evergreen Nothofagus betuloides forest in Puyehue national park, southern Chile.

The results showed that this pristine rainforest could retain vast amounts of dissolved inorganic N (DIN) in the long-term (1 year). DIN immobilization reactions mainly occur into soil organic matter (SOM) or into hydrophobic dissolved organic N (DON), an organic N-pool showing a high sorption affinity. N-losses from this ecosystem were low because total nitrate production was extremely low. We found that heterotrophic nitrification (oxidation of recalcitrant organic N to nitrate) dominated (>95%) total NO_3^- production. The produced NO_3^- is reduced to NH_4^+ via dissimilatory nitrate reduction to ammonia (DNRA), making DNRA a significant NH_4^+ production pathway. Further it was indicated that hydrophilic DON losses did not originate from DIN turnover. Hydrophilic DON flows are controlled by soil dynamics that operate independent of DIN turnover. Finally, our results showed also a functional link between autotrophic NH_4^+ oxidation to NO_2^- (nitritation) and NO_2^- "detoxification" via gaseous N production and/or condensation reactions.

BIOGEOCHEMICAL CYCLING

STABLE ISOTOPES AS A TOOL TO STUDY NUTRIENT EXCHANGE BETWEEN ORCHIDS AND FUNGI

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Most plants are forming a close partnership with fungi in their rhizosphere. In this mycorrhizal symbiosis, plants usually provide their fungal partners with carbohydrates from the photosynthesis and receive mineral nutrients, which are more efficiently taken up from the soil through the fungal mycelium. This mutualistic arrangement has been subverted worldwide by a few hundreds of plant species that are free from chlorophyll and thus lack the ability to photosynthesize. This nutrition at the cost of the fungal partner is called myco-heterotrophy. The most numerous examples of this behaviour are found among the orchid family. Although chlorophyll-free orchid species are known to be myco-heterotrophic, adult green orchids have for a long time been thought to be fully autotrophic. Recent data from stable carbon and nitrogen isotope abundance analyses, however, provide evidence that some of the putatively autotrophic orchids live partially at the cost of their fungal partners (Gebauer & Meyer 2003). Specifically green-leaved representatives of the tribe Neottieae turned out to rely only partially on autotrophic nutrient gains and to use additionally the fungal nutrient source. Based on a linear two-source stable isotope mixing model the relative carbon and nitrogen gains from either of these two nutrient sources can be estimated. This kind of partial myco-heterotrophic nutrition is always associated with a change of the fungal partner from saprotrophic towards ectomycorrhizal fungi and explains how these orchids can thrive into the deepest shade of our forests (Bidartondo et al. 2004, Zimmer et al. 2007).

Recent findings from an orchid species living typically in open-land habitats and being associated with saprotrophic fungi (Goodyera repens) indicate an additional plant-to-fungus carbon transfer (Cameron et al. 2006). This plant-to-fungus carbon transfer leads obviously also to unique carbon isotope signatures (^{13}C depletion) and thus provides potentially a tool to identify in future not only a fungus-to-plant nutrient exchange, but also a nutrient transfer in the opposite direction.

Bidartondo M.I., Burghardt B., Gebauer G., Bruns T.D., Read D.J. (2004) Changing partners in the dark: isotopic and molecular evidence of ectomycorrhizal liaisons between forest orchids and trees. Proc. R. Soc. Lond. B 271:1799-1806.

Cameron D.D., Leake J.R., Read D.J. (2006) Mutualistic mycorrhiza in orchids: evidence from plant-fungus carbon and nitrogen transfers in the green-leaved terrestrial orchid Goodyera repens. New Phytol. 171:405-416.

Gebauer G., Meyer M. (2003) 15N and 13C natural abundance of autotrophic and myco-heterotrophic orchids provides insight into nitrogen and carbon gains from fungal association. New Phytol. 160:209-223.

Zimmer K., Hynson N.A., Gebauer G., Allen E.B., Allen M.F., Read D.J. (2007) Wide geographic and ecological distribution of nitrogen and carbon gains from fungi in pyroloids and monotropoids (Ericaceae) and in orchids. New Phytol. 175:166-175.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

PHYSIOLOGICAL RESPONSES TO FERTILIZATION RECORDED IN TREE RINGS: ISOTOPIC LESSONS FROM A LONG-TERM FERTILIZATION TRIAL

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Nitrogen fertilizer applications are common land-use management tools, but details on physiological responses to these applications are often lacking, particularly for long-term responses over decades of forest management. We used tree-ring growth patterns and stable isotopes to understanding long-term physiological responses to fertilization using a controlled fertilization experiment begun in 1964 in which 3 levels of nitrogen fertilizer were applied: 157, 314 and 471 kg/ha. Because the site was nitrogen limited, basal area increment (BAI) increased over 4 fold in the highest treatment to 2 fold in the lowest, and a significant increase in BAI was observed for 20 years. Latewood $\Delta^{13}C$ sharply decreased by 1.4 ‰ after fertilization and was significantly lower than controls for 4 years, but no differences existed between fertilization levels, and the effect disappeared after 4 years indicating that intrinsic water-use efficiency (A/g_s) increased in response to fertilization. Earlywood $\Delta^{13}C$ showed similar trends, but was more variable. Latewood $\delta^{18}O$ increased significantly above controls by approximately 2‰ in all treatments, but the duration differed with treatment level, with the effect being longer for higher levels of fertilization, and lasting as long as 9 years after fertilization. Because source water and relative humidity were the same between experimental plots, we interpreted the $\delta^{18}O$ increase with treatment as a decrease in leaf-level transpiration. Earlywood $\delta^{18}O$ did not show any treatment effects. Because the Pacific Northwest has a Mediterranean climate with dry summers, we speculated that fertilization caused a substantial increase in leaf area, causing the trees to transpire themselves into drought stress during the late summer. We estimate from the $\delta^{18}O$ data that stomatal conductance (g_s) was reduced by approximately 30%. Using the $\Delta^{13}C$ data to estimate assimilation rates (A), A during the late season was also reduced by 20-30%. If leaf-level A decreased, but BAI increased, we estimated that leaf area must have increased by 4 fold with the highest level of treatment within this stand. This increase in leaf area resulting from fertilization caused a hydraulic imbalance within the trees that lasted as long as nine years after treatment at the highest levels of fertilization.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

VARIABILITY AND COHERENCE AMONG DISTANT SITES IN OXYGEN AND CARBON STABLE ISOTOPE RATIOS FROM TREE RING CELLULOSE OF SEQUOIA SEMPERVIRENS, COAST REDWOOD: LINKS TO CLIMATE AND ECOLOGICAL CHANGE

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Fog water is an important hydrologic input for redwood (Sequoia sempevirens) trees and forests and is isotopically distinct (more enriched in heavy H and O) from winter rainfall. The utilization of this resource in summer when it is the only water source for plants may depend on climatic factors such as changes in sea surface temperature, coast-inland temperature differences and precipitation abundance in winter. Increment cores from 3-5 redwood trees collected at 4 sites were cross-dated and $\delta^{18}O$ and $\delta^{13}C$ of □-cellulose extracted from subdivided annual rings was measured. Trees from southern sites had latewood cellulose over 4‰ more enriched in ^{18}O than trees from northern sites. Inter-annual variation in latewood cellulose $\delta^{18}O$ ranged between 2.3 and 3.5‰ across all sites for the 45+ years analyzed. Correlations of latewood $\delta^{18}O$ variation between sites were greatest for those in close proximity to each other (r as high as 0.84 for sites 40 km apart). However, some distant sites also showed substantial coherence (r = 0.43 for sites 380 km apart). In general, cellulose obtained from the center of the ring (middlewood) was more depleted in ^{18}O than latewood and is likely to reflect the use of winter precipitation water in middlewood cellulose and some amount of fog water for latewood. We observed significant correlations between sites for both middlewood $\delta^{18}O$ (r as high as 0.64) and the difference between latewood and middlewood $\delta^{18}O$ (r as high as 0.65). Significant between-site correlations were also observed for the inter-annual variation in $\delta^{13}C$ of cellulose for both latewood and middlewood ring segments. These data indicate that inter-annual variation in tree ring $\delta^{18}O$ and $\delta^{13}C$ is coherent across much of the redwood forest range and that the C and O stable isotope ratios in these tree rings are capturing a common environmental signal as well as a physiological response in the trees. Detailed climate record and physiological analyses performed at the same sites and on the same trees show that this tree ring "archive" provides valuable information about the coastal hydrologic regime, climate cycles and tree response for this understudied ecosystem.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

CHANGES IN NEAR SHORE FOOD WEB DYNAMICS OVER THE LAST 4500 YEARS, PENOBSCOT BAY, GULF OF MAINE

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Historically, the Gulf of Maine (GOM) has been one of the world's most productive marine ecosystems. Today, however, Atlantic cod (Gadus morhua) and other large-bodied ground fish are relatively rare in the coastal zones of the GOM. This decrease in apex predator abundance is thought to result from overfishing initiated by the first European settlers and has resulted in an increase in the abundance of prey species. Here, we present the faunal distribution and the carbon and nitrogen isotope composition of selected fish and marine mammal bone from archaeological middens located in Penobscot Bay, GOM, which spans the last 4500 years (Bourque et al., 2008). These data provide long term records of fishing practices and food web dynamics in the GOM prior to and through the arrival of western Europeans on the Maine coast.

Between 4300 and 400 years ago, the relative abundance of apex predators (particularly cod) decreased significantly, while the relative abundance of mesopredators increased significantly. These trends are thought to reflect a loss of apex predators due to the fishing practices of the first humans that occupied the region. Between 4300 and 1300 years ago, the carbon isotope composition of fish collagen remained relatively stable, with an average $\delta^{13}C$ value of -12.8 ± 1.3‰ (n = 12) for cod, -10.0 ± 1.0‰ (n = 9) for flounder, and -10.6 ± 1.6‰ (n = 6) for sculpin. The consistent $\delta^{13}C$ values over time imply a stability in food web dynamics despite the fishing practices of the first human settlers. Between 1300 years ago and today, the $\delta^{13}C$ value of cod, flounder and sculpin decreased by several permil, and converged to a common value of approximately -18‰. This more recent isotopic shift may represent a major change in food web dynamics and reduction in biodiversity which appears to have coincided with the arrival of the first European settlers.

Additional analyses are currently underway to verify the interpretations of this study, including (1) carbon isotope analysis of individual amino acids to corroborate the bulk collagen data, and (2) analysis of additional samples from key periods in time to corroborate the timing and magnitude of change.

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RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

THE MARINE LIFE OF ATLANTIC SALMON: ISOTOPIC DETERMINATION

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The wild Atlantic salmon has been in severe decline since the early 1970s. Most mortality is thought to occur in the marine stages of the life history, but the key reasons for this are unclear. The difficulty and expense of tracking and monitoring salmon at sea are prohibitive, making indirect methods of study invaluable. Fish scales contain chemical records of diet and migration in both the collagen and apatite components, and, unlike commonly used tissues such as muscle or otoliths, can be obtained without sacrificing the fish. The isotopic composition of carbon and nitrogen in fish tissues can potentially provide information on the trophic level and nutritional status of the fish and the state of primary production at feeding sites. We are using the isotopic composition of collagen in scales of Atlantic salmon from historical archives to investigate whether changes in ocean conditions correlate with periods of high or low marine mortality. Scale archives dating back decades, traditionally used for salmon ageing studies, exist around Europe, and may be used to analyse long-term changes in populations.

Variability within and between fish and cohorts of both farmed and wild fish has been determined. Inter-fish variation is low, permitting the use of single scales for analysis; similarly variation of fish within a single cohort is significantly lower than variation between years, indicating that scales record real temporal ecological data. Initial results demonstrate that nitrogen isotopes successfully distinguish between individuals with differing nutritional status, and also record differences between years and cohorts. Carbon and nitrogen results also suggest potential relationships between the state of primary production and marine mortality, but more data are needed to test whether these apparent correlations are true and widespread. Here we present results from 2 contemporaneous, multi-decadal archives from English rivers. Both archives display large, systematic fluctuations in both C and N isotope composition, but the magnitude and timing of these fluctuations are not consistent between archives, indicating a complex, population-specific relationship between ocean productivity, migration and fish survival.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

USING $\delta^{13}C$ AND $\delta^{15}N$ OF ZOOPLANKTON FOSSIL EXOSKELETONS FOR RETROSPECTIVE ECOLOGICAL STUDIES : CHANGES IN PLANKTONIC FOOD WEB DURING 150 YEARS OF HUMAN PERTURBATIONS ON LAKE ANNECY (FRANCE)

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Chitin, which constitutes arthropod exoskeleton, is a biochemical component preserved in the fossil material and unaltered by diagenetic processes. Hence, chitinous zooplankton exoskeletons, essentially from Cladocera, are recovered in lake sediments. It has been early established that the isotope composition of arthropods' chitin reflects that of their diet[1,2], hence providing a framework for using SIA analyses on cladoceran sub-fossil remains to document past changes in planktonic food webs. Surprisingly, there were only a handful of previous attempts so far.

To illustrate the potentialities of SIA of zooplankton subfossil exoskeletons, we conducted a paleo-ecological study on Lake Annecy from sediment cores covering the last 150 years.

Lake Annecy underwent three major anthropogenic perturbations for that period of time:

1. Introduction of whitefish (*Coregonus lavaretus*), a zooplanktivorous salmonid in the late XIXth century,
2. Moderate eutrophication, that peaked during the 60's,
3. Re-oligotrophication in a context of climate warming.

All these perturbations might have strongly altered lake planktonic food web.

Analyses of Cladoceran sub-fossil remains revealed that perturbations interacted, triggering strong responses from Cladoceran community structure. $\delta^{13}C$ measures of sediment and cladoceran sub-fossil exoskeletons showed that organic carbon sources to the pelagic food chain were affected by perturbations, with an increasing contribution of autochthonous carbon during eutrophication. Analyses of $\delta^{15}N$ values in sub-fossils and sediment showed that changes in zooplankton community structure came along with substantial changes in cladoceran trophic position in the food chain. From the paired use of sub-fossil remains analyses and SIA, we figured out a conceptual model of the response of the planktonic food web to 150 years of human perturbations on Lake Annecy. SIA performed on sub-fossil exoskeletons opens promising perspectives to retrospectively study long-term impacts of perturbations on aquatic food webs.

[1]De Niro, M. J. and S. Epstein (1978). "Influence of the diet on the distribution of carbon isotopes in animals." Geochimica and Cosmochimica Acta 42: 495-506.
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RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

FROM RIVER HORSES TO SEA COWS: USING STABLE ISOTOPES IN TOOTH ENAMEL TO IDENTIFY SEMI-AQUATIC MAMMALS IN THE FOSSIL RECORD

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Large-bodied, semi-aquatic herbivorous mammals have been a recurring component of most terrestrial ecosystems throughout the Cenozoic. Identification of these species in the fossil record has largely been based on the morphological similarities with present-day hippopotamids, leading to the designation of this pairing of body type and ecological niche as the hippo ecomorph. However, these morphological characters may not always be diagnostic of aquatic habits. Here, we examine the stable isotope composition of tooth enamel carbonate ($\delta^{18}O_{CO3}$) from several purported hippo ecomorphs to define the ecological preferences of these taxa. These hippo ecomorphs belong to three separate clades: 1) the Anthracotheriidae (Bothriogenys) from the early Oligocene of Egypt; 2) the Proboscidea (Moeritherium, Palaeomastodon and Phiomia) from Eocene and Oligocene deposits in Egypt; and 3) the Rhinocerotidae (Amynodontopsis and Teleoceras) from Eocene and Miocene deposits in North America. Using a linear regression developed from published hippo oxygen isotope data, we evaluate the semi-aquatic preferences for taxa from each of these groups and then combine these results with dietary evidence from enamel $\delta^{13}C$ values to reconstruct the aquatic habits and foraging preferences of each.

Enamel $\delta^{18}O$ values support the occurrence of hippo ecomorphs within the Anthracotheriidae and the Proboscidea, but not the Rhinocerotidae. Only fossil specimens of Moeritherium and Bothriogenys had $\delta^{18}O$ values within the expected range for hippo ecomorphs. Moeritherium and Bothriogenys were sympatric taxa from the Fayum region of Egypt that were both spending a significant amount of time in freshwater habitats. However, enamel $\delta^{13}C$ values for Bothriogenys were significantly lower than those for Moeritherium, which suggests that the diet of Bothriogenys may have consisted of more vegetation from aquatic or denser, forested ecosystems, while Moeritherium may have favored vegetation growing under more open or stressed environmental conditions. Neither rhinocerotid had mean $\delta^{18}O$ values indicative of aquatic habits. Enamel $\delta^{13}C$ values for Amynodontopsis were similar to those for Moeritherium and suggested a preference for vegetation growing under similar conditions, whereas those for Teleoceras varied significantly with geographic location, which suggests it was able to forage on vegetation growing under diverse environmental conditions. These results show that stable isotope analysis of fossil tooth enamel can provide a viable means of testing ecological inferences based on morphological evidence.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

VARIATION IN THE FORAGING ECOLOGY OF A CONTENTIOUS PISCIVOROUS PREDATOR

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The cormorant (*Phalacrocorax carbo carbo*) is a piscivorous predator which is currently the focus of much concern and debate regarding its impact on freshwater fisheries. Here, we use stable isotope analysis to examine various aspects of the foraging ecology of the cormorant and to examine conflict with freshwater fisheries.

Both in the UK and further afield in Europe, initial perceived conflicts reflected the impact of cormorants overwintering at and feeding in inland freshwater habitats. Although the cormorant population of Northern Ireland is comparatively small (2000 breeding individuals), there is evidence that they have significant impacts on economically important freshwater fish populations, including Lough Neagh, and the world-renowned River Bush fishery.

The current management of the River Bush includes the extensive culling of cormorants during the Atlantic salmon smolt run, a practice that remains extremely contentious with some groups. Stable isotope analysis of culled individuals revealed $\delta^{13}C$ values ranging from -14.03 to -33.46‰ and a bimodal distribution of $\delta^{13}C$ values with peaks at -17 and -27‰, indicating distinct marine and freshwater foraging strategies. Variation in long term and short term diet was revealed by different $\delta^{13}C$ values of liver (-27.79‰) and feather (-24.43‰), indicating increased assimilation of freshwater prey in the weeks of the smolt run and suggesting that the cormorants were continuing to exploit this seasonally abundant food source.

Increasingly cormorant colonies in Britain and Europe are shifting inland to breed, and consequently there is now the potential for conflict with freshwater fisheries throughout the year. There are no known inland breeding colonies currently in Northern Ireland: however, dietary analysis at a coastal breeding colony revealed that the birds were flying 70km inland to feed on pollan (*Coregonus autumnalis*), an economically and conservationally important species from Lough Neagh, which made up a third of the diet. This foraging migration represents a doubling of the maximum foraging distance previously reported for breeding cormorants. Although there are clear economic impacts, this also raises the question of why adult cormorants make this long and energetically-expensive migration, when adjacent marine habitats support apparently abundant fish stocks. Stable isotope analysis of cormorant chicks revealed a significant relationship between chick condition and the extent to which they are provisioned with freshwater fish (R^2=0.2, p=0.02). We hypothesize that birds which forage primarily on freshwater prey, and exploit the predictable pollan population in Lough Neagh, gain an adaptive advantage in terms of growth of their chicks and possibly their breeding success, despite the increased distance travelled.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

DETECTING ANTHROPOGENIC CONTAMINATION IN CORAL REEFS USING STABLE ISOTOPES OF HOLOTHURIANS

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The dynamics of carbon and nitrogen flow through the benthic sea cucumber *Holothuria leucospilota* (holothurian) has been investigated during a comprehensive ecological study of the La Saline lagoon (Reunion Island, Indian Ocean), which is partly fringed by a coral reef. Holothurians represent a major group of benthic invertebrates found in the reef system in terms of biomass and sediment reworking activity. Holothurians can ingest and excrete up to 82 kg of dry sediment.m^{-2}.$year^{-1}$ and may thus play a key role in the regulation of microphytobenthic communities, and in organic matter remobilisation for the benthic food web. However, little is known about holothurian feeding strategies and trophic position in coral reef systems.

The reef has an area of 12km^2 and is strongly influenced by both oceanic and terrestrial inputs, with marked annual changes on the reef's production due to allochthonous nutrient input. Stable carbon isotope analysis ($\delta^{13}C$) of holothurian tissue, sediment and water particulate organic matter (POM) suggest a uniform isotopic composition of *H. leucospilota*, even though seasonal variations in $\delta^{13}C$ of sediment and POM are observed. Our results support findings that *H. leucospilota* which feeds on sediment, is selective in its food choice and adaptive to temporal changes.

$\delta^{13}C$ and $\delta^{15}N$ values of *H. leucospilota* tissue were determined at 9 sites along a north-south trending eutrophication gradient. Specimens sampled from near shore sites influenced by terrestrial inputs were more enriched in $\delta^{15}N$ ($\delta^{15}N$ of 6.4-6.5‰) compared to sites supplied by fresh sea water ($\delta^{15}N$ of 4.7-5.4‰). The same specimens were also more depleted in ^{13}C ($\delta^{13}C$ = -6.7‰) compared to sampling sites which tend to be influenced by underground sea water plumes ($\delta^{13}C$ = -9.9‰). Results suggest that *H. leucospilota* is a suitable species for identifying biological assimilation of anthropogenic derived organic matter. POM and sediment from the reef complex did not record anthropogenic isotopic signals as effectively as holothurians, possibly due to factors such as strong tidal currents and/or organic production/consumption by primary producers.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

FEEDING INTERACTIONS OF CYPRINID FISHES IN IRISH LAKES

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Eutrophication and the arrival of invasive species have combined to alter the ecology of Ireland's freshwater ecosystems. This study assessed the feeding interaction of the three most common cyprinid fish taxa (bream (*Abramis brama, L.*), roach (*Rutilus rutilus, L.*) and roachXbream hybrids) in Ireland. Although non-native, the bream and the roach have been present in Ireland for over 100 years and are now naturalised in the freshwater fauna. Hybridization between roach and bream has been documented wherever both species are present, however hybrids are not usually found in large numbers. Ireland has a unique situation where hybrids are abundant, often outnumbering both parental species. In spite of this few studies have been carried out in Ireland to assess the interactions of these three taxa. In fact, the present study is the first to analyse the diet and trophic position of the roachXbream hybrid and assess the likely impact of its feeding habits on both parental species. Furthermore, by comparing dietary overlap in eutrophic and non-eutrophic conditions it was possible, to identify the impact of eutrophication on the diet of cyprinid fish in Ireland.

Sampling was carried over two years in four lakes (two eutrophic and two non-eutrophic). Each taxon was divided into three size classes representing small, medium and large fish. Where possible, twenty fish in each size class were sampled. Carbon and nitrogen isotope analyses were used to identify the trophic position of the various size class of each taxon. Invertebrate sampling was also carried out to determine food availability and provide an isotopic baseline references for the stable isotope study. Gut content analysis was used to support the stable isotope results.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

SULFUR BIOGEOCHEMISTRY IN AGRICULTURAL AND NATURAL WETLANDS: LINKING FOOD WEBS TO SEDIMENT AND WATER-COLUMN PROCESSES

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We sought to better understand the biogeochemistry of sulfur (S) in agricultural and natural wetlands in the Yolo Bypass, an area near Sacramento, CA that is used for flood control as well as seasonal habitat for fish and wildlife, particularly waterfowl. The work is part of a larger study focused on mercury cycling. Sulfur is known to play a central role in the methylation of mercury, a contaminant that is subject to biomagnification in food webs. A more detailed understanding of S transformations and fluxes through the biogeochemical compartments of aquatic ecosystems will provide insight into the pathways related to the trophic transfer of methyl-mercury. Traditional geochemical and isotopic measurements of sulfur species in the Yolo wetlands were made over an annual hydro-sequence. Contrasts between natural and agricultural wetlands (white and wild rice, fallow fields) allowed us to evaluate the influence of water management, soil disturbance, and fertilizer application.

Relationships were evident between surface water and pore-water sulfur geochemistry, suggesting that significant interaction occurred between overlying water and sediments, particularly in agricultural wetlands. Decreases in the sulfate to chloride ratio over time indicated the disappearance of sulfate from the water column following flood-up, consistent with bacterial sulfate reduction (BSR). Additionally, increases in sedimentary sulfides (mineral phase) occurred for all wetlands during the same timeframe, with concomitant isotopic enrichments ($\delta^{34}S$) in residual surface water and pore-water sulfate. BSR rates, estimated using ^{35}S radiotracer, varied seasonally in response to changes in hydroperiod and were highest in the natural permanent wetland. The larger isotopic enrichments and lower BSR rates in agricultural wetlands compared to the natural wetland appeared to be related to water depth, which was greater in the permanent wetland and likely reduced surface water-sediment interactions. During dry-down on agricultural wetlands, decreases in $\delta^{34}S$ of surface water sulfate suggest a flux of re-oxidized sulfide (secondary sulfate) from the sediments, further emphasizing the importance of hydroperiod as a control on the surface water sulfate pool. Sulfur isotope analyses of wetland consumer tissues are pending completion and these data will allow connections to be made between benthic and water-column processes and consumer organisms. Additionally, these data will build on our current geochemical understanding of the sulfur cycle, leading to a better understanding of nutrient flow through aquatic food webs, particularly as it relates to linking food webs to nutrient sources, biogeochemical processes, and the cycling of mercury.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

THE USE OF STABLE ISOTOPES AS TRACERS OF TROPHIC RESPONSE TO AN ENVIRONMENTAL FLOW IN THE REGULATED LOWER GWYDIR WETLANDS OF NSW, AUSTRALIA

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The Lower Gwydir wetlands are among the most extensive and significant terminal wetlands in north-western NSW, Australia. They provide important habitat for water plant communities, nekton and waterbirds, and perform important ecosystem functions. Upstream water resource development in the form of flow regulation and diversion for irrigation purposes has changed the flooding regime into these wetlands, and is suspected to have influenced trophic connectivity and ecosystem functionality.

A sampling programme was initiated to understand the trophic functionality of wetlands under different environmental flow conditions. Carbon and nitrogen stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) were measured in a variety of plant, invertebrate and fish species collected from the Gingham Watercourse, one of the channels in the Lower Gwydir wetland system. Initial observations found more depleted $\delta^{13}C$ and $\delta^{15}N$ values in larger fish species such as *Nematalosa erebi* (bony bream), *Leiopotherapon unicolour* (spangled perch) and the introduced *Cyprinus carpio* (European carp) after an environmental flow release compared to samples collected prior to the flow. This trophic shift indicates that larger fish species access different food items after an environmental flow release. Stable carbon isotope signatures for the macro-crustaceans *Macrobrachium australiense* (freshwater prawn) and *Cherax destructor* (yabby) did not change in samples collected before and after environmental flow. The variation of signatures among phyla implies that the effect of environmental flow on aquatic food chains may not be uniform among different trophic components.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

NITROGEN CYCLING IN AN UPLAND FOREST STREAM IN PANAMA BEFORE AND AFTER THE DECLINE OF THE DOMINANT AMPHIBIAN COMMUNITY

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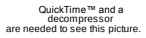
Amphibians can be important consumers in tropical streams where amphibian diversity and abundance are high. Understanding the ecological role of amphibians provides insight into the consequences of declining biodiversity. We used a $^{15}NH_4$ tracer addition in a Panamanian upland stream to quantify nitrogen uptake and turnover rates of consumers and natural isotope abundance to examine food web relationships and carbon sources among macroinvertebrates and tadpoles. While their proportional intake of nitrogen was large, tadpoles had relatively slow turnover rates. Grazing by tadpoles appeared to increase levels of N and of ^{15}N in autochthonous basal resources. Dramatic declines in tadpole abundance occurred during our study as a result of an epidemic disease caused by a chytrid fungus, with concomitant changes in relative abundance of macroinvertebrate species. Studies of amphibian declines generally focus on identifying causes and documenting patterns, but we know little of the ecological consequences of their declines. Our study suggests that amphibian declines may change N cycling in tropical streams.

POSTER PRESENTATIONS



ISOSCAPES: Spatiotemporal Distribution of Isotopes

CARBON, NITROGEN, OXYGEN, AND FATTY ACID HYDROGEN ISOTOPE ANALYSES OF POLISHED RICE FOR VERIFYING ITS GEOGRAPHICAL ORIGIN.

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In Japan, packaged polished rice requires labels indicating cultivar, cultivation area, and year of production in accordance with the Japanese Agricultural Standard (JAS) Law. Nevertheless, there is no simple analytical method to trace the cultivation area, and this leads to rice authenticity problems such as mislabelling and addition of inferior quality rice. Recently, stable isotope analysis has become an important tool to solve food authenticity problems (Kelly et al., 2005). For example, carbon isotopic composition of plant materials strongly depends on carbon fixation processes such as the C_3 or C_4 cycle, and thus useful in discriminating stock origin from their diet. Nitrogen isotopic composition is mainly influenced by soil nutrition, and oxygen isotopic composition mainly by local groundwater. For these reasons, characteristics of isotopic compositions have been used to investigate authenticity of rice (Kelly et al., 2002, Suzuki et al., 2008).

In this study, we determined stable carbon, nitrogen, and oxygen isotopic compositions ($\delta^{13}C$, $\delta^{15}N$ and $\delta^{18}O$) of polished rice from Australia (n=16), Japan (n=36) and USA (n=9) in order to develop a simple method to discriminate its geographical origin. The isotopic compositions of all rice samples were within the range of general plant materials: $\delta^{13}C$ being −27.1 to −25.3‰; $\delta^{15}N$, +0.0 to +6.1‰; and $\delta^{18}O$, +19.9 to +37.3‰. Australian rice was characterized by higher nitrogen isotopic compositions ranging from +4.9 to +6.1‰. US rice showed relatively higher carbon isotopic composition (-26.1 to –25.3‰) than Australian (-27.3 to –26.2‰) and Japanese rice (-27.7 to –26.1‰). As for oxygen isotopic composition, Australian rice showed particularly higher values (+33.3 to +37.3‰). Thus, the comparison of carbon, nitrogen, and oxygen isotopic compositions would potentially be useful for rapid and routine discrimination of geographical origin of polished rice.

We also determined compound-specific hydrogen isotopic compositions (δD) of fatty acids (C16:0, C18:1 and C18:2) for Japanese polished rice (n=12) to trace its cultivation area within Japan. A wide difference in δD values of fatty acids was observed between the northern (-213‰) and southern (-167‰) samples. The δD of fatty acids would thus be probably useful in discriminating geographical origin of polished rice within Japan.

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Suzuki, Y., Chikaraishi, Y., Ogawa, N. O., Ohkouchi, N., Korenaga, T., (2008). Geographical origin of polished rice based on multiple element and stable isotope analyses. *Food Chemistry* 109 (2008) 470–475.

ISOSCAPES: Spatiotemporal Distribution of Isotopes

GEOGRAPHICAL ORIGIN OF BEEF BASED ON BULK CARBON, NITROGEN, OXYGEN AND FATTY ACID HYDROGEN ISOTOPE ANALYSES

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Food industry has been expanding globally and consumer can obtain various food materials from all over the world. The circulation requires a valid traceability system to ensure the safety and high quality of food. In particular, the trade of cattle products such as beef and dairy products needs to be strictly controlled due to concerns relating to BSE (bovine spongiform encephalopathy) and FMD (foot-and-mouth disease). Some simple analytical method to trace cattle products is required to resolve these food authenticity problems. As one of these methods, multi-stable isotope analyses have become an important tool to provide information on the provenance of foods (Kelly et al., 2005). In general, stable carbon and nitrogen isotopic compositions ($\delta^{13}C$ and $\delta^{15}N$) of animal tissue reflect those of their diet. On the other hand, stable hydrogen and oxygen isotopic compositions (δD and $\delta^{18}O$) of animal materials (e.g. lipid, tissue water, hair and urine) reflect those of drinking water. Multi-stable isotope analysis would therefore be a useful tool to trace geographical origins of beef (Förste, 2007 and Heaton et al., 2008).

In this study, we determined bulk carbon, nitrogen, and oxygen isotope compositions of beef from Australia, Japan, and USA, in order to confirm the method as a potential tool for verifying geographical origin of beef commercially distributed in Japan. US beef is characterized by higher $\delta^{13}C$ values (-13.6 to -11.1‰) than Japanese (-19.6 to -17.0‰) and Australian beef (-23.6 to -18.7‰), which is due to the different proportion of C_3 plants (e.g. clover) and C_4 plants (e.g. maize) in diet. Australian beef is characterized by higher $\delta^{18}O$ values (+15.0 to +19.4‰) than Japanese (+7.3 to +13.6‰) and US beef (+9.5 to +11.7‰), probably due to the difference of $\delta^{18}O$ values in the drinking water. These results suggest that a comparison of carbon, nitrogen, and oxygen isotopic compositions is applicable as a potential tool to discriminate the provenance of beef between different countries (i.e. Australia, Japan, and USA).

Moreover, we determined compound-specific hydrogen isotopic compositions (δD) of fatty acids (C16:0, C18:1 and C18:2) in Japanese beef to discriminate its geographical location within Japan. A large variation in the δD values of fatty acids was observed between the northern (-251‰) and southern sites (-210‰) in Japan. The δD values of fatty acids tended to decrease with increasing latitude. Thus, the δD variation of fatty acids would probably be useful for discriminating provenance of beef among different regions within Japan.

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TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

COMBINED STABLE CARBON ISOTOPE AND C/N RATIOS AS INDICATORS OF SOURCE AND FATE OF ORGANIC MATTER IN A TROPICAL RIVER ESTUARY

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Stable carbon isotope and C/N ratios of particulate organic matter (POM) were used to define the spatial and temporal variability in a tropical river estuary, the Bangpakong River Estuary. POM samples were taken along the river and salinity gradients during the four different river discharges; the beginning, high river discharge and at the end of the wet season, and low river discharge during the dry season. The values of $[C/N]_a$ and $\delta^{13}C$ revealed significant differences from those of the offshore station. Conservative behaviors of $[C/N]_a$ and $\delta^{13}C$ in the estuary during the wet season indicated major contribution of terrigenous C_3 plants derived OM. By contrast, during the dry season, marine input mainly dominated OM contribution with an evidence of anthropogenic input to the estuary. Compositions of POM were dominated by rice paddy soil and marine derived OM during the wet and dry seasons, respectively. These results elucidate that stable carbon isotope and C/N ratios can be combined to indicate the source and fate of OM in a tropical aquatic ecosystem.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

THE USE OF STABLE ISOTOPES $\delta^{13}C$ AND $\delta^{15}N$ AS TRACERS OF THE SOURCE AND FATE OF ENERGY IN A DYNAMICAL COASTAL AREA LOCATED AT THE TEMPERATE TROPICAL TRANSITIONAL ZONE (BCS, MÉXICO).

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Recent studies have shown the importance of the stable isotopes as a tool to identify transfer of N and C from the base of the food web to top predators and their variability (e.g. different oceanographic areas). In the present study we aim to track this variability in a very dynamic region located at the west coast of Baja California Peninsula in the Pacific Ocean. The area is a transitional zone between the temperate and tropical zone and is therefore known as the Temperate Tropical Transitional Zone (TTTZ). It is also the southern limit of the California current. During spring there is strong upwelling in the area, which induces a high phytoplankton productivity and in turn high biological secondary production. The area is also one of the most important conservation areas in Mexico due to the presence of sea turtles, whales and other sea mammals. A population of more than 4000 sea lions (*Zalophus californianus*) is sustained in this area, even in the months when the upwelling events are less strong and continuous. Also it has been reported a production of more than 300 x 10^3 tons of the red crab (*Pleuroncodes planipes*) during the spring season. Four campaigns were made along the study area in order to collect samples of water, phytoplankton, sediment, and organisms collected with towing net. We decide to use demersal fishes as a monitor of the variability of the area mainly due its presence and abundance independent of the season. Using stomach content from demersal fishes we found that the red crab is very important in the diet for this group of fishes. When we compared the abundance and dominance of this group of fishes during the two different seasons we found that just few remain in the warmer season. Using stable isotopes of N and C we found some variability in the $\delta^{15}N$ and $\delta^{13}C$ signature of the top predators but the benthic-pelagic fishes formed a compact group difficult to separate between seasons. These results suggest that there is a pool of nitrogen that is present in the area, which is independent of the oceanographic variability of the TTTZ. The high presence and abundance of the red crab in the stomach contents suggest that these organisms could play a key role on the transfer of energy in this area.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

TRACING TERRESTRIAL AND AQUATIC ORGANIC MATTER SOURCES IN THE COLORADO RIVER FOOD WEB USING STABLE ISOTOPES OF HYDROGEN (DD).

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Evaluating the importance of terrestrial and aquatic energy sources to river food webs is central to understanding stream ecosystem theory. Currently, there is no universally reliable technique for elucidating source importance in lotic food webs. In some cases, stable isotopes of carbon ($\delta^{13}C$) are sufficiently different between terrestrial organic matter (allochthonous) and algae (autochthonous) to trace their relative contribution in aquatic food webs using mixing models. In others, however, δ13C values do not differ sufficiently between leaves and algae, or variation is too high among end members to allow mixing models to work. In these situations, stable isotopes of hydrogen (δD) may be useful since previous data has shown that allochthonous organic matter (OM) is uniformly more enriched (ca. 100 per mil) in δD than autochthonous OM (Doucett et al. 2007).

Here, we used δD to examine the relative importance of aquatic and terrestrial sources of OM to consumers in the Colorado River, Grand Canyon, Arizona. Our data showed that, at Glen Canyon Dam where transport of OM from the upriver watershed is drastically reduced, autochthonous OM contributed greatly to the foodbase, but this importance decreased at downstream sites as tributary-derived inputs of terrestrial OM began to dominate the organic matter budget. Following the monsoon season, which contributes even more terrestrial OM to the mainstem river, allochthonous inputs appeared to become even more important at downstream sites, as dD values of consumers were enriched relative to those measured pre-monsoon.

Doucett, RR, JC Marks, DW Blinn, M Caron, and BA Hungate (2007) Measuring terrestrial subsidies to aquatic food webs using stable isotopes of hydrogen. Ecology 88:1587-1592

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

GRAVITY MATTERS: HOW HABITAT STRUCTURE INFLUENCES FOOD-WEB STRUCTURE

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A predictive understanding of food-web dynamics requires knowing how these networks are compartmentalized into distinct energy channels, and how these compartments are coupled in space. A large literature on cross-habitat spatial subsidies has addressed this issue at the landscape scale, but we know little about how energy channels are linked at smaller spatial scales, within what are traditionally considered single habitats. Here we use stable isotopic analyses of plant and animal tissues to reconstruct the small-animal food web of a wooded grassland in Kenya. Insect herbivores in this system tended to be relatively specialized consumers of either C_3 (trees and shrubs) or C_4 (grasses) plants. Arboreal predators, both arthropods and a common gecko, were also specialized, deriving ~90% of their diet from C_3-feeding herbivores. In contrast, ground-dwelling predators preyed equally upon C_3- and C_4-feeding herbivores. This asymmetry suggests a gravity-driven subsidy of the terrestrial predator community, whereby tree-dwelling herbivores frequently fall or are dislodged from trees and contribute substantially to the energy budget of ground-dwelling predators. Prey subsidies from high to low components of vertically structured habitats have received relatively little attention; we suggest that they are likely to be both common and important to food-web function.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEM

BINGEING ON BYCATCH IN BAJA: ANTHROPOGENIC MARINE SUBSIDIES AND POSSIBLE TROPHIC CASCADES

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Ecological perturbations (e.g., disease, land-use change, weather) can mediate food web dynamics by affecting external control on the abundance or behavior of species that interact with other trophic levels (e.g., plants, herbivores, predators). These can alter the importance of top-down and bottom-up regulators of plant and animal populations. The transfer of marine nutrients to coastal areas from discarded catch by fisherman (bycatch) is an unstudied but potentially widespread form of perturbation that may impact coastal terrestrial ecosystems. On Isla Magdalena (Baja California Sur, Mexico) abundant bycatch (fish, marine mammals, sea turtles) from local artisanal fisheries washes up on the beach each summer. This seasonal pulse of marine nutrients likely subsidizes a high density of top predators (coyotes, Canis latrans) that could not be supported by in situ prey alone. Cross-habitat nutrient exchange is a widespread phenomenon of natural systems, but effects of subsidized predators on top-down trophic dynamics are not well understood in general, let alone in relatively simple ecosystems where predators range over large areas and are subsidized only seasonally.

We conducted an isotopic survey of the Isla Magdalena ecosystem to identify potential pathways of anthropogenically derived marine subsidies into the terrestrial foodweb. Dietary data from scat content and isotopic analysis show that the island coyote population consumes a wide variety of terrestrial and marine resources, however, anthropogenic marine subsidies are a major dietary component and probably the reason coyote densities are exceptionally high the summer months. Isotopic data from beach-inland transects suggest that marine subsidies are only consumed by coyotes and thus top-down effects of elevated predator densities on lower trophic levels are likely. Plant isotopic values generally segregate along taxonomic lines and do not deviate from expectations based on data from other arid systems. Mean $\delta^{15}N$ values for C4 plants range from 0‰ for N-fixing grasses to 12‰ for chenopods, while mean $\delta^{15}N$ values for C3 plants are ~6-8‰. The patchy distribution of plant types at relatively small spatial scales (<0.3km^2) on the island produce isotopically distinct, local C3-C4 gradients that are reflected in tissues of granivorous rodents (Chaetodipus arenarius and Neotoma lepida). Our ongoing study of this system aims to (1) assess the direct effect of seasonal subsidies on island coyote diet, densities, and movement patterns; (2) assess the impact of subsidized predators on prey population dynamics; (3) evaluate the indirect influence of predators on plant communities via estimating the direct impacts of prey populations on plant growth.

TRANSFER OF ENERGY/NUTRIENTS AMONG DISPARATE ECOSYSTEMS

RESOURCE PARTITIONING AMONG INSECTIVOROUS BATS: INSIGHTS FROM STABLE ISOTOPE ANALYSIS

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Sympatric animal species frequently differ in resource use; a mechanism by which these species may be able to co-exist. Understanding whether a pattern of niche differentiation is the result of ongoing competition or whether the outcome of divergent evolutionary histories is still open to debate. Insectivorous bats are one of the most speciose group of mammals, often living and foraging within the same areas and therefore potentially they provide a very interesting model to test theories relating to resource partitioning. Morphologically bats are very similar, however discrete differences of body size and wing morphology coupled with notable differences in their echolocation calls, have previously been related to microhabitat use.

The objective of this research was two-fold. First, to determine whether niche width varies at the community level as a function of competition (4 sites with varying habitat diversity, bat diversity and bat abundance) and second, at a finer-scale, to show whether neighbouring colonies of soprano pipistrelle bats (*Pipistrellus pygmaeus*) exhibit roost-specific foraging patterns. Stable isotope analysis was used as an ecological tool in this study to understand the foraging ecology of each bat species, with community-wide metrics (Layman et al., 2007) used to quantify the niche space occupied by each bat and invertebrate prey community.

The results of this research present compelling evidence that the extent and nature of resource partitioning varies between sites. We discuss competition, caused by either changes in resource availability or bat competition, as a primary mechanism. Moreover, we show that individuals of soprano pipistelle have colony specific foraging ecologies, and contend that this provides evidence of a foraging role for group living in insectivorous bats.

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METHODS IN ISOTOPE ECOLOGY

SEAWEED OR BIOFILM? EXPERIMENTAL APPROACHES TO EXAMINE THE DIET OF *PATELLA VULGATA* USING STABLE ISOTOPES.

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The intertidal limpet, Patella vulgata, has a profound effect on the structure of rocky shore communities in the northeast Atlantic. This keystone grazer forages across the shore and is generally considered to feed predominantly on the epilithic biofilms which coat intertidal rock surfaces. However, stable isotope analyses of foot tissue from mid-tidal limpets and biofilms revealed inconsistencies with this hypothesis: $\delta^{13}C$ values of limpet tissues were 3 to 4 ‰ higher than $\delta^{13}C$ values for biofilms but within the range of those obtained for intertidal seaweeds (macroalgae). These somewhat surprising results required validation, so a series of mensurative and manipulative experiments were proposed.

The first experiment used a manipulative approach to test the hypothesis that individual limpets, experimentally restricted to a diet of epilithic biofilm, would have lower carbon isotope values than those free to forage naturally. Animals were enclosed in mesh cages on bare rock for a period of six months, after which time their isotope ratios were compared with those of limpets from areas immediately adjacent to the cages. The results showed significantly lower $\delta^{13}C$ values in caged animals, compared with those of animals free to forage on both biofilm and macroalgal materials. This was consistent with the proposed hypothesis.

The second experiment used a mensurative approach to determine whether the diet of P. vulgata is affected by food availability. Limpets were sampled from three naturally contrasting habitat types and their isotope ratios compared. Significant differences between the habitats were observed: animals from bare, rocky areas had similar $\delta^{13}C$ values to those of epilithic films; animals from macroalgal habitats had similar $\delta^{13}C$ values to those of macroalgae. The carbon isotope values of limpets from barnacle-dominated areas were equivalent to those of animals from macroalgal habitats, suggesting these animals have access to macroalgal foods.

This work demonstrates the effectiveness of experimental isotope approaches to examine feeding in P. vulgata and shows that limpet diets are variable; animals from different habitat types exploit different food resources. The hypothesis that P. vulgata, feeds predominantly on epilithic biofilms must be rejected as stable isotope evidence strongly indicates seaweeds are often an important dietary component.

METHODS IN ISOTOPE ECOLOGY

EFFECTS OF TEMPERATURE AND DIET QUALITY ON CARBON AND NITROGEN STABLE ISOTOPE FRACTIONATION IN AN OMNIVOROUS FISH

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Variation in carbon and nitrogen fractionation has been observed among species and tissues types. This has led to calls for experiments on study species to determine fractionation instead of applying standard fractionation values to field data. There have also been calls to investigate factors causing variation in fractionation, such as temperature and diet. Temperature and diet are potentially two of the major causes of temporal and spatial variation in carbon and nitrogen fractionation of wild animals. Fractionation by omnivorous species is poorly understood and has the potential to be highly variable but very useful for ecosystem studies, as omnivores tend to eat whatever is available. Omnivores can adapt readily to changes in food abundance, making them some of the more successful and widespread species and ideal to use for ecosystem studies over larger temporal and spatial scales. However, as omnivore diets can be highly variable through space and time their fractionation may also be highly variable and confound results. To investigate the effects of temperature and diet quality on fractionation in an omnivorous fish, we reared black bream (Acanthopagrus butcheri) at two temperatures, 16°C and 24°C to represent local summer and winter conditions, and fed them two diets of varying quality. One feed was based on vegetable protein, considered to be a low quality diet, and the other was based on fish protein, a higher quality diet. Fish were sacrificed at the beginning of the experiment and on days 7, 14, 28 and 42 to quantify tissue turnover rates. Fish were reared in replicate tanks for each temperature, diet and sacrificial time combination. Differences in fractionation by black bream muscle were found between temperatures and diets, with a gradual change over time. Results from this experiment will be applied to future field collections across a range of different types of estuaries in summer and winter, with the aim of improving results of relative contribution of autotrophic sources to black bream diets.

METHODS IN ISOTOPE ECOLOGY

A STABLE ISOTOPE APPROACH TO IMPROVE CALCULATIONS OF CONSUMER-RESOURCE NUTRIENT IMBALANCES

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Stoichiometric theory predicts that the nutritional quality of a food resource can constrain the growth of the consumer when resource's elemental content does not match the consumer's nutritional demand (1, 2). Potential growth limitations arising from nutrient deficient food are generally evaluated by calculating consumer-resource imbalances as the arithmetic difference between the elemental composition of a consumer and its ingested food (3). For freshwater benthic macroinvertebrates, the ingested food is mostly inferred from the affiliation of the consumer to a functional feeding group (FFG), e.g. periphyton if the consumer is classified as a grazer. However, stable isotope studies have revealed that even consumers with a single food resource, according to their FFG affiliation, often assimilate nutrients from more than a single food resource (4). Thus, elemental imbalances can be misleading if they do not consider the elemental composition of the ingested food as a weighted combination of the elemental compositions of the individual food resources. Here, we present a straightforward method to calculate the elemental composition of a food mixture based on the contribution of food resources to the diet as inferred from stable isotope and mixing model analysis and the elemental composition of each individual food resource. By comparing the stable isotope approach with the FFG approach, we show to which extent the FFG approach over- or underestimates consumer-resource imbalances and demonstrate that stable isotope analyses can be successfully applied to complement stoichiometric analyses.

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METHODS IN ISOTOPE ECOLOGY

THE EFFECT OF LIPID-EXTRACTION ON HIGH LIPID-CONTENT NOTOTHENIOID (ANTI-FREEZE) FISH FROM THE ROSS SEA, ANTARCTICA.

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Ross Sea fish are dominated by a single family, the notothenioids, which comprise half of Antarctic marine fish species and 95% of all fish biomass in the region. Notothenioids characteristically lack swim bladders and the majority of species are benthic or demersal. However, a depth-related diversification has given rise to some species attaining increased buoyancy by concentrating lipid deposits in tissues and reducing skeletal mineralisation: examples being Antarctic toothfish ((Dissostichus mawsoni), Patagonian toothfish (Dissostichus eleginoides), Antarctic silverfish (Pleuragramma antarticum), and icefish (Chionobathyscus dewitti). Antarctic toothfish are particularly lipid-rich with about 10% of their body mass derived from lipids. These lipid-rich species can pose problems to trophic studies when trying to obtain reliable $\delta^{15}N$ and $\delta^{13}C$ values through stable isotope analysis. In order to establish complete lipid removal from samples analysed during a trophic study of the Ross Sea ecosystem without producing artefacts in the $\delta^{15}N$ and $\delta^{13}C$ values we carried out extensive experimental analyses on a series of internal laboratory fish standards. We used a combination of fish that we knew to be lipid-rich (Antarctic toothfish) and two Ross Sea fish that had lower lipid content: Whitson's Grenadier (Macrourus whitsoni) and icefish (Chionobathyscus dewitti). We present $\delta^{15}N$ and $\delta^{13}C$ data from these standards which underwent three types of sample preparation: no lipid extraction, single lipid-extraction and double lipid-extraction and discuss the implications of these results for other studies analysing high lipid-content materials.

METHODS IN ISOTOPE ECOLOGY

MODELING ISOTOPE INCORPORATION: ONE- OR MANY COMPARTMENTS AND DOES IT MATTER?

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Understanding rates of isotopic incorporation and discrimination factors between tissues and diet is an important focus of ecologists seeking to use stable isotopes to track temporal changes in diet. We used a diet-shift experiment to measure differences among tissues in ^{13}C incorporation rates in house sparrows (*Passer domesticus*). We assessed whether isotopic incorporation data were better described by the one-compartment models most commonly used by ecologists or by multi-compartment models. Our analyses are based on a novel extension of Cerling et al.'s (2007. Oecologia 15: 175-189) reaction progress variable. Our method allows 1) estimating average retention times, 2) the standard error of these values, and 3) finding out whether the data supports models that include one or more compartments. We found large differences in the residence time of ^{13}C among tissues, and splanchnic tissues had faster rates of isotopic incorporation and thus shorter retention times than structural tissues. We found that one-compartment models supported isotopic incorporation data better in some tissues. However, data in other tissues supported two-compartment models. More importantly, the inferences that we derived from the two types of models differed. Two-compartment models estimated longer ^{13}C residence times, and smaller tissue to diet differences in isotopic composition than one-compartment models. Our study highlights the importance of considering both one and multi-compartment models when interpreting laboratory and field isotopic incorporation studies. It also emphasizes the opportunities that measuring several tissues with contrasting isotopic residence times offer to elucidate animal diets at different time scales.

METHODS IN ISOTOPE ECOLOGY

FISH MUCUS AS A RAPID RESPONDING TISSUE IN DIET SWITCHING STUDIES

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We are using stable isotopes of C, N, O and S (H planned) to study the ecology of coho salmon in streams of the Oregon Coast Range. One aspect of our work focuses on the incorporation of marine-derived nutrients into the diet of overwintering coho salmon juveniles. These studies are complicated by the short time window of coho spawner returns relative to the time required for muscle tissues to show an isotopic response during periods of slow growth.

To investigate fish mucus as a potentially more rapidly responding "tissue," we performed diet switching studies of steelhead trout in a controlled hatchery setting using diets formulated to have either low $\delta^{15}N$ (3‰) or high $\delta^{15}N$ (13‰). Our work to date indicates that mucus responds significantly more rapidly than muscle tissue at growth rates approaching the most rapid we see in wild coho in our Coast Range streams. In contrast, rates of changes in mucus closely parallel those in muscle at hatchery growth rates well beyond what we see in the wild. In non-feeding fish, the composition (percent C, percent N) of mucus changes markedly within 1-2 days, as do $\delta^{13}C$ and $\delta^{15}N$, which both show immediate declines. In ongoing work we are examining rates of change of $\delta^{13}C$ and $\delta^{15}N$ of mucus in slowly growing fish.

Fish mucus composition probably is controlled by synthesis from both recently ingested food and recycled amino acids from tissue breakdown, with the relative contributions changing depending on nutritional status. Analysis of mucus in wild fish populations, for both elemental composition and stable isotopes, holds promise as a valuable tool in discerning ebbs and flows in nutritional status and diet sources over ranges of highly variable seasonal conditions.

METHODS IN ISOTOPE ECOLOGY

MULTI-ISOTOPE ANALYSIS OF ANIMAL TISSUE IN LIPID-CONTAINING AND LIPID-FREE MATERIAL

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Stable isotope analyses of animal tissue for ecological studies has preferentially used de-lipidised material. As there are largely unknown differences in isotopic signatures from species to species between lipid versus lipid-free material, we took the opportunity to quantify those variations from samples in two current projects at GNS Science. The one study was to discriminate provenancing of deer velvet and the other to investigate changes in spawning runs of New Zealand trout. In each study, the samples were divided into 2 subsets, fatted and defatted, and were analysed for $\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$, δD, and $\delta^{34}S$ values. We examined whether defatting materials in these two applications had significant effect on the data and interpretation, and the extent to which isotope signals differed between fatted/defatted samples.

We present results from our preliminary study which lays the groundwork for a large database that will link currently published data with the new data comparing lipid and lipid-free paired samples.

METHODS IN ISOTOPE ECOLOGY

ISOTOPIC TURN-OVER IN CLAW TISSUE OF A LONG-DISTANCE MIGRATORY THRUSH (*CATHARUS BICKNELLI*): IMPLICATIONS FOR CONSERVATION AND STUDIES OF MIGRATORY CONNECTIVITY.

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Precipitous population declines in many passerine species that migrate long distances has focused attention on connections between breeding and non-breeding areas (migratory connectivity). Calibrating stable isotopic turnover and integration times in dynamic avian tissues is essential if they are to be used as a tool in migratory connectivity studies. Claws are metabolically inert, keratinous tissues that grow continuously and can be sampled at any point in the annual cycle to provide potentially useful clues about an individual's previous movement. However, variation in the rate at which claws incorporate local δD values is not well described.

We examined stable-hydrogen isotope (δD) turnover in claws of a threatened Neotropical migrant, *Catharus bicknelli*. We sampled claws from individual *C. bicknelli* during the breeding season in 2007 (June-August) in New Brunswick and Vermont. Claws integrated locally expected hydrogen values through the breeding season at a measurable rate. From this data, we inferred a rate of turn-over for this tissue and made connections between specific breeding individuals and their non-breeding altitude of origin. The non-breeding range of *C. bicknelli* is restricted to a narrow band of latitude on Hispaniola. Therefore, the variation in δD values we expected in claws of birds captured early in the breeding season would represent growth at different elevations in the non-breeding period. We found that δD values of claws collected on arrival to the breeding ground showed that individuals spent the non-breeding period at different elevations. This has implications for conservation, as low-elevation sites on Hispaniola are under pressure from human populations.

METHODS IN ISOTOPE ECOLOGY

SHIFTS IN STOMATAL CONTROL OF PHOTOSYNTHESIS IN RESPONSE TO REGIONAL CLIMATE CHANGE: EVIDENCE FROM TREE RING $\delta^{13}C$ AND $\delta^{18}O$ OF *CALLITRIS COLUMELLARIS*.

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We examined relationships between stable carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) in tree rings of *Callitris columellaris F. Muell* in the semi-arid and subtropical Pilbara region of north-western Australia. We hypothesized that stomatal control of photosynthesis would decrease during drier periods. To test our hypothesis we developed $\delta^{13}C$ and $\delta^{18}O$ chronologies spanning 1919-1999. We then used a permutation regression approach to relate a 21-yr running correlation between $\delta^{13}C$ and $\delta^{18}O$ to rainfall and temperature at Marble Bar and our study site. The relationship between $\delta^{13}C$ and $\delta^{18}O$ switched from being always negative before 1955 to being consistently positive after 1976, suggesting an increase in stomatal control of photosynthesis in recent decades. Changes in the $\delta^{13}C$-$\delta^{18}O$ relation reflect changes in rainfall, which has increased in the region by 30% since 1976. The correlation between $\delta^{13}C$ and $\delta^{18}O$ was positively related to the 21-year running mean of normalized rainfall anomalies at both the study site ($P = 0.045$, Adj. $r^2 = 0.47$) and Marble Bar ($P = 0.046$, Adj. $r^2 = 0.48$). In addition, the $\delta^{13}C$-$\delta^{18}O$ correlation was negatively related ($P = 0.047$, Adj. $r^2 = 0.61$) to temperatures at Marble Bar. Our interpretation of the role of changes in climate affecting the relationship between tree-ring $\delta^{13}C$ and $\delta^{18}O$ is supported by additional evidence from the isotope composition of foliage samples: foliar $\delta\ ^{13}C$ and $\delta\ ^{18}O$ were negatively correlated with log stomatal conductance ($\delta^{13}C$, $r = -0.41$; $\delta^{18}O$, $r = -0.42$), while the correlation between foliar $\delta^{13}C$ and $\delta^{18}O$ was positive ($r = 0.63$, $P = 0.027$) after the summer-wet period. Our study suggests that stomatal control of photosynthesis in *Callitris* adjusts to region-wide changes in climate and that, in a warmer and drier world, trees might adapt by increasing non-stomatal control of photosynthesis.

METHODS IN ISOTOPE ECOLOGY

SHARKS VS. THE REST OF THE WORLD: LIPID EXTRACTION AND STABLE ISOTOPES

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Advancement of the application of stable isotopes of carbon and nitrogen to interpret trophic relationships in marine ecology requires a thorough understanding of complicating factors such as tissue specific lipid content and the baseline effects of the lipid extraction process on the species in question. Accepting that lipid content within a species' muscle tissue may be highly variable depending on factors such as size, sexual maturity, condition and season of sampling, lipid extraction is now regarded as a standard practice to remove ^{13}C depleted lipids. This enables a level of standardisation when examining multiple species within an ecosystem. This study consequently aimed to examine the effects of lipid extraction on $\delta^{13}C$ and $\delta^{15}N$ of muscle tissue of two shark species, the dusky shark, *Carcharhinus obscurus*, and the scalloped hammerhead shark, *Sphyrna lewini*, sampled from beach protection nets in South Africa. Lipid extraction of muscle tissue led to a small but significant positive shift in $\delta^{13}C$ for S. lewini (n=19) but no significant difference was detected between lipid extracted and bulk muscle tissue for C. obscurus (n=38). In contrast with the current literature for teleosts and crustaceans, a significant negative shift in $\delta^{15}N$ values was observed for both species of shark. Furthermore, a linear regression fitted to the difference in $\delta^{15}N$ between lipid extracted and bulk samples vs. the bulk C:N ratio was not significant for either species suggesting no effect of increasing lipid content on the variation in extracted $\delta^{15}N$ values. The negative shift in $\delta^{15}N$ between bulk and lipid extracted tissue was the same for both *S. lewini* and *C. obscurus*. Hence an arithmetic correction equation was derived and proved appropriate for the correction of $\delta^{15}N$ values when tested both on our data and data available from the literature. Clearly from the two species of shark examined, inter and intra variability in lipid content exists as would be expected and thus there is a requirement to undertake standardised lipid extraction procedures to obtain reliable $\delta^{13}C$ isotopic values. To enable an accurate and valid interpretation of the trophodynamics of shark species, it will be necessary to correct under-estimated lipid extracted $\delta^{15}N$ isotopic values.

METHODS IN ISOTOPE ECOLOGY

CALIBRATING ISOTOPIC METHODS TO STUDY SHARK ECOLOGY

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Superorder Selachimorpha (sharks) is globally distributed, with 100s of species ranging from shallow tropical oceans to deep arctic waters. Sharks play key roles as top predators in many ecosystems. Traditional methods (gut analysis, tagging) offer crucial snapshots into individuals' lives, but gathering data integrated over large spatial and temporal scales is difficult. Stable isotope analysis (SIA) offers data on diet, migration, and habitat preferences on a range of spatial and temporal scales. A crucial step in the application of SIA is calibration on animals in experimental or controlled settings. Commonly accepted fractionation factors and tissue turnover rates are calculated from terrestrial mammals, birds, and teleost fish. Phylogenetically, sharks are more primitive than teleosts, with a unique physiology that includes osmoregulation using urea. Thus the assumption that fractionation factors and turnover rates measured on teleosts, mammals, or birds apply to sharks may not be valid. We will calculate diet-to-tissue fractionation factors and turnover rates through an experiment on leopard sharks (Triakis semifasciata). We switched the diets of sharks between two isotopically distinct foods to assess turnover for plasma, red blood cells (RBC), muscle, and tooth protein. Preliminary results suggest that sharks have fractionation factors similar to mammalian carnivores and turnover rates an order of magnitude less than homoeothermic animals. These results are the first robust diet-to-tissue fractionation factors and tissue turnover rates calculated for elasmobranches. There are a growing number of studies applying SIA to shark tissues in order to elucidate aspects of life history that are difficult to study using traditional methods.

METHODS IN ISOTOPE ECOLOGY

EFFECTS OF SEASONALITY AND ONTOGENY ON THE ORGANIC $\delta^{18}O$ AND δD OF RODENT TISSUE

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Seasonal variation affects weather patterns, rainfall quantity, vegetation growth and distribution, and animal fertility and survival. Because of its interrelation with these variables, seasonality is a significant concern in both ecological and archaeological research.

Stable oxygen ($\delta^{18}O$) and hydrogen (δD) isotopes are known to reflect the seasonal variation of meteoric water intake and dietary inputs. However, the magnitude of the seasonal signal captured by different tissues of ecological and archaeological significance has not been fully established. In addition, the effects of organism age and body size on tissue $\delta^{18}O$ and δD remain unexplored.

We examine the oxygen ($\delta^{18}O$) and hydrogen (δD) stable isotopes the bone, fat, and hair of rats raised on a controlled diet and drinking local water. The rats were of two age classes, post-weanling and mature, and from two different hydrological regions having dissimilar amounts of seasonal variation in meteoric water isotopic values.

Our study indicates that seasonal variation drinking water isotopic values is reflected in the isotopic composition of bone, hair, and fat. This signal appears to be significantly dampened by the constant and identical isotopic composition of the food consumed by the two regional rat populations, suggesting that food is the predominant contributor to organic $\delta^{18}O$ and δD. Consistent ontogenetic effects were not detected in bone or hair, but do appear to manifest in fat $\delta^{18}O$. Our study indicates that seasonal variation in ingesta is more isotopically significant than ontogenetic effects in the tissues examined.

METHODS IN ISOTOPE ECOLOGY

USING ISOTOPES IN TROPICAL MACROFAUNA: IS SAMPLE ACIDIFICATION REQUIRED?

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Food web studies now frequently rely on stable isotope analyses. Tropical ecosystems and more particularly soft-bottoms from coral reef areas still require more extensive studies on this theme. Among these systems, invertebrate benthic fauna, often used as monitoring tool for ecological assessment, are sometime considered for their isotopic composition. However standard procedures for sample processing are required. Many tropical benthic invertebrates are small in size, and therefore body tissue isolation (separating organic carbon from inorganic structures) is difficult and time consuming. The usual case is to consider analyzing whole individuals for carbon and nitrogen analysis. Acidification of samples for more accurate determination of $\delta^{13}C$ and $\delta^{15}N$ is recommended by several authors but can alter nitrogen content. Here, we investigate the effects of carbonate removal via acidification on the stable carbon and nitrogen isotopic composition of 33 species of tropical benthic macrofauna. We report guidelines for standardizing this procedure for higher taxa in tropical coral reef ecosystems. We find that acidification decreases the $\delta^{13}C$ of high-carbonate samples, with shifts ranging from 0.21 to 3.20‰, which can be related to $CaCO_3$ content. Therefore acid pre-treatment is necessary for these taxa. High-carbonate taxa benefiting from acidification included Amphinomida, Terebellida (Annelida); Anomura, Brachyura, Caridea, Amphipoda, Tanaidacea (Arthropoda); Edwardsiida (Cnidaria). The $\delta^{13}C$ shifts of low-carbonate samples only varied up to 0.37‰. As the induced $\delta^{13}C$ shift was lower than the range of an average trophic level shift (0.5 to 1‰), we conclude that acid pre-treatment of these low-carbonate samples is unnecessary. Low-carbonate taxa consisted of Eunicida and Phyllodocida (Annelida) and Mollusca. We note minimal impact of acidification on $\delta^{15}N$ values except for Brachyura, which showed a shift of 0.83 ± 0.46‰, but still inferior to the mean split between two trophic levels (3.4-3.8‰). We conclude that for trophic level studies, both $\delta^{13}C$ and $\delta^{15}N$ of high carbonate containing macrofauna can be determined from the same acidified sample.

METHODS IN ISOTOPE ECOLOGY

USING ^{15}N TO TRACK TISSUE CATABOLISM DURING HIBERNATION IN AN EXTREME ARCTIC HIBERNATOR, *SPERMOPHILUS PARRYII*

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Arctic ground squirrels (*Spermophilus parryii*) are small hibernators in the extreme arctic environment. For most hibernating mammals, hibernation is a period of very low metabolic expenditure, and metabolic needs are met through burning lipid reserves. However, hibernating S. parryii experience temperatures so extreme that they must burn fuel to keep from freezing, and that fuel increasingly includes glucose as the temperatures drop below 0°C. Glucose is provided through the catalysis of tissue protein and gluconeogenesis; thus, S. parryi can lose 20-30% of their lean mass during hibernation in the field. However, it is not known which tissues are drawn on for protein catabolism, and whether the source of lean mass for gluconeogenesis changes over the duration of hibernation. Changes in stable nitrogen isotope ratios can reflect protein metabolism during fasting, and thus may be useful to elucidate the source of lean mass catabolised during hibernation.

Ambient hibernation temperatures of -10°C invoke an 8-fold increase in metabolic rate during torpor and a shift toward metabolism of glucose and amino acids. We maintained S. parryii hibernating in captivity in two thermal regimes, -10°C and 2°C, and sacrificed animals at the beginning of hibernation (control) and after 45, 68, and 90 days of hibernation (N=5 squirrels for each treatment and time point). We measured nitrogen isotope ratios in a suite of tissues, including heart, liver, small intestine, brown adipose tissue, quadriceps muscle, gastrocnemius muscle, scapular muscle, and peritoneal muscle, as well as blood plasma and red blood cells.

Heart, liver, small intestine, and brown adipose tissue showed similar trends in ^{15}N enrichment: all enriched significantly during the first 40 days of hibernation, and by day 68, animals at -10ºC were enriched relative to the +2ºC animals. In contrast, samples from four different skeletal muscles all showed little change over the first 40 days of hibernation, and a slight enrichment in -10ºC squirrels by day 68. Unexpectedly, all 4 muscle types showed a sudden increase in δ^{15}N in +2ºC animals relative to -10ºC animals between days 68 and 90, suggesting that skeletal muscle was particularly targeted for mobilization at the end of hibernation in this group. These patterns suggest a distinctly different pattern of protein mobilization for organs (early hibernation) and skeletal muscle (late hibernation), and suggest that the mobilization scheme differs for animals under differing thermal stress. Plasma δ^{15}N increased strikingly during the first 40 days of hibernation but changed little thereafter, and red blood cell δ^{15}N was constant, as red blood cells are no longer synthesized once animals enter hibernation. Urine analyses from the experimental animals are underway.

The importance of the annual lean mass cycle in *S. parryii* is not well understood, but may play a critical role in overwinter survival in this extreme environment. This study indicates that the sources of mobilized protein change both with hibernation duration and with the severity of environmental conditions. Paired with field measurements of thermal regime, lean mass loss, and isotope enrichment, we hope to arrive at a more complete

understanding of protein catabolism and its physiological impact on these extreme hibernators.

METHODS IN ISOTOPE ECOLOGY

EFFECTS OF LIPID EXTRACTION ON $\delta^{13}C$, $\delta^{15}N$ AND $\delta^{34}S$ IN AVIAN EGG YOLK

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Many studies investigating nutrient allocation to egg production in birds use stable isotope ratios of egg yolk to identify the origin of nutrients. Dry egg yolk contains >50% lipids, which are known to be depleted in ^{13}C. Currently, researchers remove lipids from egg yolk using a chemical lipid extraction procedure before analyzing the isotopic composition of protein in egg yolk. We examined the effects of chemical lipid extraction on $\delta^{13}C$, $\delta^{15}N$ and $\delta^{34}S$ of avian egg yolk, and explored the utility of an arithmetic lipid-normalization model to control for lipid content in whole yolk samples. We analyzed the dried yolk of 15 spectacled eider and 20 king eider eggs both in the original form, and following lipid extraction with a 2:1 chloroform:methanol solution. We found that chemical lipid extraction leads to an increase of 3.3‰ in $\delta^{13}C$, 1.1‰ in $\delta^{15}N$ and 2.3‰ in $\delta^{34}S$. The arithmetic correction provided accurate values of lipid-normalized $\delta^{13}C$ for captive spectacled eiders fed on a homogenous high-quality diet. It may lead to inaccurate results for wild migratory birds, which can accumulate macronutrients during migration and transfer macronutrients between isotopically distinct environments.

METHODS IN ISOTOPE ECOLOGY

A STUDY ON FEEDING HABIT OF ASIATIC BLACK BEAR BY NITROGEN ISOTOPE ANALYSIS OF AMINO ACIDS

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Stable isotope analysis is widely used to study feeding habit of wildlife. Although bulk analyses using hair and blood still predominate, it is becoming possible to reveal nitrogen isotopic composition of amino acids by GCC-IRMS. The composition in animal tissue is influenced by those of food and amino acid metabolism. This indicates that we can obtain more information about animal ecology by analyzing not only the bulk samples but also the amino acid stable isotopic compositions. We examined the feeding habit of Asiatic black bear by measuring both the nitrogen isotopic compositions of bulk and amino acids. First, bulk samples and amino acids (Phenylalanine (Phe) and Glutamic acid (Glu)) of serum were analyzed in three captive bears which had been reared on controlled diet (corn). Compared to food isotopic composition, the bulk ^{15}N in the serum was enriched by 4.8‰, and the composition of Phe by 2.8‰ and Glu by 9.3‰. The $\delta^{15}N$ value of Phe and Glu in the diet showed no significant difference, but those of bears differed by 6‰. Phe, which strongly reflects the $\delta^{15}N$ of food, is one of the essential amino acids, while Gul is one of the non-essential amino acids, the high $\delta^{15}N$ of which is influenced not only by food but also by metabolic process. We can therefore regard that $\delta^{15}N$ value of Phe retains the information of primary producer, and that the difference between Phe and Glu provide us information on feeding habit. We applied this method to six wild bears (three captured near a fish farm) in Central Japan Alps, Nagano, in order to examine their feeding habit. Two bears captured near the fish farm showed higher $\delta^{15}N$ difference between Phe and Glu than that of the rest, which indicates that these two bears consumed considerable amount of rainbow trout at the fish farm. It was shown that nitrogen isotope analysis of amino acid would be a useful tool for feeding study of animals.

METHODS IN ISOTOPE ECOLOGY

DIFFERENTIAL ISOTOPIC TURNOVER (C AND N) DETECTED IN ANTARCTIC SCAVENGER AMPHIPODS

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Metabolic activity is positively related to temperature, inversely to body mass and is a function of taxon specific life style features, in particular activity such as level of active movement. Therefore, the isotope signal transfer velocity is expected to be lower in cold environments and in larger as well as less active organisms.

Our study explores whether this may be a problem in trophic studies of a comparatively “slow” because cold system such as the high Antarctic shelf ecosystem and in comparatively large organisms such as benthic amphipod species within this system.

We compare experimentally the velocity of stable isotope signal transfer from prey to consumer in three lysianassoid amphipods, *Waldeckia obesa, Abyssorchomene plebs* and *Pseudorchomene coatsi*. They have similar alimentation, but different size and lifestyle. Indeed, W. obesa is a very sedentary species spending most of the time immobilized on diverse substrates whereas *P. coatsi* is very motile, swimming rapidly around the aquarium. The third species, *A. plebs* has an intermediate behaviour, sharing time between short swim and resting on bottom. Those species also differ significantly in size: and are good representative of scavenger trophic guild on Antarctic shelf.

After being starved, amphipods were kept by species and fed ad libitum with lyophilized fish during fifty days. Individuals were sacrificed weekly for isotopic analysis. At the end of the 7-week incubation with standardized food, rank correlation of $\delta^{13}C$ and $\delta^{15}N$ against time did not show any consistent trend for *A. plebs* ($\delta^{13}C$: $p = 0.51$ and $\delta^{15}N$ $p = 0.04$) neither for the species *W. obesa* ($\delta^{13}C$: $p = 0.77$ and $\delta^{15}N$ $p = 0.26$). By contrast, for *P. coatsi*, rank correlations were highly significant ($p < 0.0001$). The linear regression illustrated a clear increase of isotopic ratios all along the experiment. This metabolic discrepancy between species is probably a size-mass effect. Furthermore, for this species, ANCOVA of the individually measured isotopic ratios first transformed to an offset value (rate vs carbon ↔ nitrogen, covariate time) provided evidence for significant effects of the parameter “isotope” on isotopic temporal evolution. Indeed, the $\delta^{13}C$ values evolve much faster than the $\delta^{15}N$ ones. According to data, it would take double time for *P. coatsi* to balance its nitrogen isotopic signature than its carbon isotopic ratio when changing food. Those results are critically discussed.

METHODS IN ISOTOPE ECOLOGY

MODELING $\delta^{13}C$ DYNAMICS IN SOFT TISSUES AND CALCIFIED STRUCTURES OF AQUATIC ORGANISMS IN THE CONTEXT OF THE DYNAMIC ENERGY BUDGET (DEB) THEORY

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Calcified structures such as bivalve shells and fish otoliths contain isotopic clues about environmental conditions at the time of their formation. Carbon isotopic composition ($\delta^{13}C$) of shell and otolith carbonates can yield useful information on past CO_2 levels, upwelling events, mixing of waters or productivity issues. However, this carbon proxy is not routinely used, as the relative contribution of the two different carbon sources - water dissolved inorganic carbon (DIC) and respired CO_2 derived from food - remains uncertain. In order to properly reconstruct environmental conditions and individual life traits from $\delta^{13}C$ signatures of calcified structures, it is of primary importance to understand and characterize the relative influence of the metabolic and environmental carbon sources throughout the life cycle of an individual.

In the present work, we investigate the effects of metabolism and environmental conditions on the $\delta^{13}C$ signatures of soft tissues and calcified structures from a modeling perspective. A set of hypotheses is developed based on the Dynamic Energy Budget (DEB) theory. This general theory describes the uptake and use of energy and matter by an organism to achieve growth, maintenance, development and reproduction. By extending this theoretical framework to $\delta^{13}C$ dynamics, the proposed model states the joint dynamics of carbon fluxes and associated $\delta^{13}C$ values during growth and turn-over processes as functions of environmental conditions and metabolic parameters (fractionation during assimilation, growth and turn-over processes). Resulting respiration flux and inorganic carbon intake are quantified and as a straightforward by-product, the $\delta^{13}C$ value of the calcified structure is derived as a weighted contribution of the respiration and DIC fluxes. We apply the model to the whitefish (Coregonus lavaretus) of Lake Annecy, France. Different realistic environmental scenarios involving seasonal variations of temperature, food density, food $\delta^{13}C$ and DIC $\delta^{13}C$ values are tested. To our knowledge, this is the first model that couples bioenergetic processes and isotope dynamics in a deterministic way, throughout the life cycle of an individual.

METHODS IN ISOTOPE ECOLOGY

COMBINING STABLE ISOTOPE ANALYSIS AND CENSUS DATA CORRELATIONS TO COMPARE METRICS OF DETRITUS BASED FOOD WEBS IN DIFFERENT ENVIRONMENTAL CONTEXTS.

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The analysis of food web patterns in different environmental contexts is a challenging topic to explain community stability with obvious implications for conservation of natural ecosystems. To test some hypotheses about food web structure (e.g. occurrence of constant connectance, short chain length, importance of rare species and weak interaction strength) we compared the patterns of three-trophic detritus-based food webs in very different ecosystems: a lake, a lagoon, a corn field and a beech forest, using manipulative field experiments. Stable isotope approaches have been proven useful in understanding trophic relationships but results are not always clear. Conventional analyses of trophic preferences show biases, so multiple approaches are often required to construct realistic food web structures. In this study, we combined the stable isotope analysis (SIA) and the correlation matrix analysis based on the occurrence of positive correlations between the population densities of predator-prey or parasite-host species. Since positive correlations can occur also between mutualistic species, results were corrected with the $\delta^{15}N$ values. When the difference of $\delta^{15}N$ between two species was about 3‰, a link predator-prey was assigned. In this way, we described 42 food webs (20 were terrestrial and 22 aquatic) composed by 13-25 invertebrate detritivore and predator taxa. To remove trivial interactions, comparisons between complete and partial webs, obtained by progressively deleting either weak interactions or rare species, have been performed.

About 30% of positive interactions have been removed from each web after $\delta^{15}N$ data correction. Globally, differences in the web complexity among the different contexts were observed, but some patterns recurred. The number of total links was related to the number of species while the number of links per species was scale-independent. By contrast, the mean chain length, connectance, intra-habitat compartmentation, and mean interaction strength were scale-dependent, and connectance x species was ≈4. Food webs with a higher connectance were less stable (i.e. eigenvalues departed from zero) than the others, due to an increase of the mean interaction strength. After deleting weak interactions, the cybernetic parameters did not change significantly and remained scale-dependent, while the connectance of aquatic food webs increased with respect to the terrestrial ones. The combination of stable isotope analysis with correlative matrix analysis has resulted as a fertile approach to food web studies that confirms the scale invariant hypothesis on the entire data set but not on the data set of each single ecosystem.

METHODS IN STABLE ISOTOPE ECOLOGY

CONTINUOUS ISOTOPIC CO_2 MEASUREMENTS BY WAVELENGTH-SCANNED CAVITY RING DOWN SPECTROSCOPY: STUDIES OF EXCHANGE PROCESSES IN TERRESTRIAL ECOSYSTEMS

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Understanding the interdependencies of sources and sinks within ecosystems and validating models of such systems greatly benefits from fast, continuous, in situ measurements of not only CO_2 concentration, but also isotopic carbon abundances in CO_2. Such high frequency (<5 minute) isotopic measurements help validate carbon transport models of terrestrial ecosystems and are key to developing an overall understanding of the dynamics influencing global atmospheric carbon budget. By utilizing high time resolution instrumentation based on Wavelength-Scanned Cavity Ring Down Spectroscopy (WS-CRDS) the biosphere-atmosphere CO_2 exchange mechanisms can be more carefully examined. This measurement technique achieves precisions of approximately 0.3 per mil with measurement drift that is sufficiently low so as to avoid frequent calibration and can be deployed in remote, unattended locations for long-term, continuous measurements, enabling the observation of diurnal and seasonal trends in the CO_2 exchange processes. We will present new data from a recently commercialized WS-CRDS analyzer, first from a mountaintop facility, Storm Peak Laboratory, CO, analyzing clean background air, and also from Wind River Canopy Crane, WA, analyzing air within the canopy of an old growth forest. By combining this high-resolution isotopic CO_2 data with existing models of the global carbon budget, these models can be further examined to test their sensitivities to currently held assumptions about the role of photosynthesis, plant respiration and other effects on the relative isotopic abundances of carbon in CO_2.

HERBIVORY: C_3 VS. C_4

ISOTOPIC MODELING OF THE HIPPO ECOMORPH: IDENTIFYING AQUATIC HABITS OF HERBIVOROUS MAMMALS THROUGH STABLE ISOTOPE ANALYSIS

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Hippopotamids are unique among large mammals in that they spend most of the day in the water and come ashore at night to feed on terrestrial vegetation. Adaptation to aquatic habitats in this group is evident from various morphological features, including dorsally positioned orbits and nares and reduced limb length. These characters have been identified in other, unrelated groups of extinct herbivorous mammals and are often used to identify groups that may have shared a similar ecological niche to that of living hippopotamids. However, the connection between these morphological characters and ecological preferences is debated, which suggests that hypotheses about semi-aquatic behaviour should be tested using alternative methods that are independent of morphology. The stable isotope composition of fossil material has been shown to be an excellent source of ecological information, making it a prime candidate for independently testing ecomorphological hypotheses. Both the mean and the variance in the oxygen isotope composition of individuals within fossil populations have proven effective in identifying aquatic species and could be used to do the same for hippo-like species within ancient faunas. Here we assess the validity of isotopic methods for identification of aquatic and semi-aquatic taxa in the fossil record by constructing a quantitative model for the hippo ecomorph that accounts for environmental and physiological influences on oxygen isotope values. Results from this model are then compared to published isotope data for living and fossil hipppopotamids and used to evaluate what factors account for the characteristically low enamel $\delta^{18}O$ values for hippopotamids and whether or not similar values would be expected for semi-aquatic mammals outside of this clade.

Tabulation of published enamel $\delta^{18}O$ values showed that living and fossil hippopotamids typically have low mean $\delta^{18}O$ values relative to associated ungulates that fit a linear regression ($\delta^{18}O_{hippopotamids} = 0.96 \pm 0.09 * \delta^{18}O_{fauna} - 1.67 \pm 2.97$; $r^2 = 0.886$, $P < 0.001$). Our model of oxygen fluxes in hippopotamids identified three factors that may cause this decrease in the $\delta^{18}O$ composition of hippopotamid body water and enamel: 1) increased water loss through feces and urine; 2) increased water turnover rate; and 3) nocturnal foraging on plants with leaf water depleted in ^{18}O. Though nocturnal foraging is not necessarily connected to aquatic habits, the first two factors would be expected to produce similar enamel $\delta^{18}O$ values for other semi-aquatic species outside of the hippopotamid clade. Large mammals living in freshwater habitats would have no need to conserve water, but would need to develop ways of flushing water out the body while retaining electrolytes. Increased water turnover rates associated with an increase in water loss through feces or urine with low electrolyte concentrations would be an effective way to achieve this for any semi-aquatic mammal. Thus, the low enamel $\delta^{18}O$ values observed in hippopotamids could be found in other semi-aquatic mammals outside of this clade and may therefore serve as a suitable indicator of semi-aquatic habits for extinct species.

HERBIVORY: C_3 VS. C_4

CARBON ISOTOPE DISTRIBUTIONS IN MIXED-FEEDING HERBIVORES: A BROWSER-GRAZER APPROACH TO FUNCTIONAL RESPONSE

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Two mechanistic models of functional response describe the dynamic interactions between herbivorous mammals and abundances of their plant prey. Optimal foraging theory describes preference for food items based on nutritional and physical properties of plants, while intake rate is believed to be a function of bite size and thus constrained by cropping and chewing rates. Little is known, however, about the relationship between diet and abundance of the two primary food types available to herbivores – browse and grass. This is surprising because natural selection is likely to place at least as much pressure on browser-grazer transitions as it does on optimal foraging and food intake rate. To study relationships between diet with browse and grass abundance, we analyzed $\delta^{13}C$ distributions of mixed-feeders in South Africa's Kruger National Park to record changes in C_3 browse versus C_4 grass intake across several habitats and through the seasonal cycle. We tested hypotheses that C_4 grass intake is related to environmental heterogeneity at the landscape and seasonal scale, including changes in grass nutritional quality (N content) and climate. To identify constraints that might limit grass intake by herbivores, we also fitted several functional response models to the data using non-linear regression.

Results revealed that mixed-feeders include anywhere between ~10 and 95% C_4 grass in their diet. Animals show a degree of predictability in diet shifts across regions and seasons, for example increases in C_4 grass consumption from dry to rainy months. Relationship between diet and food availability were reminiscent of a Type II functional response, despite the broad scale represented in our data: mixed-feeders rapidly increased C_4 grass consumption with increases in rainfall, temperature, and grass quality, before reaching an asymptote at thresholds below the maximum observed intake level. These constraints appear to be due to reductions in grass fibre digestibility, but models depicting effects of exploitation competition from sympatric herbivores, and diet switches under conditions of high browse availability are also supported by our analyses. Additionally, we cannot rule out physiological constraints to grass consumption. Carbon isotope studies of herbivore diet variations across these (and broader) landscape scales should become integral to advances in herbivore-plant theory, and to predicting top-down impacts of large herbivores on vegetation structure, especially if C_3:C_4 consumption can be shown to scale with biomass intake. Finally, because climatic effects are explicitly addressed, these approaches can be used to model browser-grazer transitions in response to environmental heterogeneity - in the future and in the past.

HERBIVORY: C_3 VS. C_4

TINY TEETH AND THE BIG PICTURE: CARBON AND OXYGEN ISOTOPE RATIOS OF MICROMAMMAL TEETH FROM EASTERN AFRICA

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Carbon and oxygen isotope ratios of mammalian teeth are important tools for studying present and past ecosystems. Recent advances in laser ablation GC-IRMS make it possible to analyze the isotopic composition of teeth that are too small to analyze conventionally using the phosphoric acid method. Here we use in situ laser ablation to determine the carbon and oxygen isotopic composition of micromammal teeth from a range of environments in eastern Africa, including primary tropical rainforest in Kahuzi-Biega National Park in eastern Congo (ca. 2100 m), moorlands in the Bale Mountains in Ethiopia (ca. 3800 m), and in Kenya, tropical rainforest in the Kakamega Forest (ca. 1550 m), mesic bushlands and thickets near Nairobi (ca. 1650 m), xeric bushlands and thickets in Olorgesailie (ca. 600 m), and xeric grasslands and shrublands at Turkana (ca. 400 m). Most of the analyzed specimens are Muridae and belong to the Murinae, Gerbillinae, and Rhizomyinae subfamilies. Carbon isotope values range from -21.2‰ to -4.3‰ (VPDB), reflecting both a varied diet across environments and a low diet-tissue fractionation factor for micromammals compared to larger herbivores. Oxygen isotope values from the laser analysis range from -13.5‰ to +1.2‰ (VPDB) and increase with aridity. The results from this survey of micromammals in eastern Africa demonstrate the potential for using the isotopic composition of small mammal teeth to study the ecology of both extant organisms and fossil systems.

HERBIVORY: C_3 VS. C_4

^{13}C, ^{2}H AND ^{18}O VALUES OF HAIR REVEAL SEASONAL PATTERNS IN RESOURCE USE FOR AMERICAN BISON.

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The isotopic composition of hair has been used to reconstruct migration patterns and resource use in animals. In general, carbon and nitrogen isotopes in hair have been used to study diet, and hydrogen and oxygen isotopes have been used to identify location of origin for unknown samples. One confounding issue to using the isotopic composition of hair to investigate diet and location in animals is that diet can change seasonally and the isotopic composition of precipitation can also vary seasonally. For example, in the Great Basin, C_4 grasses dominate the lower elevation grasslands during the hot summer months and C_3 grasses dominate the cooler months. As well, the isotopic composition of precipitation varies seasonally with more enriched precipitation falling during the summer months. To investigate seasonal patterns in the isotopic composition of hair, we collected and analyzed tail hair from two wild populations of American bison (*Bison bison*) that live in two different ecosystems within Utah. The first, a resident population of Antelope Island in the Great Salt Lake, is rounded up yearly and hair samples were collected from the same animal in two chronological years. The second, a resident population of the Henry Mountains, is hunted and hair samples were collected from a hunter-killed bison. A hair sample was chosen that was long enough to represent ~2 years of growth. Antelope Island is a lower elevation grassland and the Henry Mountains has both lower elevation grasslands and higher elevation areas of fir, spruce and aspen. There was a repeating sinusoidal pattern in the $\delta^{13}C$, $\delta^{2}H$ and $\delta^{18}O$ values of the hair collected from the Antelope Island bison indicating a yearly change from C_3 grasses during the cooler months to C_4 grasses during the summer months. These results were supported by the $\delta^{13}C$ values of dung and plants. The pattern in the $\delta^{2}H$ and $\delta^{18}O$ values correlated well with the seasonal change in the isotopic composition of precipitation. This same sinusoidal pattern was observed in the $\delta^{18}O$ value of the hair from the Henry Mountains bison, but was not observed in $\delta^{13}C$ or $\delta^{2}H$ values. $\delta^{13}C$ values were within a tight range (~$\delta^{13}C$ = -22.8‰) except for a sharp enrichment that occurred during the summer prior to collection. This bison changed its diet to C_4 grasses during one summer but not during both summers represented by the hair. A 3-pool model indicated that this bison switched from ~100% C_3 grasses to >75% C_4 grasses. The change in diet for the Henry Mountains bison also influenced $\delta^{2}H$ and $\delta^{18}O$ values of the hair. Thus, the isotopic composition of hair can be used to detect seasonal changes in diet and resource use. However, accurate estimates of diet breadth for wild animals should include samples that record multiple years worth of information to ensure that changes in diet that may be related to location and/or a variable climate are identified.

HERBIVORY: C_3 VS. C_4

THE ISOTOPIC ECOLOGY OF RING-TAILED LEMURS (*LEMUR CATTA*) IN SOUTHWEST MADAGASCAR.

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This study examines the isotopic ecology of ring-tailed lemurs (Lemur catta) at Beza Mahafaly Special Reserve (BSMR) and Tsimanampesotse National Park (TNP) in southwest Madagascar. We determined $\delta^{13}C$ and $\delta^{15}N$ values of tail hair from 63 known individuals, all of which are part of a longitudinal study and about which sex, health status, and group membership are known. The two study areas differ in aridity, salinity, and plant species composition and the individuals analyzed came from groups with habitats that differ with regard to canopy cover, extent of anthropogenic disturbance, and plant species composition. We also obtained C and N isotope ratio data for over 200 plant samples representing 66 species in 34 families. All plants analyzed were consumed by Lemur catta as ascertained by more than 8000 minutes of focal animal sampling. The mean δ13C and $\delta^{15}N$ values of the BSMR and TNP lemurs were highly different ($P<0.0001$), as were the $\delta^{13}C$ and/or $\delta^{15}N$ values of individual groups within each reserve ($P<0.0001$). In all cases the differences were as expected given each group's observed diet and habit use. Stable isotopes also allowed us to track migration, health status, sex differences, and dietary variability within and between groups. We argue that studies of known individuals, that allow us to investigate the underlying causes of isotopic variability, will greatly improve our ability to interpret modern and fossil primate stable isotope data.

FRESHWATER ECOLOGY

TROPHIC POSITION OF BOTTOM-FEEDING FISH IN THE UPPER PARANÁ RIVER FLOODPLAIN, BRAZIL.

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The $\delta^{15}N$ composition of bottom-feeding fish (iliophagous = *Apareiodon affinis, Cyphocharax nagelii, Prochilodus lineatus, Steindachnerina brevipinna* and *S. insculpta*; detritivorous = *Loricariichthys platymetopon* and *Liposarcus anisitsi*; benthophagous = *Satanoperca pappaterra* and *Hoplosternum littorale*) and their primary alimentary sources were investigated in the upper Paraná River floodplain, Brazil during rainy season. Two hypotheses were tested: i) that the trophic position and isotopic values of the investigated organisms (fish and food resources) would vary spatially; and ii) that trophic position and isotopic composition would differ among iliophagous, detritivorous and benthophagous fish. Within this ecosystem, the Paraná, Baía and Ivinheima rivers and the Ressaco do Pau Véio, Maria Luiza, Finado Raimundo, Fechada and Ventura lakes were sampled. The last two lakes do not have a direct connection with the river and remain isolated throughout the year. Samples of the primary food sources (riparian vegetation, aquatic C_3 and C_4 macrophytes, periphyton and phytoplankton) and fish were collected at each collection point. To estimate the phytoplankton, fractions of 2.3‰ above the isotopic values of zooplankton were considered. Zooplankton samples (cladoceran and calanoid copepod filter-feeders) were collected using a zooplankton net (53 μm) and vacuum brush. The C_4 macrophytes, periphyton and phytoplankton were isotopically different in sites analyzed. Significant isotopic differences occurred in the species of each trophic category. Spatial differences were observed in the isotopic composition of *P. lineatus* and *L. platymetopon*, whose values were more enriched in the Paraná River and Ressaco do Pau Véio Lake. Significant spatial differences in trophic position were observed for *L. platymetopon* and *H. littorale*, which presented the highest values in the Paraná and Baía rivers, respectively. Trophic positions were significantly different among the species that composed each trophic category. These findings demonstrate that generalizations concerning the grouping of fish into trophic categories and/or habitats in energy-flow studies in detrital food chains should only be carried out after careful investigations of the local/specific trophic dynamics of the organisms.

FRESHWATER ECOLOGY

TEMPORAL AND INDIVIDUAL DIET VARIATION IN THE BARTON SPRINGS SALAMANDER (*EURYCEA SOSORUM*): AN APPLICATION OF STABLE ISOTOPE ANALYSIS TO THE CONSERVATION OF RARE AND ENDANGERED SPECIES.

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It is well known that many species show strong temporal variation in diet. Long-term dietary trends may be important in assessing ecological effects of environmental change such as climate change, land use change, or the introduction of invasive species. Short-term variation in food sources or prey selection may be crucial for understanding population dynamics in poorly understood species. The Barton Springs Salamander (*Eurycea sosorum*) is an endangered species endemic to four small spring outflows near downtown Austin, Texas. This species remains aquatic throughout life (it does not metamorphose) and inhabits benthic rocky substrate. While little is known about its foraging ecology, *E. sosorum* is assumed to be a generalist predator with the abundant amphipod Hyalella azteca as its primary food source. The salamander's secretive behaviour and obscure microhabitat make direct foraging observations impossible. Thus, stable isotope analysis may be the only feasible means of estimating diet in these animals.

Measurements of $\delta^{13}C$ and $\delta^{15}N$ for wild-caught *Eurycea sosorum* and a suite of potential invertebrate prey (amphipods, mayfly larvae, flatworms, fly larvae and caddisfly larvae) were taken quarterly from fall 2006 to spring 2008. Quantitative invertebrate censuses track seasonal changes in invertebrate relative abundance. A multi-source mixing model is applied to field isotope data, and a distribution of likely prey item contributions to salamander diet is obtained for each season. Measurement of $\delta^{13}C$ and $\delta^{15}N$ from captive-bred *E. sosorum* raised on a constant diet indicate minimal fractionation of $\delta^{13}C$ (<1‰) and approximately 2.3‰ enrichment in $\delta^{15}N$ per trophic level. Initial results show that salamanders take advantage of seasonally available food resources (e.g. Baetid mayfly larvae), and that *Hyalella azteca* is not the primary food source during some seasons. Furthermore, individual variation in diet was small across seasons.

These techniques allow investigation of how diet composition responds to temporal changes in prey availability in field populations and the degree to which intrapopulation diet variation influences overall population diet estimates. This work provides conservation biologists working to preserve the species with essential information on the diet and ecology of *E. sosorum*, which is being used to improve species management plans that will be applicable to other spring systems. Furthermore, it adds to the growing body of research on amphibians using stable isotope techniques, a group that is currently underrepresented in the literature compared to other vertebrate taxa.

FRESHWATER ECOLOGY

REPEATED PATTERNS OF ISOTOPIC VARIATION WITH DEPTH IN LAKE BENTHOS.

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Isotopic variation along the pelagic-benthic axis of lakes has been recognised for several years [1] and has allowed isotope ecologists to estimate the relative contribution of energy from pelagic or benthic/littoral primary production modes to higher trophic levels [2-4]. Many workers assume that isotopic values within individual benthic macroinvertebrate taxa are relatively similar throughout littoral habitats. Here we show repeated non-linear patterns of isotopic depletion ($\delta^{13}C$) and enrichment ($\delta^{15}N$) with depth in benthic macroinvertebrates from a series of 7 sub-Arctic lakes from Finland. Benthic macroinvertebrates in these lakes displayed clear isotopic differentiation between littoral, sub-littoral and profundal habitats. These differences were reflected in the isotope ratios of specialist fish predators and suggest that more detailed analyses can provide an increased level of habitat resolution beyond the littoral-pelagic endpoints typically used by lake isotope ecologists.

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FRESHWATER ECOLOGY

USING STABLE ISOTOPES TO INVESTIGATE TREE WATER SOURCES AND GROUNDWATER-SURFACE WATER INTERACTIONS IN THE MACQUARIE MARSHES, NSW AUSTRALIA.

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The Macquarie Marshes are important wetland habitats that have been created by irregular flooding of topographically low areas located along a section of the Macquarie River, New South Wales, Australia. They are important breeding habitats for birds and have been justifiably acknowledged with their listing as Wetlands of International Importance under the Ramsar Convention. At present, the marshes are in a critical state and in some areas are at risk of irreversible decline. This is because the frequency and extent of flooding that is required to sustain the marshes has been threatened by climate variability, drought and the extraction of water for irrigation from the Macquarie River upstream from the marshes. Integrated management of the wetlands requires a detailed understanding of the degree of connectivity between the hydrological resources (groundwater and surface water) and their dependent ecosystems.

This study is investigating where the riparian vegetation is sourcing its water from, with a focus on the iconic River Red Gum (*Eucalyptus camaldulensis*), and how the vegetation may respond to changes in the hydrological system. We are examining the stable water isotopes (^{18}O and ^{2}H) in groundwater, soil water, precipitation and plant xylem to identify the most likely sources of water for the River Red Gums. In addition to the use of stable water isotopes, physical and chemical properties of the soils are being used to evaluate recharge mechanisms to the shallow aquifer and the degree of connectivity between the surface and groundwater. Preliminary results suggest that the primary source of water for the River Red Gums is the soil water that has been recharged by large rainfall events or floodwaters, and that the degree of connectivity between fresh surface water and saline shallow groundwater seems to be very limited in this system. The outcomes of this study are important for developing suitable management options in a wetland system such as the Macquarie Marshes which is influenced by declining groundwater levels and limited fresh surface water availability essential for sustaining riparian vegetation such as the River Red Gums.

FRESHWATER ECOLOGY

REDUCING FOOD MILES: AN INVESTIGATION OF GARDENING BY A SEDENTARY CADDISFLY

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Sedentary macroinvertebrates face a trade off between the benefits gained from defending food within the vicinity of their homes and the costs of such defence. Therefore, sedentary organisms are likely to be most successful at sites where food levels and replenishment rates are intermediate. However, it has been suggested that sedentary grazers such as the caseless caddis larva *Tinodes waeneri* (Trichoptera), which can form a dominant component of the stony littoral community of lakes, may overcome this restriction through manipulating food resources within its feeding territory, i.e. gardening.

T. waeneri build galleries of silk bound sediment which were assumed simply to provide protection for the larva. However, it has recently been postulated that nutrients secreted by larvae might fertilize algae growing on the gallery walls providing the larvae with a better quality or quantity of food. We tested this hypothesis by analysing the carbon and nitrogen stable isotope ratios of larvae, their galleries and the biofilm on rocks collected from six lakes spread across a natural nutrient gradient.

We found evidence of nutrient recycling within the Tinodes gallery community. Galleries were ^{15}N-depleted compared to the rock biofilm, suggesting that algae on the gallery walls preferentially assimilated ^{14}N from larval excretions that would themselves have been ^{15}N-depleted relative to the larval food source. In addition, mixing models suggest that galleries formed an important carbon and nitrogen source for the larvae. These results provide evidence that *T. waeneri* galleries can act as a garden. This has important implications for community structure and ecosystem function within the littoral of lakes.

FRESHWATER ECOLOGY

TROPHIC INTERACTIONS BETWEEN PLANKTIVOROUS FISH AND ZOOPLANKTON IN LAKES OF CONTRASTING DOC CONCENTRATIONS

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Stable isotopes have been frequently used to decode and understand the complexities within populations and communities of freshwater ecosystems. As animals consume their food they become increasingly enriched in heavier isotopes such as ^{15}N. Furthermore, as they develop and increase in size there is often increasing enrichment. This has been the case for some fish populations and species, consequently dietary changes during growth associated with changes in morphology, foraging tactics and habitat use often leads to shifts in their isotopic signatures. Conversely, strong trends between fish size and isotopic composition can be obscured for fishes that are opportunistic and omnivorous.

For this study we will examine relationships between body size (length) and $\delta^{15}N$ isotopic composition (trophic level) at the species and community levels for temperate freshwater fishes. A number of common fish species with contrasting feeding strategies such as pumpkinseed (*Lepomis gibbosus*), common shiner (*Notropis cornutus*), smallmouth bass (*Micropterus dolomieui*), creek chub (*Semotilus atromaculatus*), yellow perch (*Perca flavescens*) and brown bullhead (*Ameiurus nebulosus*) will be used. It is important that we study and understand trophic dynamics of these fish species because they are an integral part of temperate freshwater communities.

FRESHWATER ECOLOGY

FOOD WEBS OF LAKES FROM IBERÁ WETLANDS (NORTHEASTERN ARGENTINE): SPATIAL VARIATION IN THE STABLE ISOTOPE COMPOSITION

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Iberá wetlands are a complex system (12.300 km^2) of lakes, swamps and streams harboring high diversity of fishes. Using stable isotope ratio analysis of carbon (C) and nitrogen (N) we provide in three lakes (Ipucú, Galarza, Iberá), a preliminary description of the food webs C-sources and trophic position of fishes sampled during spring-summer period. The majority of the vegetation (terrestrial, floating and submerge) were C_3-plants and had a wide range of δC_{13} values from -22.7 to -32.4; and the δC_{13} mean of the C_4-plants was -12.7±0.27. In invertebrate's collectors-gatherers, a Chironominid and Ephemeroptera larva, the mean δC_{13} value was -28.3±0.30 and -33.4±0.64, respectively. Bivalve revealed closed values (δC_{13} = 29.1±0.73). In contrast, gastropod scrapers (*Ancylidae sp. A*, *Heleobia spp.* and *Pomacea spp.*) showed a mean value of -25.4±0.62. The fishes δC_{13} values ranged from -21.9 to -29.2, but for most of them was closed to mean value -25.4±0.46 revealing that both macrophytes and epiphytic algae (-15.0 to 32.7) are the predominant sources of energy. There were inter-lake differences, up to 2.3‰, in the $\delta^{13}C$ values of fishes and invertebrates that in general showed a similar tendency. These differences suggest a qualitative change in C-source (C_3 versus C_4 plants or periphyton).

Nitrogen isotope ratios and stomach contents of fishes (r^2=0.68; $p<0.05$) indicated three trophic levels. *Cyphocharax spilotus*, *Steindachnerina brevipinna* and *Hyphessobrycon elachys* were primary consumers. *Hyphessobrycon anisitsi*, *H. wajat*, *Astyanax asuncionensis*, *A. pynandi*, *Moenkhausia intermedia*, *Leporinus lacustris*, *Gymnogeophagus balzanii* and the two catfishes *Trachelyopterus galeatus* and *Loricariichthys platymetopon* were secondary consumers. Highest trophic level was represented by *Acestrorhynchus pantaneiro*, *Roeboides descalvadensis*, *Hoplias malabaricus* and *Serrasalmus maculatus*.

ANIMAL MIGRATION

PATTERNS OF $\delta^{18}O$ IN FISH TISSUES IN TWO OREGON COAST RANGE STREAMS

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We are using stable isotopes of C, N, O and S (H planned) to study the ecology of coho salmon in streams of the Oregon Coast Range. As part of this work we have examined changes in $\delta^{18}O$ in coho salmon juveniles (from eggs to smolting) and sculpin (from 0.5 to 20 gm.).

For fish of the West Fork Smith River we found a monotonic decline in $\delta^{18}O$ from coho spawner muscle tissue (+16‰) to eggs (+14.5‰), to recently emerged fry (+12.5‰) to a rapid attainment by juveniles of a near-constant range of $\delta^{18}O$ (+10.5 to 11.5‰). Sculpin from West Fork Smith River rapidly attained the same range of values as coho in that stream, as did sculpin from another Coast Range stream, Winchester Creek.

Attainment of a constant muscle $\delta^{18}O$ for coho occurred more rapidly (within one month post emergence and at a size range of 1-2 gm) than that of $\delta^{15}N$ (approximately six months at a weight of 5-6 gm) for the same individual fish, indicating the operation of controls more rapid than growth and tissue turnover alone. Sculpin muscle for fish from Winchester Creek also reached a constant range (from values initially below this range) at a size of 1-2 gm. We hypothesize that direct exchange reactions between tissues and absorbed ambient stream waters ($\delta^{18}O \sim -8$‰) largely govern these rapid changes.

Oxygen stable isotope values in fish muscle might prove useful (especially in combination with other isotopes and other tissues) as an indicator of timing of fish movement between waters (e.g., large mainstem vs. small tributaries) possessing different values of $H_2\delta^{18}O$.

ANIMAL MIGRATION

TRACKING MIGRATORY PATHWAYS OF ATLANTIC BLUEFIN TUNA (*THUNNUS THYNNUS*) TO GULF OF MEXICO SPAWNING GROUNDS THROUGH ELECTRONIC TAGGING AND STABLE ISOTOPE ANALYSES

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Since 1981, Atlantic bluefin tuna (*Thunnus thynnus*) (ABFT) have been managed as two separate stocks based on an understanding of migration routes, mixing rates, maturity schedules and spawning areas that is incomplete, at best. The recent collapse of Atlantic-wide fisheries and gaps in knowledge of basic life history parameters suggest that new approaches are needed to understand ABFT population dynamics before rebuilding can occur. ABFT are apex predators fished throughout the north Atlantic and historically, off Brazil, and their known spawning grounds include the Gulf of Mexico and Mediterranean Sea. While trans-Atlantic mixing has been demonstrated through conventional and electronic tagging studies, spawning site fidelity and links between eastern and western forage grounds and spawning sites are poorly defined. New analyses consider ABFT as a potential meta-population characterized by a diversity of migration, foraging, and reproductive patterns. Here we utilize stable isotope analysis (SIA) to test the hypothesis that ABFT using the Gulf of Mexico for spawning comprise a stock component exhibiting similar behaviour in regard to migration routes and foraging history. We analyzed $\delta^{13}C$ and $\delta^{15}N$ from liver (rapid turnover) and white muscle (intermediate turnover) tissues of commercially harvested bluefin tuna (>183 cm curved fork length, n= 60) collected there as well as from western Atlantic forage grounds off New England and Nova Scotia (summer-fall, n= 62), winter forage grounds along the Mid-Atlantic Bight (n=40) and offshore areas of the eastern central Atlantic (n=43). We also conducted SIA for bigeye tuna and Atlantic swordfish (n=52), which presumably occupy the same trophic position as ABFT in the central north Atlantic. We use observed geographic differences in ABFT isotope values between coastal and offshore forage grounds as chemical tags to track migratory routes into Gulf of Mexico spawning grounds. Results from SIA are compared with spatial and temporal information returned by pop-up satellite archival (PSAT) tags on fish entering the Gulf of Mexico at the same time of year.

ANIMAL MIGRATION

CHANGING PLACES? CONTRARY WINTER MOVEMENTS OF SMALL SEABIRDS FROM BOTH SIDES OF THE DRAKE PASSAGE

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Based on growing knowledge about the distribution of stable isotopes in marine food webs, a powerful tool to study movements and trophic position of seabirds has been developed. This can be applied to seabirds that are too small to carry the devices available for satellite or GPS tracking, and thus, are difficult to follow. We studied two common pelagic seabirds in the Southern Ocean, using $\delta^{13}C$ and $\delta^{15}N$ to evaluate diet and foraging areas. We sampled adult and chick feathers of subantarctic Thin-billed prions *Pachyptila belcheri*, breeding at the Falkland Islands, and compared them to feathers of Antarctic Wilson's storm-petrels Oceanites oceanicus, breeding at King George Island, south of the Drake Passage. Our analysis revealed that the two species have contrary wintering movements: Most Thin-billed prions spent the summer north of the Drake Passage and the winter south, while Wilson's storm-petrels showed the opposite distribution. We discuss the possible advantages of these contrary strategies for the two species.

MARINE ECOLOGY

TROPHIC INFLUENCES ON HEAVY METAL PATTERNS IN SOUTH GEORGIAN PROCELLARIIFORMES

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Heavy metal contamination is wide-spread throughout the marine environment, with hot spots in waters immediately adjacent to high anthropogenic or geologic activity. Yet, some elements have been found in increasingly high levels in the most remote regions of our planet, such as the Southern Ocean. Procellariiformes are exposed to elevated pollutant levels by way of their wide-ranging foraging habits coupled with the redistribution of heavy metals around the globe through oceanic and atmospheric processes. While heavy metal concentrations have previously been examined in a number of Procellariiform species, less is known regarding the influence of foraging patterns and trophic structure on these pollutants at the community level.

In this study we examined a suite of heavy metals (both essential and non-essential) across 10 Procellariiform species breeding on Bird Island, South Georgia. We also investigated heavy metal variation among tissue types. We confirmed known associations between mercury and trophic level (using $\delta^{15}N$ as a proxy) at the community level, and identified patterns between trophic level and arsenic across all species studied. Until now, there has been some dispute regarding the biomagnifying properties of arsenic. This study demonstrated a significant and positive correlation between arsenic and trophic level (using $\delta^{15}N$ as a proxy) across a community of Procellariiformes. We investigated the effects of particular prey items on heavy metal accumulation and their potential to cause variation between Procellariiform species. This study has allowed us to better understand pollutant pathways in the Southern Ocean in relation to apex predators. We conclude that South Georgian Procellariiformes experience elevated levels of heavy metals as a result of exposure through diet and relative trophic position. Moreover, co-occurrence between elements is discernable in some instances and consequently the potential for synergistic and/or antagonistic physiological effects. Finally, we identified that arsenic, as well as mercury, biomagnifies in Procellariiformes and hence may pose a threat to the health of Southern Ocean seabird communities. For this reason the potential for sub-lethal effects from certain heavy metal contamination requires further investigation in Procellariiformes.

MARINE ECOLOGY

VARIABILITY AND ISOTOPIC FRACTIONATION OF $\delta^{13}C$ AND $\delta^{15}N$ IN ZOOPLANKTON SPECIES FROM UPPER PARANÁ RIVER FLOODPLAIN, BRAZIL.

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This study evaluated the isotopic composition of three zooplankton species and phytoplankton community from Upper Paraná River floodplain (Brazil), aiming to synthesize the informations about isotopic fractionation of $\delta^{13}C$ and $\delta^{15}N$ and trophic positions among these three species. We predicted that phytoplankton is the main food resource used by zooplankton species, independently of sampled locals. Samplings were undertaken during May 2007, in three lagoons from Baía subsystem (Porcos, Guaraná and Maria Luiza lagoons) and in two from Paraná subsystem (Garças lagoon and Leopoldo backwater). At each local, we measured abiotic data and collected three to four zooplankton samples, and three phytoplankton samples. Each zooplankton sample was compounded by a variable number of individuals, according to the species size (*Notodiaptomus amazonicus*, *Moina minuta* and *Bosmina hagmanni*). These species did not present significant differences in relation to subsystems; however they were isotopically distinct in the lagoons, with variations of approximately 10.8‰ considering the $\delta^{13}C$ and 5.8‰ for $\delta^{15}N$. The phytoplankton also was significantly different among sampling stations, presenting variations of approximately 9.3‰ for $\delta^{13}C$ and 7.4‰ for $\delta^{15}N$. The identified trophic positions for *M. minuta* ranged from 0.6 to 2.3, whereas for N. amazonicus, they were similar (from 1.5 to 1.8) in the different environments, except the Guaraná lagoon, where the trophic position was 3.7. These results evidenced that, possibly, these species were using other food sources beyond the phytoplankton. We conclude that the estimative in relation to fractionation are subjected to uncertainties that may vary depending on physiological and environmental factors. Moreover, for a consistent determination of different trophic levels from plankton food chain, it is still necessary researches approaching the bacterioplankton. We highlight that studies regarding trophic structures in environments subjected to constant changes must be meticulously developed.

MARINE ECOLOGY

FOOD WEB STRUCTURE OF DEEP MEDITERRANEAN COLD SEEPS: A MULTIPLE STABLE ISOTOPE ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) APPROACH

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Deep sea bottoms cover 65% of the world's surface but are still poorly known. Given the low turnover rate of species occurring at great depths, deep ecosystems (in particular on continental margins) are becoming vulnerable to overfishing and pollution. There is thus an urgent need to better understand the functioning of these systems. Cold seeps are continental margins areas where fluids enriched in reduced compounds escape from the seafloor. Seeping methane and sulphide sustain free living and symbiotic bacteria activity, which form the basis of complex food webs. On these chemosynthetic communities, megafauna (size > 1cm) are often dominated by symbiotic siboglinid tubeworms and bivalves, but the trophic role of smaller fauna has been much less studied.

In the framework of the multidisciplinary European HERMES program, we investigated the benthic food web of two recently discovered cold seeps (the mud volcanoes "Napoli" and "Amsterdam") located in the deep eastern Mediterranean (2000m depth). Sampling of benthic species and sediment was achieved by the victor ROV in October 2007. For each system, we aim to describe the overall structure of the benthic food web by the use of multiple stable isotope ($\delta^{13}C$, $\delta^{15}N$, $\delta^{34}S$) analysis. Here, we show preliminary data on the isotopic signatures of the dominant consumers and we address in particular the following questions: (1) Given that the mud volcanoes are located in the most oligotrophic part of the Mediterranean Sea, does assimilated carbon exclusively originate from chemosynthesis? (2) What are the relative contributions of thiotrophic and methanotrophic pathways at the basis of the food webs?

MARINE ECOLOGY

MERCURY LEVELS IN HAWAIIAN PREDATORY PELAGIC FISHES AND THEIR LOWER TROPHIC LEVEL PREY AS A FUNCTION OF DEPTH AND ECOLOGY

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Mercury is distributed throughout the Earth's physical and biological systems and is an active component of biogeochemical cycles. Mercury enters food webs following microbial methylation, where it then bioaccumulates and is retained in trace amounts in plants and animals. Of particular interest to the scientific and medical communities is the variation of methylmercury levels seen in widely consumed pelagic fishes. Inter- and intra-specific variations have been previously linked to size, age, trophic position, and location of capture. Ingestion of mercury from food has been confirmed as the dominant pathway of mercury uptake in fish, thus recording the integrated feeding behaviour of the consumer. Furthermore, biogeochemical studies of mercury in the ocean report that low-oxygen, typically deeper waters are sites for enhanced mercury methylation, and thus have higher concentrations bioavailable to organisms inhabiting and foraging in these deeper waters.

This study examines mercury levels in pelagic fish with distinct foraging behaviours (bigeye tuna (*Thunnus obesus*), yellowfin tuna (*T. albacares*), skipjack tuna (*Katsuwonus pelamis*), broadbill swordfish (*Xiphias gladius*), Opah/Moonfish (*Lampris guttatus*), and common dolphinfish (*Coryphaena hippurus*) and numerous representatives of their micronektonic prey in relation to vertical depth of occurrence in the water column. Coupling mercury levels with the use of stable isotopic and stomach content analyses provides insight on trophodynamics and the flow of energy and contaminants within pelagic ecosystems.

MARINE ECOLOGY

THE CONSUMER-DIET $\delta^{13}C$ AND $\delta^{15}N$ ENRICHMENT IN THE BENTHIC SYSTEM OF A TROPICAL-SUBTROPICAL CONTINENTAL SHELF IN SOUTHWESTERN ATLANTIC

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The Southwestern Atlantic continental shelf, off Brazil, is an oligotrophic system in a tropical-subtropical region, under seasonal intrusion and upwelling of South Atlantic Coastal Water (SACW), processes that seasonally increase nutrient supply. A study of $\delta^{13}C$ and $\delta^{15}N$ was conducted to describe trophic interactions among benthic organisms, zooplankton, suspended particulate matter (SPM), and sediments, on the continental shelf, in summer and winter, between 2001 and 2002. The isotopic ratios identified the trophic position of each component of the food web. Enrichment (δ) of $\delta^{13}C$ or $\delta^{15}N$ values of consumers were estimated as the difference of $\delta^{n}X_{consumer}$ – mean $\delta^{n}X_{diet}$, diet being SPM for zooplankton and supensivores, and bulk sediment for invertebrates that burrowed or fed on sedimented particles in surface or subsurface sediments. For carnivorous invertebrates, the relative importance of each food item was assessed using literature references, and by using mean $\delta^{13}C$ or $\delta^{15}N$ values of food items (bivalves, polychaetes, peracarid crustaceans, etc.), weighted to estimate$\delta^{15}N$ of the predator.

The main source of carbon for the benthic system was pelagic primary production (SPM $\delta^{13}C$ between –24.17 and –20.26‰). Sediment $\delta^{13}C$ values ranged from –25.25 to –20.78‰. Invertebrates $\delta^{13}C$ values ranged from –22.34 to –14.30‰. Mean enrichment (δ) of $\delta^{13}C$ of zooplankton (1.84 ± 0.87‰), suspensivores (3.57 ± 1.48‰), and depositivores (4.55 ± 0.92‰), was variable but was always larger than the expected trophic fractionation (~ 1‰). $\delta^{15}N$ values of SPM ranged from 4.10 to 8.55‰, whereas those of sediment ranged from 5.34 to 10.46‰ and from 5.37 to 14.50‰ in consumers. The enrichment (δ) of $\delta^{15}N$ values between consumers and its diet were also variable but in general lower than the 3.4‰ referred to in the literature. Suspension feeders had the lowest enrichment in relation to its food source (SPM) (0.41 ± 1.04‰), followed by zooplankton (1.14 ± 1.43‰), and surface deposit feeders (1.41 ± 1.12‰) in relation to sediment, whereas the subsurface or borrowers deposit feeders had the highest (2.98 ± 1.16‰), followed by carnivores (2.26 ± 1.03‰) in relation to diet, except for one sea star and gastropods of larger sizes.

The overall mean value, considering all the consumer taxa, of enrichment was 1.49 ± 1.42‰ for $\delta^{15}N$ and 3.28 ± 1.49‰ for $\delta^{13}C$. Although many sources of variation might influence fractionation, the enrichment values found between trophic levels differed from expected values. Similar results have been reported in other coastal systems, and this suggests we need to revisit the fractionation involved, and we also need to reassess how we assign trophic positions in coastal food webs.

MARINE ECOLOGY

SPATIAL VARIATION OF THE BENTHIC MARINE FOOD WEB IN ADMIRALTY BAY (KING GEORGE ISLAND, ANTARCTICA): ANALYSIS USING STABLE ISOTOPES

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The sources of organic matter and its flux through the benthic marine food web were investigated at four different coastal areas in Admiralty Bay, King George Island, by the use of C and N stable isotopic ratios. Suspended particulate matter (SPM), net plankton, microphytobenthos, macroalgae, sediment, and several benthic invertebrates were analyzed.

The area off Polish Station “H. Arctowski”, along the entry of Admiralty Bay, under the influence of a penguin rockery, is subjected to high hydrodynamics and presents a community coupled with the organic matter from pelagic and kelp origin, and with no relationship with sediments, which are very enriched in ^{15}N ($\delta\ ^{15}N$ = 16.6 ‰) due to the penguin rockery. In contrast, the communities at the three areas in Martel Inlet, more sheltered inside the bay, were strongly dependent on microphytobenthic and sediment organic matter, besides the other two sources. The area in front of the Brazilian Antarctic Station “Comte Ferraz”, subjected to some slight sewage and oil influence, had significant lower $\delta\ ^{13}C$ values of some invertebrates that depend on microphytobenthos in relation to the other two reference areas. Considering the four studied areas, $\delta\ ^{15}N$ ranged from low values (-0.9 to 1.9 ‰) of SPM and macroalgae to 9.0 to 12.1 ‰ of benthic carnivores, showing 3 to 3.5 steps in the trophic web.

MARINE ECOLOGY

MULTI-SOURCE MIXING MODEL ANALYSIS OF DIET IN THE FORMIDABLE MARINE PREDATOR, MANTIS SHRIMP

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The paradigm that form fits function has pervaded biological research for centuries. This idea is especially prevalent in feeding studies, which show that many animals have specialized feeding structures for consuming specific prey types. Surprisingly, predators with highly derived, fast-moving feeding morphology have been observed consuming a wide range of prey types. Mantis shrimp (Stomatopoda, Crustacea) provide an excellent system for study, because they produce one of the fastest predatory strikes in the animal kingdom to smash hard-shelled prey. While mantis shrimp morphology has been well-described their diet remains unknown beyond general prey type categories. Stable isotope analysis has made it possible to analyze diet over longer time scales and to develop measures of diet specialization that are comparable across taxa. Specifically, stable isotope mixing models can determine the percentage of prey types in a predator's diet in order to measure diet specialization with standard diversity metrics. The purpose of this study was to test the accuracy of a multi-source mixing model and to analyze diet in the mantis shrimp species, *Neogonodactylus wennerae*. The first step of stable isotope diet analyses is to determine the fractionation factors of isotope ratios. I fed N. wennerae exclusively *Tegula funebralis* (a Pacific marine snail) for 50 days and found that the fractionation factors of $\delta^{13}C$ and $\delta^{15}N$ in muscle tissue were +2‰ and +2‰ respectively and those of exoskeleton were +2‰ and +4‰ respectively. With these values, I ran a four-source mixing model on individuals that were fed a known diet and then compared these values to a second analysis on individuals that were caught in the field. The first analysis used the same individuals as above that were fed solely T. funebralis. The mixing model included *T. funebralis* and three other potential prey items collected from *N. wennerae*'s natural habitat (xanthid crabs, hermit crabs, and a marine snail *Astraea teca*). The analysis revealed that 96%—100% of the diet was T. funebralis, verifying that the four-source mixing model accurately determined the known diet even when other prey items were included in the analysis. The second analysis determined percent prey type in 15 individuals of *N. wennerae* that were collected from their natural habitat along with their potential prey (xanthid crabs, hermit crabs, and two species of marine snails). The minimum and maximum percent prey type values were 0-35% xanthid crabs, 0-41% hermit crabs, and 59-84% marine snails. On average, the majority of *N. wennerae*'s diet appeared to be marine snails, despite the wide range of other suitable prey items available in coral reefs where *N. wennerae* typically live. Given that *N. wennerae*'s raptorial appendages generate high accelerations that yield high force to crush hard-shelled prey, these findings suggest that form fits function for the majority of prey items that *N. wennerae* consumes. This research is the first of its kind in mantis shrimp and lays the foundation for conducting large-scale analyses of diet breadth across mantis shrimp taxa.

MARINE ECOLOGY

COUPLING STABLE ISOTOPE AND METAL ANALYSIS AS ECOLOGICAL TRACERS TO STUDY THE FEEDING ECOLOGY OF THE LEATHERBACK TURTLE

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Dietary studies in marine vertebrate are now widely performed with stable isotope analysis on several tissues that offers insight in long term feeding preferences. But coupling stable isotope and metal analysis may offer several benefit to add information on dietary, feeding grounds and pollution accumulation.

This approach would be moreover very important when dealing with species difficult to study in lab as in field, such as protected species dispersing over large scale in their life cycle. This is the case of the leatherback turtle, Dermochelys coriacea, which migrates over several thousand kilometres between nesting sites and foraging grounds. Samples are only available when females come to nest on nesting beaches during the nesting season. Stable isotopic ratios ($\delta^{13}C$, $\delta^{15}N$) and selected toxic trace elements (Mercury Hg, Cadmium Cd, Lead Pb) were measured in blood of leatherback turtles nesting in French Guiana in order to improve knowledge on foraging grounds, toxic metal accumulation and associated threats.

We found that $\delta^{15}N$ values, which reflect a diet oriented towards low trophic level prey (mainly jellyfish), were similar between turtles with remigration interval (RI) of 2 and 3 years (interval between two successive nesting seasons). In contrast, $\delta^{13}C$ values in Red Blood Cells (RBC) differed significantly between turtles displaying a 2-yr remigration interval and those with a 3-yr remigration interval, indicating different feeding grounds during the migration. Indeed, $\delta^{13}C$ values are typically higher in species from coastal compared to offshore food webs. This coastal-versus-offshore effect may be combined with the tendency of $\delta^{13}C$ values to decrease on going from low to high latitudes due to oceanographic processes. Thus, our observation of lower RBC $\delta^{13}C$ values in the 2-year remigration interval turtles suggests that the carbon source of these turtles is situated in a more northern and/or offshore region than that of the 3-yr remigration interval turtles. Consistent with this notion, our data show a definite link between RI and feeding habitats (offshore vs. more coastal) and latitude (North Atlantic vs. West African coasts).

Metal analysis confirmed the result of isotopic analysis in the sense of the low metal accumulation reflects the low trophic level (gelatinous zooplankton). Second, Cd concentrations in blood were negatively correlated to $\delta^{13}C$ measurements in RBC and Plasma. These concentration gradients in blood according to isotopic signature in $\delta^{13}C$ reflect a different exposure linked to latitudinal and/or coastal vs. offshore feeding habitats. The increased Cd levels in turtles having a low $\delta^{13}C$ signature could be related to their feeding habits and foraging grounds (higher Cd concentrations in preys or an increase of the proportion of preys with higher Cd concentration towards high latitudes). The present study confirms result from various studies on Cd in marine vertebrate from temperate regions indicating that animals from lower latitude displayed lower Cd concentration in their tissues than animals foraging in higher latitudes. In this field study, coupling stable isotope and ecotoxicological approaches have been useful in understanding differences in feeding grounds and metal accumulation between the two groups of leatherback females.

MARINE ECOLOGY

$\delta^{13}C$ AND $\delta^{15}N$ REVEAL SIGNIFICANT DIFFERENCES IN THE COASTAL FOODWEBS OF THE SEAS SURROUNDING THE ISLANDS OF TRINIDAD AND TOBAGO.

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This study assessed near-shore, marine ecosystem function around Trinidad and Tobago. The coastline of Trinidad and Tobago is highly complex, bordered by the Atlantic Ocean, the Caribbean Sea, the Gulf of Paria and the Columbus Channel, and subject to local terrestrial runoff and regional riverine inputs (e.g. the Orinoco and the Amazon Rivers). Coastal organisms can potentially assimilate energy from a range of allochthonous and autochthonous sources.

We assessed whether stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) could be used to provide a rapid assessment of trophic interactions in primary consumers around the islands. Filter feeding (bivalves and barnacles) and grazing organisms (gastropods and chitons) were collected from 40 marine sites during the wet season and analysed for $\delta^{13}C$ and $\delta^{15}N$.

Results indicate significant variation in primary consumers (by feeding guild and sampling zone). This variation was linked to different energy sources being assimilated by consumers. Results suggest that offshore production is fuelling intertidal foodwebs, for example, a depleted $\delta^{13}C$ signature in grazers from the Gulf of Paria, Columbus Channel and the Caribbean and Atlantic coastline of Tobago indicates that carbon with an offshore origin (e.g. phytoplankton and dissolved organic matter) is more important than benthic or littoral algae during the wet season. Results also confirm findings from other studies indicating that much of the coastline is subject to cultural eutrophication.

This study revealed that ecosystem function is spatially variable around the coastline of Trinidad and Tobago and has clear implications for marine resource management, as a single management approach is unlikely to be successful at a national level.

MARINE ECOLOGY

CHARACTERISING MARINE FOOD WEBS USING COMBINATION OF C, N, AND S STABLE ISOTOPES, FATTY ACID BIOMARKERS, AND COMPOUND-SPECIFIC C STABLE ISOTOPE ANALYSIS: A CASE STUDY OF SUBTIDAL SAND-BOTTOM COMMUNITY

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Pelagic particulate organic matter, microphytobentos, or sedimentary detritus are usually recognized as the main food sources supporting marine near-shore benthic food webs. Recently, dual carbon and nitrogen stable isotope ratio analysis (SIRA) is used to distinguish relative contribution of pelagic versus benthic primary food sources. However, these sources are highly heterogeneous, and the relative importance and quality of their various components for benthic invertebrates, playing main part in benthic-pelagic coupling, remains unclear.

The aim of this study was to assess discriminatory power of multidimensional biomarker assay (combination of carbon, nitrogen and sulfur SIRA, trophic fatty acid marker analysis, and compound-specific carbon SIRA of fatty acid markers) to distinguish food sources available for particular macroconsumer species of temperate marine benthic community, where planktonic and benthic diatoms are dominating primary producers.

Sand-bottom community was sampled at 7 to 9 m water depth in open Vostok Bay (Sea of Japan) characterized by high production of microphytobenthos.

Dominating species of primary macroconsumers in studied community, even those belonging to the same trophic guild, showed significant interspecific differences in isotopic and/or fatty acid biomarkers and occupied their particular trophic positions in the food web in accordance with trophic niche differentiation and resource partitioning. In addition to the interspecies variations of carbon and nitrogen isotope markes, broad range of macroconsumer $\delta^{34}S$ values was recorded, despite obvious absence of ^{34}S-depleted primary producers. Correlations of bacterial fatty acid markers and macroconsumer $\delta^{34}S$ values suggest that microorganisms associated with the decomposition of organic matter in sediments are possible source of ^{34}S -depleted sulfur.

We used compound-specific carbon SIRA of individual fatty acids to identify algal sources of essential polyunsaturated fatty acids (PUFA) used by consumers. The fatty acid 20:5(n-3) was the main PUFA in diatom microalgae and showed significantly different $\delta^{13}C$ values in benthic and planktonic diatoms. The $\delta^{13}C$ analysis of this essential PUFA in lipids of various consumers allowed us to reevaluate the relative contribution of benthic versus planktonic microalgae to the benthic food web.

MARINE ECOLOGY

RESOURCE AND HABITAT UTILIZATION OF SOUTHERN OCEAN PENGUINS INFERRED FROM THE $\delta^{13}C$ and $\delta^{15}N$ VALUES OF AMINO ACIDS

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Spatial variation in the $\delta^{13}C$ and $\delta^{15}N$ values of marine predators can reflect geographical variations in the isotopic baseline and have been used to determine their habitat utilization. However, only a few studies have directly compared baseline and predator isotope values. Instead, baseline isotopic variation is inferred from oceanographic properties or measured proxies for the baseline. Previous work suggests that compound-specific isotopic analysis (CSIA) of individual amino acids (AAs) isolated from marine consumers can distinguish the isotopic value of the source of carbon or nitrogen at the base of the food web from the diet of the consumer. Thus, by analyzing a predator's $\delta^{13}C$ and $\delta^{15}N$ AA values, the predator's trophic level (resource utilization) and the baseline isotopic value (habitat utilization) could be determined.

Southern Ocean (SO) penguins could be ideal species to test the efficacy of CSIA to determine the ecological niche of marine predators. First, there are clear differences in the foraging strategies of four SO species: northern rockhopper (NRP), southern rockhopper (SRP), king (KP), and Adélie (AP) penguins. Their foraging ranges differ in extent, with some species foraging locally and others distantly. Second, the breeding colonies of these species encompass a large latitudinal range with large variations in baseline $\delta^{13}C$ and $\delta^{15}N$ values.

We analyzed the $\delta^{13}C$ and $\delta^{15}N$ values of individual AAs isolated from chick blood of these four SO penguin species. Based on our current knowledge, we developed 3 hypotheses: (1) NRP forage in the subtropical zone where baseline $\delta^{15}N$ values are higher than at the polar front and Antarctic zones. Since the $\delta^{15}N$ values of source AAs should reflect the isotopic baseline, its value should be greater in NRP than SRP, KP, and AP that forage at higher latitudes; we found that NRP was higher than SRP, but not higher than KP and AP. (2) KP forages at a higher trophic level than NRP, SRP and AP. As predicted, KP had the greatest difference between source and trophic transfer AA $\delta^{15}N$ values, indicating the highest trophic position. Using published data on the trophic level of these species, we back-calculated the TEF_{AA} for blood to be 3.5‰, which differs from the 7‰ literature value. However, the TEF_{bulk} between penguin blood and their diet is 1.7‰, instead of a TEF_{bulk} that approaches 3.4‰. Thus, similar to bulk isotope analysis, the TEF_{AA} depends on the tissue analyzed. (3) High-latitude marine ecosystems have lower baseline $\delta^{13}C$ values than subtropical regions. This latitudinal gradient was previously documented in the bulk $\delta^{13}C$ values of SO penguins. Both the essential and non-essential AAs $\delta^{13}C$ values of penguins decreased with increasing latitude, but there were no clear patterns between essential vs. non-essential AAs. Although this work leads to new insights on the application of CSIA to ecological studies, the results highlight the need for controlled experiments.

MARINE ECOLOGY

TROPHIC CONNECTIVITY OF ESTUARINE BIOTA ELUCIDATED BY STABLE ISOTOPE SIGNATURES OF CARBON & NITROGEN

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Scientists concerned with organic matter flow and food web structures in aquatic ecosystems are increasingly realising the potential of stable isotopes as natural tracers. Stable isotope techniques offer an accurate and cost effective way of understanding critical pathways of energy and pollutant transfer in aquatic environments. Here we present some examples from our ongoing research using stable carbon and nitrogen isotope ratios to define energy and nutrient sources and food web connectivity in coastal and estuarine ecosystems. Carbon and nitrogen stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) were measured in a variety of plant, invertebrate and fish species collected from Botany Bay and Sydney Harbour in New South Wales, Australia. These observations indicate that several distinct food chains exist within the complex trophic structure of estuarine food webs. No direct feeding relationship was evident between resident crabs and snails and the adjacent saltmarsh or mangrove communities. Due to the similar isotope values of crab larvae and copepods, the use of a two-source mixing model was unable to estimate the relative contributions of each of these major food sources to Glassfish (*Ambassis jacksoniensis*) diet. In comparing a common set of species collected contemporaneously from two markedly different estuaries, the $\delta^{15}N$ and $\delta^{13}C$ signatures did not vary significantly for the plants whilst the fauna from the polluted site were enriched with $\delta^{15}N$ and depleted with $\delta^{13}C$ compared to the nominal reference site.

MARINE ECOLOGY

MARINE FOOD WEBS

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Stable nitrogen ($\delta^{15}N$) and carbon isotopes ($\delta^{13}C$) are increasingly being used to structure marine food webs. The marine environment is inherently complex because species are often dispersed over large spatial scales and in several different habitats and potentially food webs (e.g., inshore, offshore, benthic, pelagic, deep water). Stable isotopes are especially adventitious in marine environments because they allow researchers to asses trophic relationships among a sub-sample of the total species present in an environment, as long as appropriate baseline organisms are chosen. However, the acquisition of baseline organisms (e.g., sessile filter feeders) for all potential habitats in a marine ecosystem is often logistically difficult, especially for deep water habitats. The combination of stable isotopes with additional tracers, such as mercury (Hg), could help validate results from stable isotopes when baseline organisms are difficult to obtain. Although log [Hg] has been consistently shown to increase linearly with $\delta^{15}N$ in aquatic organisms, any potential variability between $\delta^{15}N$ and log [Hg] within species (i.e. mercury and $\delta^{15}N$ data not suggesting similar trophic positions) could be informative concerning an individual's feeding behaviour. We utilized $\delta^{13}C$ and $\delta^{15}N$ to structure the food webs of sampled species from the waters surrounding Iceland and from Cumberland Sound, Nunavut, Canada. We then determined the ability of mercury to provide further resolution of food web structure by assessing $\delta^{15}N$ and log [Hg] within- and among- species sampled from these food webs. The waters about Iceland are deep and sub-Arctic, whereas Cumberland Sound is a relatively shallow water system constricted to the waters in the sound and is seasonally ice-covered, yet both support the same top predator, the Greenland shark, *Somniosus microcephalus*. Log [Hg] increased with $\delta^{15}N$ in the Iceland food web and both $\delta^{15}N$ and log [Hg] were highest in the Greenland shark, confirming our hypothesis that the shark was a top trophic level organism in the food web. One species, the deep water teleost *Lycodes frigidus*, had high $\delta^{15}N$ values that were inconsistent with other teleosts. Specifically, the $\delta^{15}N$ value of *L. frigidus* suggested a similar trophic position to that of Greenland sharks, but the lower mercury suggested that *L. frigidus* was feeding at a lower trophic position that more closely agreed with published diet information for this species. Therefore, the mercury provided a reason to suggest that the stable nitrogen isotope data were not reflecting the diet of this species and that the variability between $\delta^{15}N$ and log [Hg] could be a result of *L. frigidus* feeding in a different food web with different baseline isotope values. Our results indicate that the inclusion of additional tracers, like mercury, aid in the correct interpretation of stable isotope data and that comparing results from multiple tracers and between environments provides a way to increase confidence that results from tracers are representative of what is actually occurring in the environment.

MARINE ECOLOGY

SPATIAL AND TEMPORAL VARIATION OF STABLE ISOTOPES SIGNATURES OF MARINE FISHES IN THE COASTAL WATERS OF SOUTHEASTERN BRAZIL

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This study addressed the effect of season, habitat, and feeding habits on the stable isotope signatures of demersal fish species of the coastal area of Santos (SP). Samples of 42 fish species (n = 454 composites) and bivalves (n = 25) were collected in Santos Bay (~10m) and in two depth stratum (~30m and ~75m) of the continental shelf, during Sept/2005 (late winter) and Feb-Mar/2006 (summer). According to the main preys identified in the stomach content, those species were pooled into four trophic groups: zooplanktivores, benthivores, piscivores, and teuthophagous. The trophic level (TL) of each species was calculated as follow: $TL_{fish} = [(\delta^{15}N_{fish} - \delta^{15}N_{bivalve}) / 3.4] + 2.5$.

The mean $\delta^{13}C$ of individual species varied from -19.18 ‰ to -15.69 ‰ and that of $\delta^{15}N$ from 9.99 ‰ to 14.17 ‰. The trophic level of the species ranged from 3.1 to 4.3.

In both seasons the mean $\delta^{13}C$ signatures of fish (groups pooled) decreased slightly with depth. This pattern was more consistent in the benthivore group and may be reflecting the major contribution of the more enriched benthic microalgae to the coastal food web. Comparison among trophic groups within the same habitat and season resulted in no significant differences

During the winter, fish (pooled) from the bay and the shallower area of the shelf were more enriched in $\delta^{15}N$ than those from the deeper shelf; however no difference among habitats was observed during the summer. This result is probably associated to different sources and abundance of nitrogen entering the food web in both periods. The Santos Bay is a eutrophic environment, receiving nutrients from the Santos and São Vicente estuaries all over the year. The waters of the continental shelf present oligotrophic conditions during winter, however, during late spring and early summer the euphotic zone can be nutrient enriched by the intrusion of the cold South Atlantic Central Water (SACW) toward the coast. During winter, the phytoplankton production is supported by recycled ammonia while during spring-summer by new nitrate introduced in this system via upwelled SACW in addition to the run-off contribution increased by rainfall.

Piscivores were expected to be more enriched in ^{15}N than zooplanktivores and benthivores but with few exceptions the mean $\delta^{15}N$ of different trophic groups were very similar in the same habitat and season. This may be related to ontogenetic changes on the diet since some zooplanktivore species increase the consumption of fish as they grow and some piscivores feed also on zooplankton when younger. Piscivores that prey on benthic fish may be feeding on small specimens that feed in low trophic level $\delta^{15}N$ signatures similar to those of benthivores.

MARINE ECOLOGY

BODY SIZE AND δ ^{15}N RELATIONSHIP OF MARINE FISH ON THE COASTAL WATERS OFF SOUTHEASTERN BRAZIL

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Nitrogen stable isotope natural abundance has been a valuable tool in trophodynamic researches and is also used to indicate the trophic position of organisms in the food web. However, some species may change their diet as they grow, shifting their trophic level. To investigate this relationship, the δ ^{15}N signatures and stomach content of fish have been analyzed, according to body size.

Fish were collected during two otter trawl surveys carried out in the bay (8.9 ~ 11 m) and continental shelf (19.8 ~57 m) off Santos (SP), Southeastern Brazil, in September 2005 and February 2006. Each sample was a composite of white muscle from 1~10 specimens per total length classes (30, 50 or 100 mm), and whenever fish were available, replicates were obtained. Stable isotope analyses were carried out at the "Stable Isotope Facility", University of California, USA. The sable isotope signatures were obtained for 30 demersal fish species. In order to minimize temporal and spatial variability samples of bay and continental shelf were analyzed separately, taking into account the time of sampling. A regression analysis was performed between δ ^{15}N and mean body length (mm) of the individuals used in the composite.

The proportion of species that showed positive correlation between δ ^{15}N values and mean body length ($p < 0.05$) were 71% and 60% in Santos bay, and 58% and 89% in the continental shelf, in September and February, respectively. The δ ^{15}N enrichment in bigger fish might be related to the shift in prey type, from organisms belonging to low trophic position to those with higher position in the food web; or to the ingestion of bigger specimens of the same prey that also may present increasing trophic position with size. The low correlation observed in some species may be resulted from predators of different body sizes feeding on the same trophic level, or the size classes of our samples were not representative of the size in which shift in diet takes place.

MARINE ECOLOGY

TROPHIC ECOLOGY OF THE MEDIO-LITTORAL ROCKY SHORE IN THE BAY OF BANYULS-SUR-MER (NORTHWEST MEDITERRANEAN, FRANCE)

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The stable isotope approach has been used to assess trophic relationships in a northwest Mediterranean medio-littoral rocky shore. $\delta^{13}C$ and $\delta^{15}N$ were determined for the main potential sources of organic matter and their macro-invertebrate consumers. Three sources were considered: the macroalgae, the suspended particulate organic matter (SPOM) and the biofilm. Stable isotopic ratios of animal tissues are related to those of their foods and can be used to infer food sources of consumers. The trophic position of invertebrate species was consistent with their presumed diets. Mytillus galloprovincialis was enriched in ^{13}C and in ^{15}N (-18.87‰ and 5.31‰, respectively) and was closely linked to the isotopic composition of SPOM (-22.24‰ and 4.24‰). The two species of limpet (*Patella rustica* and *Patella aspera*) were the most ^{13}C-enriched (-12.11‰ and -11.32‰) suggesting they mainly feed on biofilm. *P. aspera* was more ^{15}N-enriched than *P. rustica* (5.88‰ and 3.55‰, respectively), which indicates that *P. aspera* also consumes sprout of macroalgae although both species occupy the same level in the rocky shore. The third group of consumers was composed of the three anemonia species. *Actinia equina* showed the highest $\delta^{15}N$ values (7.27‰) reliable with its known predator behavior. *Anemonia sulcata* and *Aiptasia mutabilis* contain symbiotic microalgae in their tissues, which is consistent with their lower trophic position. The last group was composed of the sea urchins *Paracentrotus lividus* and *Arbacia lixula*. $\delta^{13}C$ values for sea urchins suggested that macroalgae was their main sources of food. Laboratory observations confirmed their preference for calcareous algae. However, *P. lividus* was more ^{15}N-depleted than *A. lixula*, which could be explained either by the assimilation of biofilm or the presence of diazotrophic microorganisms into the gut. Our study highlighted that distinct trophic pathways exist between the different sources of organic matter and the main benthic invertebrates in a Mediterranean medio-littoral rocky shore. The lack of consistent ^{15}N-trophic enrichment observed between primary consumers and their food, especially for the sea urchin *P. lividus*, indicated that $\delta^{15}N$ values of algae cannot be used as a suitable baseline to estimate the consumers' trophic levels. Rocky shore of Mediterranean Sea is a zone exposed to human perturbations and the knowledge of trophic relationships between organisms is essential for future studies on nutrient and contaminant transfers.

MARINE ECOLOGY

EVOLUTION OF THE TROPHIC STRUCTURE OF A COASTAL ANTARCTIC FOOD WEB DURING PACK ICE BREAK-UP

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In Antarctic marine ecosystems, food web dynamics are inextricably linked to sea ice conditions that affect the nature and magnitude of primary food sources available to higher trophic levels. The potential for receding sea ice associated with climate change highlights the need to develop a predictive understanding of how marine ecosystems will change with changes in sea ice distribution and thickness (Clarke & Harris, 2003; Smetacek & Nicol, 2005). This requires a good understanding of ecosystem structure and function and how it relates to environmental drivers.

This study investigated the relative importance of the multiple primary food sources (including phytoplankton, sea ice algae, microphytobenthos, and particulate organic matter) in the food web during different periods of sea ice cover in coastal Antarctica at the French base Dumont D'Urville. Stable isotope ratios of carbon and nitrogen were measured for the different potential primary food sources and for three suspension feeder species (two bivalves and an ascidian) before, during and just after the pack ice breaking up (from December 2007 to February 2008). For the two bivalve species, two organs were chosen: muscle and digestive gland, the first one present low turnover and the second one higher turnover.

The mass balance model IsoSource (Phillips & Gregg, 2003) was chosen to assess the different primary food source assimilated by the three species during the different periods of the study. Our results allow us to provide a basis for understanding the links between the ice cover and the benthic food web in Antarctica.

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MARINE ECOLOGY

DIET AND NUTRITION OF WESTERN ROCK LOBSTERS, *PANULIRUS CYGNUS*, IN SHALLOW COASTAL WATERS: THE ROLE OF HABITAT

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Generalist consumers often have diets that vary considerably over time and space, which reflects changes in resource availability. Predicting diets of consumers can therefore be difficult. The western rock lobster, *Panulirus cygnus*, is an omnivorous generalist consumer that uses limestone patch reefs as shelter during that day but adjacent habitats to forage at night. These patch reefs and adjacent habitats such as seagrass beds, sand and macroalgae-dominated pavement form a heterogeneous landscape in shallow (<20m) coastal waters of the lower west coast of Australia. Potentially, the habitat surrounding these patch reefs may be a good predictor of diet for these lobsters.

The aim of this study therefore was to determine if surrounding benthic habitat influenced the diet of *P. cygnus* from shallow water reefs. We used stable isotopes ($\delta^{13}C$ and $\delta^{15}N$) to enable us to elucidate long-term trends in diet and also to reveal information on the nutritional role of food sources. Using distance-based redundancy analysis, we compared habitat related variation in diet with the influences of site, month, sex and size (carapace length). We used a modified mass balance mixing model (IsoSource) incorporating the concentration weighting principles of IsoConc to investigate important food sources from a number of potential sources.

Habitat explained a significant level of variation in the diet of *P. cygnus* (>50%), far greater than any of the other potential influences examined (<20%). The diet of lobsters from macroalgae-dominated pavement and sand habitat differed from that of lobsters from seagrass (*Amphibolis spp.* or *Posidonia spp.*) habitat. Articulated coralline algae were more prominent in the diet of lobsters from macroalgae-dominated pavement and sand habitat. The assimilation of coralline algae nutrients into muscle tissue suggests that this food source can be used for muscle maintenance as well as for supplying Ca for shell maintenance. Mixing model data suggested that mobile invertebrate prey in particular were important for tissue maintenance in *P. cygnus*. Seagrass is unlikely to be an important food source but is an important habitat for invertebrate prey. Previous research has shown growth to be positively linked to increased consumption of invertebrate prey by *P. cygnus*. Thus lobsters from seagrass habitat may grow faster than those from macroalgae-dominated pavement and sand habitat, where coralline algae appear to be more important to diet.

MARINE ECOLOGY

A NOVEL APPROACH TO MONITORING CHANGES IN THE DIET OF LACTATING MOTHERS THROUGH ISOTOPIC ANALYSIS OF YOUNG STELLER SEA LION VIBRISSAE

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Although it is critical to understand the dietary patterns of adult female Steller sea lions for the development of sound fisheries management policy, the capture of adult females for research purposes remains logistically difficult and is currently prohibited under US Marine Mammal Protection Act permits. Fortunately, underwater capture techniques have significantly improved our ability to capture young Steller sea lions up to the age of 3 years. Steller sea lion pups are born with developed vibrissae, thus the tip represents in-utero growth, and reflects the maternal diet during this period of fetal development. While young sea lions are maternally dependent, vibrissae carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) signatures directly reflect the ingested milk diet (with a 2.0‰ and 2.5‰ enrichment in ^{13}C and ^{15}N, respectively; Stegall et al. 2008), and thus can be used to infer diet of lactating females at the time of milk production.

Strong seasonal changes in the ^{13}C and ^{15}N profiles of pup vibrissae in Southeast Alaska (SEA; n=25) and Prince William Sound (PWS; n=15) suggest that adult females switch to a higher trophic level diet (with a resulting 1.8 to 4.3 ‰ enrichment of ^{15}N, mean 2.6 ± 0.6‰) after they leave the breeding rookeries on the outer coast to continue raising pups at more inshore haulout locations. This pattern closely reflected changes in the C/N profile of ingested milk samples collected from pups and juveniles 2 to 17 months of age (SEA n=27; PWS n=19). Fatty acid signature analysis performed on ingested milk samples collected in SEA (n=49) and PWS (n=16) also supports the contention that lactating females changed diet seasonally, regardless of location. These results suggest that stable isotope analysis of vibrissae collected from young sea lions can provide a timeline that will allow us to evaluate changes in diet for reproductively active adults from different regions and for times of the year where scat diet analysis is not feasible.

MARINE ECOLOGY

NUTRITIONAL STATUS OF SAN FRANCISCO BAY HARBOR SEALS BY ASSESSING δ ^{13}C AND δ ^{15}N AMINO ACID PATTERNS

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San Francisco Bay (SFB) harbor seal populations have remained stagnant or decreased slightly since the Marine Mammal Protection Act was passed in 1972, and has yet to reach maximum population capacity predicted for this region. Hypotheses as to why this population has not increased in this location include human disturbance, contaminants leading to lower reproduction rates through immunosuppresion and disease, and decreased survival rates or fecundity due to reduced prey availability or quality. Isotope analysis has been used extensively in ecological studies for decades, generally focusing on diet and trophic information. However, with the advent of gas chromatography-combustion-isotope ratio mass spectrometry (GC/C/IRMS), it is now possible to use the isotopic shifts in targeted biochemicals to explore nutritional state and dietary patterns.

We are exploring a novel compound-specific isotope approach ($\delta^{13}C$ and $\delta^{15}N$ on amino acids) to understand the nutritional and physiological states of marine mammals. We have used this method in a pilot project to test whether or not the isotopic patterns of amino acids in blood samples (SFB harbor seal population; *Phoca vitulina*) can be linked to nutritional stress due to lack of prey, changes in prey items, metabolic trauma from pollutants, or other factors. We first present isotope pattern data from 'healthier' seal populations in the Channel Islands and Tomales Bay, in order to investigate AA-isotope patterns as indicators of nutritional status and level of trophic feeding. We next compare these patterns to those from both SFB seals, as well as deceased and rehabilitating harbor seals (from the Marine Mammal Center) to explore extreme effects of catabolic vs. anabolic states. Bulk isotope analysis suggest differences among pups and yearlings (less than a year in age) vs. adult seals in SFB and Tomales Bay. Preliminary compound-specific amino acid results also indicate potential dietary stress (low $\delta^{15}N$ threonine and high glutamic acid) and lower trophic level feeding (2.5 vs. 3.0) in these younger populations.

MARINE ECOLOGY

STABLE ISOTOPE ANALYSIS OF SOME REPRESENTATIVE FISH AND SQUIDS OF A SUBTROPICAL CONTINENTAL SHELF FOOD WEB, SOUTHWESTERN ATLANTIC

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The Ubatuba (23°30'S 45°06'W) shelf system, southeastern Brazil, is under a intermittent input of relatively cold water of the South Atlantic Central Water (SACW) during the year. Inputs increase during spring and summer.

To verify if the flow regimes lead to temporal changes in the food web, we used stable isotope of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) to analyze trophodynamics of fish and squids, which were sampled during two cruises carried out during the colder (July 2001) and warmer (February 2002) seasons, between 30 and 100 m depth. Thirty-five fish species and two squid species were collected, adding up to 59 (July) and 71 (February) composite samples.

Isotope signatures of fish ranged from 9.63‰ to 14.51‰ for $\delta^{15}N$, and from –20.72‰ to -15.33‰ for $\delta^{13}C$. For the squids the range was 11.30‰ to 12.83‰ for $\delta^{15}N$, and –18.90‰ to -18.17‰ for $\delta^{13}C$. The higher average values of $\delta^{15}N$ and $\delta^{13}C$ were observed, in general, in July.

The trophic level (TL) of each species was calculated according to Jennings et al (2002; Mar. Biol., 141:1085-1097) equation ($TL = [\delta^{15}N \text{ species} - \delta^{15}N \text{ bivalve})/3.4] + 2.5$), considering $\delta^{15}N$ (7.02‰) of the suspensivore bivalves (n=7) (Corbisier, 2006; writing com.). TL ranged from 3.3 (secondary consumer) to 4.5 (tertiary consumer). In general, piscivores showed higher values.

Temporal comparison of the isotope values was made among eight trophic groups: zooplanctivores (n=1); zooplanktivore and piscivores (n=7); benthic feeders, mainly crustaceans (n=3); benthic feeders, mainly polychaetes (n=6); benthic feeders and piscivores (n=13); pelagic piscivores (n=2); benthic piscivores (n=3); bentho-pelagic piscivores (n=2). The average values of the trophic groups ranged from 11.29‰ to 14.51‰, and from –18.53‰ to -16.05‰ for $\delta^{15}N$ and $\delta^{13}C$, respectively. Higher values occurred in July than in February for $\delta^{15}N$ (n=6) or for $\delta^{13}C$ (n=5). Zooplankton $\delta^{13}C$ value was somewhat enriched in July, and sediment and zooplankton showed higher $\delta^{15}N$ values, suggesting higher values at the base of the food web in that month, although the particulate suspended matter value was lower.

These changes are probably associated to the seasonality of the oceanographic conditions and to the input of new nitrogen by the intrusion of the cold SACW. During warm months of the year, the new production is enhanced by the injection of NO_3^- in the euphotic layer. During the cold months, regenerated primary production based on biological recycling of nitrogen (NH_4^+) is produced. Therefore there is circumstantial evidence that there might be a link among these processes.

MARINE ECOLOGY

TROPHIC RELATIONSHIPS AND CARBON FLOW IN THE SCOTIA SEA FOOD WEB

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The Scotia Sea is one of the most productive regions in the Southern Ocean, comprising high-nutrient-low-chlorophyll open ocean areas as well as productive shelf areas. It is also downstream of the Antarctic Peninsula, one of the fastest warming areas on the planet. In time these temperature changes are expected to have an impact on the structure of species interactions in the Scotia Sea food web. It is therefore necessary to first understand the major trophic routes in this ecosystem to be able to predict the magnitude of the effect environmental perturbation will have on this system in the future.

The trophic position of the key species (n = 33) in the Scotia Sea was investigated using carbon and nitrogen stable isotope tracers. Species chosen ranged from particulate organic matter, across primary consumers such as herbivorous copepods to euphausids, salps and pelagic fish and the higher land-based predators such as fur seals, penguins and flying birds. To investigate spatial variation in trophic interactions samples for the pelagic species were furthermore chosen from four noticeably different locations: the ice edge, a low and a high productivity regime in South Georgia waters and the Polar Front.

Although a wide range of carbon and nitrogen values was found across all species, overlap existed between species at individual stations suggesting common food sources. The majority of marine species showed similar nitrogen and carbon values between the ice-edge station and the high-productivity station and between the polar-front station and the low-productivity station respectively. Furthermore ranges of nitrogen ratios between species were narrower at the ice edge and the high-productivity station, suggesting that prey diversity was lower in these locations and more species fed on similar trophic levels. Overall the largest arrays in nitrogen values within species were found in the flying birds, indicating a more varied diet or possibly wider feeding ranges.

MARINE ECOLOGY

USING STABLE ISOTOPES OF CARBON ($\delta^{13}C$) AND OXYGEN ($\delta^{18}O$) TO DIFFERENTIATE WINTER FLOUNDER NURSERY AREAS

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Elemental fingerprinting has become a powerful tool in fisheries science for identifying fish migration patterns, seasonal changes in habitat use, and for delineating the nursery origins of adult fish populations. In this study we investigated the temporal variability in isotopic signatures of oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) in fish otoliths and whether these signatures could be used as natal fingerprints for juvenile winter flounder (*Pseudopleuronectes americanus*) populations.

Juvenile winter flounder (45-65mm) were collected (2002-2004) from different locations and habitats (unvegetated, macroalgae, and eelgrass) within Narragansett Bay, RI (USA), surrounding coastal ponds, and from a tidal river system. Sagittal otoliths were removed from the vestibular apparatus, cleaned under a laminar flow hood, and analysed for $\delta^{18}O$ and $\delta^{13}C$ using a ThermoFinnigan MAT Delta Plus XL Mass Spectrometer connected to a Gas Bench II carbonate device.

Mean $\delta^{18}O$ values in juvenile Winter flounder otoliths ranged from -0.75 ± 0.14 to -4.83 ± 0.35 ‰ among nursery areas. Salinity measurements were relatively constant from year-to-year at each of the stations. There were significant positive correlations between salinity and mean $\delta^{18}O$ values in otolith carbonate for each year (2002: r=0.93; 2003: r=0.80; 2004: r=0.97). Stable isotopes of oxygen in otolith carbonate were more depleted at sites with freshwater inputs compared to sites having higher salinity. Our results suggest that differences in $\delta^{18}O$ were correlated with salinity rather than temperature.

Measured $\delta^{13}C$ values in juvenile winter flounder otoliths followed a similar trend year-to-year at each of the stations and ranged from -3.87 ± 0.70 to -0.44 ± 0.33 ‰. Fish collected from sites receiving more terrestrial and anthropogenic inputs had the lowest $\delta^{13}C$ values. In comparison, fish collected from sites dominated by more marine sources of carbon had the highest $\delta^{13}C$ values. It is unclear what sources (diet, temperature, metabolic rate, or dissolved inorganic carbon) were responsible for the differences in $\delta^{13}C$ values in otolith carbonate. We speculate that the carbon isotopic composition was derived from the dissolved inorganic carbon of the water or food sources at each of the stations. Based on these results, $\delta^{18}O$ and $\delta^{13}C$ values in otolith carbonate may help differentiate juvenile winter flounder nursery areas.

MARINE ECOLOGY

DIET AND STABLE ISOTOPE ANALYSIS OF THE FISH *RANEYA BRASILIENSIS* ON CONTINENTAL SHELF OFF SOUTHEASTERN BRAZIL

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Understanding changes in food web structure is a fundamental component of ecosystem management. Stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes were employed to access the trophic dynamic of Raneya brasiliensis (Ophidiidae), an abundant fish species of the shelf community off southeastern Brazilian coast. Stomach content analysis was made for access the diet composition. Samples were collected during two cruises carried out during the colder (July 2001) and warmer (February 2002) seasons, between 30 m (inner) and 100 m (outer) depth on the continental shelf off Cabo Frio (22°89S- 42°02W) and Ubatuba (23°43S-45°07W), adding up to 16 composite samples for the isotopic analyses, from specimens ranged from 73 mm to 307mm in the total length.

Average signatures of $\delta^{13}C$ and $\delta^{15}N$ were almost similar in Cabo Frio shelf as well as in Ubatuba shelf. In Cabo Frio, ranging from –16.02 to -17.71‰ for $\delta^{13}C$, and from 12.92 to 13.77‰ for $\delta^{13}N$, in inner and outer shelf, respectively. And in Ubatuba the values ranged from –16.02 to -17.71‰ for $\delta^{13}C$, and from 11.28 to 11.20‰ for $\delta^{13}N$.

The observed seasonal and geographic variations could be associated to the upwelling dynamics during the warmer months, when there is an input of cold water to the inner shelf. The trophic level (TL) was calculated according to Minagawa & Wada (1984; Geochim. Cosmochim. Acta, 48:1135-1140) modified equation (TL= [(δ^{15}Nfish - δ^{15}Nzooplankton) /3.4] +2). TL showed some variation depending on the location and season. It ranged from 3.14 (inner) to 3.56 (outer) in the Ubatuba shelf, and from 3.06 (inner) to 3.85 (outer) in the Cabo Frio shelf. It ranged from 3.56 to 2.82 in Ubatuba and from 2.85 to 3.79in Cabo Frio in the warmer and colder season, respectively. The observed values characterize the species as a secondary consumer.

The diet was composed of Polychaeta, Ophiuroidea, Mollusca, Crustacea and Teleostei. It was observed seasonal and geographic variation in the composition. Based on the diet and $\delta^{15}N$, we could trace the food web of the study species, the main prey showing lower $\delta^{15}N$ (Corbisiser, 2006; writing com.), and the main predator, Blackfin goosefish (*Lophius gastrophisus*) (Pucci, 2003; writing com) more enriched $\delta^{15}N$.

BIOGEOCHEMICAL CYCLING

SOIL AND PLANT $\delta^{15}N$ AS INDICATOR FOR WILDFIRE EFFECTS IN A NOTHOFAGUS – ARAUCARIA ECOSYSTEM IN SOUTHERN CHILE

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Pristine temperate rain forests in southern Chile are considered as biodiversity hot spots. However, (natural) wildfires can threaten these ecosystems. Between December 2001 and February 2002 ca. 20.000 ha of the Parque Nacional Tolhuaca (38º10'S, 71º40'W to 38º15'S, 71º50'W at ca. 1.200 m a.s.l.) in southern Chile was affected by a severe, stand removing, wildfire. The temperate rainforest that has been affected was dominated by endemic tree species such as Araucaria araucana (Mol) K. Koch and Nothofagus sp.

It has been suggested that heavy ecosystem disturbances (e.g. wildfire, clear cut) results in increased foliar and soil $\delta^{15}N$ values, due to losses of depleted N in the form of N oxides during the fire and post fire nitrate leaching. Moreover fire is affecting soil organic matter quality (C:N ratio, polyphenol content,…) potentially influencing soil N processes. It has further been hypothesised that these changes in N cycle patterns will, in short-term, feed back on foliar $\delta^{15}N$ development and, in the long-term, on soil $\delta^{15}N$ profile development (Högberg, 1997).

We selected tree plots (20 x 50 m) in the burned and unburned part of the Parque Nacional Tolhuaca. The burned plots were (so far) sampled 1.5, 2.5, 4.5 and 6 years after the wildfire. Soil $\delta^{15}N$ profiles, foliar $\delta^{15}N$, species regeneration rates and nitrate concentrations in river discharge were measured. The unburned plots were sampled to establish control $\delta^{15}N$ and nitrate data, and to carry out an artificial burning experiment in the laboratory to verify whether soil $\delta^{15}N$ values from the burned plots could be reconstructed via combinations of different burn durations and temperatures. Finally, we also measured gross N transformation rates form the burned and unburned sites using ^{15}N isotope dilution.

The average $\delta^{15}N$ value for 12 plant species in the unburned site was -5.7 ± 3.0‰, while foliar $\delta^{15}N$ remained significantly enriched in the burned site (-0.2 ± 1.9‰ for our last campaign in March 2008, 6 years after the fire). Nitrate concentrations in river water discharging from the burned site were ca. 3.5 mg NO_3^--N L^{-1} immediately after the wild fire and reached background concentrations (< 10 µg NO_3^--N L^{-1}) 3 years after the fire. Moreover, fire intensified gross NO_3^- and NH_4^+ turnover. Soil $\delta^{15}N$ profiles became enriched (up to 4‰) in the top 20 cm and did not yet return to values observed in the unburned area. The shift in soil $\delta^{15}N$ enrichment could be linked to fire intensity of the different selected pots via plant regeneration data and verification via artificial burning experiments (the latter being analyzed at the time of finalizing this abstract).

In conclusion, we claim that soil and plant $\delta^{15}N$ values can provide valuable information on wildfire intensity and ecosystem resilience upon wildfire damage.

BIOGEOCHEMICAL CYCLING

NEW ISOTOPIC EVIDENCE OF FUNGAL NETWORKING IN THE PLANT TRIBE PYROLEAE (ERICACEAE)

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Historically it has been thought that the primary limiting factor for plant establishment in understories of temperate forests is light availability. For understory plants to establish and compete for light they have evolved numerous aboveground traits including: slow growth, expansion through clonal reproduction, and evergreen leaves for year-round photosynthesis. However, an additional, yet less studied factor that may play a key role in understory plant establishment and competition is carbon transfers from surrounding plants via shared mycorrhizal fungi. Mycorrhizal fungi are normally thought to facilitate plant nutrient uptake in exchange for carbon derived from photosynthesis. This exchange is usually mutually beneficial, but some non-photosynthetic plants, known as myco-heterotrophs, have evolved to cheat this symbiosis and act as a carbon sink, tapping into carbon assimilated by trees via shared mycorrhizal fungi and thus avoid light limitations. Recently it has been shown that even some green plants exploit mycorrhizal fungi to fulfil their carbon demands. These plants are referred to as mixotrophs and are thought to be an ancestral state to myco-heterotrophy. If mixotrophy is a geographically and phylogenetically widely distributed adaptation in understory plants this would fundamentally change our current understanding of the factors that influence plant community structure.

Members of the Monotropoideae, a nonphotosynthetic subfamily of the Ericaceae, provided the first example of fully myco-heterotrophic plants, and many orchids provide additional prime examples of myco-heterotrophs and mixotrophs. Using the stable isotopes of C and N as food-web tracers, the goal of this study was to investigate the mixotrophic and myco-heterotrophic abilities of plants within the tribe Pyroleae (Ericaceae). We chose to focus on this group of common understory plants as it potentially contains species across the myco-heterotroph-autotroph spectra and is a sister group to tribes containing solely myco-heterotrophic plants.

Samples of two green and one non-photosynthetic Pyroleae species, along with autotrophic and known myco-heterotrophic plants were collected from throughout California and analyzed for their stable isotopes of both N and C. Enrichment factors of the Pyroleae species were calculated on a site-by-site basis using the surrounding autotrophic plants as references. These enrichment factors were then tested for significant difference from autotrophic and myco-heterotrophic species using a nonparametric Bonferroni-corrected Mann-Whitney U test. The results revealed a new example of myco-heterotrophy within the Ericaceae and that both green species of Pyroleae access a N source significantly distinct from autotrophs and most similar to myco-heterotrophic plants, supporting the potential for mixotrophy outside the orchid family.

BIOGEOCHEMICAL CYCLING

THE OXYGEN ISOTOPIC SIGNATURE OF BIOGENIC NITROUS OXIDE IS DETERMINED BY H_2O THROUGH OXYGEN EXCHANGE

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In order to derive accurate budget estimations and effective mitigation strategies for the greenhouse gas nitrous oxide (N_2O), it is essential to identify the processes involved in its production. Analyses of the isotopic composition of N_2O are increasingly used to characterize the importance of these processes. However, we argue that the reliability of results based on oxygen (O) isotopic analysis of N_2O may be questioned due to insufficient consideration of O exchange between H_2O and nitrogen oxides.

We studied the process of O exchange in 12 widely varying soils using a novel combination of ^{18}O and ^{15}N tracing experiments. Incorporation of O from ^{18}O-enriched H_2O into N_2O exceeded theoretical maxima based on reaction stoichiometry, revealing the presence of O exchange. Novel methodology based on the retention of the ^{18}O:^{15}N-enrichment ratio of NO_3^- in N_2O allowed to quantify O exchange during denitrification: up to 97% of N_2O-O originated from H_2O instead of NO_3^-.

Our results show that in soil, the main source of N_2O, the conventional assumption that the O isotopic composition of N_2O is determined by reaction stoichiometry and isotopic fractionation during its production does not hold. In all cases, the O isotopic signature of N_2O was found to be dominated by the effect of O exchange between nitrogen oxides and water. We speculate that the implications of O exchange will extend across terrestrial and aquatic ecosystems, and possibly to other nitrogen oxides as well. Especially, a potential effect of O exchange on the O isotopic signature of NO_3^- needs to be studied, as this is routinely used for NO_3^- source determination. Our results may facilitate the development of improved methodology to study and understand the global N cycle.

BIOGEOCHEMICAL CYCLING

NET N MINERALIZATION AFFECTS ^{15}N NATURAL ABUNDANCE OF THE SOIL MICROBIAL BIOMASS

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The soil microbial biomass (fungi and bacteria) is the key regulator of nitrogen (N) availability to primary producers in natural systems. As soil organic matter is decomposed, the products of N mineralization, NH_4^+ and NO_3^-, may be assimilated by the soil microbial biomass or released into the soil mineral N pool. Microbial assimilation and mineralization are processes that lead to N transformations and the movement of N between soil N pools, during which kinetic and equilibrium fractionation occurs. We propose that: 1) microbial and extractable N pools have distinct and dynamic $\delta^{15}N$ signatures, 2) during mineralization ^{14}N is preferentially exported from microbial cells, 3) high rates of net N mineralization cause an increase in microbial ^{15}N enrichment.

We conducted field and lab experiments with soils from grass dominated ecosystems along an elevation gradient in northern Arizona. We measured net N mineralization over an annual cycle under field conditions and during a one month laboratory incubation. ^{15}N natural abundance of soil microbial and extractable N pools were measured and compared to the relative rates of net N mineralization.

A change in the $\delta^{15}N$ values of microbial and extractable N pools was observed within a one month period. The $\delta^{15}N$ signature of the microbial biomass increased significantly when net N mineralization was high, but remained stable when net N mineralization rates were low. These results support our hypothesis that during mineralization, microbial cells preferentially retain the heavier N isotope and export lighter N, which accumulates in the extractable N pool.

BIOGEOCHEMICAL CYCLING

MULTIPROXY ISOTOPE ANALYSIS SHOWS ANAEROBIC OXIDATION OF METHANE IN HIGH ALPINE LAKE SEDIMENTS

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Owing mainly to anthropogenic production, atmospheric methane concentrations have doubled from 850 ppb to approximately 1750 ppb over the last 150 years. A significant proportion of the methane emitted to the atmosphere is of natural origin (30%); however, this number is not well constraint and recent publications hint to lakes as an overlooked source of methane emissions. In ocean sediments anaerobic oxidation of methane (AOM), beside gas hydrate formation, generally hinders its release from the seafloor, since methane is almost quantitatively converted to bicarbonate. Whereas the process of AOM has been shown in marine sediments and seep areas and the key organisms have been identified (Boetius et al. 2000) almost nothing is known from lake sediments (e.g. Eller et al. 2005).

We have used organic geochemical, isotopic, and molecular tools to evaluate AOM in sediments of Lago di Cadagno (Ticino/Switzerland). A 30 cm sediment core was taken at around 20 m water depth. A clear sulfate/methane transition zone was seen at approximately 7 cm with a one to one relationship between both. Hydrogen sulfide did also increase from almost zero to 600 µM above 12 cm sediment depth. The carbon isotopic composition of methane ranged from -70 ‰ VPDB at the sediment bottom to the uppermost 7 cm where a strong increase of ^{13}C values up to -40 ‰ VPDB was observed. This hints to a strong methane oxidation in the top sediment layers.

Archaeal 16S rRNA gene analysis resulted in 6 different phylogenetic groups. Sequences affiliated with the known groups of anaerobic methanotrophs (ANME 1-3) could not be retrieved, however, a group of sequences distantly related with ANME-2 was detected. This group also includes sequences from freshwater archaea which form aggregates with bacteria and couple AOM to nitrate reduction (Raghoebarsing et al. 2006). Initial in situ analysis with highly specific probes showed the presence of this archaeal group in sediments of Lago di Cadagno. The cells form aggregates ($<1 \times 10^6$ aggregates cm-3) apparently without having any bacterial partner.

Our research clearly shows that AOM is not only restricted to marine settings but occurs also in lacustrine sediments where it hinders the methane to be transported into the water column and further to the atmosphere.

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RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

APPLYING STABLE ISOTOPE ANALYSES OF EXTANT TAPIRS TO CONSTRAIN PALEOECOLOGICAL HYPOTHESES

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Understanding the paleoecology of forested environments is critical to comprehending the context of mammalian evolution, particularly of forest dwelling taxa. In order to understand the ecology of ancient forests it is first necessary to elucidate the source and extent of stable isotope variation in forest taxa. Tapirs are of particular interest because they are potential model organisms for identifying forested environments as they are highly conservative in diet, habitat preference, and migratory behavior. Here, I document carbon and oxygen isotope variation in extant tapirs at the individual and population level, assess if small sample sizes can yield reliable estimates of population means, and determine how extant tapirs track carbon and oxygen isotopes in areas with different climatic parameters (e.g. temperature, precipitation).

Extant tapirs (*Tapirus bairdii*) from Acapulco, Mexico (collected in 1873-1874) were sampled for stable isotopes in order to quantify dietary variation and potential ontogenetic dietary shifts. Ontogenetic diet shifts demonstrate that $\delta^{13}C$ values of late erupting teeth are significantly greater (1.5‰ to 1.7‰) than the early erupting M^1 ($p<0.001$ for M^1-P^4 and M^1-M^3). This indicates that juvenile tapirs are consuming ^{13}C deplete milk and/or consuming browse in the denser canopy, as compared to average adult diets. $\delta^{18}O$ values do not show this same pattern, with M^1 and P^4 teeth sharing identical means (-5.8‰). Instead $\delta^{18}O$ values of P^4 and M^3 teeth are significantly different from each other (difference of 0.5‰, $p<0.05$), likely reflecting seasonal differences due to their chronological eruption timing. Additionally, dietary variation at the population level is low with $\delta^{13}C$ variation of 2.2, 2.3, and 2.9 ‰ for M^1s, P^4s, and M^3s, respectively. Next, by comparing the "population" mean (n=11-33) with the mean of three randomly selected samples from the total "population" (replicated 100 times) it was determined that only a few samples can approximate a populations mean. This is because mean $\delta^{13}C$ values were consistently within 1.5‰ of the "population" mean, with average variation of 0.3‰ for P^4, 0.4‰ for M^3, 0.4‰ for late erupting teeth (P^4s and M^3s), and 0.5‰ for all sampled teeth (M^1s, P^4s, and M^3s). Mean $\delta^{18}O$ values were also all within 1.1‰ (mean = 0.3‰) using all combinations of tooth positions sampled.

It is predicted that $\delta^{18}O$ isotopes increase or remain similar with increased aridity in evaporation sensitive and insensitive taxa, respectively (Levin et al. 2006). However, extinct tapirs appeared to show a unique pattern with decreased $\delta^{18}O$ values with increased aridity. The pattern of decreased $\delta^{18}O$ values with decreased precipitation was seen in the extant tapir, *T. bairdii* ($R^2=0.71$, $y=25.6+161.4$, $p<0.001$). In contrast, the lowland tapir (*Tapirus terrestris*) which is typically present in areas with greater precipitation than T. bairdii, instead shows the predicted pattern of increased $\delta^{18}O$ values with decreased precipitation, although not significant. *T. terrestris* shows a highly significant correlation between $\delta^{13}C$ and $\delta^{18}O$ values ($R^2=0.87$, $y=1.0x-12.3$, $p<0.001$) indicating that tapirs in wetter areas are getting a larger proportion of their water from leaves that are experiencing lower evaporation in denser canopies. T. bairdii is instead interpreted to increase its consumption of water via drinking when present in dryer areas. This change in behavior in extant tapirs is consistent with the anomalous extinct tapir data, thus declining $\delta^{18}O$ values indicate increased aridity in tapirs specifically. With a solid understanding of extant tapir isotope variation, it is now possible to make informed stable isotope interpretations of fossil localities.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

GEOCHEMICAL RECORDS OF GEODUCK SHELLS (*PANOPEA ABRUPTA*) AND THE LOW DISSOLVED OXYGEN CONDITIONS IN HOOD CANAL

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The Hood Canal of Puget Sound, Washington, suffered significant fish kills in 2002-03 due to low dissolved oxygen (DO) concentrations. Although the dead marine life which occurred in the southern Hood Canal is not new, the difference today is that the low DO conditions last longer and are more widespread. In this study, we demonstrated how the geochemical approach (e.g., stable isotope $\delta^{18}O$ and $\delta^{13}C$, trace element Sr, Mg, Fe, Mn, and Cd) can provide independent chemical records of environmental conditions that an individual animal experienced. Geoduck clams (*Panopea abrupta*) are an economically important species in Puget Sound, with a long lifespan over 160 years. In Hood Canal, the $\delta^{18}O$ values of geoduck shells ranged from –1.34 to +0.95‰ VPDB, while the $\delta^{13}C$ values ranged from –2.19 to +0.35‰ VPDB. The low DO concentrations in the southern Hood Canal started from 1994 and reached the lowest levels in 1997 or 1998. There were no apparent correlations between DO and water temperature and salinity; however, comparisons between DO and $\delta^{18}O$, $\delta^{13}C$, and Sr/Ca and Fe/Mn ratios showed consistent changes over the past 16 years during which significant fish kills occurred in Hood Canal. Overall these geochemical tracers appeared to suggest that the low DO events might be related to marine water conditions and habitat changes.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

THE UTILITY OF PALEOECOLOGY AND SEDIMENTARY $\delta^{15}N$ AS INDICATORS OF PAST SALMON ABUNDANCE IN COASTAL BRITISH COLUMBIA, CANADA

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Pacific Salmon (*Oncorhynchus* species) are important components of North Pacific ecosystems and serve as a food resource, keystone species, and as a cultural icon for First Nation's people. Over the last century declines in salmon numbers due to fishing, habitat destruction, and possibly global climate change has resulted in habitat restoration projects and the listing of some salmon populations as endangered. Parks Canada has a mandate to maintain the ecological integrity of terrestrial and marine ecosystems in representative regions within Canada and its national waters. In order to understand the ecological integrity of any given ecosystem it is essential to understand the natural range of variability in which the system exists as well as the impact people and climate change have had on it. It has been identified that a better understanding of long-term salmon abundance is necessary to adequately manage these species. Recent paleolimnological analysis of sockeye salmon (*Oncorhynchus nerka*) rearing lakes using diatoms and stable isotope analysis has shown some promise as a tool to examine past salmon abundance. Successful studies have been published using $\delta^{15}N$ as an indicator in Alaska, British Columbia, and Idaho.

This study presented here is a multiproxy investigation that uses paleoecological methods to reconstruct environmental conditions for the last ~300 years in three lakes and their watersheds on the west coast of Vancouver Island. Pollen, diatoms, cladocera, sediment, and stable isotope analyses of ^{210}PB dated sediments from lakes in or near Pacific Rim National Park Reserve of Canada reveal changes in forest structure, limnological conditions, and salmon populations. This paper will also describe research undertaken at a number of sockeye salmon bearing lakes along the coast of British Columbia, Canada (mainland and adjacent islands) using stable isotope analysis and paleolimnology. The results of this research program contribute to our understanding of the role of marine derived nutrients in regard to lake productivity along the west coast of North America. This research indicates that while salmon derived nutrients may be of key importance in juvenile salmonid development in some lakes, this may not be the case in all systems, especially those in which flushing rates are high. In these systems diatom communities appear to be more sensitive to fluctuations in salmon populations than stable isotope methods, provided that other changes in trophic status are minor. The role of this type of research in ecosystem management is important to Parks Canada and the utility of $\delta^{15}N$ in understanding the complexities of land sea interactions and the interplay between terrestrial and marine protected areas will be discussed

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

THE SULFUR STABLE ISOTOPE COMPOSITION OF PEAT-FORMING PLANTS – A POSSIBLE RECORD OF ENVIRONMENTAL CONDITIONS?

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Organic sediment, which consists of well preserved plant material, could potentially be read as a geochemical archive of paleoenvironmental conditions if we are able to correctly interpret stable isotope signals and confirm their preservation (e.g. Coulson et al. 2005). The sulfur stable isotope composition potentially could be read as a record of water level variations as well as distribution of air pollutions (e.g. Thompson and Bottrell 1998). Stable isotopic composition of in-plant sulfur reflects the isotopic composition of the sulfur source, mainly the surface water sulfates. The simple physiology of primitive plants, such as mosses or liverworts, makes these plants useful for tracing changes in environmental parameters because they are not able to limit uptake of elements including sulfur. The gases and aquatic ions directly diffuse to cells; however any fractionation during sulfur assimilation may occur respectively to the sulfur concentration in the environment. Based on the seasonal study of Sphagnum from Sudety Mts. (Poland) this relationship can be described by Rayleigh's distillation model with high statistical significance ($p<0.01$), with possible fractionation during sulfur assimilation ranging between 3.2 and 4.5‰ for low mineralized bog water (Skrzypek et al. 2008).

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RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

STABLE ISOTOPE ANALYSES OF STRATIFIED SEDIMENTS COLLECTED FROM AN ELEPHANT SEAL WALLOW IN ANTARCTICA SHOWS LATE-HOLOCENE CHANGES IN DIET AND FORAGING LOCATION.

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Currently, the distribution of the southern elephant seal *Mirounga leonina* is circumpolar and restricted to the oceans and land masses between Antarctica and about 40ºS. The present-day foraging ecology for the species has been well investigated and the findings related to changeable environmental variables such as sea-ice extent and ENSO events. However little is known of how the seals operated earlier in the Holocene, the period since the last glaciation within which biologically significant temperature fluctuations have occurred. Remarkably, elephant seals moult their hair and skin annually in defined areas known as “moult wallows”. Hair is not easily degraded over time and it contains stable isotopes of carbon and nitrogen that reflects an organism’s dietary record. Through repeated use of a wallow area, moulted hair can accumulate as a stratigraphic sequence, although this phenomenon appears to be a rather rare occurrence. Conditions suited to the accumulation of elephant seal hair can be found at some wallows in the Vestfold Hills, East Antarctica. Here a stratified matrix of hair and sand bound together by the seals weight, excrement and winter snow has been deposited to a thickness of ca. 1.0 m. I obtained sediment cores from one such deposit and collected hair samples from live and mummified elephant seals found in the Vestfold Hills for comparisons. With the use of carbon dating together with carbon and nitrogen isotope analyses of these samples I have investigated (1) the occupational history of the wallow and (2) late-Holocene fluctuations and shifts in the seals’ paleodiet. From these findings it may be possible to place current elephant seal foraging behaviour into perspective with past natural variability, and have better means to predict future changes.

RETRO ECOLOGY: Stable Isotopes as Indicators of Past Ecological Change

DEVELOPMENT OF $\delta^{13}C$ IN CHIRONOMID CUTICLES AS A NEW PALAEOLIMNOLOGICAL PROXY

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Chitinous head capsules of chironomid larvae are preserved in lake sediments and can be used for stable isotope analysis. A strong relationship exists between $\delta^{13}C$ values of chironomids and their food source. By culturing chironomids, the $\delta^{13}C$ values of food sources can be related to $\delta^{13}C$ in chironomid exoskeletons (cuticles). Based on $\delta^{13}C$ analysis of fossil chironomid cuticles, this relationship can in turn be used to reconstruct past changes in lacustrine food webs and carbon cycling in lake ecosystems.

We studied which pre-treatment steps are most suitable for measuring $\delta^{13}C$ in chironomid cuticles. A major issue is the optimization of the methodology so that a maximum weight of chironomid fossils can be isolated from sediments in a minimum amount of time. Initial results indicate that processing time can be greatly reduced if the standard 100 □m mesh-size sieve used to isolate chironomid head capsules in standard palaeoecological analyses is replaced by a 200 □m mesh. Furthermore, we tested the effect of different chemical pre-treatment methods on chironomid $\delta^{13}C$. None of the treatments led to systematic shifts in the $\delta^{13}C$ of the fossils.

Finally, we demonstrated the effect of culturing larvae on a ^{13}C-labelled diet. The $\delta^{13}C$ value of tissue and head capsules became 39‰ and 53‰ higher, respectively, indicating that the ingestion of ^{13}C-labelled food was traceable in the carbon isotopic signature of the larval cuticles. Our results indicate that chironomid $\delta^{13}C$ has the potential to be used as a proxy to reconstruct past changes in food sources of benthic chironomid larvae in lake ecosystems.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

CARBON AND OXYGEN STABLE ISOTOPES OF RICE AS PROXY PARAMETERS FOR CHANGES IN RICE PRODUCTION WITH CLIMATE WARMING

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Rice is one of the most important traditional natural food resources in Japan, which have been produced for more than 2000 years. The Japanese Archipelago extends over a distance of about 2000 km, the meteorological conditions of which range from subtropical to subarctic. There is a concern that climate warming affects the production and quality of rice. It is regarded that climate warming enhances rice production in the northern Japan, while reduces the production by at least 15-30% in the south-central and southwestern part of Japan due to high temperatures during the flowering period.

Carbon and oxygen stable isotopes of plants are known as good indicators of habitat environments such as temperature and moisture. To test the hypothesis that the carbon and oxygen stable isotopes of rice reflect climate conditions during grain filling and production, we collected rice from the northern latitudes of 31.20 to 37.14 degrees along Japan, and analyzed the carbon and oxygen stable isotopes.

Our results showed that the carbon stable isotopic composition of rice positively correlate to rice production, and negatively to temperature and precipitation, whereas the oxygen stable isotopic composition negatively correlate to rice production, and positively to temperature. The carbon and oxygen stable isotopic compositions of rice were thus shown to relate to climate conditions during grain filling. We may use these isotopic compositions to predict changes in rice production with climate warming, and to restructure paleoenvironment.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

EFFECTS OF AN INVASIVE N-FIXING TREE ON A HAWAIIAN STREAM FOOD WEB

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Invasion of riparian forests by nitrogen (N)-fixing trees may dramatically impact ecological processes within streams. In Hawaii, USA, Falcataria moluccana is an invasive N-fixing tree that has become increasingly common in riparian zones; however its impact on streams is currently unknown. This study examined impacts of F. moluccana leaf litter on the food web of a 1st order stream located in Hawaii, using naturally occurring carbon (^{13}C) and ^{15}N isotope tracers. Isotopic signatures of particulate organic matter (POM), macroalgae, invertebrates (amphipods, Cheumatopsyche analis, juvenile and adult Procambarus clarkii), and fishes (Poecilia reticulata, Xiphophorus helleri, and juvenile poeciliids) were collected and compared between a non-invaded and invaded site along a stream on Hawaii Island. Stable C isotope signatures of all species from the invaded site, with the exception of POM, were significantly depleted in ^{13}C in comparison to the non-invaded site ($p < 0.001$). In contrast, all species from the invaded site, with the exception of amphipods, were enriched in ^{15}N in comparison to the non-invaded site ($p < 0.001$). To determine if F. moluccana was responsible for these differences in $\delta^{13}C$ and $\delta^{15}N$ signatures between non-invaded and invaded sites, food webs were examined using IsoSource and two-source mixing models. These analyses indicated that F. moluccana leaf litter had extensively altered the food web of this Hawaiian stream by directly contributing to the diets of primary and secondary consumers. Results showed that F. moluccana was a major contributor to the diets of amphipods and C. analis, displacing POM and macroalgae as their major food source within the invaded site. Furthermore, F. moluccana was found to be a minor food source for P. clarkii and all three fishes. N mixing models indicated that N-derived from F. moluccana contributed 49% of the $\delta^{15}N$ signature expressed by macroalgae in the invaded site, suggesting that F. moluccana is contributing biologically available N to primary producers. These findings provide some of the first evidence that invasive riparian N-fixing trees alter the structure of stream food webs.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

IMPACT OF MOUNTAINTOP MINING/ VALLEY FILL ON THE STABLE CARBON ISOTOPIC COMPOSITION AND CONCENTRATION OF DISSOLVED ORGANIC CARBON AND DISSOLVED INORGANIC CARBON IN HEADWATER STREAMS

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Headwater streams are the dominant land-water interface across much of the landscape and provide many important ecological services. Cycling and transport of various carbon fractions, which serve as important food sources for downstream aquatic ecosystems, are among the important functions of headwater streams. Dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) are two of the most ecologically important carbon fractions. Mountaintop mining/valley fill (MTM/VF) coal mining results in burial of headwater streams and causes sedimentation and elevated levels of various chemical constituents. We are using a wet chemical oxidation analyzer coupled to an isotope ratio mass spectrometer to measure the stable carbon isotopic composition ($\delta^{13}C$) and concentrations of DOC and DIC and other parameters in reference and MTM/VF-impacted streams in eastern Kentucky (KY) and southern West Virginia (WV).

Results to date indicate that: (1) mining-impacted streams in both areas have greater concentrations of DOC (20 to 50 %) and DIC (factor of 6 to 10) compared to reference streams; (2) DOC in the mining-impacted streams ($\delta^{13}C$ = - 27 to - 21‰) of both areas is, on average, about 1 to 3 ‰ less ^{13}C-depleted than reference stream DOC ($\delta^{13}C$ = - 28 to - 26‰); and (3) the DIC in the WV mining-impacted streams ($\delta^{13}C$ = - 14 to - 2 ‰) is, on average, about 4.5‰ less ^{13}C-depleted than reference stream DIC ($\delta^{13}C$ = - 21 to - 4‰). These results suggest that DOC in MTM/VF impacted streams is a mixture of relatively ^{13}C-rich organic carbon released by mining activities and organic carbon derived from intact parts of the watershed. Because the mining-released organic carbon is likely old and refractory, the resulting stream DOC is probably a lower quality food resource for downstream aquatic communities than DOC provided by the undisturbed terrestrial ecosystem. Rapid weathering of carbonates in the disturbed soils is the likely cause of the large DIC concentration increases observed in the mining-impacted streams. Concentration and stable carbon isotopic differences between mining-impacted and reference streams are greater for the WV streams than for the KY streams. This may reflect that the pulse of carbon released by coal mining is of relatively short duration and the WV streams have been more recently mined.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

COMPARATIVE STUDY OF THE FOOD WEBS OF TWO NORTHWESTERN MEDITERRANEAN LAGOONS UNDER VARYING DEGREE OF ANTHROPOGENIC INFLUENCES: A $\delta^{13}C$ AND $\delta^{15}N$ ASSESSMENT

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The food web structure and functioning of two northwestern Mediterranean lagoons exhibiting contrasted trophic conditions and marine influences were compared through $\delta^{13}C$ and $\delta^{15}N$ analysis of major potential food sources and consumers. The Lapalme Lagoon is well preserved and has kept a natural and temporary connection with the open sea. Conversely, the Canet Lagoon is heavily eutrophicated and its water exchanges with the open sea are artificially reduced. In Lapalme, all potential food sources and consumers exhibited $\delta^{15}N$ values indicative of unpolluted coastal areas. Suspended particulate organic matter (POM) and sedimented organic matter (SOM) pools seemed to constitute the main food sources of most consumers. The basis of the food web was also characterized by a seaward increasing $\delta^{13}C$ gradient. Both primary producers and consumers were much more ^{15}N-enriched (by almost 10‰) and more ^{13}C-depleted in Canet than in Lapalme. This reflected: (1) the assimilation of important amounts of anthropogenic nitrogen by the food web, and (2) a marked and uniform continental influence. Based on the mean $\delta^{15}N$ of primary consumers in each lagoon, and assuming the same stepwise +3.4‰ trophic enrichment, we found rather similar food web lengths in both lagoons with top consumers at trophic levels 3.7 and 4.0 in Canet and Lapalme, respectively. However, the eutrophication of the Canet Lagoon resulted in some changes in the structure of the food web with: (1) a single main trophic pathway from a ^{15}N-enriched fraction of the SOM pool to top predators, and (2) a tendency of some consumers to exploit primary producers in a higher proportion than in Lapalme, thus exhibiting lower trophic levels.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

USING $\delta^{15}N$ VALUES OF THREE RED ALGAL SPECIES TO EXAMINE NUTRIENTS SOURCES IN INTERTIDAL AND SHALLOW SUBTIDAL HABITATS AT EWA BEACH: IS STORM-DRAIN WATER A POSSIBLE NUTRIENT SOURCE?

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Ewa Beach, located along south Oahu, is historically prone to local episodic floods. Storm-water drains traditionally have been used to control flood-waters. Yet storm-drains can focus enriched runoff from developed communities directly into culturally important coastal reef habitats. This research employed $\delta^{15}N$ stable isotope signatures from three closely related red algae *Acanthophora spicifera*, *Laurencia majuscula*, and *L. mcdermidae* collected from onshore to offshore reef habitats at Ewa Beach to examine nutrient sources and determine the influence of storm drain-water on seaweed nutrient status. Sampling of seaweeds was conducted in dry and rainy seasons, along an on-off shore gradient at seven sites (three large existing drains and five adjacent areas located 130 m away (no-drain sites)) as part of a Before After Control Impact (BACI) design. Presently, one sampling site is the location of a proposed drain. Sampling will be carried out at this site prior to and after the construction of this drain. Our goal was to determine for seaweeds if 1) nutrient sources are anthropogenic in origin 2) sources change seasonally and 3) drains are a contributor to nutrient status. Preliminary results suggest that nutrient sources along Ewa Beach are anthropogenic in origin. $\delta^{15}N$ values ranged from 6.5-15.8 $^{0}/_{00}$ and are above published background nutrient levels indicative of open-ocean and pristine groundwater sources (0-3 $^{0}/_{00}$). In further support of terrestrial loading, $\delta^{15}N$ signatures decrease in an onshore to offshore gradient in both dry and wet seasons. Continued analyses of seaweed and water samples from additional drain and no-drain sites will be needed to make robust statements about the influence of drain water on seaweed nutrient status.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

RECOVERY OF SALT MARSH TROPHIC STRUCTURE IN RESTORED MARSHES OF VENICE LAGOON, ITALY

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While salt marsh restoration has had a long history in the USA, it has become increasingly common in other parts of the world. Venice Lagoon has been a site of increased salt marsh restoration over the last 15 years. Tracking the success of these projects has largely focused on plant recovery, with some recent focus on understanding faunal recovery. In many cases, studies examined the structural complexity of the restored marshes, with comparisons to natural marshes serving as a reference. More recently, scientists have recognized the importance of restoring community function as well as structural recovery. Salt marsh functions include habitat provision and trophic support for resident, transient, and endangered species. The primary goal of this study was to determine the rate and extent of trophic function recovery of restored marshes in Venice Lagoon. We examined a range of restored (ages 2-14yrs) and natural systems to allow tests of rates and trajectories of food web recovery. In addition, we examined different marsh elevation/vegetation zones (unvegetated pond, Salicornia/Limonium, Sarcocornia) to allow tests of landscape-scale variation in food-web structure within and across marshes. We characterized the primary food sources important to fauna residing in natural and restored marshes of different ages. Our specific trophic questions included (1) what is the trophic structure of mature (natural) Venice salt marshes and which primary producers are supporting secondary production (2) does the trophic structure of restored marshes resemble that of the natural marshes (3) can we construct a generic food web for Venice marsh ecosystems and (4) is there evidence of successional changes in trophic structure as a function of marsh age? We analyzed primary producers and consumers for stable carbon and nitrogen isotope values and applied isotope mixing models to assess food source utilization by consumers.

The youngest restored salt marsh (2 yrs) exhibited a narrow range of $\delta^{13}C$ and $\delta^{15}N$ values, reflecting limited trophic diversity and the presence of few trophic levels. Somewhat older restored marshes (4 yrs) had greater isotopic separation in algae and fauna between low and mid-elevation zones, suggesting greater maturation and vegetation influence. However, there was no clear isotopic separation between the mid and high elevation zones, indicating that the high zone was immature. In contrast, the oldest restored marshes (8-13 yrs) had stronger separation of algal and faunal isotope values by elevation, a broader range of $\delta^{13}C$ values reflecting greater food source diversity, and a greater range of $\delta^{15}N$ values indicating better development of higher trophic levels. The natural reference marshes exhibited clear separation of micro and macroalgal and faunal isotope values by elevation zone. Microalgae and macroalgae are a primary food source for marsh invertebrates, especially at low and mid marsh elevations, whereas carbon derived from vascular plants becomes more important at upper marsh elevation zones and as marshes mature. Overall, our results from stable isotope analysis and applications of mixing models indicate these food webs are highly complex, with contributions to the base of the food chain from microalgae, macroalgae, particulate organic carbon, sediment organic matter, and vascular plants. We are currently generating a set of isotope metrics to characterize and compare the different Venice marshes with respect to food-web structure.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

SOIL RESPIRATION AND PLANTS ISOTOPIC COMPOSITION IN A CERRADO SENSU STRICTO AREA

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Changes in land use in the Brazilian savannas (Cerrado), have produced modifications in the structure and functioning of this ecosystem. The anthropogenic activities have disturbed hydrological and biogeochemical functioning of this region. Recent climate models have predicted that the replacement of native vegetation for agriculture and pasture can induce to the decline of total precipitation and increase of the frequency short dry periods in Central Brazil. Moreover, the Cerrado biome is potentially an important uptake and storage system, especially in the soil due to dense root system and slow decomposition of soil organic matter. The objective of this work was to use the isotopic methodology to evaluate the gaseous exchanges and thus soil carbon dynamics in Cerrado sensu stricto in Southern Brazil (State Park of Vassununga, São Paulo). Carbon isotopic ratios were evaluated in the following component of the system: (i) soil respired CO_2; (ii) CO_2 from fine and coarse litter; (iii) respired CO_2 from leaves and branches; and soil organic matter

The isotopic composition of the CO_2 from the soil respiration showed a maximum variation of 4‰ (-29,8 to -25,7‰) between the dry and rainy season. This suggests that physiological changes in the driest months (April-July) led to substantial losses in ^{12}C as CO_2. The litter layer did not influence the isotopic values of CO_2 respired. The isotopic composition of the respired CO_2 by the leaves and branches varied between -23,2 to -32,4‰.This can be related with seasonal differences in hydric availability. In terms of SOM there was an enrichment of $\delta^{13}C$ with depth. The values varied between -28,4 ‰ at (5 cm) to -22,6‰ (30 cm) between dry and rainy season. The differences found between $\delta^{13}CO_2$ of respired CO_2 and soil carbon indicated that during the decomposition of SOM lighter CO_2 is prefencially used by the soil microorganisms during the respiration process

This variability in the isotopic values was basically controlled by environmental and physiological variables, indicating their influence in the dynamic of the carbon in the Cerrado.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

DIETARY INVESTIGATIONS OF YELLOWSTRIPE GOATFISH (*MULLOIDICHTYS FLAVOLINEATUS*) USING STABLE ISOTOPES

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We investigate the diet of the Yellowstripe goatfish (*Mulloidichtys flavolineatus*) as part of a comprehensive research programme on trophic webs in tropical coral reef systems. This carnivorous fish is known to feed on macrofauna living in soft bottom sediments. However, its diet is still relatively unknown as investigations using stomach contents have differed between the few authors who have studied this tropical species.

We focused on goatfish populations in the La Saline Reef complex (Reunion, Indian Ocean), over two seasons, in both the outer and inner reef areas. Sampling sites were distributed along an eutrophic gradient. The fish population was characterized by three size categories ("S" for length ≤12 cm, "M" for 12cm≤ length ≤18cm," L" for length >18cm), which were heterogeneously distributed around the reef system: with smaller individuals mainly present in the back reef, while larger fish were not commonly found in the reef. Stomach content analysis from M. flavolineatus juveniles in Reunion is reported for the first time, and has found they mostly feed on meiofauna. Isotopic analysis of goatfish tissue ($\delta^{13}C$ and $\delta^{15}N$) was used to highlight dietary differences between size categories, as the stomach content analysis was not able to draw fine distinctions.

"S" individuals had uniform $\delta^{15}N$ composition among sites. On the other hand, M and L specimens showed spatial variability in $\delta^{15}N$, with specific patterns related to the enrichment gradient. Thus we hypothesize that smaller "S" individuals have higher mobility for feeding rather than larger "M" and "L" fish, which tend to have site specific nitrogen composition. Moreover, the $\delta^{13}C$ values indicated that juvenile "S" individuals have a more depleted carbon signal ($\delta^{13}C$ = -17.0± 0.2‰) than "M" size individuals ($\delta^{13}C$ = 14.1±0.3 ‰) and adult "L" individuals ($\delta^{13}C$ = 10.4± 0.6‰). This difference suggests tissues of the "S" specimens of M. flavolineatus could reflect their recent larval life in pelagic off-shore systems ($\delta^{13}C$ pelagic POM = -22.5±0.4‰). Conversely, the "M" individuals are more likely to feed on the reef system ($\delta^{13}C$ reef sediment = -15.6±1.1‰) as opportunistic carnivores. "L" specimens with a $\delta^{13}C$ of –10.4±0.6‰ feed on amphipods and annelids as shown by both stomach content and stable isotope analysis of these taxa.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

CHEMICAL MARKERS OF NICHE SPACE FOR HAWAIIAN RED MANGROVES

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The coastal red mangrove Rhizophora mangle was introduced to the Hawaiian Islands from Florida 100 years ago, and has spread to cover many shallow intertidal shorelines that once were unvegetated mudflats. This has led to many small forest stands of island mangroves that could differ strongly in their biogeochemistry related especially to local freshwater and nutrient inputs from developing watersheds. This differentiation at the "forest niche" level is not easy to assess with conventional techniques, so we used stable isotopes along with other cation, trace element and nutrient markers to provide a chemical profile of different sites. This profiling expanded upon well-established use of high $\delta^{15}N$ in coastal macrophytes values to indicate pollutant N inputs from upland sources. During 2001-2002, we sampled mangroves on southern Molokai and Oahu for 14 leaf variables including isotopes ($\delta^{13}C$, $\delta^{15}N$), macronutrients (C, N, P), trace elements (B, Mn, Fe, Cu, Zn), and cations (Na, Mg, K, Ca). Results showed mangrove forests with differing leaf N and P nutrient concentrations, with low nutrient mangroves present on Molokai and southeastern Oahu in relatively pristine rural areas, and high nutrient mangroves present on Oahu in urban Honolulu and in a coastal lagoon receiving groundwater inputs. Results also showed that leaf $\delta^{15}N$ values were not associated with high N and P levels in leaves in a simple manner. Thus, although leaf $\delta^{15}N$ values were high (>7‰) in areas receiving nutrient-rich groundwater runoff, mangroves with highest leaf N and P contents in urban areas did not have highest $\delta^{15}N$ values. Lower $\delta^{15}N$ values in urban mangroves probably occurred because runoff is rapid in urban Hawaii, so that nutrient-rich water did not have enough time for ^{15}N enrichment during N processing by soil microbes in upstream watersheds. Overall, $\delta^{15}N$ was the better indicator of N loading at a site with groundwater inflows and still relatively low pollution, while leaf N content was the better indicator at urban sites with high N loading. Leaf B, Cu, Mg, K, and Ca showed parallel variations across sites likely related to salinity and freshwater inputs from watersheds to coastal mangrove forests. Using stable isotopes in combination with a suite of other chemical markers appears promising for showing how sites and forests differ in their biogeochemical niches; this broader chemical approach also works well for distinguishing species-level niche separation among mangroves on other Pacific islands.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

N_2O SINK FUNCTION IN A FOREST SOIL AS INDICATED BY CONCENTRATION AND STABLE ISOTOPE PROFILES

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Nitrous oxide (N_2O) is a potential and long-lasting greenhouse gas of the atmosphere. The atmospheric N_2O concentration currently increases by about 0.3 % per year and reached 319 ppbv in 2005. With a contribution of about 70 % soils act as the main source for atmospheric N_2O. Soil N_2O emissions originate from microbial nitrification and denitrification, with the latter process also potentially being able to consume N_2O. Both processes are mainly driven by soil temperature, soil moisture and substrate availability. Changes in meteorological conditions as predicted for the future are, therefore, expected to affect N_2O emissions from soils.

In this study we investigated effects of experimentally induced drying/rewetting and freeze/thaw events on soil N_2O emissions in a mature Norway spruce forest in the Fichtelgebirge (NE Bavaria, Germany). Drought was induced by roof constructions and freezing by snow removal. The experiments were run in three replicates each. Unmanipulated plots served as controls. In addition to N_2O flux measurements between soil and atmosphere we analysed N_2O concentrations and stable isotope signatures ($\delta^{15}N_{N2O}$ and $\delta^{18}O_{N2O}$) in soil air collected along soil profiles. The latter approach provides information on localisation of N_2O sources and sinks as well as identification of N_2O production and consumption processes.

Drought reduced the N_2O emission from the soil or even turned the forest soil temporarily to an N_2O sink. N_2O emission peaks after rewetting could not compensate for the drought effect. Soil frost caused a burst of N_2O emission.

Soil air N_2O concentration and stable isotope profiles provide a new and hitherto almost unconsidered mechanistic explanation for all of these observations. N_2O concentration in the soil air decreased in most cases exponentially from the subsoil to the soil surface. This observation identifies microbial activity in the subsoil as source for N_2O and diffusion to the soil surface along a concentration gradient. A shift in the N_2O isotope signature along the concentration gradient towards increasingly positive δ values indicates, furthermore, a simultaneous microbial N_2O consumption (reduction to N_2). Drought reduced the source strength of the subsoil for N_2O while simultaneously the sink strength of the topsoil for N_2O remained constant. Both of these factors resulted in the temporary occurrence of below-atmospheric N_2O concentrations in the air of the topsoil and thus a soil sink function for atmospheric N_2O. Frost in the topsoil was the only exception for these trends in N_2O concentration and isotope signature. Under conditions of soil frost the topsoil served no longer as a sink for N_2O, thus leading to the observed burst in N_2O emission.

The until now almost unconsidered sink function of soils for N_2O sheds a new light on the hitherto poorly resolved global N_2O budget. We suggest the consideration of a soil N_2O sink function for future model calculations on global N_2O budgets.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

DIETARY SHIFTS ON HUMAN-IMPACTED COASTLINES: CONSEQUENCES OF SUBTIDAL HABITAT CHANGE

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Subtidal ecosystems are being degraded as forests of erect macroalgae (e.g., kelps) are replaced by habitats comprising of simpler and less productive species (e.g., turf-forming algae; Connell et al. 2008), that benefit from high nutrient conditions typical of human-dominated coastlines. We used $\delta^{13}C$ and $\delta^{15}N$ isotopic signatures of common macro-invertebrate herbivores and their potential algal food sources to test for higher trophic level consequences of this habitat alteration. Modelling of feasible food source mixtures (see methods; Phillips and Gregg 2003) from replicate human dominated and natural coasts (i.e., impacted v. natural) showed that herbivores from impacted areas relied on turf-forming algae to a greater degree then canopy-forming algae. We then showed a positive relationship between consumer diet and greater areal covers of turfing habitat from impacted coasts compared to those of natural coasts. Further, these data correlated well with densities of macro-invertebrate herbivores, which had greater abundance within natural than impacted sites. We suggest that human-mediated shifts in subtidal habitat structure (i.e., from erect canopy forming macroalgae to turf-forming species) can directly affect the relative contribution of algal resources to the diet of resident herbivores. In this way, shifts in natural food resources may rival habitat loss as a factor bringing change to human-dominated coastlines.

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ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

STABLE ISOTOPES AS TOOLS HELPING TO UNDERSTAND BENTHIC COMMUNITY RESPONSES TO COASTAL EUTROPHICATION

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Increasing nitrogen inputs in coastal ecosystems often induce major shifts in primary producers as well as consumers composition and abundances. In the present study we used N and C isotopic ratios to analyze the coupling of macrobenthic food webs to primary producers from two basins of the bay of Brest, receiving different nitrogen inputs. In this ecosystem, the Northern basin is under heavy nitrogen inputs from urban and agricultural origin, while nitrogen inputs to the southern basin are much lower.

A total of 1600 stable isotopes analyses were included in the study, covering more than one hundred different species. On both grounds, the major potential sources of energy were identified to originate either from epiphytic macroalgae and microphytobenthos both growing, together with sedimenting (sedimentary) particulate organic matter (POM) originating from the water column.

The majority of the macro- and megafaunal organisms investigated were filter feeders, selective-deposit feeders and predators/scavengers. Filter feeders fall into three different groups representing different trophic pathways, feeding either directly on POM, POM and zooplankton, or on microphytobenthos or decaying sedimented POM. Selective deposit feeders were also divided into two subgroups, feeding either on sedimenting organic matter at the sediment/water interface or on more refractive organic matter integrated to the sediment. These analysis also allowed to show that trophic levels of the species were identical between the two parts of the bay (under eutrophication or not), but that the whole food web of the northern basin was enriched in ^{15}N compared to the less polluted southern basin.

Isotopic analyses were coupled to long term benthic community data (15 years) within the ecosystem (species richness, abundance, biomass and dominating species) This analysis revealed completely different functioning between the two basin. The southern basin benthos food web depends mainly on microphytobenthos, while the northern basin food web is based on seasonal opportunistic benthic macroalgae.

Thus, first responses to eutrophication was characterized by a switch from benthic microalgae to macroalgae dominance of primary productivity. Carbon stable isotope analysis showed that the redistribution of primary production lead to a shift from microphytobenthos to macroalgae in the diets of the macrobenthic community.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

CONDUITS OF CONTAMINATION TO CONTEMPORARY FOOD WEBS OF THE NORFOLK BROADS (UK) FROM AN ORGANOTIN LEGACY

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Organotins in anti-fouling paints were banned from use on craft <25m in UK waters over 20 years ago. Much research has been conducted on the environmental impacts of organotins but the majority of studies focussed on marine systems. Recent palaeolimnological evidence form the Norfolk Broads, which are a series of man-made lakes interconnected and used extensively for pleasure boating, suggested that the regime shift from macrophytes to phytoplankton dominance in these shallow lakes may have been in part due to organotins. Furthermore, it was revealed that a legacy of organotins is still present in the sediments.

We have analysed stable isotopes of carbon and nitrogen to characterise the food webs of eight sites within the Broads representing a scale of likely organotins burden: two highly contaminated boatyards; two popular boating broads with marinas; two partially navigable broads; and two non-navigable broads (controls). We have also analysed various components of the food webs and the sediments for organotins. Thus, by combining the two approaches, we aimed to identify likely sources and potential transfer routes through food webs to accumulation in apex predators. We also focussed on chironomid larvae as a key mediating species, hypothesising that because of their lifestyle and abundance that they would be important vectors from the sediments to benthivorous fish, and potentially across ecosystem boundaries to terrestrial predators such as riparian spiders and birds.

Organotins were found in the surface sediments at all sites except for controls at high theoretical pore-water concentrations, and reflected our expected gradient of burden. Primary consumers such as chironomids and bivalves also contained detectable quantities of organotins but lower than would be expected at given pore-water concentrations. Initial results suggest that transfer to fish is low. However, higher concentrations found in larger bivalves (that have escaped gape-limited predation by fish) may be a potential source of contamination into birds like coot that target such resources overwinter. Isotopic measures of community-wide trophic structure are different between contaminated and non-contaminated sites.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

STABLE ISOTOPIC STUDIES ON ECOLOGICAL CONSEQUENCES OF THE THREE GORGES DAM, CHINA

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The water table in the Three Gorges Reservoir (TGR) has been raised significantly since the construction of the Three Gorges Dam across the Yangtze River (TGD), the world's largest dam in China. In addition, a number of permanent and seasonal islands will be formed when the TGD begins to operate in full capacity in 2009. Although possible effects of TGD construction on biodiversity and ecosystem processes have attracted much attention from scientists around the globe, little is known about how TGD construction will affect the ecophysiology of plants along the bank of TGR and the animal population dynamics on newly-formed islands.

We have applied stable isotopes to study the water relations of the dominant plants along the TDR banks and the dietary composition of dominant rodent species on paired island-mainland sites at selected geographic locations in the Three Gorge Reservoir Area (TGRA).

Our results indicate that plants at the newly-formed riparian area along the TGR bank do not depend on the Yangtze River water for their water sources and that rising water levels in this reservoir may not necessary alter water relations of the plants along the bank. However, the habitat insularization in TGRA associated with TGD construction has affected both the species composition and population dynamics of the local rodent communities.

Although little has been done on other taxonomic groups of plant and animals, our findings may also be indicative of the fate of other similar organisms in this region.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

STABLE ISOTOPES INDICATE THE EFFECTS OF RIVER REGULATION ON INVERTEBRATE FOOD WEBS IN TRIBUTARIES OF THE HUNTER RIVER, NSW

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Flow is most the fundamental characteristic of streams. Water velocity, depth, habitat availability, chemical characteristics, organic matter influx and interactions with and between aquatic biota are all influenced by flow. Disruptions to the natural flow regime, such as regulation, potentially affect the type, productivity and availability of resources to riverine food webs, hence altering food supply, presence and persistence of suitable habitat and the distribution of food resources within these habitats.

Stable isotope ratios of carbon and nitrogen have often been used to describe riverine food webs, but are seldom used to assess the potential effects of regulation on interactions between organisms and their food resources. Invertebrates, organic matter and algae were collected in two regulated and two unregulated tributaries of the Hunter River, NSW, in October 2006 and May 2007. The contribution of autochthonous and allochthonous sources to food webs in pools and riffles were assessed and the possible effects of flow regulation are discussed.

This study provides some of the first data on food web interactions in Australian coastal rivers and highlights the need for a more holistic approach to water management.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

USING STABLE ISOTOPES AND OTHER CHEMICAL TRACERS TO QUANTIFY THE INFLUENCE OF ANTHROPOGENIC ALTERATION OF HYDROLOGIC REGIMES IN ESTUARINE FOOD WEBS

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Effects on community structure and function from natural and anthropogenic factors are often difficult to detect and quantify. As a result there is a growing need to develop tools designed to improve our ability to recognize community and environmental change. One such need focuses on improving our comprehension of food web structure and how that structure is affected through time. Stable isotopes ratios of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) are commonly used in ecological studies and have provided valuable insights into food web ecology. However, uncertainty remains with using multiple sources, varying fractionation between species and tissues, variability in isotope signatures and into ability to resolve food web structure in complex environments, such as estuaries, that receive inputs from terrestrial, freshwater and marine environments. Coupling of other chemical tracers (i.e. fatty acids, organochlorine contaminants and mercury) with stable isotopes may provide further insight into the movement of energy, nutrients, and contaminants through the food web, which offers the opportunity to define food web structure, and predator-prey interactions, in combination with existing environmental conditions (i.e. biological, chemical).

Salinity variations in the Charlotte Harbor-Pine Island Sound Estuary of southwestern Florida, specifically the Caloosahatchee River, have been documented to follow a seasonal pattern and vary between a polyhaline and oligohaline state (0-30 ppt) as a result of water management practices for Lake Okeechobee. These alterations likely affect productivity, population dynamics, community composition, food web structure and place stress on obligate-estuarine species. We examine the utility of the naturally occurring chemical tracers, stable isotopes of carbon and nitrogen, and fatty acids, as well as mercury to characterize the food web dynamics of a high trophic level euryhaline predatory fish, the bull shark (*Carcharhinus leucas*), in a changing estuarine environment.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

IMPLICATIONS OF DROUGHT INDUCED CHANGES TO THE PRIMARY ENERGY SOURCES SUPPORTING THE FOOD WEB OF A SUB-TROPICAL RESERVOIR.

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The south east Queensland region of Australia has experienced persistent drought conditions combined with rapid population growth over recent years. This has resulted in record low water levels in many of the regions major drinking water supply reservoirs. Many of these reservoirs are considered eutrophic and have experienced periods of poor water quality and cyanobacterial blooms. In order to sustainably manage these reservoirs as future drinking water supplies, it is imperative to determine the role of the food web in the cycling of nutrients and how the system shifts in response to periods of low water levels. Stable isotopes were used to reveal the ecological responses to drought and to trace food web shifts following significant reductions in the available energy sources to one of the regions major water supplies, Lake Samsonvale.

Prior to the onset of the unprecedented low water levels, the energy sources supporting the food web were diverse including pelagic and littoral production, detritus and catchment supplied nutrients. The lake contained abundant littoral macrophytes (~140 tonnes, King & Everson 1978) and high phytoplankton biomass (mean annual chlorophyll a = 11.17μgL^{-1}, SD ± 5.5). Following two consecutive failed summer wet seasons in which the lake fell to unprecedented low water levels, there was a complete loss of littoral macrophyte production and negligible catchment nutrient inputs. Coincidentally, there was an increase in the mean annual chlorophyll a concentration (18.2μgL^{-1}, SD±7.8). During the same period there were major shifts in the diet, health and abundance of a number of dominant species including herbivorous and carnivorous fish and omnivorous invertebrates. The herbivorous Snub-nose Gar (*Arrhamphus sp.*) and Tilapia (*Oreochromis mossambicus*) showed the greatest shifts in $\delta^{13}C$ (14.5, SD±1.3) and $\delta^{15}N$ (11.1, SD±1.1) in 2005, to 2007 ($\delta^{13}C$ =22.1 SD ± 1.7 and $\delta^{15}N$ = 15.0 SD ± 1.9). This shift is consistent with a change in diet initially dominated by macrophytes, to one of zooplankton and detritus. Over the same period the length/weight relationship for Gar decreased approx. 30%. Similar reductions in fish condition were observed for a range of species including the dominant predators of the lake. The drought affected food web is now largely supported by pelagic autochthonous production and has exhibited progressive enrichment of $\delta^{15}N$ signatures across a wide range of species, a pattern consistent with progressive starvation.

This research reveals ecosystem wide trophic cascades due to the drought conditions and subsequent loss of an important energy source to the food web, in littoral macrophytes. The food web is now reliant on pelagic primary production and detritus to meet energetic requirements. Condition indices from a range of species suggest the current trophic structure is inferior to support the biomass in the absence of littoral macrophyte production. The loss of macrophyte production coincides with increased algae concentrations, indicating the importance of macrophytes in nutrient cycling. These findings highlight the need for greater ecosystem process understanding in sub-tropical reservoirs and provide an insight into how low water levels may affect the structure and functioning of reservoir ecosystems.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

FOOD WEB RELATIONSHIPS OF HAMILTON HARBOUR USING $\delta^{13}C$ AND $\delta^{15}N$ ANALYSIS

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Located at the western end of Lake Ontario is Hamilton Harbour, a highly perturbed environment that is the focus of significant ecological remediation efforts. As such, understanding the food web interactions of the harbour is important for appropriate environmental management. Carbon and nitrogen stable isotopes were used to document seasonal food web. From May to October 2006 all components of the food web were sampled from three distinct areas of the harbour: the east end, which opens to Lake Ontario and mixes with lake water; the north shore, an open coast affected by urban run-off; and the west end, which is influenced by exchanges with a large natural wetland. Among site comparisons of $\delta^{15}N$ for eleven fish species, after correction for baseline, showed significantly higher values in the west end. The same spatial pattern was found for benthic invertebrates, which had $\delta^{15}N$ signatures ≥2x in the west than elsewhere. The higher $\delta^{15}N$ values may result from nutrient loading from the wetland. Benthic invertebrate samples along the northern shore had the highest carbon values ($\delta^{13}C$ = -20.1‰) and the smallest range (-16.4 to -21.6‰). Values in the east and west were lower, $\delta^{13}C$ = -23.3 and -23.8 respectively, and more varied, -18.3 to -26.7 in the west and -18.0 to -23.8 in the east. Fish showed little variation in $\delta^{13}C$ between sample sites. $\delta^{13}C$ ranges for fish at the east and west sites indicated a large overlap with the benthic invertebrate carbon range suggesting close connectivity to the littoral food web. Fish in the north did not overlap as greatly with local benthic signatures suggesting less reliance on the local littoral zone. Low fish biomass and diversity in the north further support the notion of less intensive littoral zone use. Fish in the harbour appear to use a common carbon pool regardless of location of capture, but are spatially dependent on the localized baseline $\delta^{15}N$ effects of shoreline development state.

ANTHROPOGENIC FORCINGS ON ECOSYSTEMS

SOIL RESPIRATION SOURCE PARTITION AND NET WHEAT-SOIL ECOSYSTEM PRODUCTIVITY UNDER ELEVATED ATMOSPHERIC PCO_2

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Abstract: Split-root gas collection chamber, ^{13}C and free-air CO_2 enrichement (FACE) techniques were used to study the influence of elevated atmospheric pCO_2 on soil respiration source intensity (heterotrophic respiration, root respiration) and net wheat-soil ecosystem productivity. Results showed that elevated atmospheric pCO_2 increased cummulative soil respiration by about 14 % at high (225 kg N ha^{-1}) and low nitrogen (112.5 kg ha^{-1}) during 2004-2005 and 2005-2006 wheat (Triticum aestivum L. cv Yangmai-14) season (end of October to mid June in next year). No significant influences were found on cummulative root respiration. The contributions of new organic carbon heterotrophic respiration, old soil carbon heterotrophic respiration and root respiration to soil respiration were 34.1%, 40.8% and 25.1% at enriched CO_2-high nitrogen treatment, respectively; 19.9%, 50.4% and 29.7% at ambient CO_2-low nitrogen treatment, respectively; 30.9%, 44.1%, and 25% at enriched CO_2-low nitrogen treatment, respectively; and 16.2%, 54.9%, and 28.9% at ambient CO_2-low nitrogen treatment, respectively. Elevated atmospheric CO_2 increased aboveground biomass carbon by 16.3% and 14.1% at high nitrogen and low nitrogen treatment, respectively, but no significant effects on belowground biomass carbon were found. Net wheat-soil ecosystem productivities were enhanced from 488 to 653 g C m^{-2} at high nitrogen treatment and from 375 to 508 g C m^{-2} at low nitrogen treatment by elevated atmospheric pCO_2, respectively. Results indicated that elevated atmospheric pCO_2 would reduce the decomposition of soil organic carbon and increase soil carbon sequestration under future higher CO_2 scenarios.

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