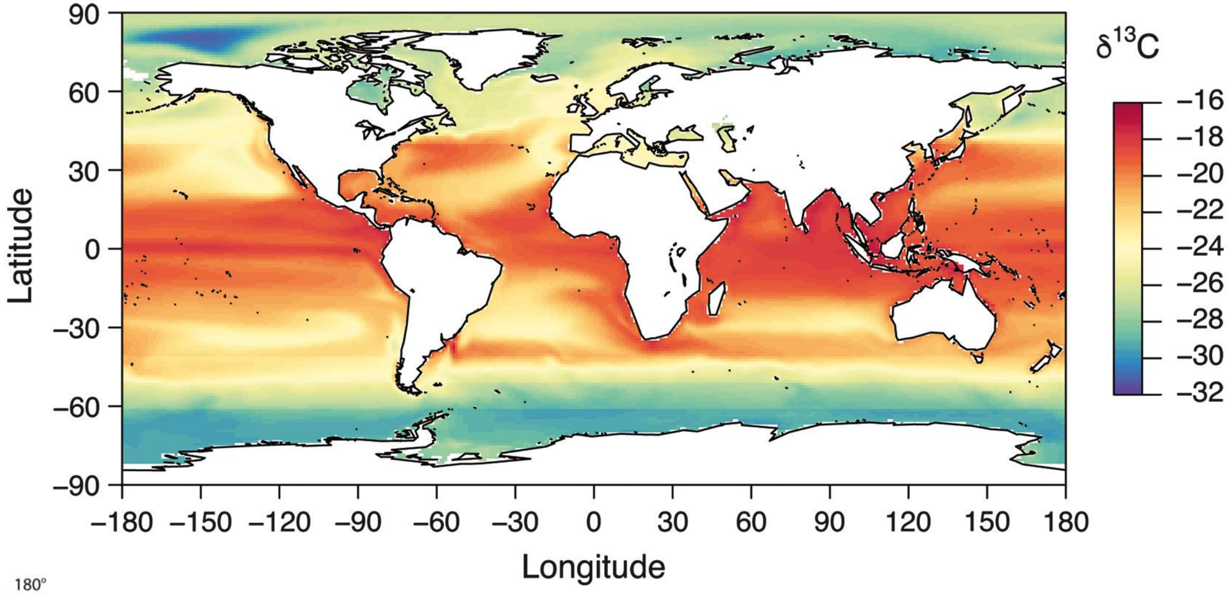
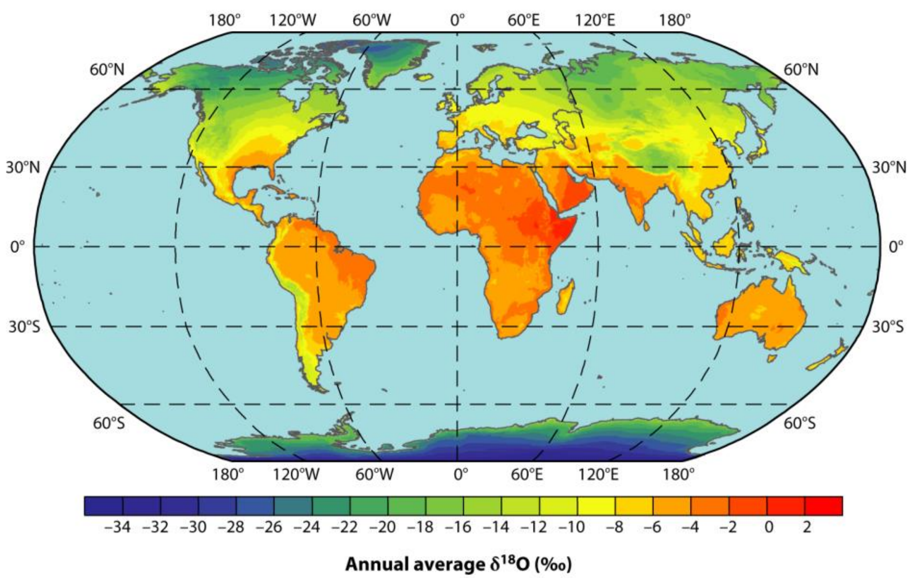
Isotopes and spatial ecology



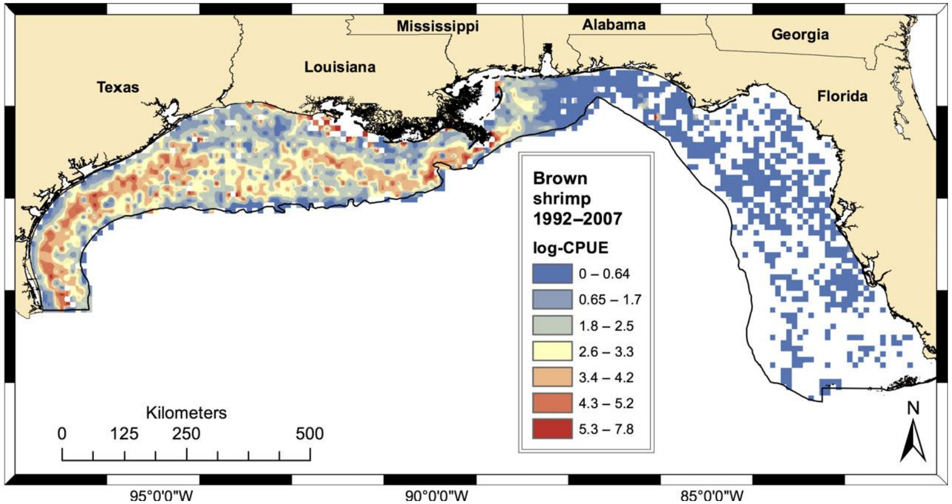


Loïc MICHEL – loicnmichel@gmail.com

Course "Etude des isotopes stables et applications au milieu marin"

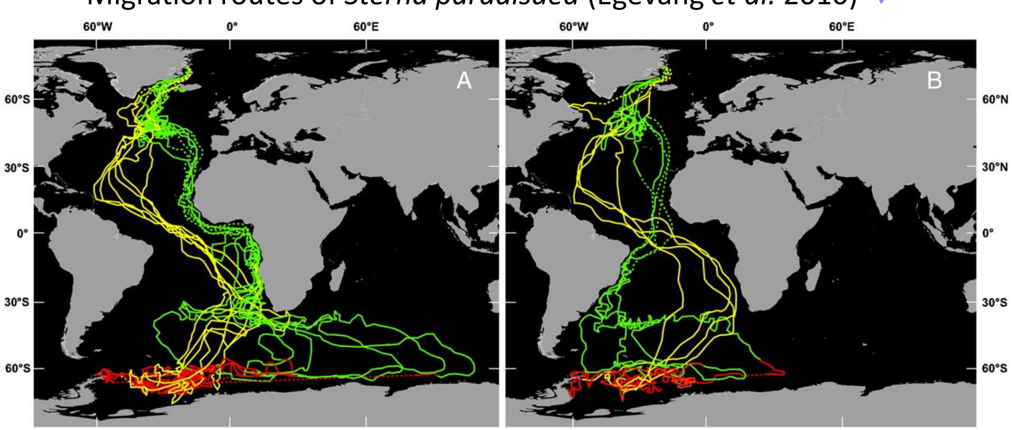
Spatial ecology

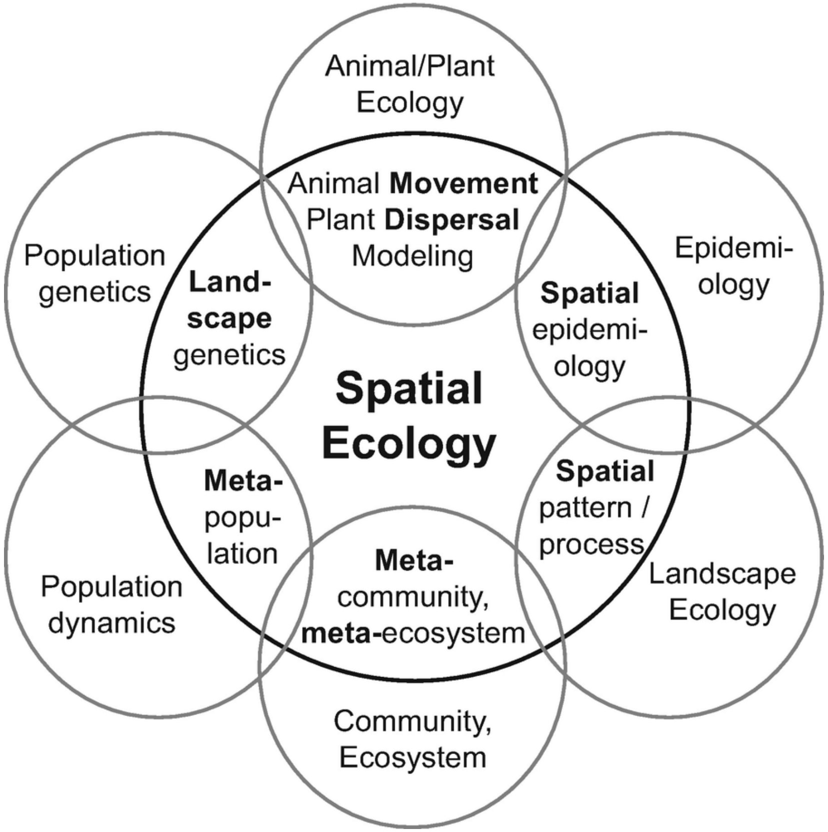
Spatial ecology: study and modeling of the role of space on ecological processes, including spatial distribution of organisms in ecosystems and its dynamics (landscape ecology) as well as organisms' movements and migrations (movement ecology)



▲ Density distribution of *Farfantepenaeus aztecus* in the Gulf Of Mexico (Montero *et al.* 2016)

Migration routes of *Sterna paradisaea* (Egevang *et al.* 2010) ▼





Fletcher & Fortin 2019
doi.org/10.1007/978-3-030-01989-1

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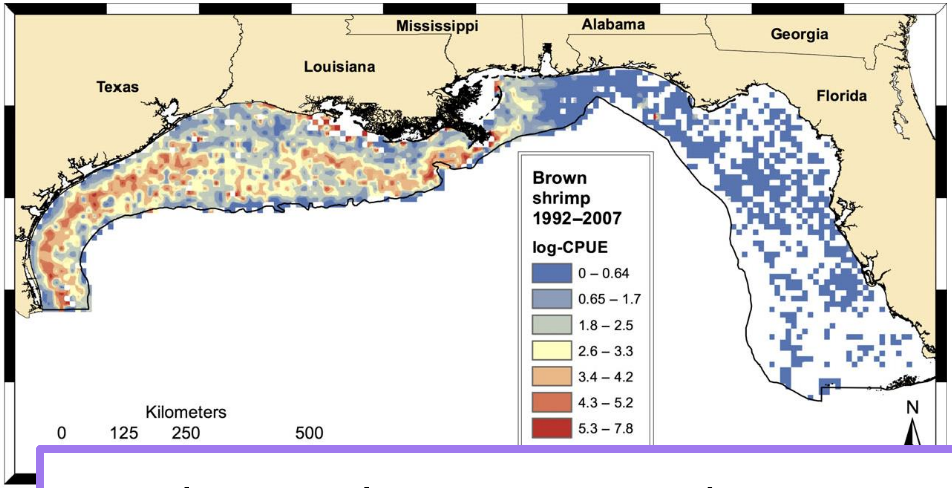
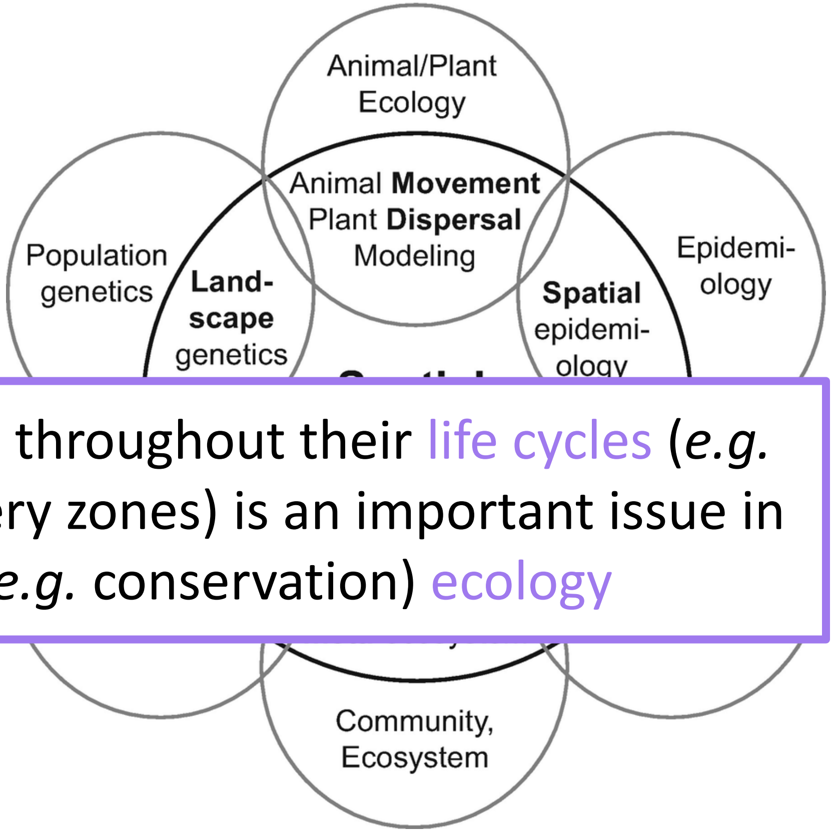
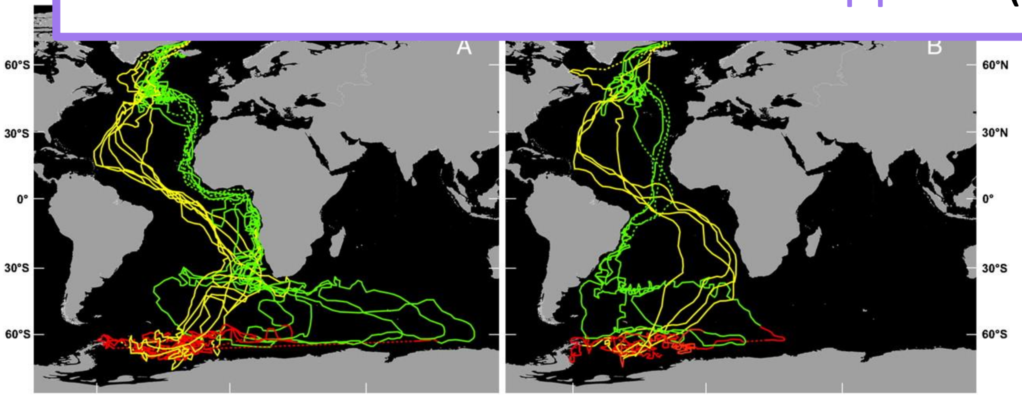




Understanding space use by organisms throughout their life cycles (*e.g.* identifying breeding grounds and nursery zones) is an important issue in both fundamental and applied (*e.g.* conservation) ecology



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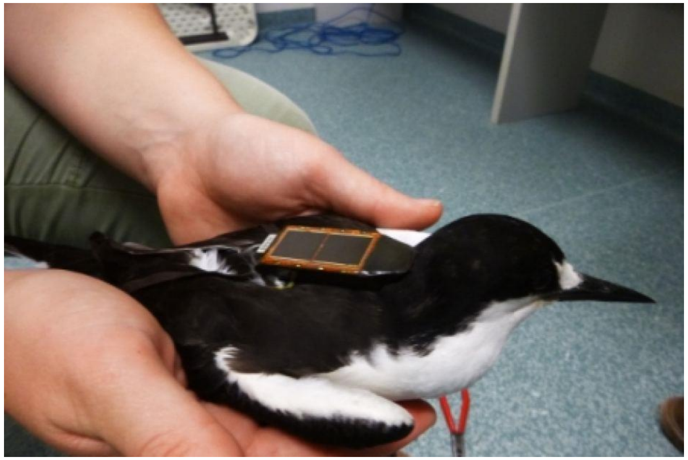
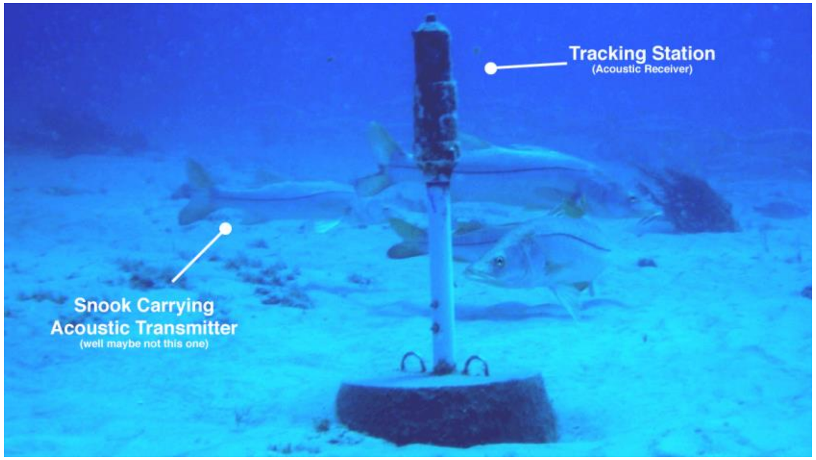
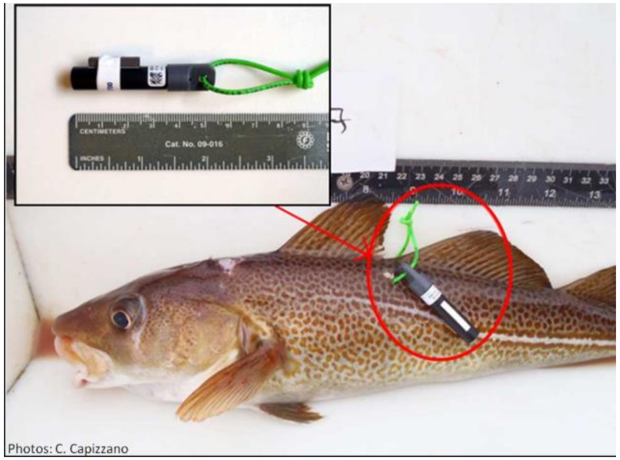
Spatial ecology: how?

Animal tracking through tagging and capture / recapture or telemetry







Can be very powerful and achieve high resolution, but costly, time-consuming, sometimes hard/impossible to apply and representativity can be questioned (parallel with gut contents)

Spatial ecology: how?

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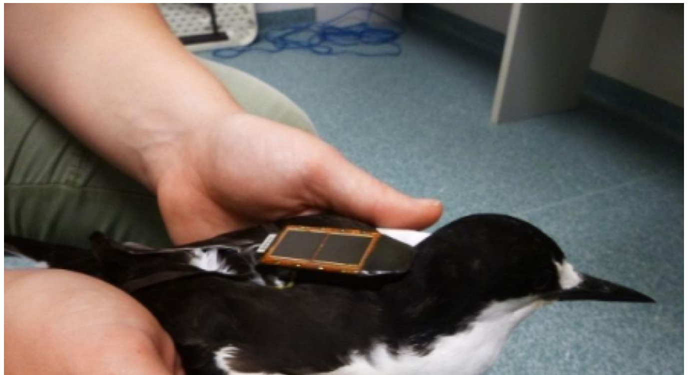
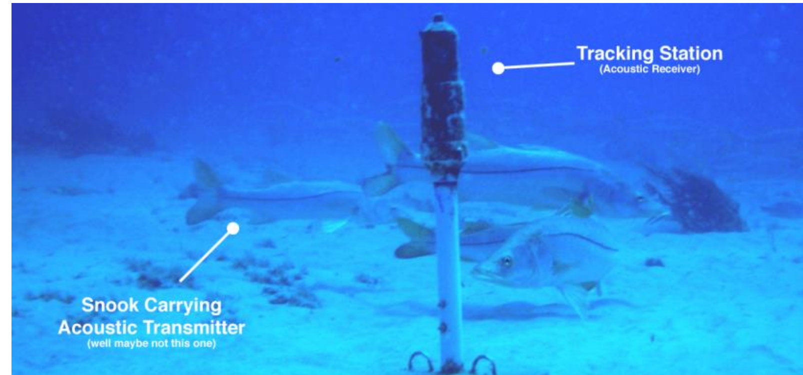
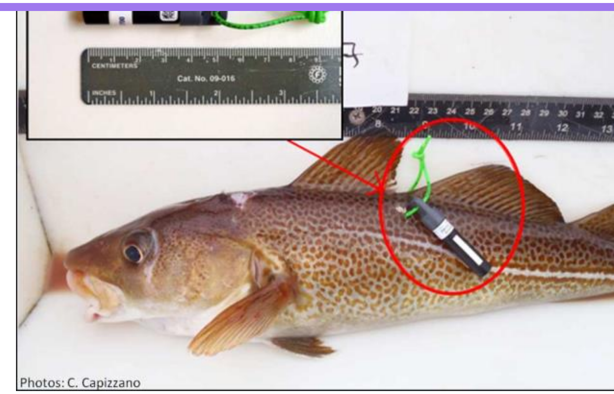




These shortcomings can be circumvented by the use intrinsic proxies such as stable isotopes

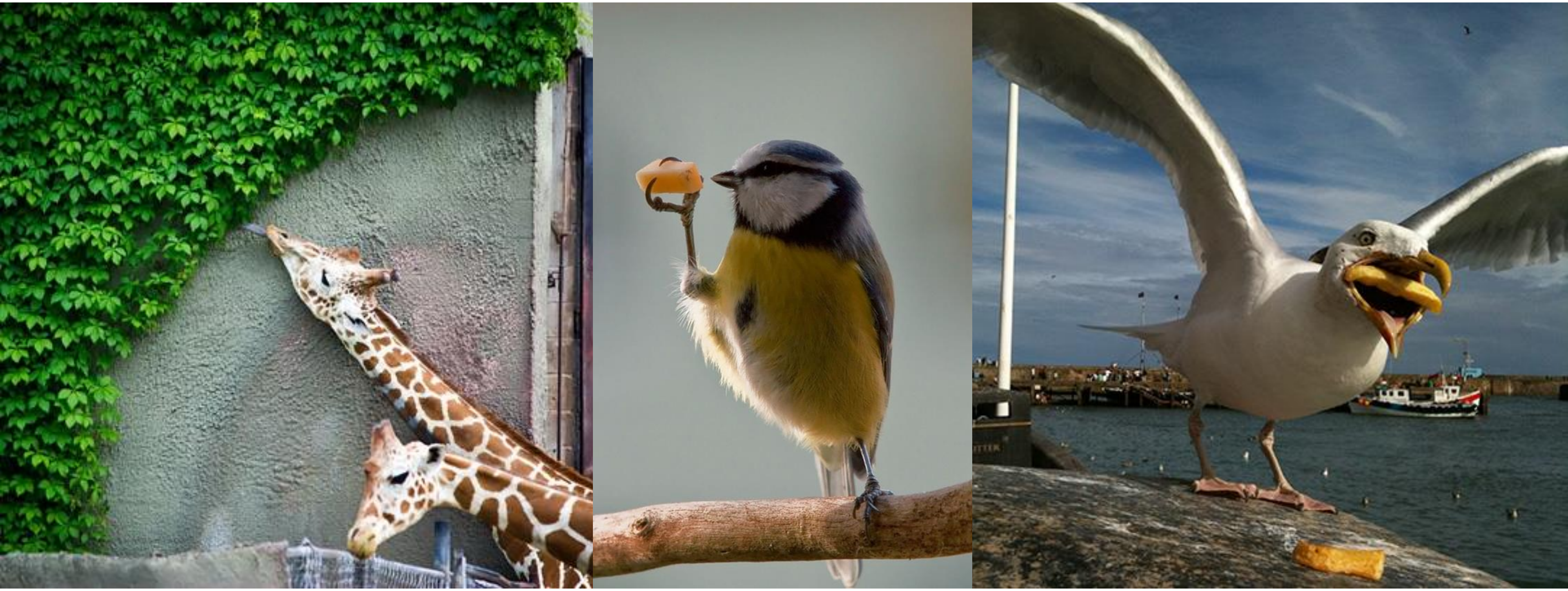


Can be very powerful and achieve high resolution, but costly, time-consuming, sometimes hard/impossible to apply and representativity can be questioned (parallel with gut contents)

Spatial ecology and stable isotopes

The stable isotope composition of resources varies spatially, in relation with multiple biogeochemical processes and changes in environmental conditions (temperature, light availability, etc.)

This variability is transferred to higher trophic levels: animal tissues bear the "signature" of the resources upon which they depend. You are what you eat… But also where you eat it!



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If you know 1) an animal's isotopic composition and 2) how its resources' isotopic compositions vary spatially, you can infer where this animal used resources, and therefore where it lived

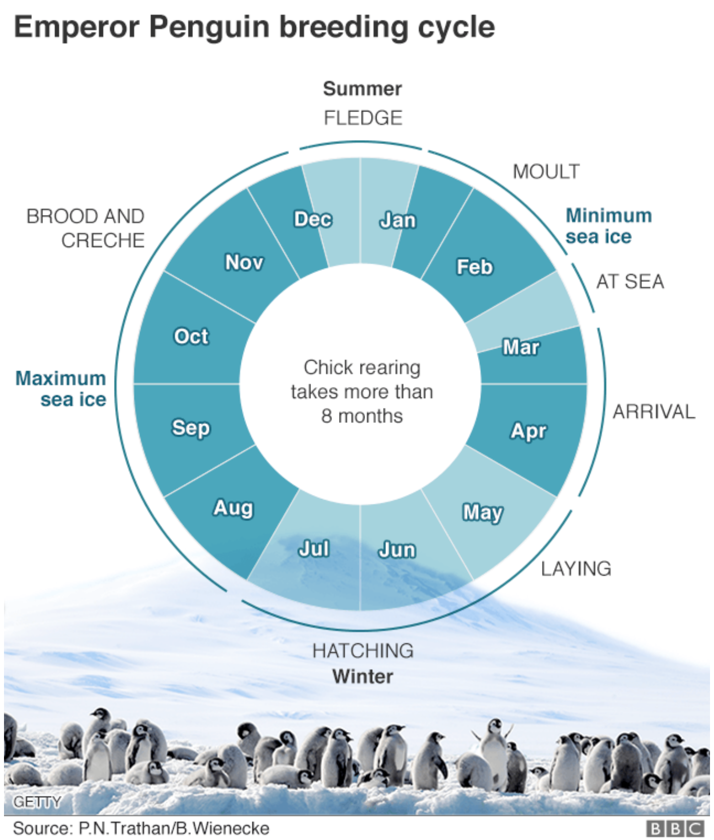
Spatial ecology and stable isotopes

These isotopic signals persist for a period of time that varies according to the tissue turnover rate: from a few days (blood plasma) to a few weeks (whole blood, muscle) or the entire lifetime of the animal (bone collagen)

Spatial ecology and stable isotopes

These isotopic signals persist for a period of time that varies according to the tissue turnover rate

Some tissues (hair, feathers, nails) are metabolically inert after synthesis: they maintain a permanent record of where they were synthesized. Possibility to use stable isotopes as a "time machine" to study specific periods of animals' life cycles.

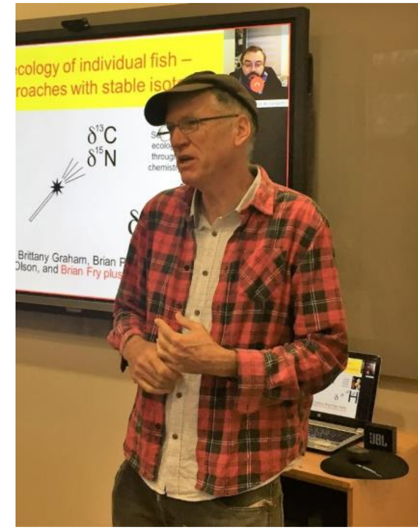


An (early) example

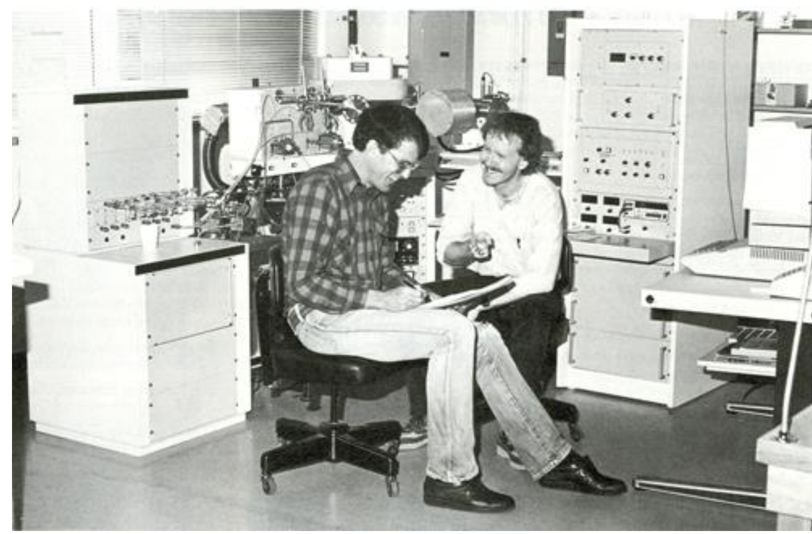
NATURAL STABLE CARBON ISOTOPE TAG TRACES TEXAS SHRIMP MIGRATIONS[1]

BRIAN FRY[2]

Fry 1981 Fishery Bulletin 79 (2): 337-346

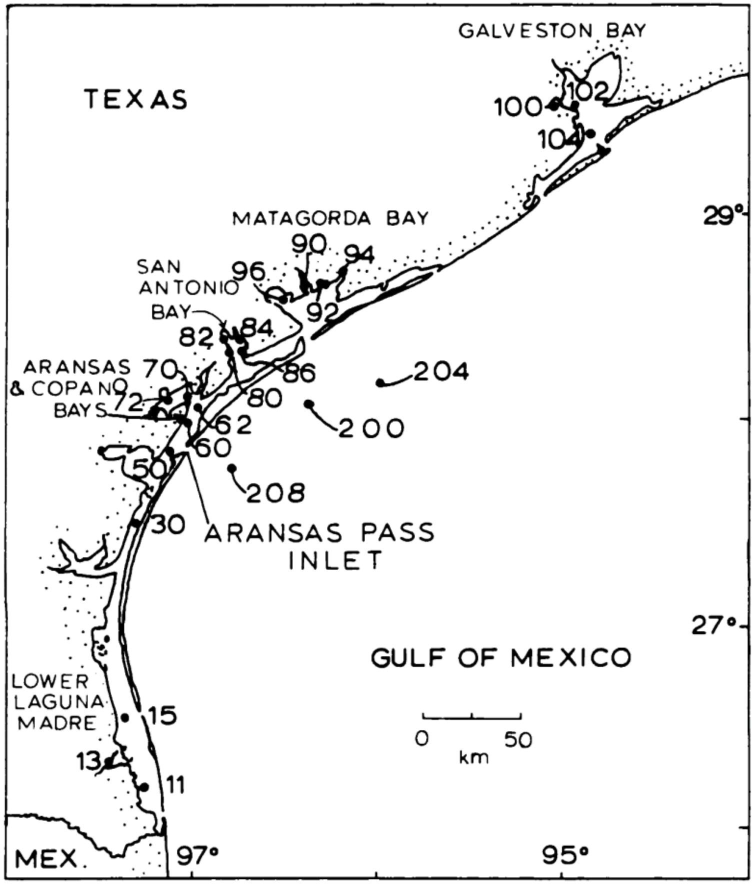


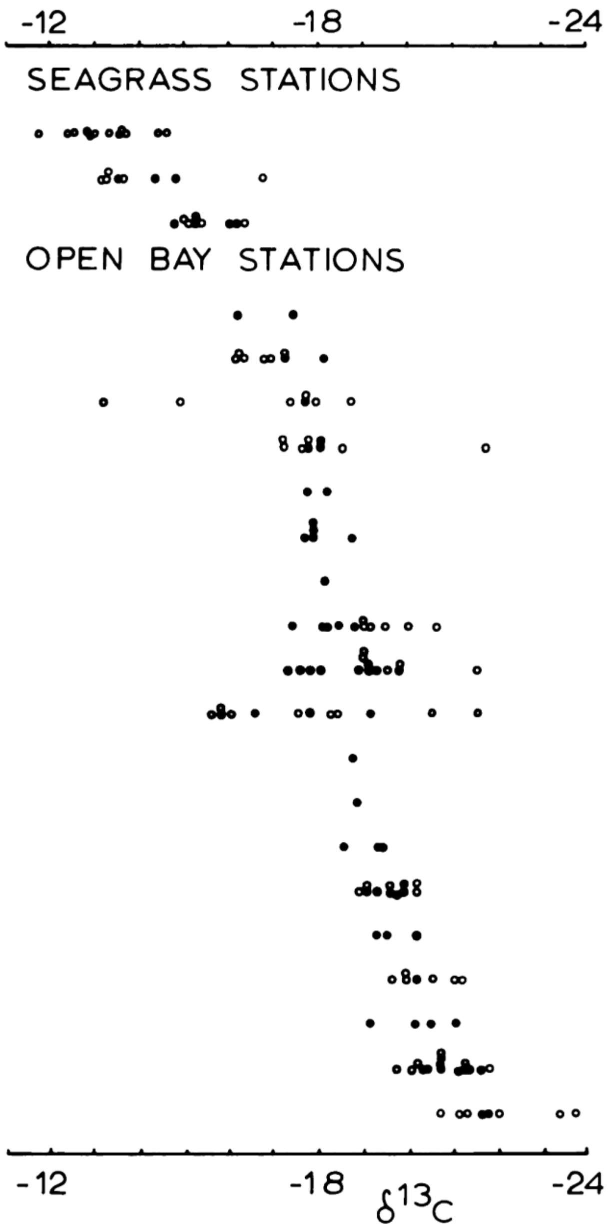
Farfantepeneaus aztecus (brown shrimp)



Brian Fry now and then (more or less)

An (early) example

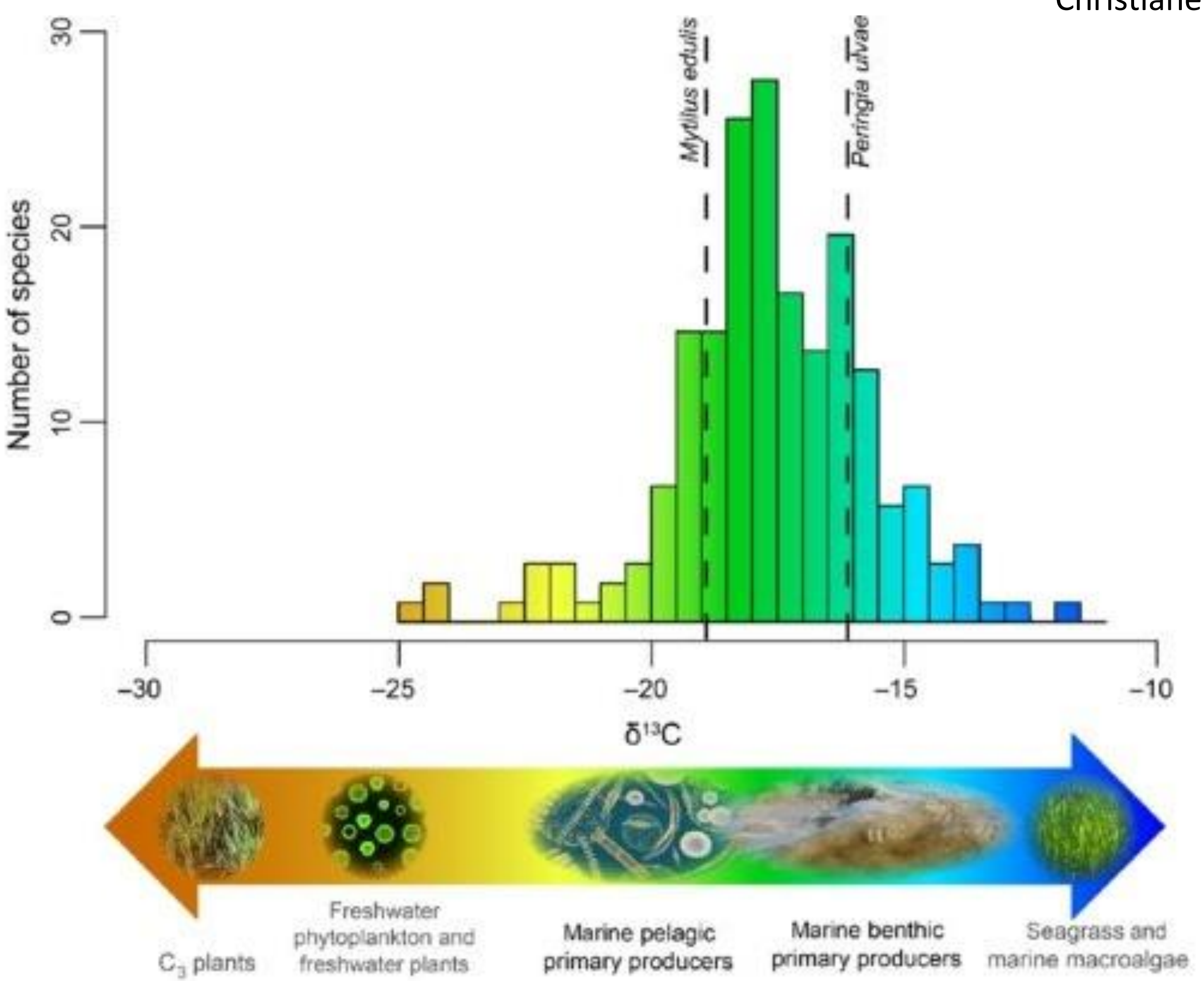




Shrimps from stations featuring seagrass meadows have less negative $\delta^{13}C$

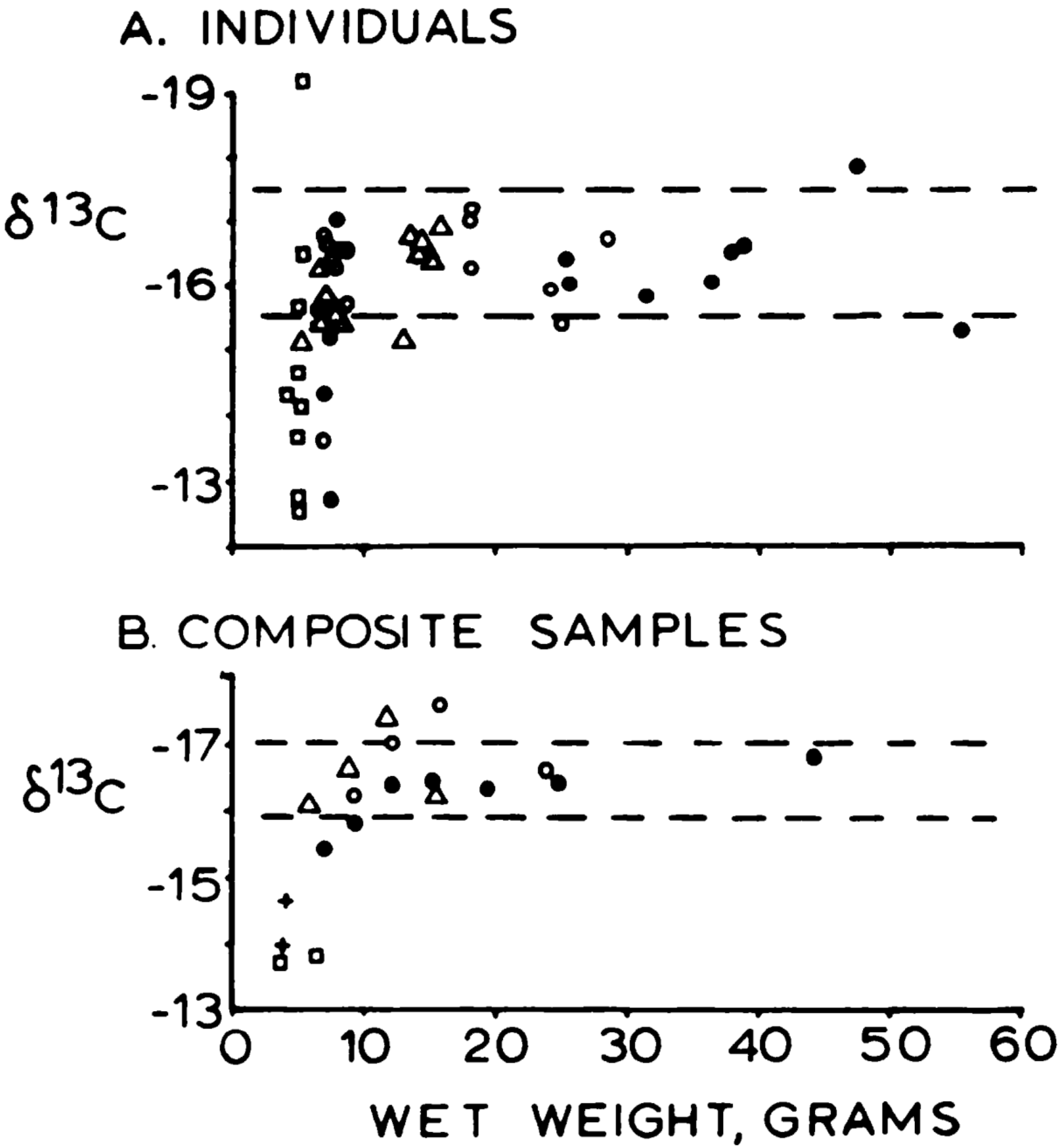
An (early) example

Christianen *et al.* 2017 Ecology 98: 1498-1512



Seagrass have a less negative $\delta^{13}C$ than planktonic primary producers, and this isotopic signal (sometimes called "signature", but be wary of this term) is transferred to animals feeding in seagrass-associated food webs, including brown shrimps

An (early) example



Inverse correlation between shrimp $\delta^{13}C$ and mass: small shrimps depend more on seagrass carbon

Importance of seagrass meadows as nursery zones for this commercially important species

A terrestrial example: African elephants

Past ivory harvesting had a dramatic effect on many African elephant (*Loxodonta africana*) populations, and was completely prohibited in 1989. However, illegal poaching persists.

Environmental managers need tools to determine ivory provenance, and therefore which countries / regions require extra protection measures

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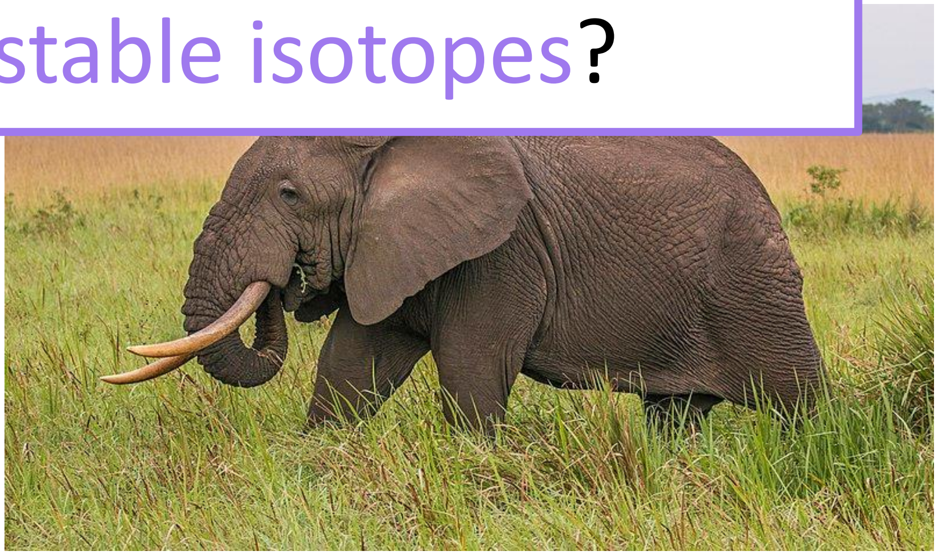
Why not use stable isotopes?



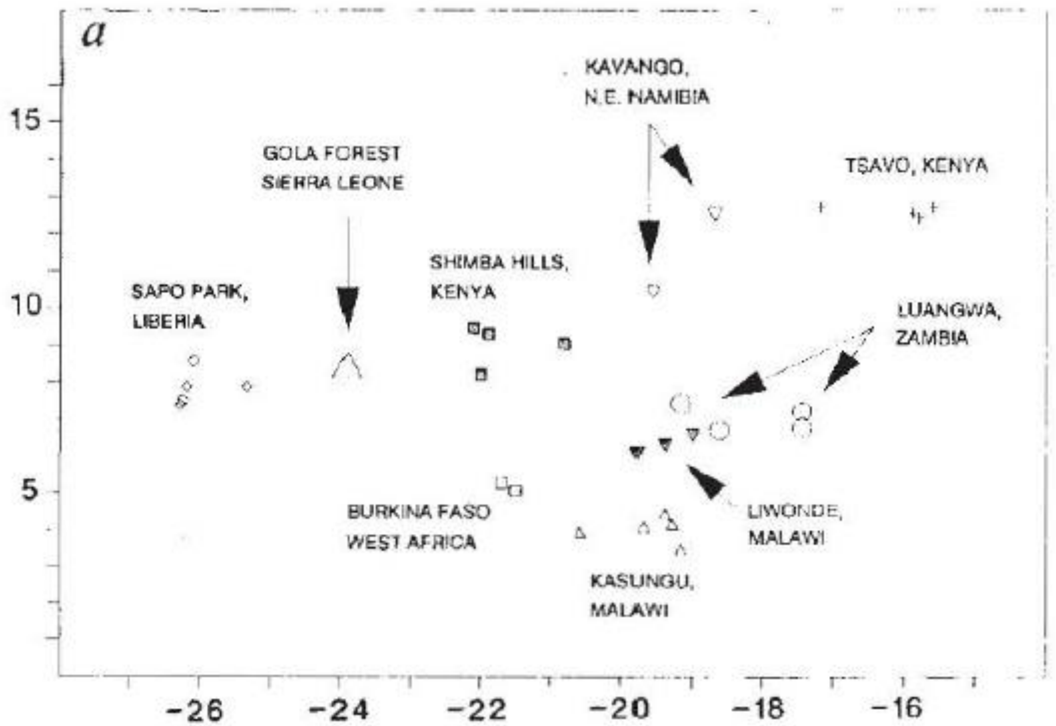
Source-area determination of elephant ivory by isotopic analysis

N. J. van der Merwe*†, J. A. Lee-Thorp*, J. F. Thackeray*, A. Hall-Martin†, F. J. Kruger§, H. Coetzee§, R. H. V. Bell¶ & M. Lindeque‖

Isotope fingerprints in elephant bone and ivory

J. C. Vogel, B. Eglington & J. M. Auret

A terrestrial example: African elephants



Elephants from woodland locations (mostly C3 plants) have more negative $\delta^{13}C$ than those from savannah grasslands (C4 plants)

Elephants from arid locations: drought stress causes protein catabolism in both plants and consumers ➔ higher $\delta^{15}N$

Vogel *et al.* 1990 Nature 346: 747-749; van der Merwe *et al*. 1990 Nature 346: 744-746

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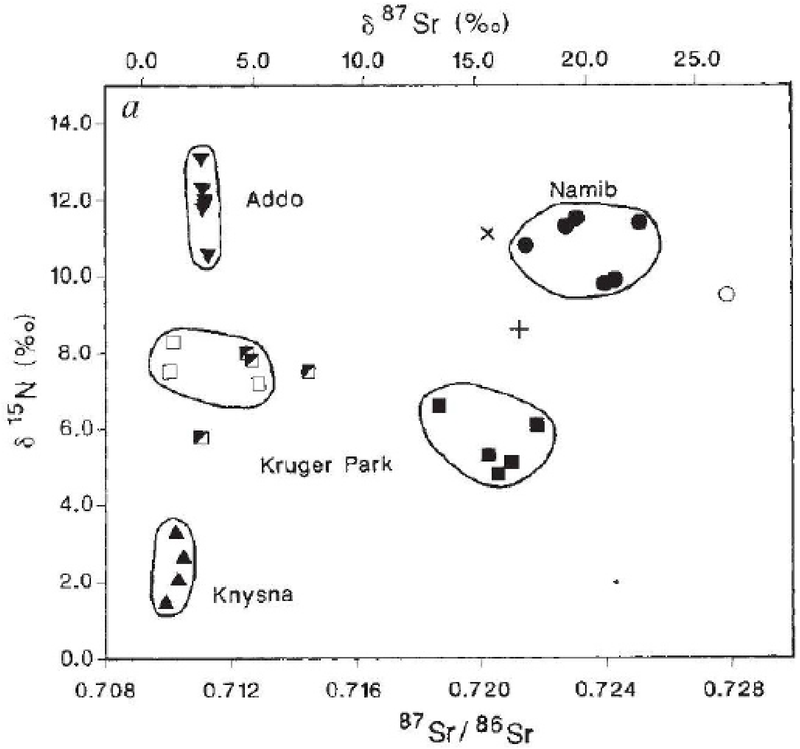

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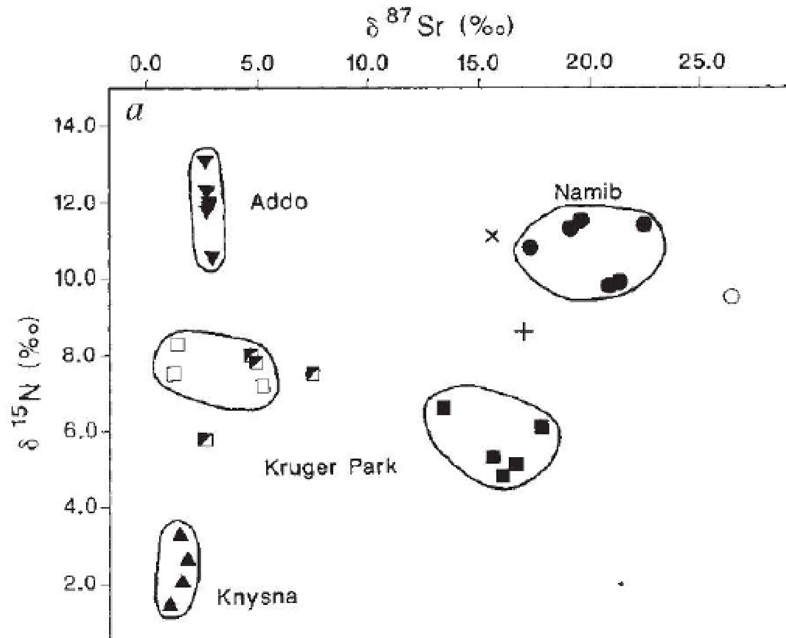

Joint use of stable isotope ratios of multiple elements ("fingerprinting") can help linking ivory to the place where the elephant came from

Elephants from arid locations: drought stress causes protein catabolism in both plants and consumers ➔ higher $\delta^{15}N$

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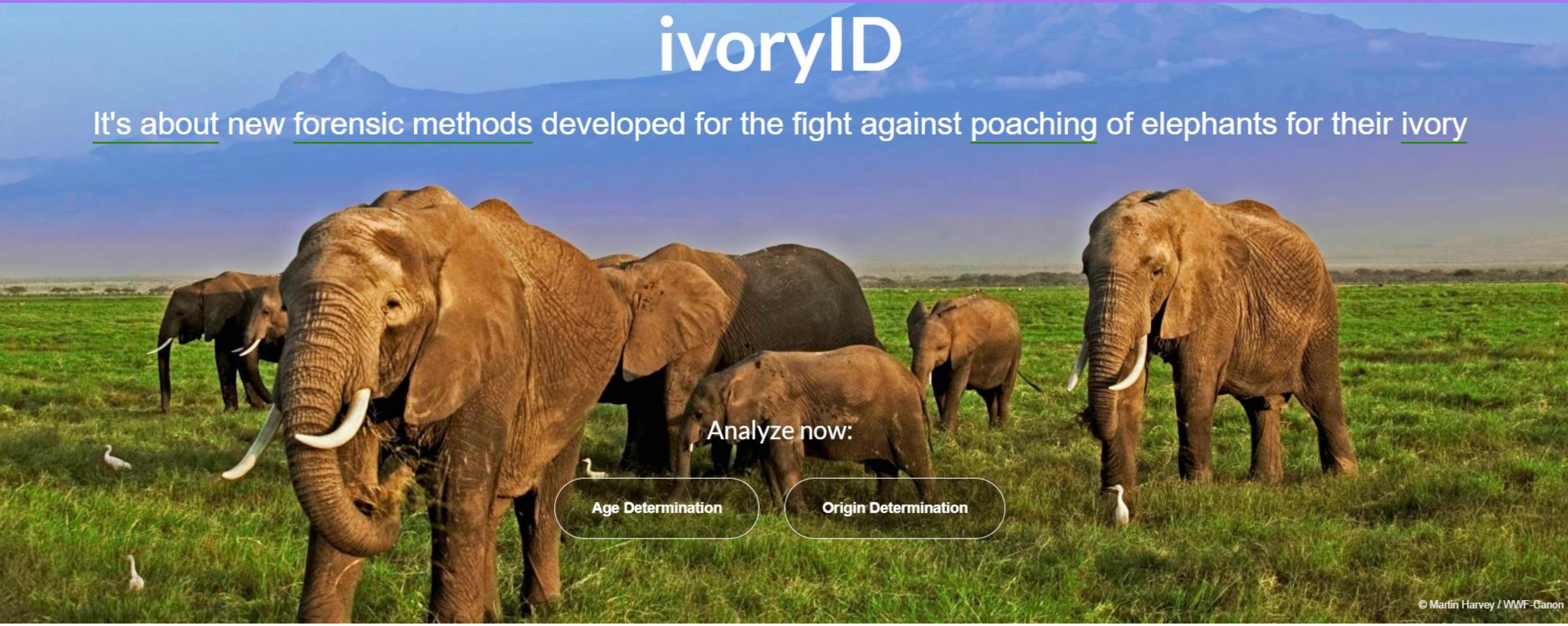


715 samples of ivory of known origin

Users can measure stable isotope ratios of their own ivory and compare it to the database to estimate most likely origin

Check it out: https://ivoryid.org/

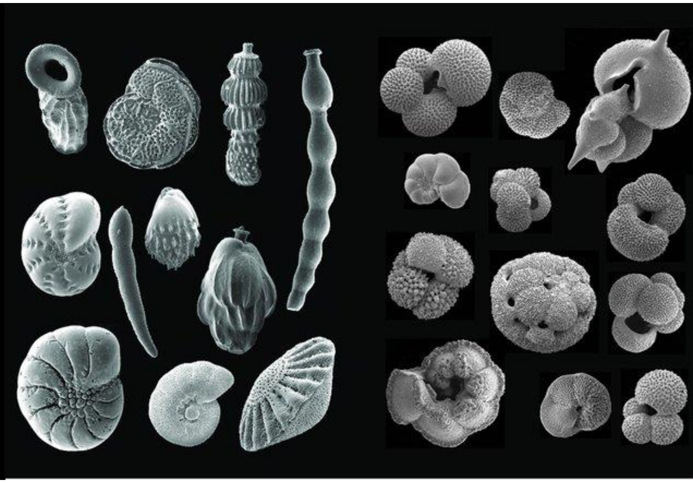
Spatial ecology and stable isotopes

In the previous examples: discrete differences in use of and/or shifts between resources differing in isotopic compositions…

But the concept also works with continuous variation in a single resource pool!

δ^{18}O of carbonates





The δ^{18}O of carbonates contained in hard tissues (e.g. shells) of aquatic organisms is influenced by the temperature (and, to some extent, the salinity) of the water in which they were synthesized

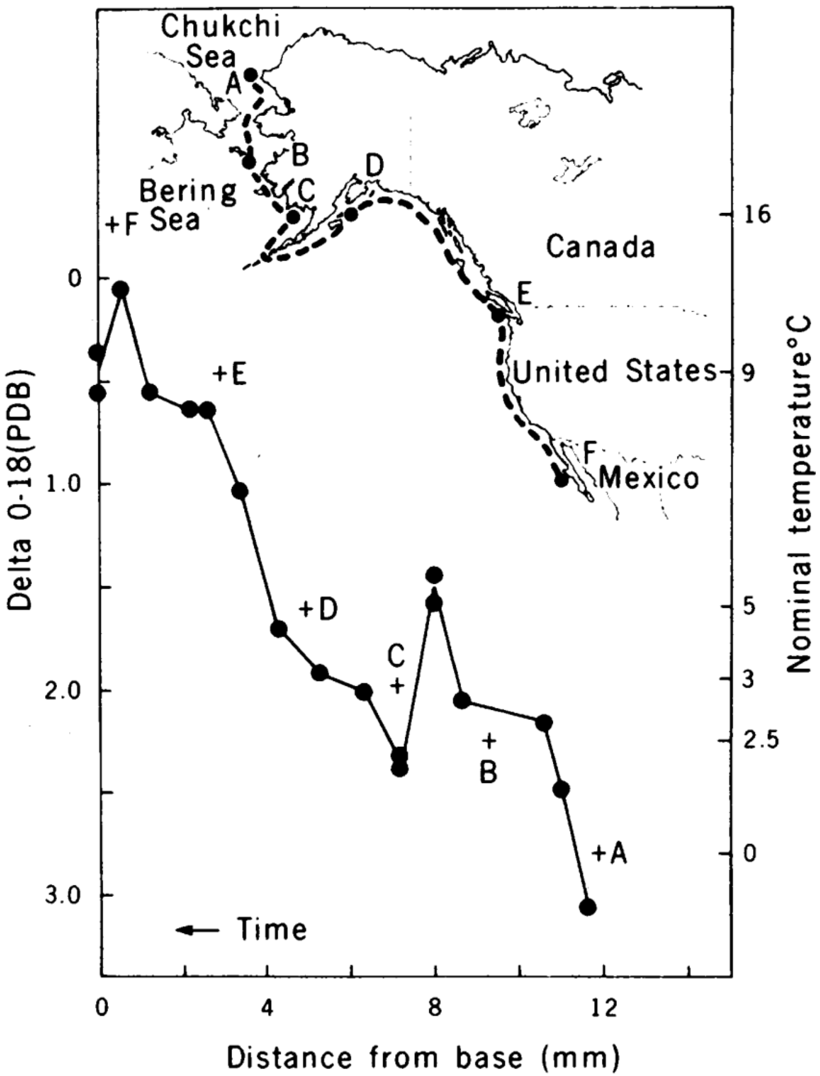
↓

δ^{18}O of carbonates can help tracking migrations of animals between water masses of different temperature / salinity

δ^{18}O of carbonates

California gray whale *Eschrichtius robustus* and their epizoic barnacles *Cryptolepas rhachianecti*

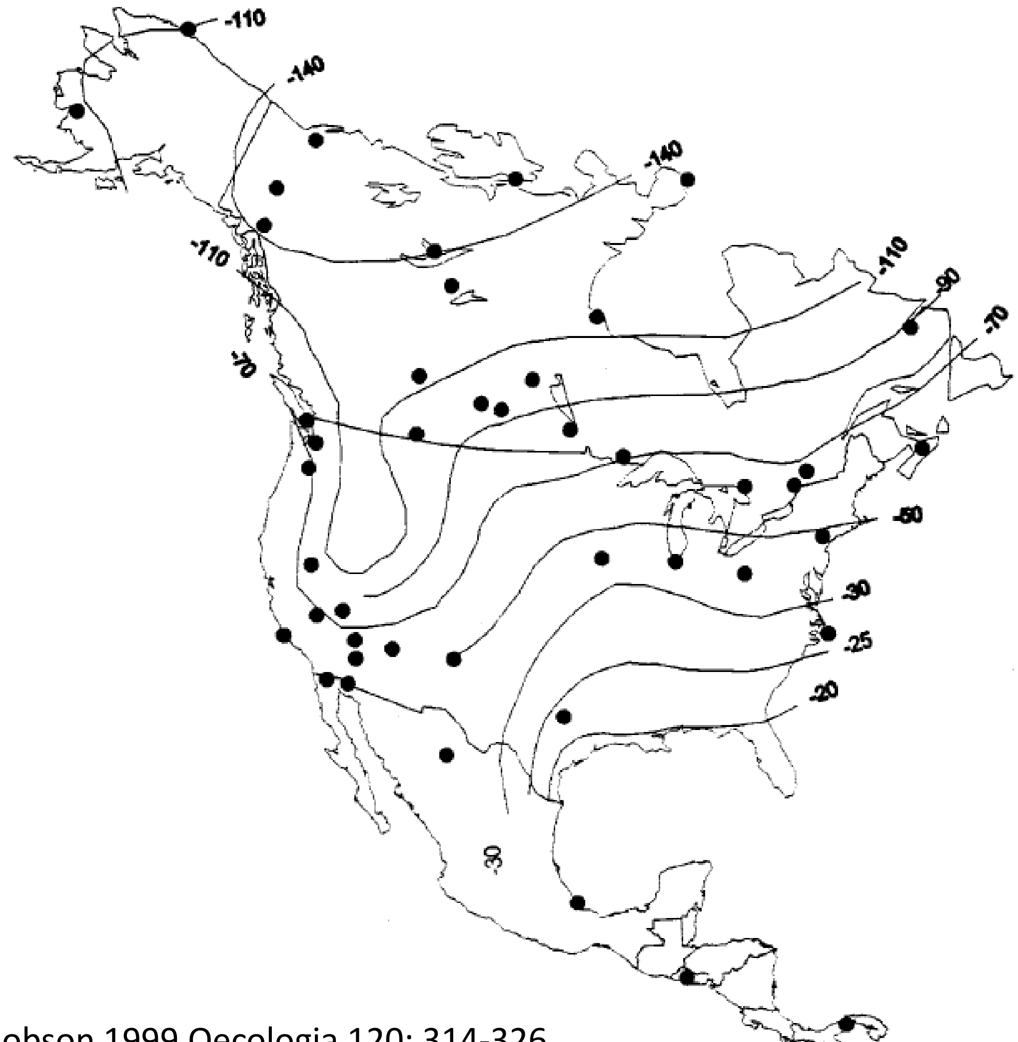
Decrease of barnacle δ^{18}O as the whale moves southward



Killingley 1980 Science 207: 759-760

δD and bird migration

δD of surface water is strongly influenced by isotope effects associated to evaporation and condensation. Therefore, temperature (linked to latitude), precipitation intensity, altitude and distance to the ocean drive natural δD gradients



Hobson 1999 Oecologia 120: 314-326

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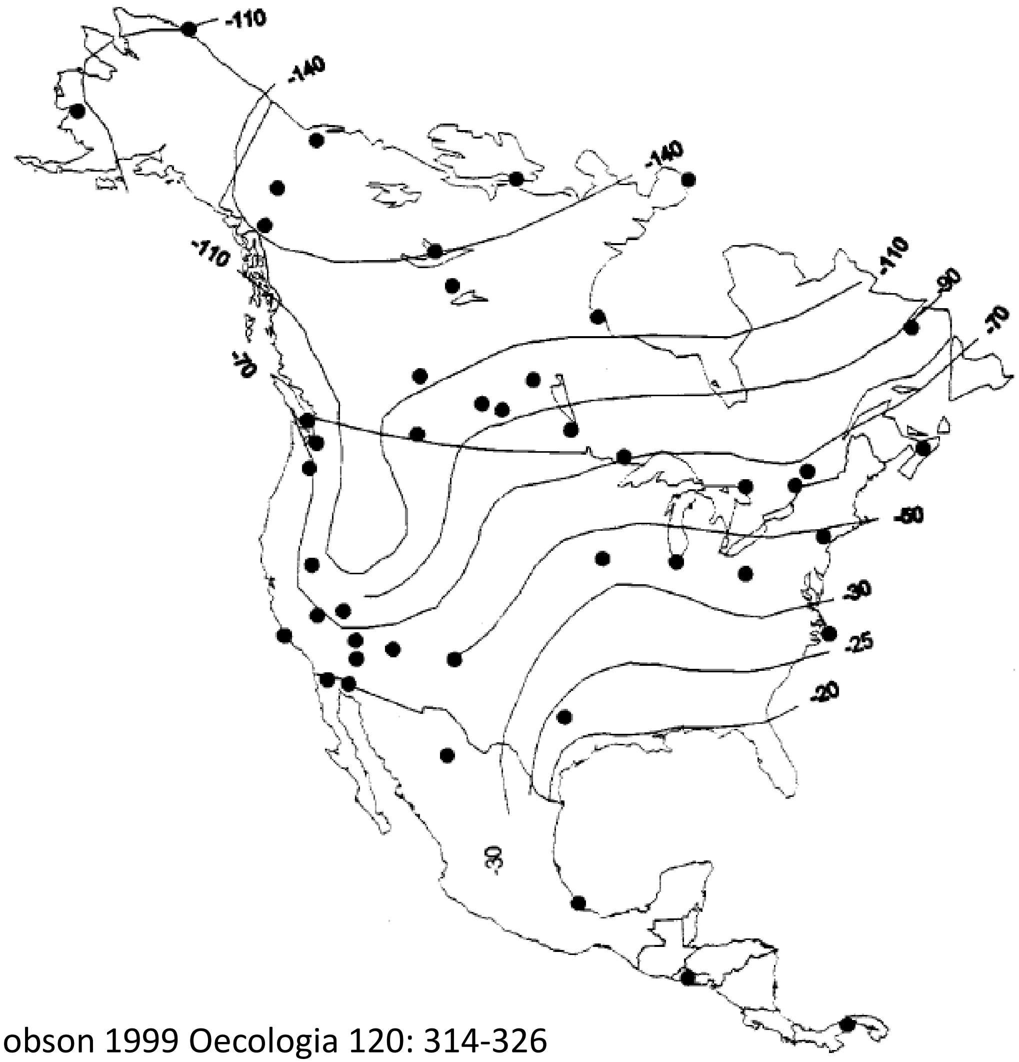
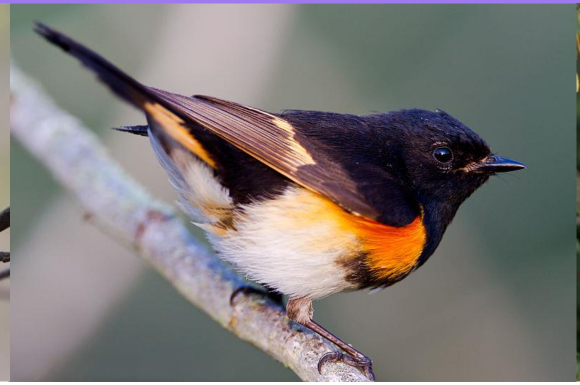


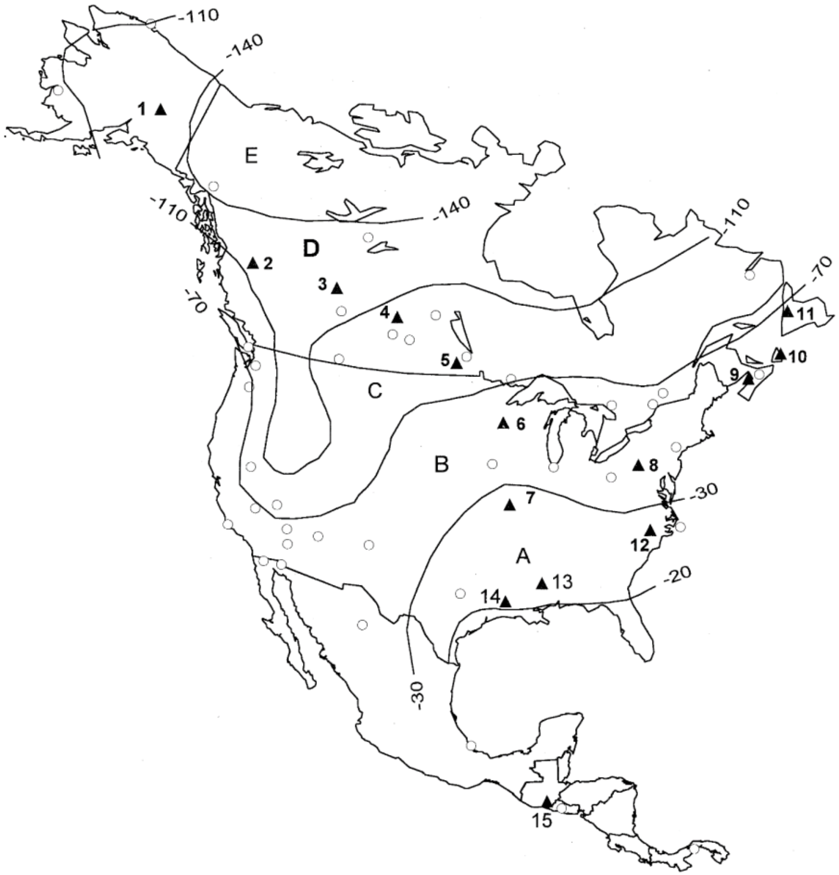
Hobson 1999 Oecologia 120: 314-326

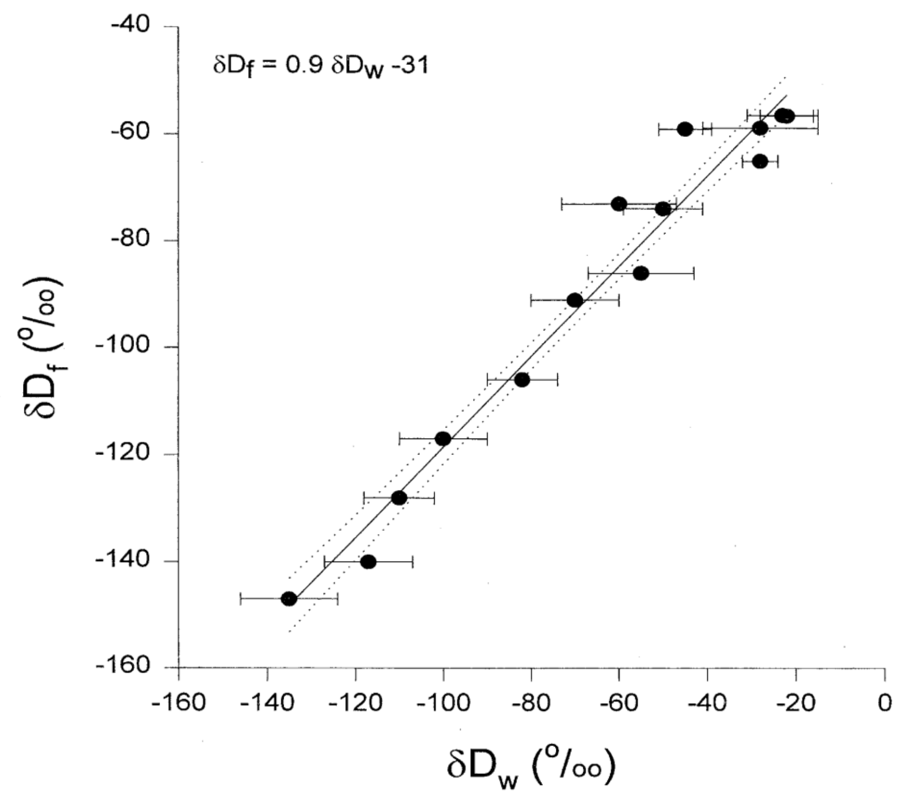
In birds, feather δD reflects δD of the of the water consumed during feather synthesis (metabolic + drink water)

Many migrating species moult at a specific stage of their life cycle. Since feather are inert tissues, their isotopic composition does not change after synthesis, and their δD remains permanently linked to the one of environmental water available where they moulted.

δD and bird migration

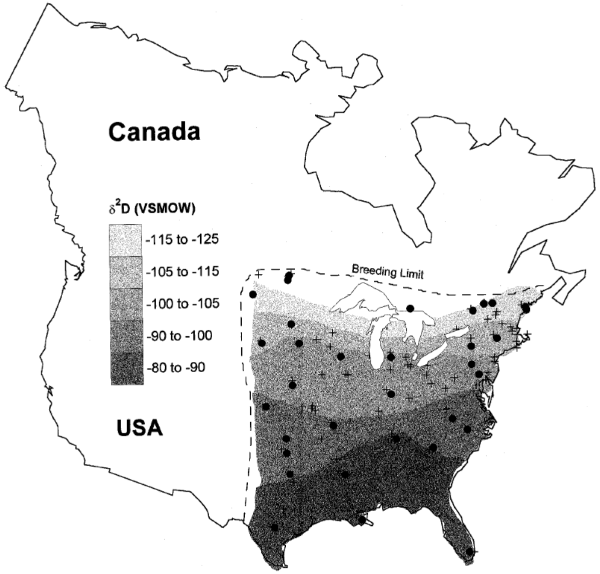


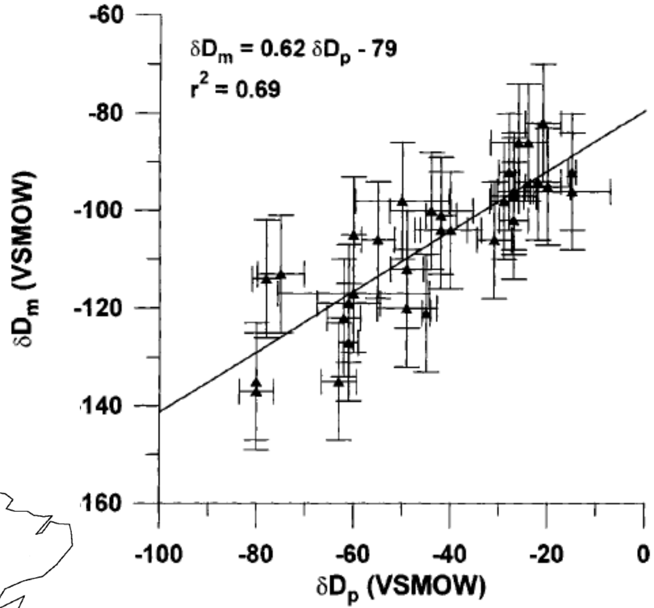




Hobson & Wassenaar 1997 Oecologia 109: 142-148

δD and butterfly migration



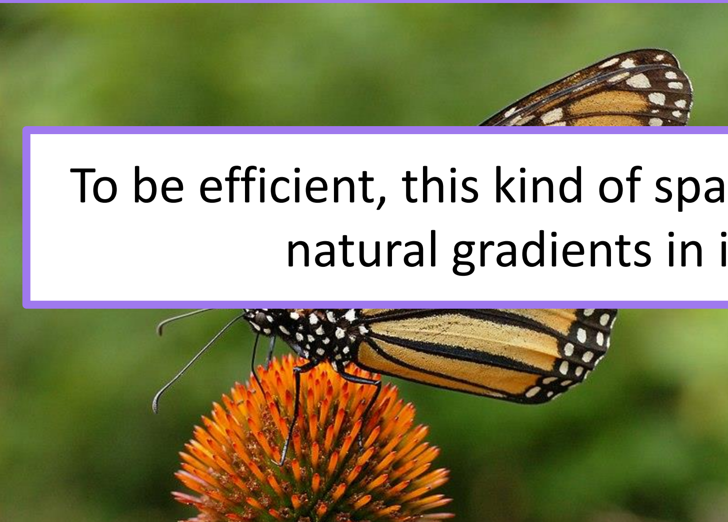


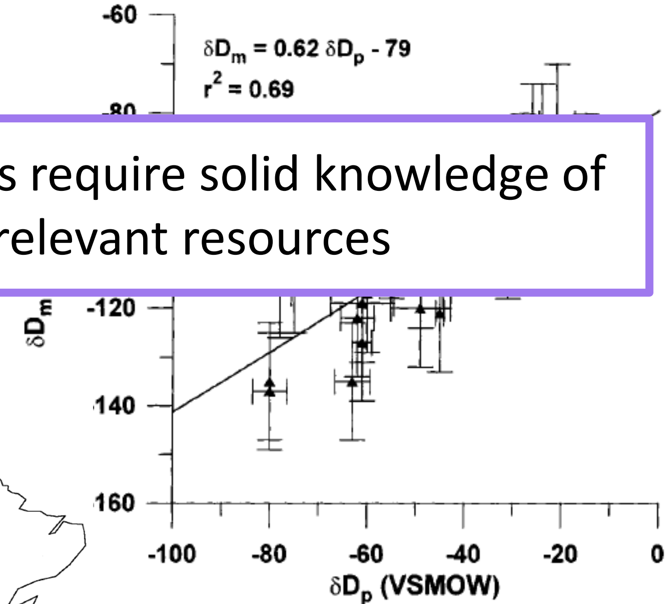
Monarch butterflies (*Danaus plexippus*) perform multi-generational migrations across North America

Wing δD allows to identify each butterfly's origin

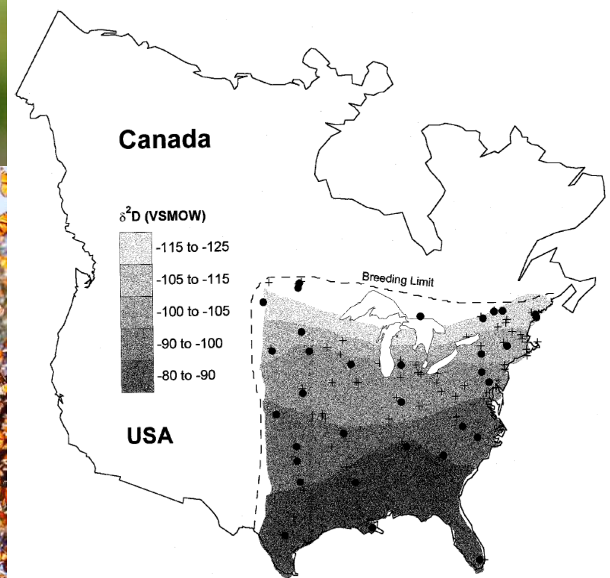
Hobson *et al.* 1999 Oecologia 120: 397-404

δD and butterfly migration





To be efficient, this kind of spatially explicit approaches require solid knowledge of natural gradients in isotopic composition of relevant resources



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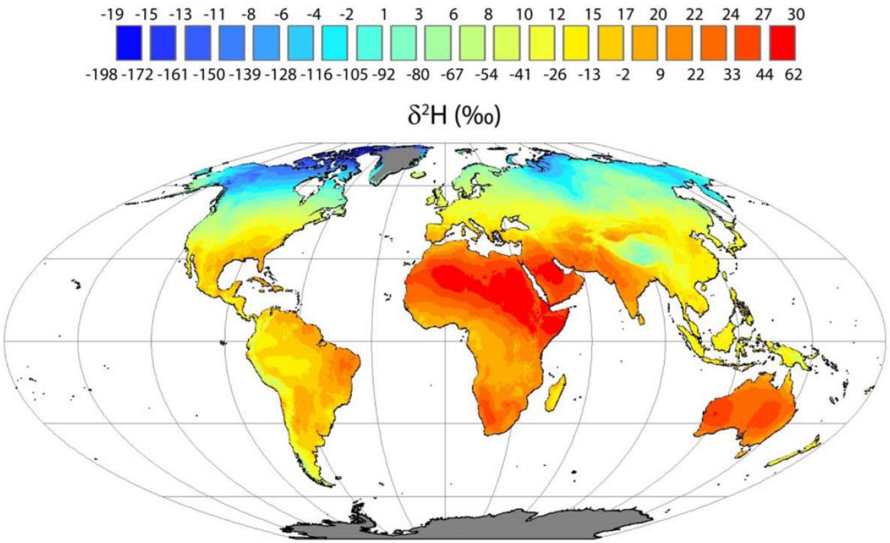
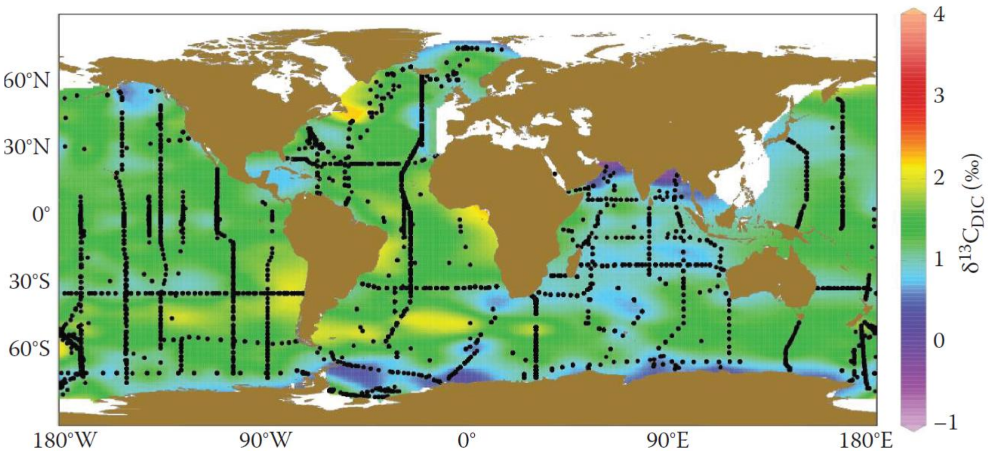
From discrete measurements to isoscapes

Isoscapes (contraction of "isotopic landscapes") are spatially continuous projections of isotopic compositions, modelled using discrete measurements as input data



δD of plant leaf water



δ^{13}C of surface seawater DIC

West *et al.* 2008 PLoS One 3: e2446; McMahon *et al.* 2013 Ocean. Mar. Biol. Ann. Rev. 51: 327-374

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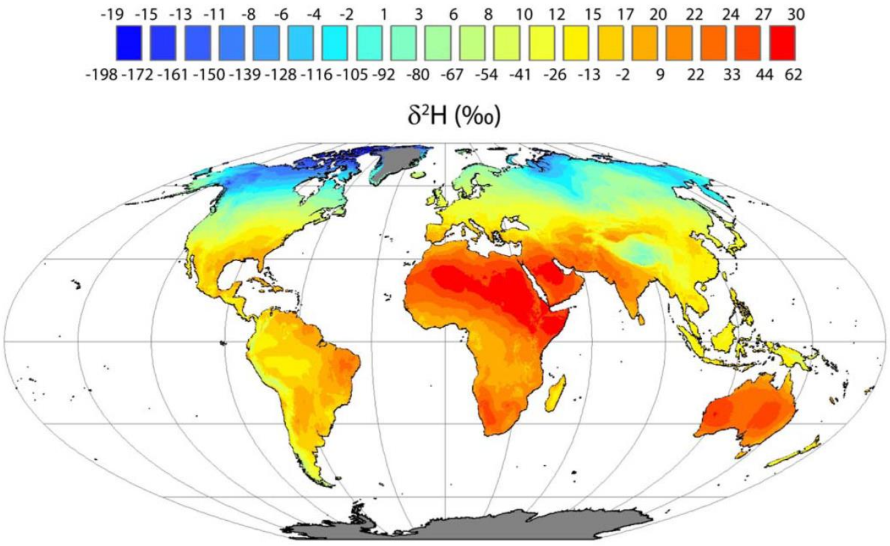
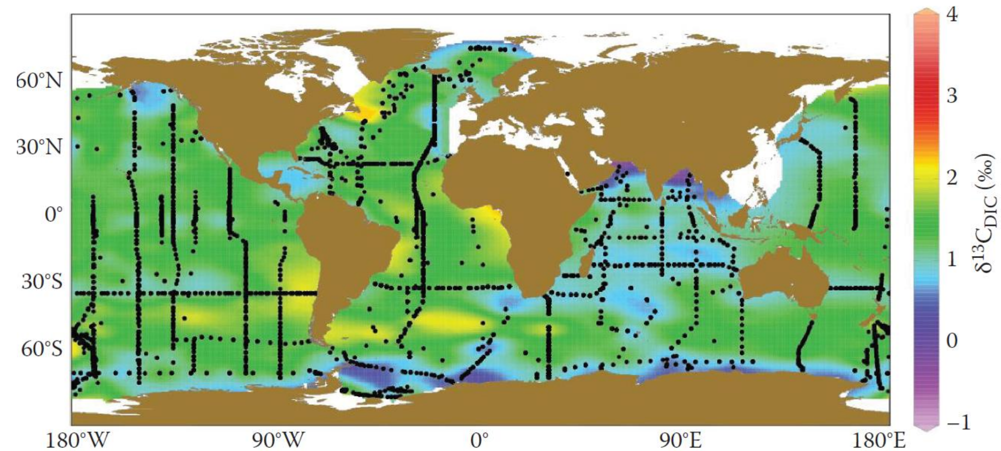


δD of plant leaf water

Mechanistic model



$\delta^{13}C$ of surface seawater DIC

Statistical model

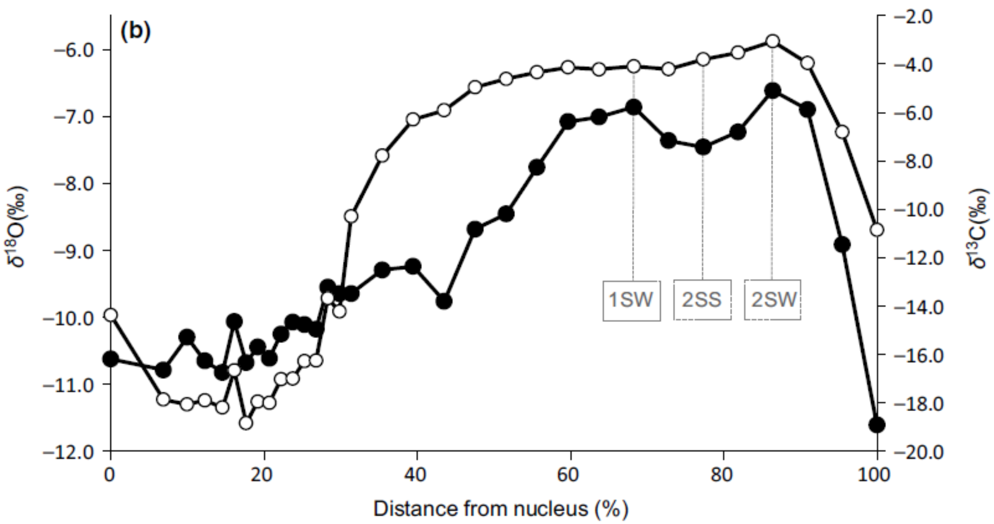
Spatial interpolation via DIVA – ULiège product!

https://github.com/gher-ulg/DIVA

West *et al.* 2008 PLoS One 3: e2446; McMahon *et al.* 2013 Ocean. Mar. Biol. Ann. Rev. 51: 327-374

Isoscapes in action: baltic salmons

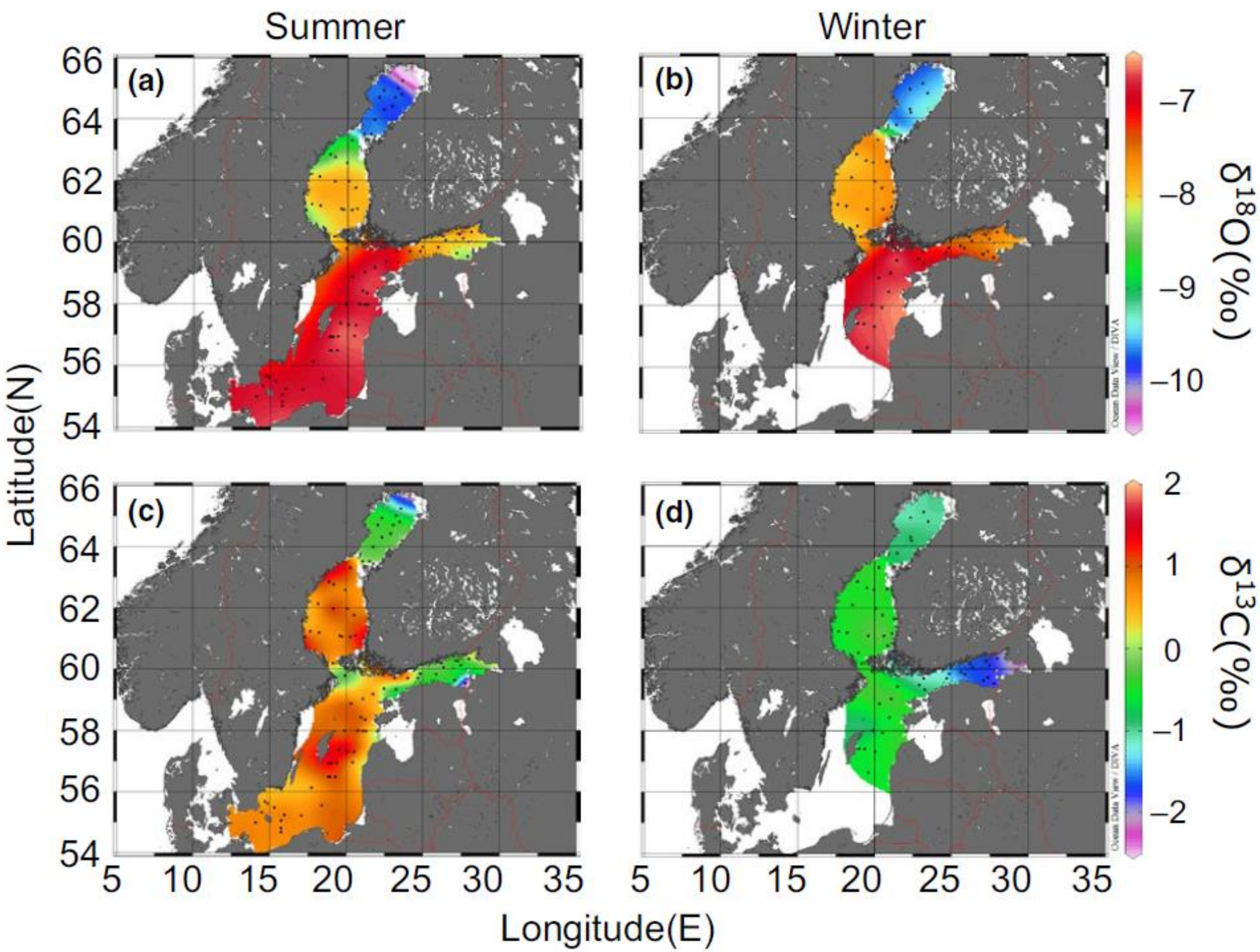
Atlantic salmon, *Salmo salar*



Changes in otolith isotopic composition through seasonal migrations

Torniainen *et al.* 2017 Ecol. Evol. 7: 2255-2267

Isoscapes in action: baltic salmons

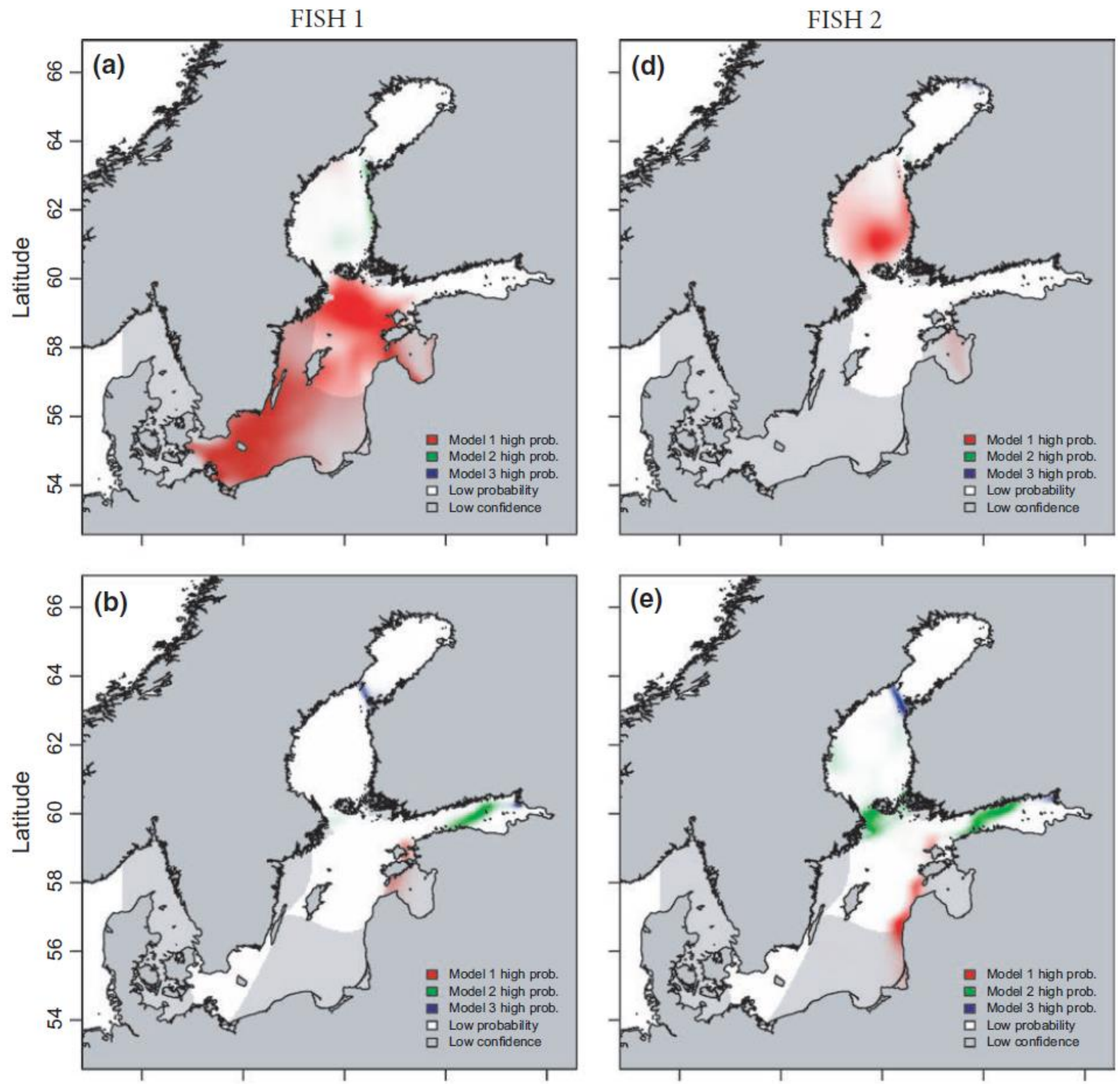


Isoscapes of seawater $\delta^{18}O$ and DIC $\delta^{13}C$
(resources used by fishes for otolith synthesis)

Torniainen *et al.* 2017 Ecol. Evol. 7: 2255-2267

Isoscapes in action: baltic salmons

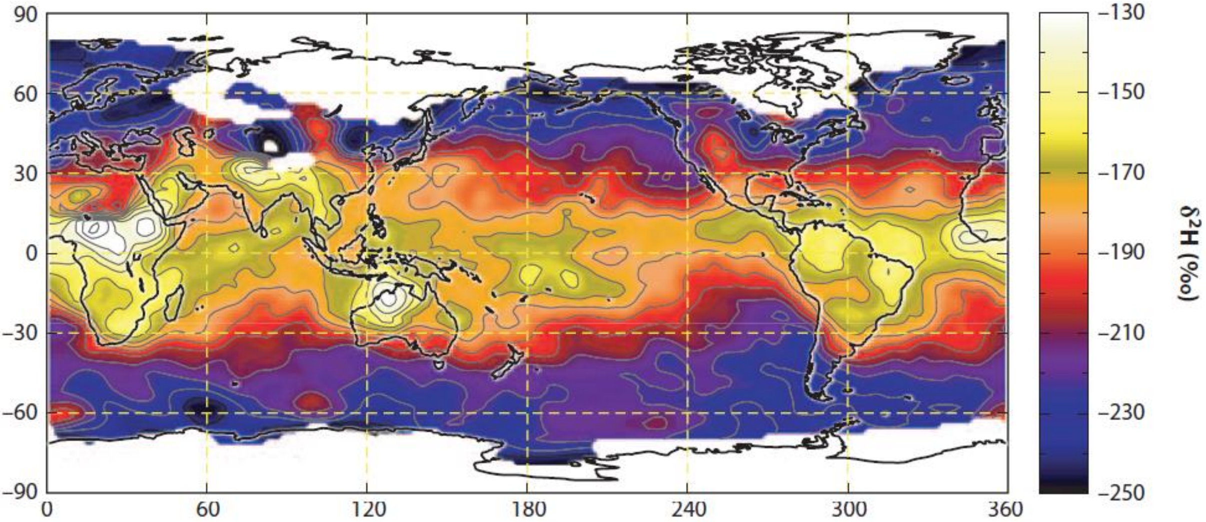
Use of a probability model to assign fishes to their winter & summer habitat



Torniainen *et al.* 2017 Ecol. Evol. 7: 2255-2267

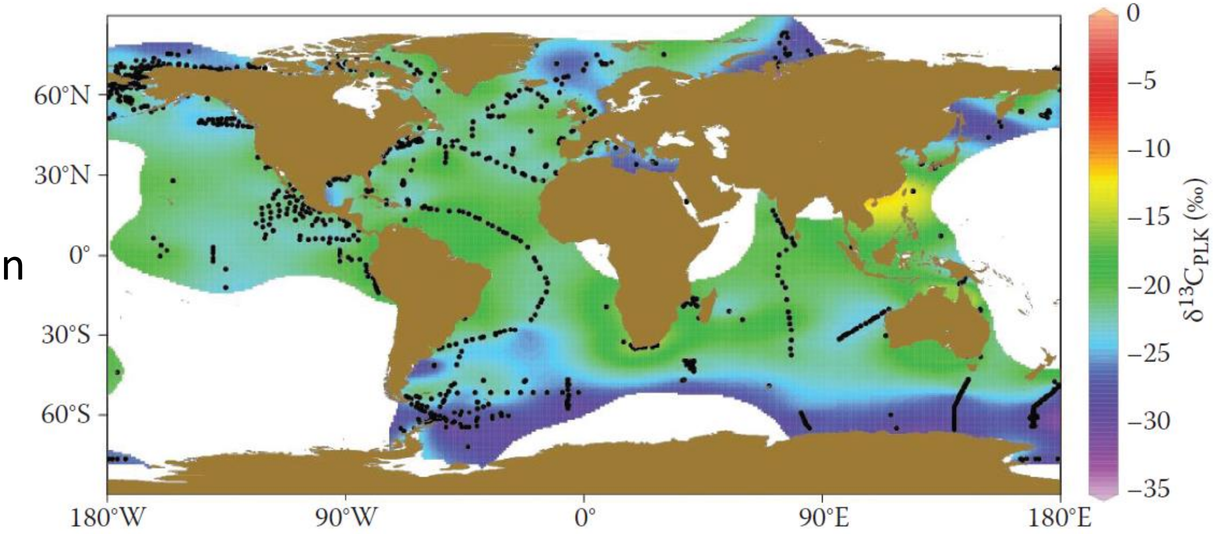
Isoscape coverage & resolution

The spatial extent and resolution of isoscapes depend on the quality of input data (number of samples, evenness of distribution, etc.)



δD of troposphere water vapor

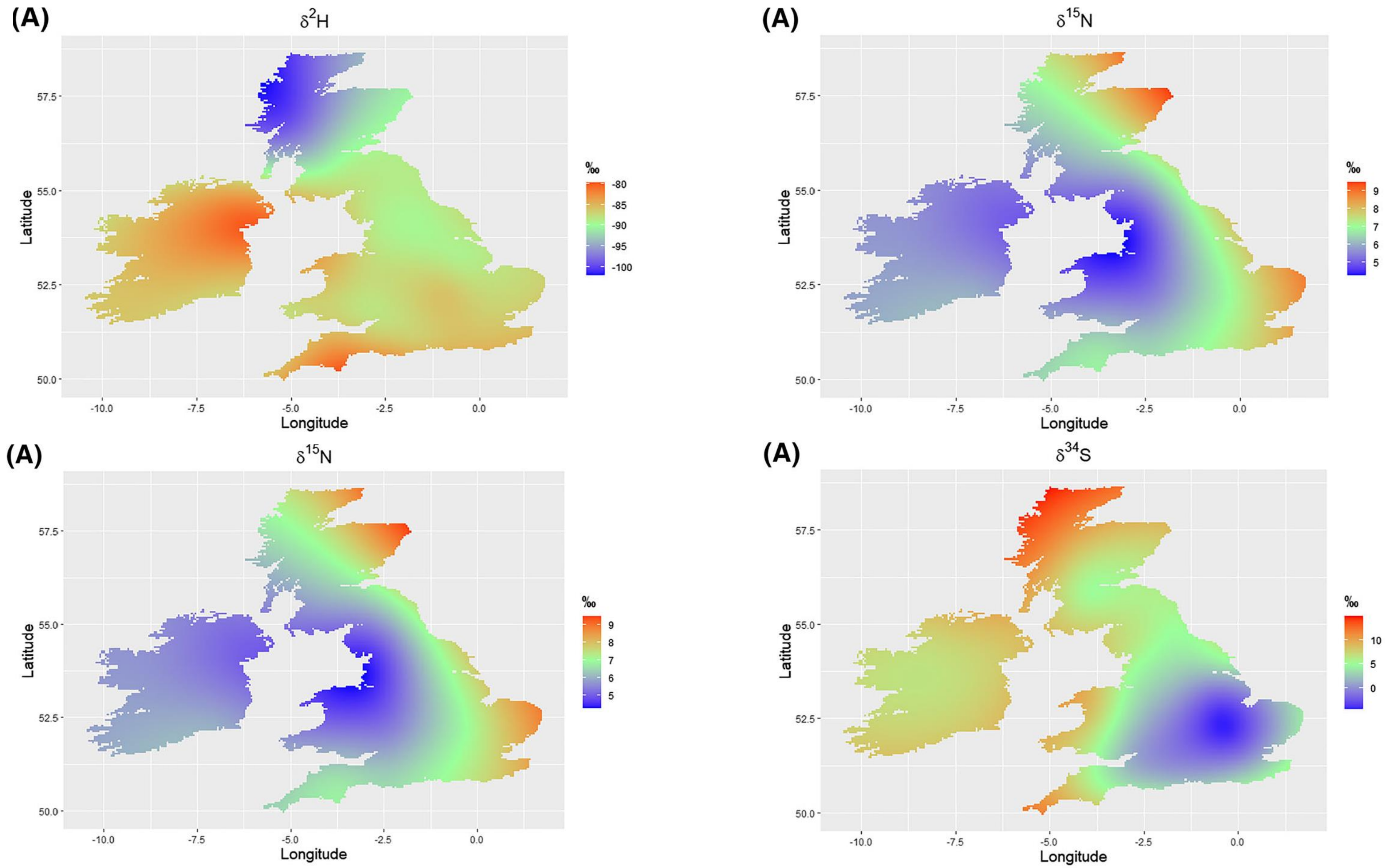
δ13C of plankton



Bowen 2010 Annu. Rev. Earth Planet. Sci. 31: 161-187 ; McMahon *et al.* 2013 Ocean. Mar. Biol. Ann. Rev. 51: 327-374

Building more reliable isoscapes

When applicable: taking as many samples, as regularly distributed as possible



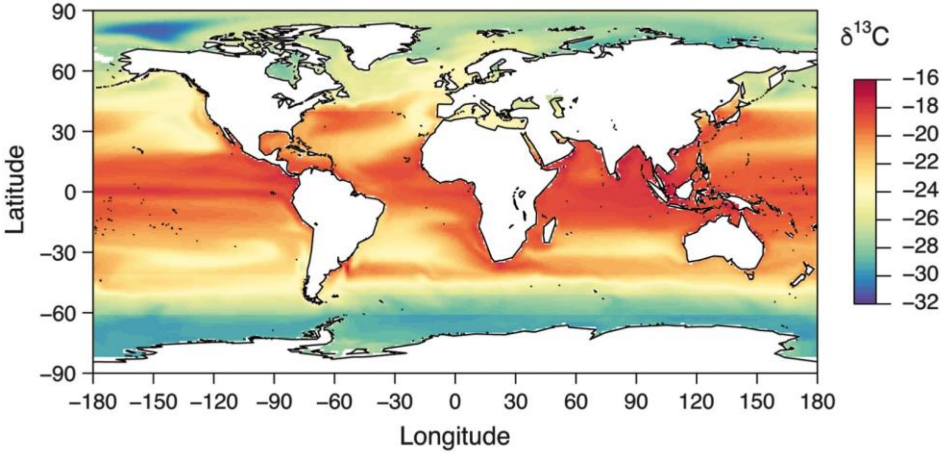
Use of citizen science (network of volunteers) to build moth (*Opisthograptis luteolata*) isoscapes across the British Isles

Newton 2021 Rapid Comm. Mass Spec. 35: e9126

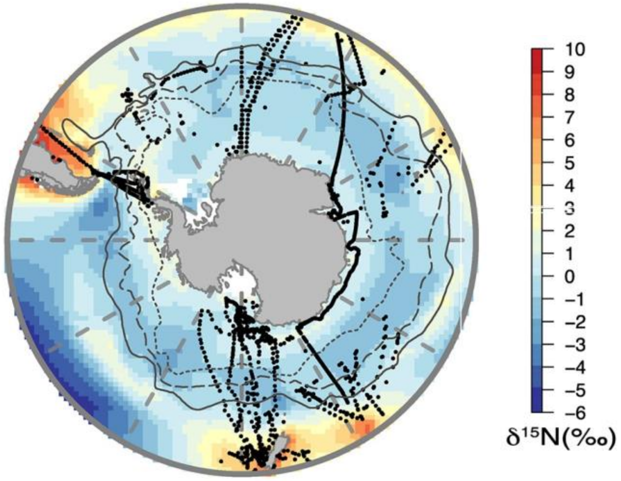
Building more reliable isoscapes

Improving modelling methods: combining statistical (spatial interpolation based on most comparable values in the dataset) and mechanistic (taking into account environmental covariates driving isotopic composition gradients) approaches

An exemple: INLA (Integrated Nested Laplace Approximation, a Bayesian hierarchical spatial modelling framework)



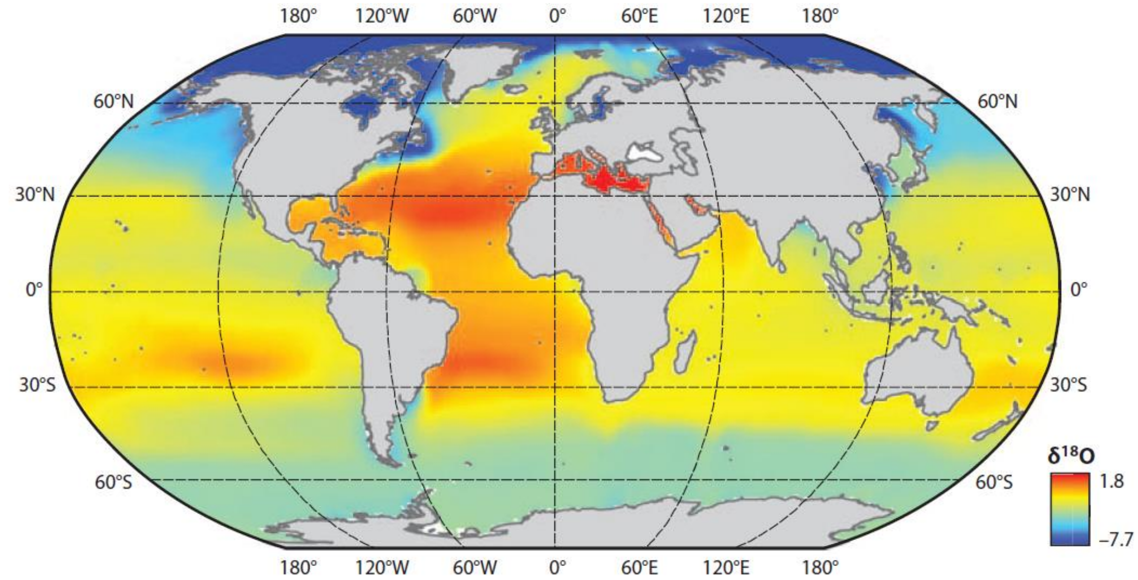
Global ocean plankton $\delta^{13}C$



Southern Ocean POM $\delta^{15}N$

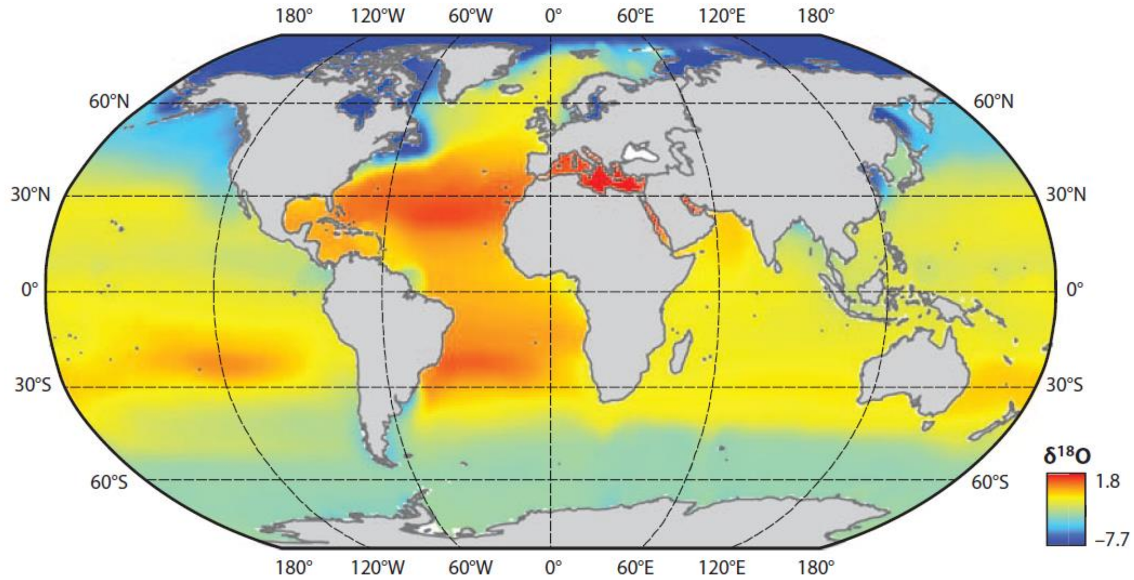
St John Glew *et al.* 2019 Methods Ecol. Evol. 10: 518-531; Magozzi *et al.* 2017 Ecosphere 8: e01763; St John Glew *et al.* 2021 Global Biogeoch. Cycles 35: e2020GB006901

Conclusions



Stable isotopes can be powerful tracers in spatial ecology. Multiple elements and tissues/matrixes offer a "toolbox" able to adress a wide variety of questions about animal distribution, migration and habitat use.

Conclusions



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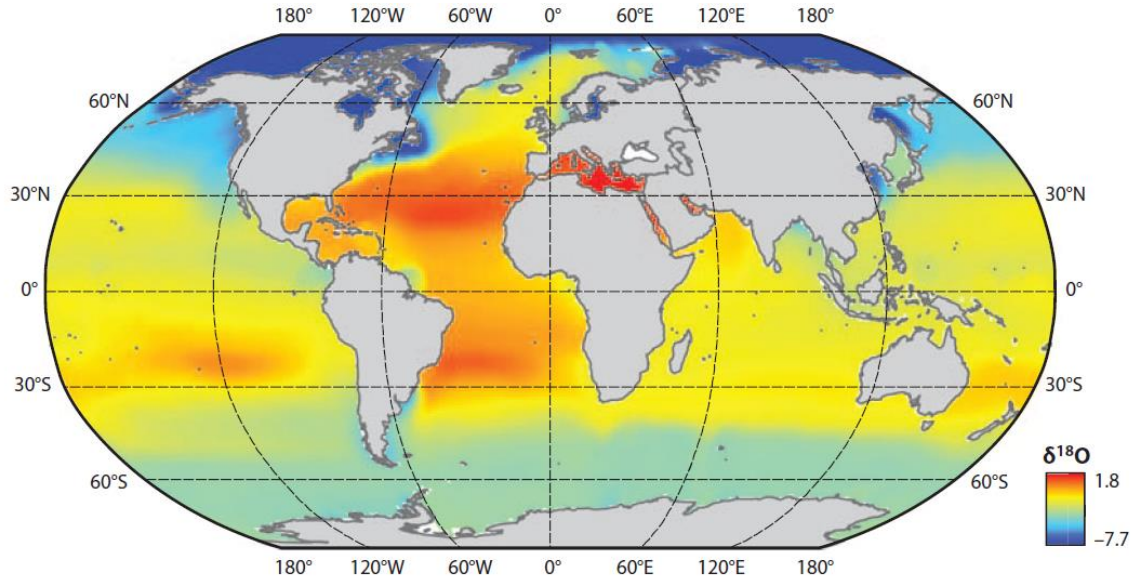
Critical (and sometimes overlooked) aspects to take into account: environmental and physiological (fractionation) drivers causing isotope effects. Know your system!

Conclusions



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Critical (and sometimes overlooked) aspects to take into account: environmental and physiological (fractionation) drivers causing isotope effects. Know your system!

Junk in, junk out: a model is only ever as good as the data and methods it is build upon...

Thanks for your attention

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