USING CHEMISTRY TO UNRAVEL

The ecology of trout

Dr. Jonathan Grey, reader in Aquatic Ecology at Queen Mary University of London, describes the importance of stable isotopes.

To my ears, pressed against the cold fabric roof of a pop-up VW campervan, damp from where my breath had condensed, it was deafening. How could a fish make such a resounding crash? I'd spent many hours peering down into the peaty waters of the Scottish Borgie River trying to spot it. There was a patch of displaced scales near to the adipose fin that just caught the light even if I couldn't make out the whole fish and which seemed to sway ever wider the longer I stared. Dad told me it was about 20lb, a salmon. To me it was a monster. During the day, my father was photographing golden plover and greenshank and I would help him by walking him to the cramped canvas hide we had carted up from Surrey and stapled together over the previous days. I would then retire, thread a wind-knotted leader and line to my old 7ft Fibatube to bounce Bloody Butchers and March Browns off the boulders strewn throughout the nearby burns and winkle spotty golden bars of joy from their lies, cradle them for a second, then slip them back. I never did try for that monster.

Twenty years later I returned to Scotland for work. I'd followed my boyhood passion, fascinated by what I couldn't see and couldn't understand beneath the surface of the water, and become an aquatic ecologist. Scottish waters are often difficult to see into, a function of the humic acids leached from the surrounding peat, and it was actually these, or at least their carbon component, that drew me back. I was charged with characterising the food web of Loch Ness.

Earlier studies of the loch had revealed that the percentage of carbon in living biomass made up a paltry one per cent in the height of summer and less so in the colder seasons of course. The majority was in dissolved form (60–80 per cent) and the remainder was particulate or detrital. Little obvious food then to fuel another Scottish monster! As the production of bacteria in the loch far outstripped that of phytoplankton, it was thought that they must be subsidised by these dissolved and particulate forms, which likely originated in the catchment. Cue my project. I use a particular technique called stable isotope analysis (SIA), which uses the ratios of naturally occurring forms (isotopes) of carbon, nitrogen, sulphur, oxygen and hydrogen amongst others as natural tracers. Carbon and nitrogen are most commonly used, often in conjunction, as they are acquired through diet and so can be useful in identifying energy sources and trophic structure in food webs. Through lots of study and careful experimentation in the lab, we know how these ratios of isotopes change as they are passed to a consumer from its prey (Figure 1). Provided that different food resources have distinct and robust isotope values, they can be traced throughout food webs. Carbon and nitrogen fixed in marine, estuarine or freshwater systems are typically very different in their ratios of isotopes, so tracking migration history in sea trout, for example, is certainly possible. I was relying upon terrestrial plant-fixed carbon to differ from aquatic plant-fixed carbon for my study at Loch Ness. We can use isotopes from different tissues to tell us different things as well. Isotopes in bone or scales reflect a longer time period or the life history of the fish as the tissue turnover is very slow or negligible. Conversely, isotopes in blood plasma, mucus or even the liver turnover much more rapidly and can tell us about more recent dietary history.

The Scottish Tourist Board will not like me saying this, but my research showed that the top of the Loch Ness food web was the ferox trout (Figure 2), samples of which I gleaned from a local fishing operator. I must admit I did fish for them a few times as well. To maximise the information from these rare samples, I not only took samples from the ferox, but from their gut contents as well, using them as matryoshka dolls! Out of the guts of the ferox came Arctic char, salmon parr and smaller brown trout, and in turn from their guts came invertebrates and zooplankton, and even from the guts of the zooplankton I could identify diatoms. The data revealed some interesting patterns. Clearly some ferox were being rather opportunistic and targeting all and sundry, while others seemed to target only char or specialised in cannibalism (Figure 3). This was one of the first studies to use stable isotopes of multiple individuals to try and reconstruct dietary shift through development. It also revealed that the carbon base for the food web was heavily subsidised from the catchment; peat-derived carbon was the main resource for 40 per cent of the food web on an annual basis. Clearly then, what we do in the catchment – perhaps many miles away from lakes or lochs – has ramifications for the organisms that live there, a point to which I will return.

Incidentally, as so much of the aquatic food web is reliant upon terrestrial carbon, one way for a Loch Ness monster to exist would be to feed like a hippopotamus, actually leaving the water to graze on surrounding vegetation at night, but most often being seen in the water during the day where it would not actually feed. This fits rather neatly to one of the earliest hoaxes at Loch Ness, whereby a big game hunter named Marmaduke Wetherell was sponsored by the *Daily Mail* to hunt down the monster in 1933. Although he found no monster, he apparently found enormous footprints on the shore of the loch leading into the water. Unfortunately, when researchers from the Natural History Museum examined the tracks, they determined that they had been made with a preserved hippo's foot of the kind that were used as umbrella stands! But I digress.

Luxurious stands of water crowfoot in a Hampshire chalkstream

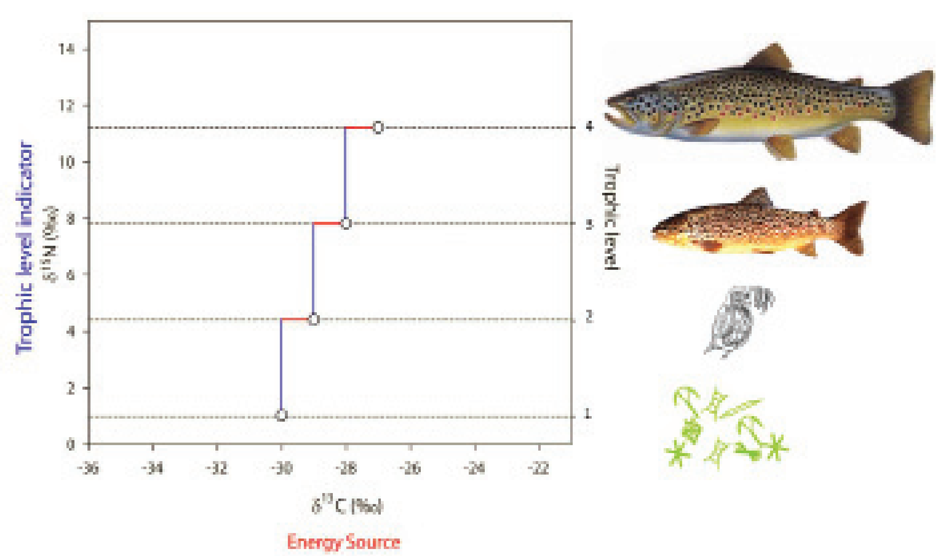


Figure 1. Classic 'rules-of-thumb' in stable isotope ecology using a simple food chain from phytoplankton to zooplankton to zooplanktivore to piscivore. Carbon is transferred relatively conservatively between trophic levels, whereas nitrogen is fractionated to a greater extent, thereby allowing us to infer source and trophic position, respectively

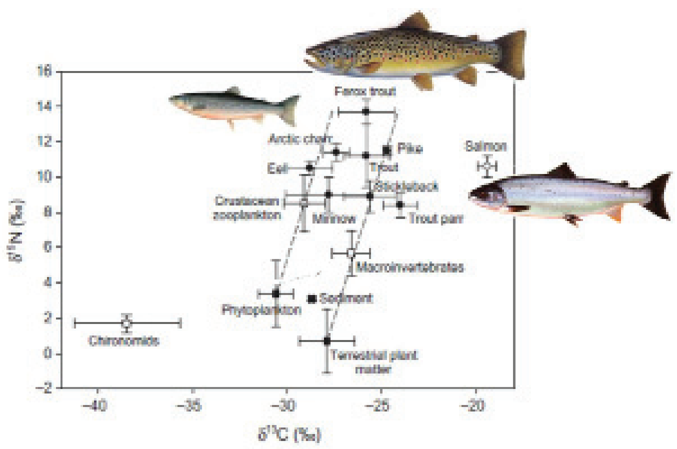
One question gnawing away at me, and which has been in the press for many years, relates to the impact of trout farms on the environment. While most work has focused on the negative impacts of the sedimenting waste products or the uptake of dissolved nutrients by phytoplankton, I wondered whether any of the animal community in the recipient ecosystem actually used the nutrients and to what extent did they come to rely upon those rather than their natural food. An isotopic approach proved useful in the late 1990s because the pelleted food back then had a relatively high content of marine-derived fishmeal, which had a very distinct isotope signal relative to typical freshwater food resources. The managers of the Esthwaite trout farm were very helpful and allowed me to sample around one of their rainbow trout cages for zooplankton, benthic chironomids and roach, to compare to the same components of the food web at the other end of the lake as a control. Pellet-derived nutrients contributed >50 per cent of the biomass of chironomid larvae and zooplankton and up to 80 per cent of the 0+ to 1+ roach which could have assimilated pelleted material directly, as well as via zooplankton prey.

The majority of my work is not trout or even directly fish related, although as I tend to work on organisms further down the food web, they could be thought of as potential fish food! The two main threads to my research are on the use of methane-derived carbon as an alternative energy pathway for fuelling food webs and the impact of invasive species, and I employ stable isotope techniques to help me answer questions about both. It was actually a bi-product of my work at Loch Ness and Esthwaite Water that revealed the benthic chironomids in both (very different) lakes to be extremely isotopically light in both carbon and nitrogen. They just didn't 'fit' into a conventional food web (Figure 2). Further survey work and experimentation has allowed us to deduce that biogenic methane produced in anoxic sediments and converted by bacteria into biomass was being assimilated via the diet of these chironomids. Of course chironomids emerge to imago stage and thus transfer energy out of the lake into terrestrial predators such as insectivorous birds and spiders. Simple mass balance calculations indicate that 20 per cent of riparian spider biomass may comprise methane-derived carbon following peaks of mass emergence. While many bird species such as swallows time their breeding to coincide with mass emergences of aquatic insects like chironomids to maximise growth and survival of their chicks, the readers of *Salmo Trutta* will have tuned into the fact that at certain times of year, buzzer fishing is the only method to employ – so spare a thought then, because it is likely for a few short weeks that the trout you are catching are greenhouse gas powered!

Surprisingly, methane contributes to the food webs of chalkstreams too. Our gin-clear chalkstreams are classically described as being some of the most autochthonous rivers on the planet, which means the production stems from photosynthesis within the river – think of the luxurious stands of water crowfoot and the epiphyton, single-celled plants that coat them (main picture). Many other rivers are allochthonous in that they rely heavily upon nutrient subsidies in the form of leaf litter from the catchment. Indeed, a focal argument in freshwater biology for the last 30 years has been deciding upon the balance of these two forms of production. My group at Queen Mary University of London has been studying how methane-derived carbon may provide a further alternative pathway following the discovery that some of the cased caddis like *Agapetus* and *Silo* had stable isotope values akin to the chironomids we had found in lakes. Despite being highly oxygenated, chalkstreams are often oversaturated with methane, on average about 50 times atmospheric concentration, and we are not exactly sure where that methane comes from or how old it is. A part of this is definitely 'new' methane, produced in the lee of the water crowfoot each summer as organic rich sediments accumulate around the root masses, but there is a background concentration apparent all-year round associated with the groundwater. Some of this could be truly ancient, diffusing up slowly from oil rich shales below the chalk. Indeed, the *Agapetus* we have dated using radio isotopes of carbon are around 2,000 years old, or at least the carbon that comprises their body mass is that age on average. They might not be very large caddis but they are extremely abundant in the gravels of many of our chalkstreams and hence, post hatch, the trout that will have been feeding upon them may be older than we think! We are exploring the dynamics of methane in chalkstream food webs using replicated experimental channels at the facilities of Vitacress in Hampshire.

Recently, the Natural Environment Research Council, which funds much of my work, created an initiative to assess the role of biodiversity in delivering the key ecosystem services on which we rely. Diversity of Upland Rivers for Ecosystem Service Sustainability (DURESS nerc-duress.org) was launched in May 2012 and is led by Cardiff University. It brings together a consortium of researchers from a range of disciplines and institutions, and key stakeholders from the water industry, the leisure industry, policy makers, land owners and land managers. We are currently assessing the links between biodiversity, ecosystem process and ecosystem services. Across Wales we are manipulating and modelling upland river food webs and the processes that they drive to determine how biodiversity can affect ecosystem services now and, under land use and climate changes, in the future. First we have to define the relevant meanings of biodiversity within an ecosystem services framework such as: fish abundance and type; fish size and growth; invertebrate abundance and type as prey of suitable quality; and whole food web structure and dynamics in producing prey in sufficient quantity. My role within this project is to use stable isotopes to characterise and quantify the dominant energy resources in river food webs across different land uses (deciduous woodland; coniferous forest; moorland; farmland), and assess how efficient each food web is. A simple measure of efficiency is the number of trophic steps from basal resource to top predator which, in most of our Welsh river sites containing fish, is, of course, the trout.

Figure 2. An isotopic 'map' of the Loch Ness food web modified from Jones & Grey 2011. The dashed lines represent classic trophic fractionation (Figure 1) stemming from the two main basal resources. Ferox trout are the apex predator; salmon derive their carbon from the marine environment; and chironomids assimilate some carbon from biogenic methane



There is one trout project I have yet to launch fully and it is something I have been discussing at length with potential project partners like the Wild Trout Trust, the Salmon & Trout Association, the Game and Wildlife Conservation Trust and Natural England. This is to return to the other main thread of my research, on invasive/introduced species, and consider whether triploid trout, when stocked into waterbodies, really fulfil the role of their native counterpart within food webs. I am not a 'trip nay-sayer', and I am fully supportive of the genetic reasoning for using trips, but the wider ecological impacts of stocking triploids have not been studied across a range of waterbodies using a well replicated, experimental approach, despite the fact their use is to be rolled out as National Policy by 2015. An isotopic approach is ideal to answer questions such as how quickly stocked trout 'switch' from pelleted food to natural prey, whether triploid trout would occupy the same isotopic niche space as native trout if they were introduced into native ecosystems, and whether triploid trout occupy the same niche space as native trout if they are stocked to supplement an existing native population. By measuring the stable isotope values of many individuals, I can quantify the variability between those individuals and the amount of overlap, or lack thereof, in isotopic space. Some preliminary work in this area is being carried out by one of my PhD students at Esthwaite Water.

Despite the fact that I am not a fish biologist *per se*, looking back, I have managed to apply this stable isotope alchemy to work with a wonderful variety of our wild (and not so wild) trout from the large deep lochs of Scotland, via the flashy upland rivers of Wales, to the more manicured groundwater-fed rivers of southern England. While I have focussed on my particular studies in this article, others have identified natal streams using strontium in otoliths, extracted migration history from scales or determined the onset of piscivory for example, so stable isotopes have been extremely useful in scientific studies of trout to date with plenty of potential for future work.

For access to the scientific papers behind the research please contact me on j.grey@qmul.ac.uk; Tel: 020 788 25688. Or visit webspace.qmul.ac.uk/jgrey/index.html

Figure 3. Dietary shift (change in stable carbon isotopes with fish length) in brown trout from Loch Ness, modified from Grey 2001. Open circles – eggs; closed diamonds – trout parr in natal streams; open squares – trout and char from littoral and open water, respectively; closed circles – ferox trout. Inter-individual variability in the ferox trout stable isotope values is large demonstrating considerable specialisation