Tuna, the spy who came in from the sea

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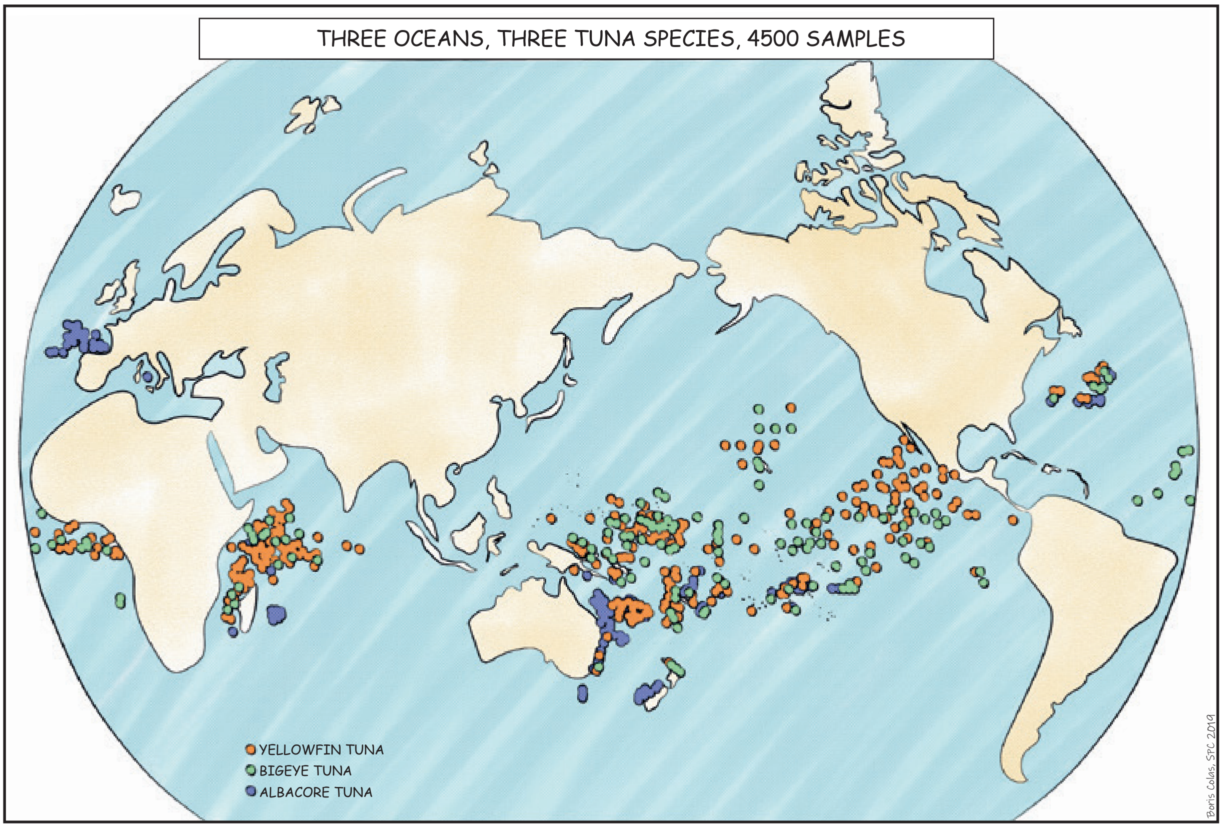
Much appreciated for its flesh, tuna is now also revealing another feature of great interest to scientists (again showing its versatility). Research on the carbon composition of tuna flesh has revealed that, over the past 15 years, deep changes have occurred in the carbon cycle and the phytoplankton underpinning ocean food webs. A multidisciplinary study published in November 2019 (Lorrain* et al. *2019) is based on a broad network of international cooperation making it possible to collectively assess 4500 muscle samples from three tuna species caught in the Pacific, Indian and Atlantic oceans between 2000 and 2016. Biological observations on such an extensive spatial and temporal scale are unusual and of prime importance for the validation of climate forecasts and their consequences for food webs.

Tracing the carbon cycle through isotopes

Carbon is a fundamental element that can be inorganic, like that contained in atmospheric carbon dioxide (CO_2), or organic. The human body contains 18% carbon in terms of weight, making it the second biggest component after oxygen, and this carbon can be found throughout the body, e.g. in muscle proteins, fats and DNA. It is therefore present in living beings, the air, the Earth's crust and the oceans. The ocean absorbs more than 90% of the heat associated with climate warming and over 30% of the carbon emissions from fossil fuel burning. The consequences of this on the functioning of the ecosystem and marine organisms through, for example, ocean acidification are not yet fully known. Until now, only some localised observations from certain oceanic regions have provided fragmented information on this topic. This new study, carried out by some 20 international researchers, for the first time provides some elements of overall understanding through analysis of the stable isotopes in the carbon present in 4500 specimens of tuna harvested from the Pacific, Indian and Atlantic oceans between 2000 and 2016 (Insert 1 - tuna map).



INSERT 1 (Illustration: Boris Colas, SPC)

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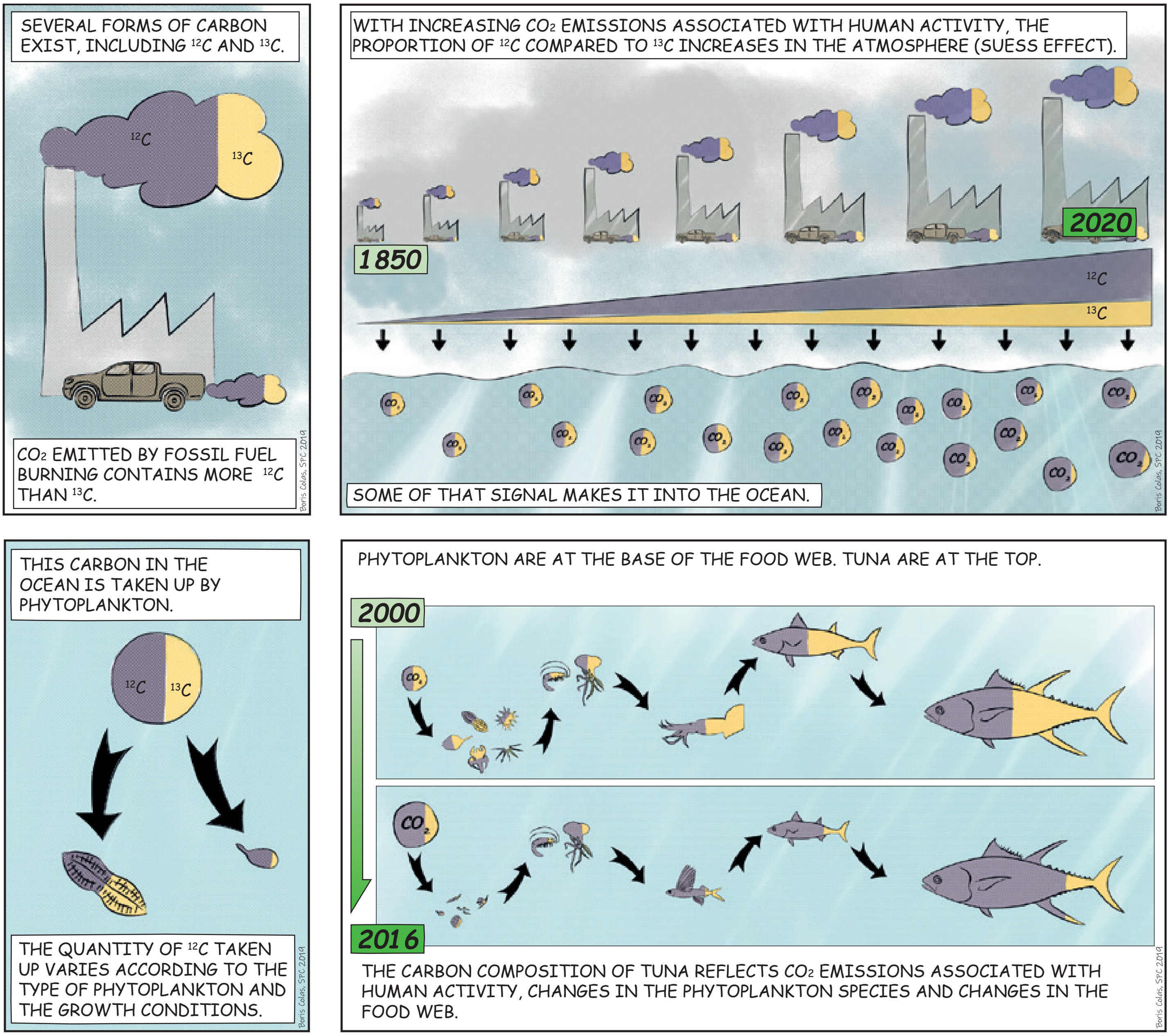
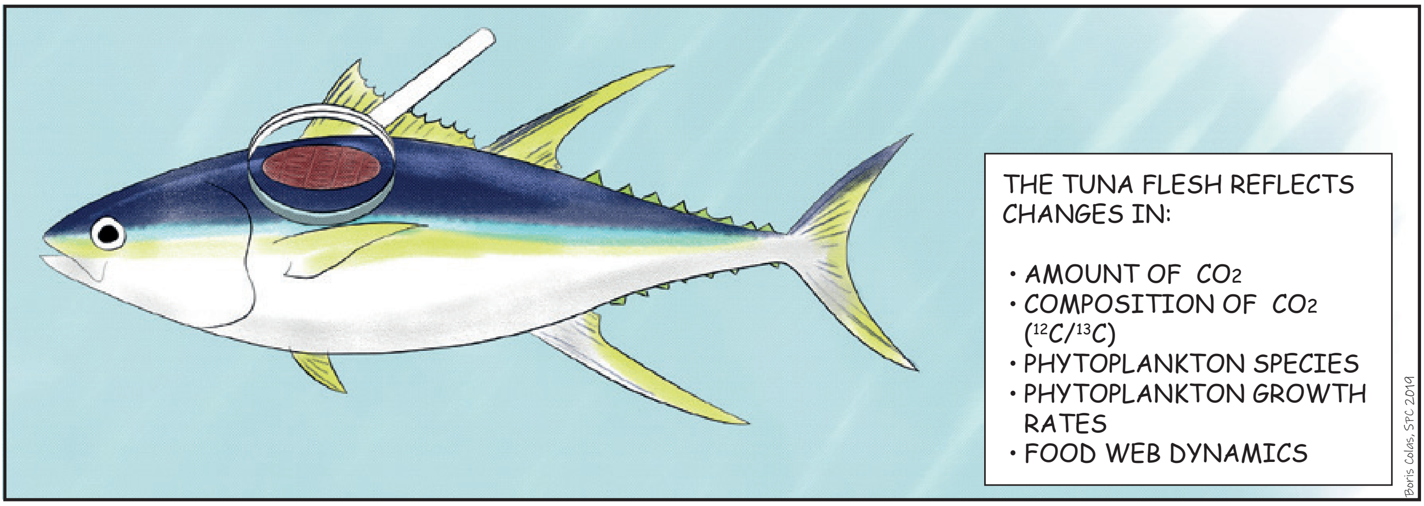
Carbon exists in various forms, called stable isotopes, with special reference to ^{12}C and ^{13}C (articulated as Carbon 12 and Carbon 13, please see Insert 2A). These isotopes do not have the same mass, with ^{12}C being lighter than ^{13}C. Because of this difference in mass, ^{12}C and ^{13}C react differently during chemical, physical or biological change processes. For example, when a process of water evaporation involving dissolved carbon occurs, the light carbon (^{12}C) tends to evaporate more readily and the water vapour contains more ^{12}C than the residual unevaporated water. The distribution of ^{12}C and ^{13}C is not uniform throughout the world, in the atmosphere or in living organisms with a majority carbon content. Measuring their respective abundance levels makes it possible to shed light on these various processes and understand the carbon cycle. For example, it makes it possible to trace atmospheric CO_2 emissions due to human activity.

Fossil fuels at the dinner table

Since the end of the 19th century, the burning of fossil fuels (oil, coal) has released into the atmosphere light carbon enriched with ^{12}C, (or depleted in ^{13}C): this is what is commonly referred to as the Suess effect (Insert 2B). The heavy isotope content reduction in the atmosphere moves by diffusion into the ocean and then travels up the food web to the tunas (Insert 2D). Measuring relative abundances of carbon isotopes (also referred to as measuring isotopic ratios) in tuna muscle makes it possible to trace the proportion of CO_2 emitted by humans and absorbed by the ocean. The reduction in ^{13}C in tuna muscle is five times higher than that expected if it was solely due to the Suess effect. Increasing use of fossil energies is therefore not sufficient to explain the low ^{13}C value observed in tunas.



INSERT 2 A, B, C, D (from left to right and top to bottom) (Illustrations: Boris Colas, SPC)



INSERT 3 (Illustration: Boris Colas, SPC)

But what causes tuna's isotopic composition to fall?

In our study, we sought to determine what other factors could explain the steep decline in ^{13}C in tuna by examining every stage in carbon conversion through the marine cycle, from water composition to tuna.

The carbon composition of tunas is governed by a number of factors, acting synergistically, i.e. (Insert 3):

- the quantity of CO2 present in the oceans, a majority of which is due to the CO2 emissions associated with human activities;
- the types of phytoplankton present in the oceans and their growth rates; and
- the various trophic relationships at play and culminating at the tuna level.

Atmospheric carbon enters the oceans through diffusion and is absorbed by phytoplankton, which need it in order to develop. The proportion of ^{12}C and ^{13}C absorbed is variable depending on the kind of phytoplankton and their growth rate (Insert 2C). Phytoplankton is the foundation of the food web and is consumed by larger organisms, which themselves are in turn consumed by bigger and bigger organisms up to the top predators like tunas. The proportion of $^{12}C/^{13}C$ in phytoplankton is then propagated throughout all levels of the food web and can be changed at each level depending on the organisms concerned. In this way, the changes in $^{12}C/^{13}C$ proportions in the phytoplankton populations find their way through the food webs to the apex tunas (Insert 2D). Changes in the type of trophic relationship (changes in the type of prey or the number of different steps in the food web) can also influence the proportions of $^{12}C/^{13}C$ observed in tuna muscle.

Tuna as climate change sentinels?

Through a modelling approach taking into consideration all the processes set out above and known to have an influence on isotopic values (summarised in Insert 3), we demonstrate that, while all the factors at work can influence the isotopic composition of tuna muscle, the one with the most impact is linked to the kind of phytoplankton occurring in the oceans. These results suggest that deep changes in the phytoplankton population structures at the foundation of the food webs that culminate in tuna have been taking place for the past 15 years. These data are of inestimable value for the calibration and validation of climate models and for projecting the effects of climate change onto ocean productivity. Few biological datasets are in fact available at such spatial and temporal scales.

We also suggest that the phytoplankton communities are constantly shrinking because the smaller species contain more ^{12}C than the larger species such as the diatoms. These changes in populations are not improbable because, with climate warming, changes are being forecast in the way water masses are structured (ocean stratification, in other words less mixing between surface water and deep water), with a reduction in the quantity of nutrients present in surface waters. Faced with the available nutrient quantities, not all phytoplankton species adapt in the same way and, for example, smaller-sized species show higher suitability when the waters are nutrient-poor, which could explain a change in population structure.

Consequences on energy transfers and health?

A change in the phytoplankton communities could have extensive repercussions on trophic webs, for example by reducing the amount of energy and nutrients available for fish. Research in fact suggests that the smallest phytoplankton species synthesise less of the omega-3 polyunsaturated fatty acids essential for the growth of many species of fish and beneficial for human health. This opens promising research avenues for further exploration, as tunas are a source of the fatty acids essential for human health.

The importance of long-term biological datasets and international collaboration

This multidisciplinary study involving biologists, biogeochemists and physical oceanographers represents a hitherto unprecedented application of the analysis of stable isotopes in the large marine predators such as tunas in order to identify decadal changes in the ocean carbon cycle.

These measurements do however need to be performed on a long-term basis, i.e. over a 30-year period, to be able to confirm that they are indeed linked to climate change and not natural variability.

Whatever the case, these results demonstrate the relevance of using tuna as environmental change sentinels and militate for the introduction and long-term maintenance of biological tissue banks such as the marine specimen bank at SPC (http://www.spc.int/ofp/PacificSpecimenBank, Smith et al. 2017), which contain a real wealth of information.

In addition to the time dimension over more than 15 years, this study is especially robust because of its spatial amplitude and the number of specimens analysed in the three oceanic basins (Pacific, Atlantic and Indian). This upscaling is the fruit of a very broad network of international cooperation, initiated as part of the CLIOTOP (Climate Impact on Top Predators, http://imber.info/science/regional-programmes/cliotop) task force in 2009, which unites more than 12 institutions from around the world (Pacific Community, French Institute of Research for Development, Commonwealth Scientific and Industrial Research Organisation, Duke University, GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Institut Pierre-Simon Laplace, Inter-American-Tropical-Tuna-Commission, Division of Marine Fisheries New Bedford Office, Australian River Institute, Seychelles Fishing Authority, AZTI Tecnalia, New Zealand National Institute of Water and Atmospheric Research).

References

Lorrain A., Pethybridge H., Cassar N., Receveur A., Allain V., Bodin N., Bopp L. *et al.* 2019. Trends in tuna carbon isotopes suggest global changes in pelagic phytoplankton communities. Global Change Biology, 0. [https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.14858 (Accessed 12 October 2019)].

Smith, N., Donato-Hunt, C., Allain, V., McKechnie, S., Moore, B., and Bertram, I. 2017. Developing a Pacific Community Marine Specimen Bank. SPC Fisheries Newsletter, 152: 43–47. [http://purl.org/spc/digilib/doc/4kxdc (accessed 19 December 2019)]