Marine Biodiversity: Where, What and Why?

Uncovering the patterns of diversity in the ocean

Tom Webb

The great fanfare that greeted the publication back in October 2010 of the first Census of Marine Life (CoML) (www.coml.org) was wholly justified. This is a landmark achievement in the study of marine biodiversity, and the Census has done a great deal to convey the sheer excitement of basic exploration that the marine environment still offers. Certainly, I have been charmed by photos of some of the weird and wonderful organisms discovered over the 10 years of concerted exploration of the depths and breadths of the oceans (Figure 1). But as a biodiversity scientist and macroecologist what excites me most about CoML is its vast potential as a source of data.

In particular, we now have an unprecedented opportunity to address fundamental questions in biodiversity science thanks to a concerted effort to collate and disseminate existing information on the geographic distributions of marine species. Perhaps the most profound of these questions is: *Where are you?* Or, to put it another way: *How is marine biodiversity distributed throughout the seas?* It is only once we have described such patterns that we can begin to try to explain them, and a promising way of doing this is to ask of the different species making up a community, *What do you do?* Using information on the biological characteristics of each species, we can begin to understand their particular ecological roles within the ecosystem. Finally, we can apply this understanding of marine macroecology to addressing some of the questions currently being asked by policy makers and society more generally, regarding for instance how best to weigh the needs of biodiversity against human requirements for food and energy. In other words we can ask of biodiversity: *Why do you matter?*

Figure 1 *The Census of Marine Life was responsible for discovering an estimated 6200 new species, including this new species of* Polybrachia *(a polychaete) from a mud volcano in the Gulf of Cadiz. Many of these new species may turn out to be widespread in the world's oceans, which highlights how little we still know about the distributions and basic biological characteristics of most marine organisms.*

(By courtesy of Ana Hilario, University of Aveiro, Portugal)

Where are you?

Knowing where a species occurs is fundamental to understanding its ecology. If all of the world's oceans had been sampled to an equal (and sufficient) extent, simply plotting on a map those locations at which a species had been recorded would tell us a great deal. We could immediately separate tropical from temperate, coastal from oceanic, cosmopolitan (i.e. widespread) from endemic, and (providing our map included a third dimension) benthic from pelagic species. Combining such information across numerous species provides the raw material for a 'macroecological' analysis of marine biodiversity, i.e. a study of patterns that only emerge at large spatial scales – for example, gradients in species diversity from the Equator to the poles, or from the shallows to the abyss.

Of course, it's highly unlikely that all the world's oceans have been equally and sufficiently sampled. In fact, *none* of the large marine ecosystems of the world has been sampled at a sufficient intensity to allow us to reliably assume that the absence of a species from a survey reflects a true absence in the environment. And it is certain that sampling of the marine realm has not been equal everywhere.

Although marine biologists would have been able to tell you this before the CoML (based on personal experience and general 'gut feelings'), we can now show systematically such spatial biases in sampling intensity. Largely, we can do this thanks to the Ocean Biogeographic Information System (OBIS, www.iobisl.org), which serves as the biogeographic arm of CoML. OBIS collates, standardises, and delivers to any interested party a vast collection of marine biodiversity 'records' – with each record representing the occurrence of a given taxon at a given geographic location. Currently, OBIS holds some 31 million records, for over 140 000 taxa (and – an invaluable service – each taxonomic name is checked against a standard taxonomy).

This phenomenal coverage means that we can start to identify those parts of the world that are particularly well – or particularly poorly – covered by OBIS. For instance, the 'state of knowledge' of marine biodiversity has recently been shown to be very variable across different regions of the world. Unsurprisingly, regions such as the Mediterranean and Atlantic Europe are typically far better known than the tropical East Pacific and tropical West Africa.

There is another yawning gap in our knowledge, which was revealed by an analysis I undertook together with Edward Vanden Berghe from OBIS and Ron O'Dor from CoML. Rather than split the world's oceans into geographic regions, we instead considered how OBIS records were distributed with respect to water depth. Specifically, we used only those records (about 7 million at the time) which reported the depth at which the specimen had been recorded. By comparing the depths of these records with the depth of the sea-bed at the same location, we were able to plot the distribution of recorded marine biodiversity through the water column (Figure 2).

The most striking pattern to emerge from this analysis is that the shallow waters of the continental shelf, which cover only about 10% of the area of the global oceans, together contribute more than 50% of the records stored in OBIS. But there is another important pattern too: when the deep seas *have* been sampled, this has typically occurred either in the surface waters, or on the sea-bed. The deep pelagic ocean, by a large margin the largest habitat on Earth and home to countless animals which never experience a hard surface, remains virtually untouched by biodiversity surveys.

So, while the CoML has compiled sufficient data on certain groups to enable global-scale analyses of their biogeography (examples include tunas, sharks, cetaceans and corals), it has also revealed the depths of our ignorance of other taxa, and of entire habitats such as the vast deep pelagic ocean. There are two positive sides to this newly-revealed ignorance. First, once you know what it is that you don't know, you

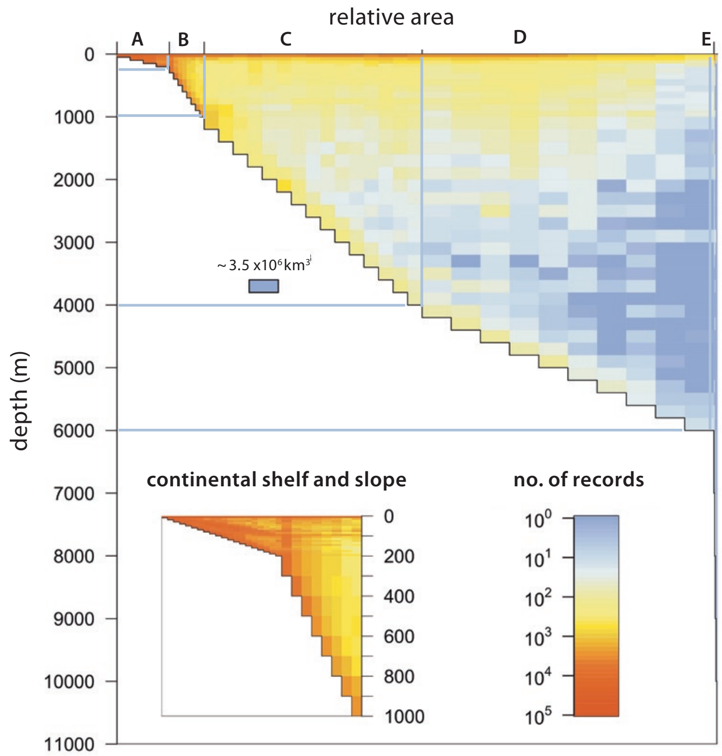


Figure 2 Global distribution within the water column of recorded marine biodiversity. *The horizontal axis splits the oceans into five zones on the basis of depth (A: continental shelf, B: continental slope/mesopelagic; C: continental slope and rise/bathypelagic; D: abyssal plain, E: hadal zone), with the width of each zone on this axis proportional to its global surface area. The vertical axis is ocean depth, on a linear scale. This means that area on the graph is proportional to volume of ocean. For instance, in the deep sea each cell of 200 m depth represents ~3.5 x 10^6 km^3 (see cell for scale). The number of records in each cell (each unique combination of sample and bottom depth) is standardised to the volume of water represented by that cell, and then $\log_{10}$-transformed. The inset shows in greater detail the continental shelf and slope, where the majority of records are found. (From Webb* et al.*, 2010)*

can target future efforts to fill the gaps in your knowledge. And in the meantime, if you know about biases in your datasets, you can take steps to control for them in any analysis you may wish to conduct.

What do you do?

It is clear from the above examples that we remain a long way from knowing with any certainty where in the world the majority of marine species occur. Nonetheless, in some regions this basic knowledge is probably sufficiently complete to allow us to document macroecological patterns in more detail. The seas around the UK, for example, have been subject to exploration for scientific and commercial reasons for many decades, and so our basic knowledge of what occurs where is reasonably good. This means that we can start to ask more detailed questions such as, *Which kind of species occur where*, or *What kind of biological characteristics enable species to become widespread?*

Such questions require basic biological information across the range of species co-occurring across a set of sites. As we are discovering in an ongoing project, such information is, however, surprisingly scarce – even for relatively common British marine species. Even if we restrict ourselves to the macrofauna (organisms larger than about 1 mm or so), there is simply no documented knowledge of the ecology and behaviour of a large proportion of invertebrates. Basic information that would be required to construct simple models of population dynamics – things like the number of offspring produced in a year, or the typical lifespan of an individual – is incredibly scarce. We don't even know how big some species get.

With Lizzie Tyler at the University of Sheffield, and Paul Somerfield from Plymouth Marine Laboratory, I was able to collate sufficient information for nearly 600 species of bottom-dwelling invertebrates from the North Sea to perform some analyses. The results are intriguing, if rather subtle (Figure 3). Species which can grow to large sizes show a different kind of spatial distribution from smaller species: they tend to be more evenly distributed across their range, whereas small species are more clustered. We suspect that other traits – for instance, the presence or absence of a planktonic larval stage – will also influence spatial distribution. But before powerful statistical tests are possible, we need to obtain data on traits like this for more species.

Results like these suggest that a species' biology can affect its geographic distribution within a relatively uniform environment such as the North Sea, in a predictable way. This means that the macroecology of an entire assemblage will depend on the relative proportions of species displaying different collections of biological traits. In other words, in order to understand large-scale patterns in marine biodiversity, we really need to have some idea of what it is that the component species actually *do*.

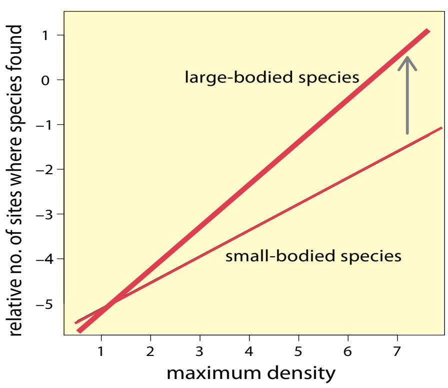
Unfortunately, an extended analysis of nearly 1000 species of common UK marine fish and invertebrates has shown that this basic knowledge simply doesn't exist for the majority of species. And there is little place in today's hectic research environment for the kind of basic natural history observation required to supply such information. It might be possible to fill some gaps by using statistical models which compare patterns of trait variation with the evolutionary relationships between species, but whether such models can cope with a situation in which the gaps outnumber the data remains to be tested.

Why do you matter?

It is tempting, when gazing out to sea, to imagine it as some vast, untouched wilderness. And yet with a little investigation the effects of human activity can be seen throughout the world's oceans, from the ravaged sea-beds of the heavily-trawled European continental shelf, to the accumulation of plastic debris in the central Pacific and the Deepwater Horizon oil spill, to bleached corals in the Indian Ocean.

Our dependence on marine ecosystems is also becoming ever clearer. Efforts to put a monetary value on the ecosystem services provided by the marine environment remain controversial, but it is undeniable that we benefit enormously from the seas – for example, from the food and raw materials that we extract, the carbon they absorb, and the pleasure that we derive from activities as varied as whale watching, wind-

Figure 3 Spatial distribution of North Sea benthic species varies with body size.
For a given population density (individuals m^{-2}) large-bodied species occur at more sites than small-bodied species, indicating a less aggregated distribution.
(Simplified from Webb et al.*, 2009)*



surfing and whispering sweet nothings in front of the setting sun.

The maintenance of these ecosystem services is at the forefront of efforts to mitigate some of the consequences of past and ongoing human activities. For instance, plans for the creation of substantial Marine Protected Areas, as well as for enormous offshore wind farms, are well advanced in the UK. The importance of aquaculture (which brings its own set of environnmental problems) is increasing as fast as wild fisheries are depleted. Vast geoegineering schemes no longer seem quite so far-fetched. Between unintentional environmental change, and concerted efforts to reverse such change, all we can say for certain about biodiversity is that it will be affected somehow.

What also remains very unclear is the role that biodiversity plays in the provision of this suite of services. The ecosystem is composed of communities of coexisting species, and it follows that all the different biological traits expressed by different species will interact to produce ecosystem-level properties – including those functions that we value highly. From this, it becomes clear that understanding which species occur where, and how they live their lives – which biological traits they possess – is fundamental both to understanding the functioning of ecosystems, and predicting the consequences of different kinds of environmental change.

These are the kinds of questions that are motivating an increasing number of marine ecologists. If my contributions appear somewhat negative – with too much emphasis placed on what we *don't* know, rather than what we *do* – then I apologise. But in my defence, I am firmly of the opinion that it is better to know what we don't know, and to take steps to incorporate this uncertainty into our models and predictions (if we're not in a position to fill in gaps in our knowledge), than it is to simply sweep the issue under the carpet. To paraphrase an accidental philosopher, better a known unknown than an unknown unknown.

Further reading

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Tom Webb is a Royal Society Research Fellow and marine ecologist in the Department of Animal and Plant Sciences, University of Sheffield. He writes a regular blog, *Mola mola*, on the Nature Network (blogs.nature.com/tomwebb), in which marine biodiversity often features.
t.j.webb@sheffield.ac.uk

The growing problem of 'green tides'

The mass blooms of seaweeds known as 'green tides' have returned yet again to Chinese coastal waters. In July 2011, the North China Sea Marine Forecasting Centre reported that green seaweeds could be found over 20 000 km^2 of the Yellow Sea, with a quarter of that area completely covered. A 'green tide' in China's marginal seas was first reported in 2007, and just a year later the area of ocean impacted by the bloom was ~40 000 km^2, making it the world's largest. This was very unfortunate timing as the green tide algae spread to the Beijing Olympics sailing venue adjacent to Qingdao. The authorities were left with no other option but to bring in 10 000 workers to clear away one million tonnes of algae from coastal waters and the shore in advance of the Olympic regatta.

China is by no means alone in its green tide problem. The incidence of these blooms has increased worldwide over the last 40 years, with annual green tides reported along the coastlines of countries including Denmark, the Netherlands, France and the UK. The culprits are ephemeral, fast-growing pale green seaweeds of the class Ulvophycae, such as *Enteromorpha* and *Ulva,* whose filamentous or sheet-like morphology allows rapid nutrient uptake. The high nutrient levels that permit these algae to reach the high biomass associated with green tides result from agricultural fertiliser application and other farming activities, waste disposal and aquaculture. Green tides are unsightly and when suspended in the water column interfere with recreational and fishing activities, but they also have a much more sinister side. When the seaweeds are washed up on the shoreline they start to decompose; the decomposition consumes oxygen and creates anoxic zones resulting in the production of the potentially lethal gas hydrogen sulphide (H_2S). Emissions of H_2S have been blamed for animal fatalities in areas impacted by 'green tides', including the deaths of 33 wild boar on the beaches of Saint-Brieuc in northern Brittany in July 2011, and they could potentially pose a threat to human health. This, together with other ecological implications – including wiping out indigenous flora and blanketing important bird-feeding grounds – means that green tides really are a problem.

The quandary is whether to try to reduce the severity and/or frequency of effects of the blooms or to manage (and possibly utilise) the huge amounts of biomass that they produce. Reducing the blooms would require reducing nutrient inputs to coastal areas by altering agricultural practices and adjusting the ways in which wastes are dealt with. One management idea is to allow the blooms to occur, 'mopping up' excess nutrients, and then to harvest the seaweeds for use as an agricultural fertiliser or in the production of animal feed. With increasing frequency of these events worldwide, understanding the environmental implications of green tides, and working out ways to deal with them, will remain high on the research and management agenda.

Claire Hughes
University of York