hope that we might discover the function of all genes in a single cell type. Such progress would help to answer fundamental questions about the relationship between an organism's genetic make-up (its genotype) and its physical form (phenotype). Extension of such understanding to a parent cell and its two progeny, coupled with cell-biological experiments, would exploit the potential unlocked by Sulston and Horvitz to reveal how the lineage history of a cell influences its fate. ■

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MARINE CONSERVATION

# How to heal an ocean

**Marine protected areas are being implemented at an accelerating pace, and hold promise for restoring damaged ecosystems. But glaring shortfalls in staffing and funding often lead to suboptimal outcomes.** **See Article p.665**

BORIS WORM

Humans have arrived at an interesting juncture in their relationship with the ocean. After using (and overusing) it for centuries as a free food source, highway and dumping ground[1], there is a growing political resolve to reverse some of the damage that has been inflicted[2]. Marine protected areas (MPAs; Fig. 1) represent a cornerstone of our global strategy to heal compromised ecosystems[2,3], but their success has been varied and uneven in practice[4–6]. On page 665, Gill *et al.*[7] expose some of the reasons behind this variation, identifying global capacity gaps — shortfalls in staffing, funding and scientific monitoring — that have been opened by the rapid, but woefully underfunded, expansion of protected areas worldwide.

On the surface, the extraordinary growth of MPAs looks like an environmental success story. Since the 1960s, global coverage of these areas has been growing exponentially at a rate of more than 8% per year (Fig. 2). The past decade, in particular, has seen a dramatic expansion of extremely large MPAs in some of the remotest corners of our planet, and especially of strongly protected areas that ban commercial extraction of natural resources such as fish, minerals or oil, and where recreational or subsistence fishing is light.

Later this year, the world's largest conservation area of any kind will come into force, protecting 1.55 million square kilometres of the Ross Sea in Antarctica. This means that nine of the ten largest protected areas on Earth will be marine. Still, the combined coverage of designated and implemented MPAs currently accounts for just 4% of total ocean area (Fig. 2), compared with 15% on land. Several international agreements have committed coastal nations to reach higher to correct this imbalance, aiming at 10% MPA coverage by 2020, as ratified under the Convention on Biological Diversity and reaffirmed by the United Nations Sustainable Development Goals.

Despite such commitments, further MPA expansion can be controversial, and the utility and effectiveness of protected areas are sometimes questioned. Like parks on land, MPAs can flourish or fail. Previous analyses[4–6] that sought to disentangle some of the complex reasons for this have focused largely on biophysical aspects, such as the size, age, connectivity or remoteness of a particular area, all of which proved influential. Social factors influencing the effectiveness of management or governance have been more difficult to quantify. Gill *et al.* provide a new perspective by focusing squarely on the role of people in MPA effectiveness[7].

The authors compiled an impressive database of management features in 433 MPAs around the world, and matched it with fish population data in 218 MPAs, thus providing a 'deep dive' into the relationship between socio-economic factors and biological outcomes. The management data included a variety of indicators, ranging from budget constraints to the inclusion of stakeholders in decision-making processes.

The aggregate results were sobering, with 79% of MPAs in the global sample not meeting even half of the thresholds for adequate

JIANGANG LUO/MARINE PHOTOBANK

**Figure 1 | A diver monitors marine life at the Dry Tortugas Ecological Reserve in Florida.** Gill *et al.*[7] report that the biggest factors in the success of marine protected areas are adequate staffing and funding.

management. For example, just 35% of MPAs were appropriately funded, only 13% were informed by scientific monitoring, and 9% reported adequate staffing. Staffing and funding gaps were the strongest predictors of conservation outcomes, quantified as increases in fish biomass in an MPA relative to that in unprotected areas nearby. Despite their shortcomings, 71% of MPAs still secured substantial positive outcomes. But the degree to which they succeeded was mainly a function of human and financial resources.

To some extent, these results might not surprise. To use an analogy, we cannot just build hospitals and hope that they will somehow ensure public health — the number of staff, the quality of their training and the level of funding clearly are crucial. The same goes for ocean conservation efforts, but it takes careful analysis to quantify capacity gaps and to show empirically where new investment is most likely to pay off. For example, Gill and colleagues' analysis suggests that raising staff capacity to adequate levels might increase fish biomass almost threefold. This investment would translate into downstream benefits for both tourism operators inside the MPA and fishermen outside it, who would benefit from fish spilling over reserve boundaries[8].

Gill and colleagues' work raises a broader point about the value of integrating social sciences into the study of human-dominated ecosystems. Another study[9] reported that the effectiveness of management schemes for small-scale fisheries depended mainly on factors such as leadership and social cohesion in the fishing community, and less strongly on biophysical aspects of the system under study. Other work has shown that enforcement of fishing rules is one of five key features that predict conservation outcomes on reefs worldwide[6]. Clearly, meaningful conservation measures need to be embedded in a social fabric that enables appropriate measures both inside and outside protected zones.

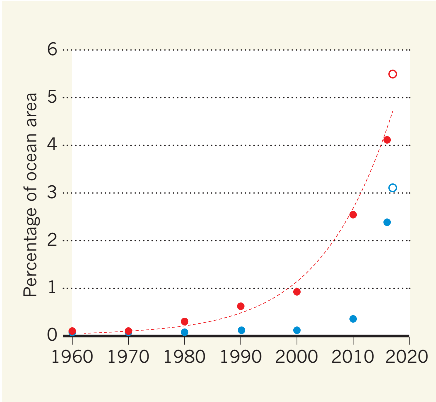


**Figure 2 | Rapid growth of marine protected areas (MPAs).** The percentage of the global ocean that has been designated and implemented as MPAs has grown exponentially since the 1960s (red symbols and line). Blue symbols indicate the subset of MPAs that are strongly protected — where commercial extraction of natural resources such as fish, minerals or oil is banned, and recreational or subsistence fishing is light. Open circles indicate coverage if current MPA proposals or announcements were implemented in 2017. (Adapted from ref. 2; data from J. Lubchenco, K. Grorud-Colvert and MPAtlas.org)

Later this year, policymakers will gather at the United Nations to discuss global development goals related to the conservation and sustainable use of the ocean. They should take note of Gill and colleagues' study, because it provides a timely warning that rapid expansion of protected areas by itself will not provide desired outcomes if there are large shortfalls in our capacity to manage, monitor and finance those areas. If the billions of dollars of subsidies that are currently spent on unsustainable fisheries were channelled into marine conservation, then the cited capacity gaps could be erased in one broad stroke[10].

Of course, money is only part of the solution. Public engagement, staff training and the capacity for scientific assessment should all be enhanced to build a truly robust, global MPA network. There is certainly no easy recipe for success, but global meta-analyses such as that of Gill *et al.* and others[6,9] will help us to further constrain what is needed to heal the ocean, and to provide long-term benefits to people. ■

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NEUROSCIENCE

# Auditory landscape on the cognitive map

**Subpopulations of neurons fire at specific geographical locations, providing a mental map of an animal's position in space. The finding that the circuitry can also support auditory maps sheds light on the neuronal structure of cognition.** **See Letter p.719**

JON W. RUECKEMANN & ELIZABETH A. BUFFALO

All animals face the challenge of navigating their environment, and are aided by an internal, mental map of where they have been and where they are going. Neurons in a brain region called the hippocampal formation are thought to form the substrate of such maps in mammals. But whether mental maps can also be used to organize other types of information is not known. On page 719, Aronov *et al.*[1] provide evidence that the same neuronal circuitry can be used for both spatial and non-spatial mental maps in rats.

Neurons in the hippocampal formation, which includes the hippocampus and the adjacent entorhinal cortex[2], provide an intricate representation of an animal's location in space. Hippocampal place cells and entorhinal grid cells fire at specific physical locations as a rat traverses an environment[3,4]. Some researchers think that these neurons function primarily as the brain's navigational system. However, others[5,6] suggest that these neuronal ensembles might instead contribute in a more general way to the organization of information. This hypothesis accordingly raises the question of whether such neurons might represent non-spatial aspects of experience in a map-like way, similarly to their representation of space.

To address this question, Aronov *et al.* investigated whether neurons in the hippocampal formation can represent a 'map' of a non-spatial environment, choosing for their example an auditory landscape. They trained rats to use a joystick to manipulate a tone that got higher the longer the joystick was pressed. The rats were rewarded with a drop of water for releasing the joystick when the sound reached a particular frequency range. In this way, the authors could analyse the pattern of neuronal activity that occurred as the frequency changed, and compare this with the neuronal responses that represent a rat's changes in position as it navigates during a foraging task.