Seafaring in the 21st Century: The Malaspina 2010 Circumnavigation Expedition

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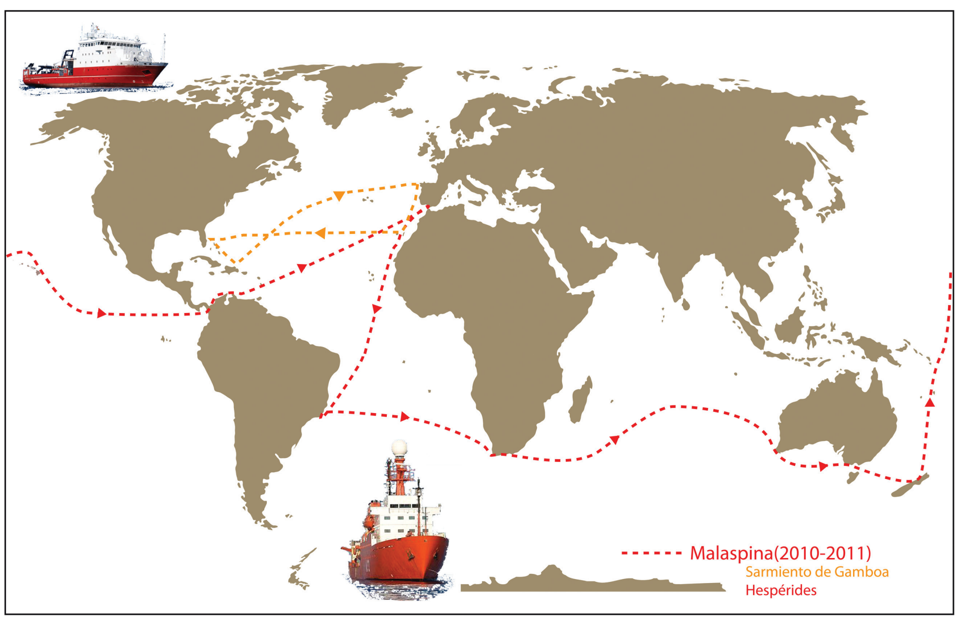
Half a millennium ago Spain completed, under the leadership of the Portuguese mariner Fernão de Magalhães, the first circumnavigation of the ocean. A quarter of a century later, Alessandro Malaspina, a navy officer and scientist, led the first Spanish circumnavigation with scientific goals. These were to provide an account of the flora, fauna, and natural resources of the Spanish kingdom, which at the time extended from Italy to the Philippines. In December 2010 a new expedition, the Malaspina Circumnavigation Expedition, on the 200 anniversary of Alessandro Malaspina's death, departed from the same harbor of Cadiz to circumnavigate the planet on a quest to advance our understanding of the ocean.

Five hundred years following the first circumnavigation, the question may be raised if old-fashioned seafaring has still much to add to our understanding of the ocean (Laursen 2011). One might think that recent advances in remote sensing and autonomous vehicles have done away with the need to sail the oceans once more. However, I argue that seafaring is still essential to further our understanding of the oceans and that neither one of the key goals of the Malaspina Circumnavigation Expedition would have been met through the use of remote sensing or autonomous vehicles.

The goals of the Malaspina Circumnavigation Expedition were to provide an assessment of the state of the oceans in 2011 and to explore, using advanced next-generation sequencing tools, the diversity of life in the ocean, with a particular emphasis in the dark ocean (cf. www.expedicionmalaspina.es). In addition, the project aimed at shifting the interactions among Spanish marine research groups from an excessive focus on competition to a balance between competition and cooperation through the demonstration of the benefits of a cooperative approach and, in doing so, build critical mass and leadership capacity. Furthermore, it aimed at prompting the interest for marine science by the Spanish public and to foster scientific vocations among its youth.

The project involved 35 Spanish research groups and a total of 28 international partners from a total of 18 nations across the world, with an estimated total of about 400 scientists and a total of 700 persons involved in various capacities, including logistics, outreach, technical, and administrative support.



Tracks of Spanish R/V Sarmiento de Gamboa (upper left corner, orange), and R/V Hespérides (bottom center, red) during the Malaspina 2010 Circumnavigation Expedition.

The six-year project was seeded with 4.3 million euros by the Spanish Ministry of Science and Technology, and provided with a total of 10 months of ship time, including seven months on board *R/V Hespérides*, operated by the Spanish navy, which circumnavigated the ocean and three months on board *R/V Sarmiento de Gamboa*, operated by the Spanish National Research Council (CSIC), the institution organizing the expedition. This research vessel conducted a detailed study of a section, along 24.5 N, of the Atlantic Ocean and served as a platform for a floating university in her return to Spain. The original resources were supplemented with additional investments from the Spanish government to the project, to upgrade the scientific equipment on board the vessels as well as to fund the sequencing of the Malaspinomics global ocean genome collection. The Malaspina Expedition also received significant funding from the Fundación BBVA, CSIC, the Spanish Institute of Oceanography, AZTI Foundation, a number of Spanish universities (Granada, Cadiz, Vasque Country and Barcelona), and the King Abdullah University of Science and Technology in Saudi Arabia. All in all, the project received close to 7 million euros in direct funding and an estimated 10 million through indirect contributions.

The Malaspina Expedition sailed the ocean from 13 December 2010 to 14 July 2011, sampling the tropical and subtropical Atlantic, Indian, and Pacific Oceans. The cruise track was designed to sample ocean gyres and the previously poorly sampled areas of the ocean, particularly in the Southern Hemisphere and the Indian Ocean down to about 4000 m depth. The timing was carefully planned to avoid adverse weather, all within the boundary conditions imposed by the total seven months of ship time allotted to circuling the globe. In total only six days of ship time were lost to sampling due to adverse sea conditions.

Our knowledge of many ocean properties at a global scale is based on data from a patch work of standard research cruises conducted largely in ocean regions close to the main oceanographic hubs of the world (e.g., Regaudie de Gioux and Duarte 2013). Most of the sampling effort has been, thus far, allocated to the North Atlantic and Pacific, with a very poor representation of the tropical and subtropical regions in the Southern Hemisphere and, particularly, the Indian Ocean (e.g., Regaudie de Gioux and Duarte 2013), where many of the

Carlos Duarte, past president of ASLO (2008-2010) led the Spanish Malaspina Circumnavigation Expedition. Photo: Joan Costa, CSIC.

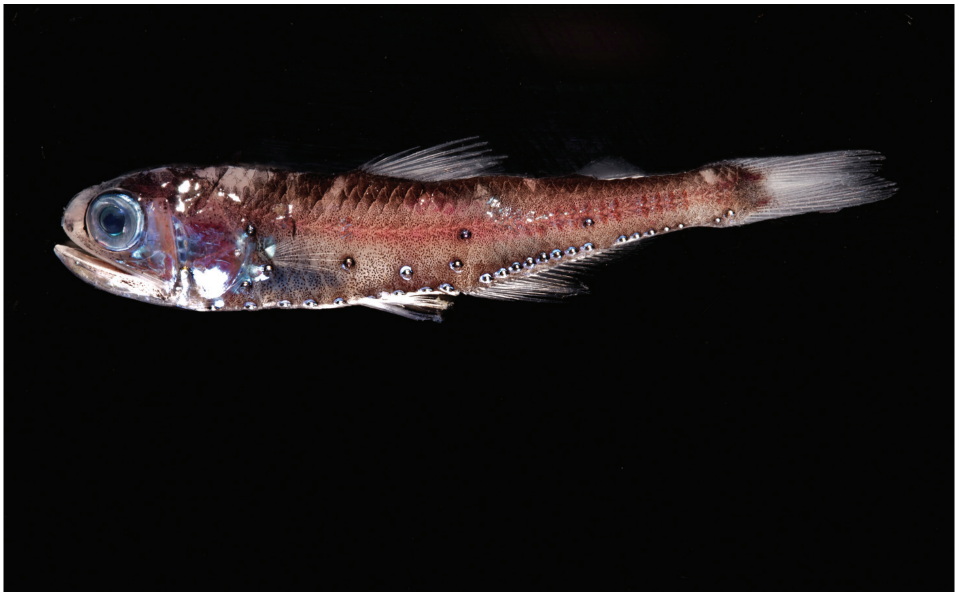
properties measured in the Malaspina Expedition were recorded for the first time.

The value of programs such as the Malaspina Expedition lies in the fact that whereas some parameters such as temperature can be accurately estimated from remote sensing, many other fundamental properties needed to resolve the state of the ocean cannot be resolved from space or using autonomous vehicles. These include biogeochemical properties and processes such as the total pools and fluxes of nutrients, carbon and pollutants, key biological processes, such as primary production, community metabolism, plankton and fish biomass and community composition, or biodiversity. Even primary production, for which satellite products are available, is resolved with unacceptable uncertainty from remote sensing relative to the in situ measurements they are calibrated against, with characteristically very poor or no correlations and model skill. This is particularly the case for the oligotrophic ocean, where much of the autotrophic biomass supporting production occurs much too deep to be detected from satellites.

Clearly, circumnavigation expeditions using coherent sampling designs and analytical methodology (Moreno 2012) deliver data on key properties and processes at a global scale in a more balanced manner, thereby accelerating our understanding of the global ocean ecosystem. Indeed, a number of global expeditions have sailed the ocean in the 20th century, including Japan's Blue Earth Global Expedition, Denmark's Galathea three expedition, the Sorcerer II global ocean sampling expedition and the Tara Oceans Expedition. The Malaspina 2010 Circumnavigation Rxpedition is, arguably, more encompassing than those above, as it was designed as an interdisciplinary study of the ocean extending from its mean depth, at nearly 4000 m depth, to the atmosphere over the ocean.

To date the project has produced over 60 research papers. A sample of key outcomes, thus far reported in these papers include:

- The finding of widespread loads and inputs of pollutants, such as Polycyclic Aromatic Hydrocarbons (González-Gaya et al. 2014*a*), Perfluoroalkylated substances (González-Gaya et al. 2014*b*), Polychlorinated Dibenzo-p-Dioxins, Dibenzofurans, and Biphenyls (Morales et al. 2014) in the global ocean, and the widespread presence of floating plastic litter across the open ocean, but with processes, yet to be identified, removing a significant load of small-sized (< 4 mm) microplastics into a yet unresolved fate (Cózar et al. 2014).
- The finding that two ubiquitous humic-like fluorophores, with turnover times of 435 yr and 610 yr, represent prevalent components of DOC across the



Mesopelagic fish, such as this lanternfish, represent the most abundant vertebrates on Earth with the assessment of their biomass conducted in the Malaspina Expedition raising the estimated global fish biomass by a factor of 10 (Irigoien et al. 2014). Photo: Joan Costa, CSIC 2014.

deep ocean. These findings suggest that the in situ microbial production of fluorescent humic-like materials in the dark global ocean is a sink of reduced carbon in the time scale of hundreds of years (Catalá et al. in press).

- A first assessment of the global biomass and diversity of heterotrophic protists in the dark ocean, with their biomass decreasing from 280 pg C mL^{-1} in the upper mesopelagic layer to 50 pg C mL^{-1} in the lower bathypelagic layer. Protist biomass averaged approximately 20% of prokaryote biomass in the global bathypelagic realm, with this ratio increasing at depth as heterotrophic protist biomass declines faster with depth than prokaryote biomass does (Pernice et al. in press).
- The finding that the global fish biomass is at least 10 times greater than previously assessed due to gross underestimation of the phenomenal biomass of mesopelagic fish as well as the efficiency of the food webs of the oligotrophic ocean (Irigoien et al. 2014).

Many more results are currently in review and will be presented at the forthcoming ASLO conference in Granada, Spain (22 February 2015–27 February 2015, http://sgmeet.com/aslo/granada2015/), most of them to be presented in the special session "The Global Ocean Ecosystem: Patterns, Drivers and Change" (special session #8).

I estimate that the results published thus far represent only 10% of the total output of the project, which will also contribute to 70 Ph.D and 35 M.Sc. theses. Hence, the mosaic of the state of the ocean in the 21st century the project is creating at present only contains 10% of the final composition. The rate of publication is accelerating as the results from this great effort emerge from the labs and I anticipate that by the end of 2015 about half of the results will be published or submitted. Accordingly, it is difficult as yet to foresee what will be the final aspect of this mosaic of the state of the global ocean. Hopefully, these findings will portray a healthier and more resilient ocean than we would have been anticipated.

We have also kept one in every 10 samples of plankton, genome, gases and water samples collected preserved in five different sample repositories. These samples will remain untouched to be analyzed 20 yr to 30 yr from now. The idea behind this repository, ***The Malaspina Collection***, is to preserve a sample of the ocean from 2010/2011 for a new generation of marine scientists that will use the samples to quantify ocean change using technology that we cannot yet anticipate and to resolve questions we cannot imagine today.

To put the costs of the Malaspina 2010 Expedition in perspective, consider that the budget, which in per capita terms represents about 3500 euros per researcher and year, represents the costs of building about 250 m, only one quarter kilometer, of high-speed railway. During the six years of the project Spain built around 1500 km of high-speed railway, so that, comparatively, the Malaspina 2010 Expedition represented 0.01% of such investment. The key for a global expedition of these dimensions to have been possible at such modest cost is the cooperation between many research groups committed to deliver on a unified set of goals.

The ocean holds the key, with its yet unlocked resources and capacity to regulate global climate and processes, to the future of human kind. If the calculations above are indicative of what may be the cost of advancing our understanding of the ocean, would marine research organizations, governments and funding agencies not engage in even broader collaborative efforts to deliver an ultimate impetus to ocean exploration?

Two millenia after Pompeius encouraged his sailors amidst a rough storm by saying "*navigare necesse est vivere non est necesse*" (to sail is necessary; to live is not necessary), seafaring remains a necessary underpinning of ocean exploration.

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