Food and Agriculture Organization of the United Nations

©Fisheries and Oceans Canada

The economic value of deep-sea sponges

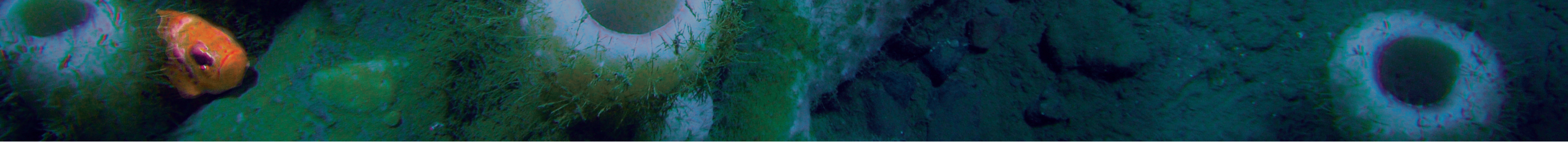
Deep-sea sponges are primitive multicellular organisms that live on the sea floor and feed on bacteria and on suspended and dissolved matter. They are found at depths below 200 m from polar regions to the tropics, and often form aggregations known as sponge grounds, which are rich in biodiversity. Deep-sea sponges are accessible only through offshore vessels and underwater specialized equipment.

Although deep-sea sponges are far away and seem apparently disconnected from human life, they can provide multiple benefits to human society.

A full economic valuation of deep-sea sponges should assess the value that deep-sea sponges can have at present and in the future, as well as for different stakeholders and the society. Much of the economic value of deep-sea sponges is still to be determined as the more detailed knowledge of these organisms in the deep sea is just unfolding. A first overview on the large economic benefits potentially conveyed by deep-sea sponges based on current research findings is here provided.

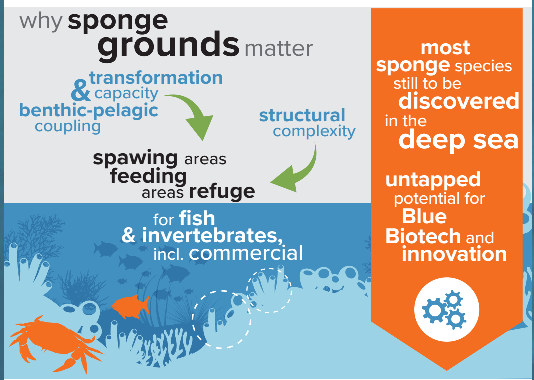
SponGES

SponGES has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 679849. This document reflects only the author's view – the Executive Agency for Small and Medium-sized Enterprises is not responsible for any use that may be made of the information it contains.



BOX 1 Ecosystem services from deep-sea sponges

- **Provisioning services:** providing direct, tangible benefits to society (e.g. discovery of sponge-derived pharmaceuticals).
- **Regulating services:** providing benefits related to the maintenance of the deep sea ecosystem (e.g. water filtration and recycling of nutrients).
- **Habitat services:** providing benefits in terms of living space for other marine organisms (e.g. habitat for commercial fish species).
- **Cultural services:** providing non-material benefits to society (e.g. scientific knowledge and amenity services).



Source: University of Bergen

Provisioning services

PHARMACEUTICALS

Biomolecular scientists and pharmaceutical companies consider sponges to be a marine drug "treasure". Sponges are benthic organisms and they are exposed to predators as well as to attacks by bacteria and viruses. Evolution has made sponges very efficient in their chemical defence. Sponges are associated with a large diversity of symbiotic bacteria and, through sponge-bacteria metabolic interactions, they can produce a remarkably high diversity of chemical compounds. These chemical substances have biological activity (i.e. bioactive leads) as they affect biological processes at the levels of cells, tissues and/or body organs and functions.

Sponges are considered the group of organisms with the largest number (4 800) of isolated substances with detected bioactivity, comprising 49 percent of all substances discovered between 1999 and 2009 in marine invertebrates (Leal *et al*., 2012). Indeed, the first marine substances of pharmaceutical interest were isolated from the Caribbean sponge (*Tectitethya crypta*) (AAAS, 1998).

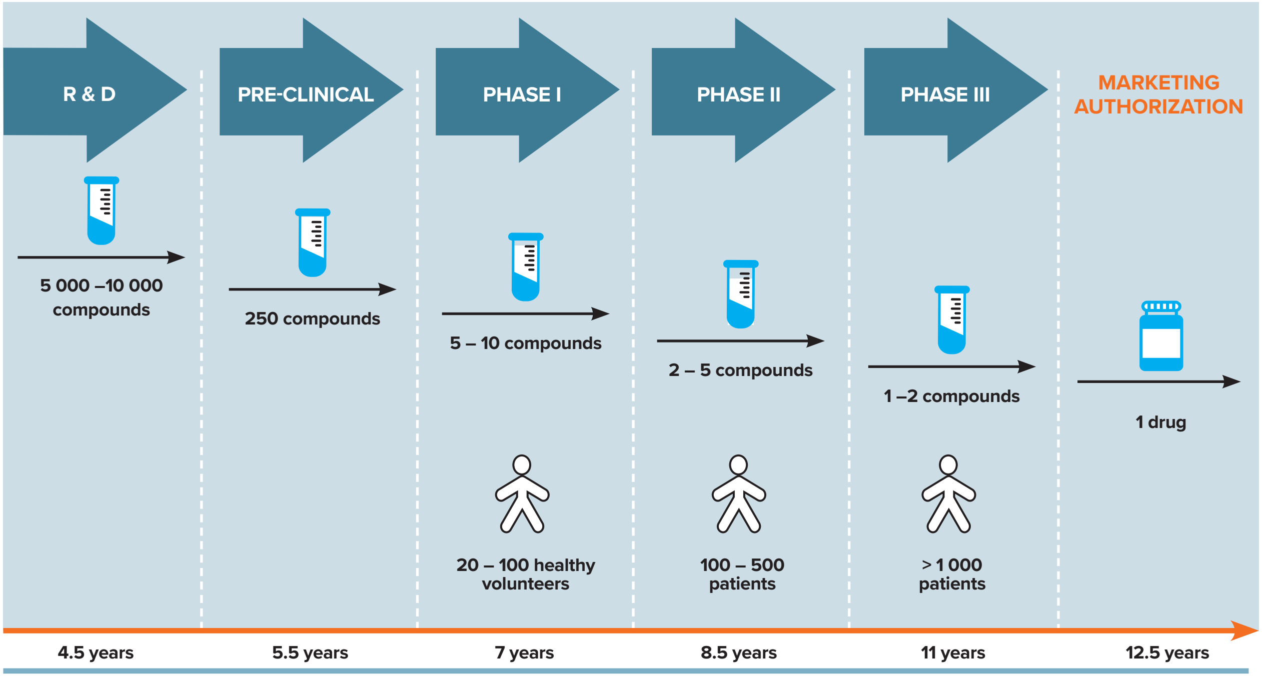
Bioactive leads are usually found in living sponges in trace amounts. Therefore, direct harvest of sponges as a source of raw pharmaceutical material is not a viable option either ecologically or financially. To bring a new drug to the market, pharmaceutical companies need to be able to reproduce the molecule of interest *in vitro* and subsequentially test it in pre-clinical and clinical trials (Figure 1). It is also worth considering that out of the six pharmaceuticals of marine origin that today are marketed all over the world, two of these compounds Halaven® and cytarabine are derived from sponges (Martins *et al*., 2014).

Halaven® is an anticancer drug for the treatment of metastatic breast cancer. Its use was approved by the Food and Drug Administration (FDA) in the United States of America in 2010 and by the European Medicines Agency in 2011.

Halaven® is marketed in more than 70 countries worldwide with global sales estimated at USD 1.1 billion/year (FAO, 2020a). It represents the ultimate resource as single-agent therapy for about 126 000 women/year.

Cytarabine is a chemotherapy drug primarily used for the treatment of acute

FIGURE 1 **Research pipeline for development of a new drug**



Source: FAO, 2020a

myeloid leukaemia (AML). Its use was approved by the FDA as long ago as 1969. In 2012, almost 352 000 patients worldwide were estimated to be affected by AML. The global market for drugs based on cytarabine is vast. Considering the cost of chemotherapy for the treatment of AML (about USD 8 000/patient), **the global sales of cytarabine were estimated at USD 2.8 billion/yea**r (FAO, 2020a). Several other interesting chemical compounds have recently been discovered in deep-sea sponges (FAO, 2020a), but none of them has yet reached the end of the research pipeline to be marketed as a new pharmaceutical.

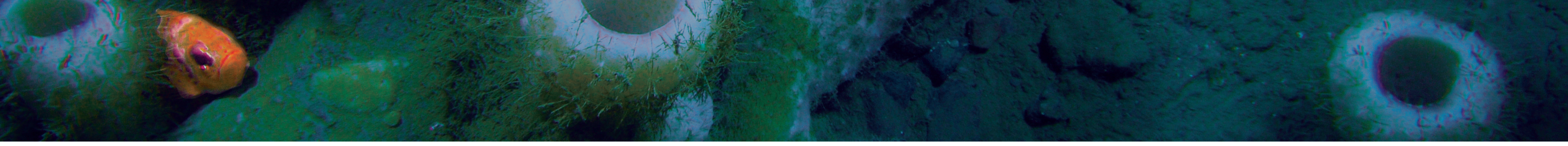
BIOTECHNOLOGICAL APPLICATIONS

The high bioprospecting potential of deep-sea sponges is not restricted to pharmaceuticals but also includes other possible innovative biotechnology applications in healthcare. **Deep-sea silica sponges potentially constitute a valid model to construct bone-graft substitutes.** Sponges bio-architecture closely resembles that of bone tissue. Moreover, sponge spicules contain a type of protein that catalyses the deposition of biosilica, which stimulates the synthesis, deposition and mineralization of new bone tissue.

Although research is still in its early development, initial experiments of transplants of biosilica in laboratory animals with fractured bones are encouraging (FAO, 2020a). Worldwide there is high demand for bone grafts and bone-graft substitutes owing to the global orientation towards minimally invasive surgery approaches. **By 2026, the future market for bone grafts and bone-graft substitutes is forecasted to reach USD 4.2 billion/year** (Zion Market Research, 2019).

Regulating services

Deep-sea sponge grounds play an important ecological role in the deep sea. Sponges are filtering organisms and very efficient in pumping water through their body. A *Geodia* sponge with



BOX 2 What is the market size of new pharmaceuticals and biotechnology applications derived from sponges?

- Deep-sea sponges are still an untapped reservoir of chemical compounds that could be used to develop new pharmaceuticals.
- Sponges are a promising source for anticancer compounds. Two out of six currently marketed pharmaceuticals of marine origin are anticancer drugs developed from sponges.
- Halaven® is a sponge-derived drug for the treatment of metastatic breast cancer with a global market value estimated at USD 1.1 billion/year.
- Cytarabine is a fundamental drug in the treatment of acute myeloid leukaemia with a global market value estimated at USD 2.8 billion/year.
- Deep-sea silica sponges may be used as architectural model for biosilica implants and bone-graft substitutes. By 2026, the future market for bone grafts and bone-graft substitutes is forecasted to reach USD 4.2 billion/year.

a wet weight of 1 kg can filter almost 350 litres of water in a day (Leys *et al.*, 2017). Thus, sponge grounds can be considered as a powerful water-pumping system.

As sponges pump ocean water through their body, they affect the quantity and quality of nutrients in the water column. Sponges remove bacteria and other dissolved organic matter; they take up ammonium; and they can absorb dissolved silicon from the water to build their skeleton.

If the water-pumping system of sponges is damaged or destroyed, what will be the consequences? How will this change impact the overall deep-sea ecosystem? How far will the consequences of sponge-ground destruction reverberate?

Scientists still do not have enough data to answer these questions. Measuring the metabolic activity of a sponge grounds in the deep sea requires specialized equipment, such as incubation chambers operated by remotely operated underwater vehicles (ROVs). These measurements recorded *in situ* are necessary as baseline data to start making simulations of the role played by sponges in the deep sea.

A recent scientific publication (Pham *et al.*, 2019) estimated the *Geodia* sponge biomass (about 2 600 tonnes) removed in the Flemish Cap area in the Northwest Atlantic Ocean by trawling fishing activity between 2010 and 2012. Although the sponge biomass seemed quite limited in absolute terms, considering the intensity of trawling activities occurring in a very extensive geographical area, the loss in ecological function was not at all negligible.

To try to put this loss of ecological function into an economic perspective, it can be considered that the water-pumping activity and filtering capacity of the removed sponge biomass is similar to that of the Ashbridges Bay Treatment Plant (ABTP), which is the second-largest plant in Canada, operating in the city of Toronto and serving a population of 1.5 million people (Figure 2). The capital and operating costs of the ABTP assessed just for primary and secondary treatments aimed at bacteria removal were estimated at USD 187 million (Pham *et al.*, 2019).

It should be considered that the whole sponge ground mapped in the Flemish Cap area is estimated to filter more than 56 000 million litres of seawater daily (Pham *et al.*, 2019). This comparison indicates that deep-sea sponges must be considered as a biological system with high proficiency in terms of water-pumping and filtering capacity. **The costs of replacing such an ecological function would be prohibitive** and, moreover, humans currently have no means

FIGURE 2 **Comparison of water pumping capacity between *Geodia* sponges and a conventional wastewater treatment plant**

2 600 TONNES OF SPONGES
FLEMISH CAP AREA, NORTHWEST ATLANTIC

pumping 627 million liters of water per day

ASHBRIDGES BAY TREATMENT PLANT
TORONTO, CANADA

pumping 598 million liters of water per day

Source: Left: ©Fisheries and Oceans Canada. Right: ©FAO.

BOX 3 **How substantial is the filtering activity of sponges in the deep sea?**

- Deep-sea sponge grounds provide a very efficient water-pumping engine operating in the deep sea.
- Deep-sea sponge grounds filter bacteria and dissolved organic matter from seawater and also affect other chemical parameters in the water column.
- The consequences of the destruction/damage of deep-sea sponge grounds in the regulation of the deep-sea ecosystem still need to be fully quantified.
- Preliminary evidence shows that humans have no means to match the massive water filtration carried out by deep-sea sponges with artificial infrastructures.

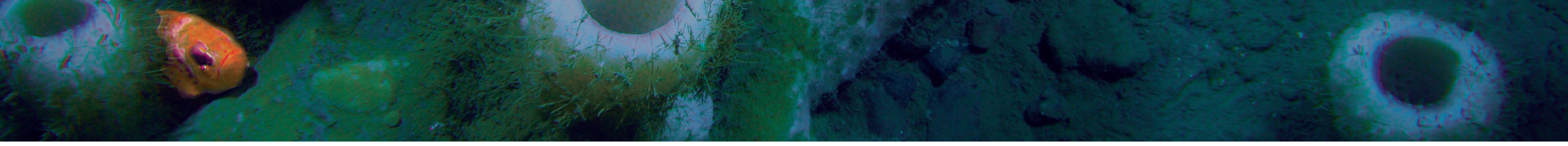
to potentially replace the filtering activity of existing deep-sea sponge grounds with artificial infrastructures.

Habitat services

HABITAT FOR COMMERCIAL FISH

Deep-sea sponge grounds create three-dimensional structures, providing additional habitat complexity to the sea floor. There is little doubt that increased structural complexity is linked to increased biodiversity and abundance of organisms.

Species that live on or just above the bottom sediments will be more directly associated to deep-sea sponge grounds. As expected, statistically significant higher abundance of crustaceans such as shrimps (*Pandalus montagui*) and crabs (*Cancer borealis*) has been recorded on Hexactinellid sponge grounds located in the Emerald Basin, Nova Scotia, Canada (Hawkes *et al*., 2019). Other studies have observed several commercial fish species, such as roughhead grenadier (*Macrourus berglax*), roundnose grenadier



(*Coryphaenoides rupestris*), Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes* spp.), haddock (*Melanogrammus aeglefinus*) and pink shrimp (*Pandalus borealis*) on sponge grounds dominated by *Geodia* sponge species (FAO, 2020a).

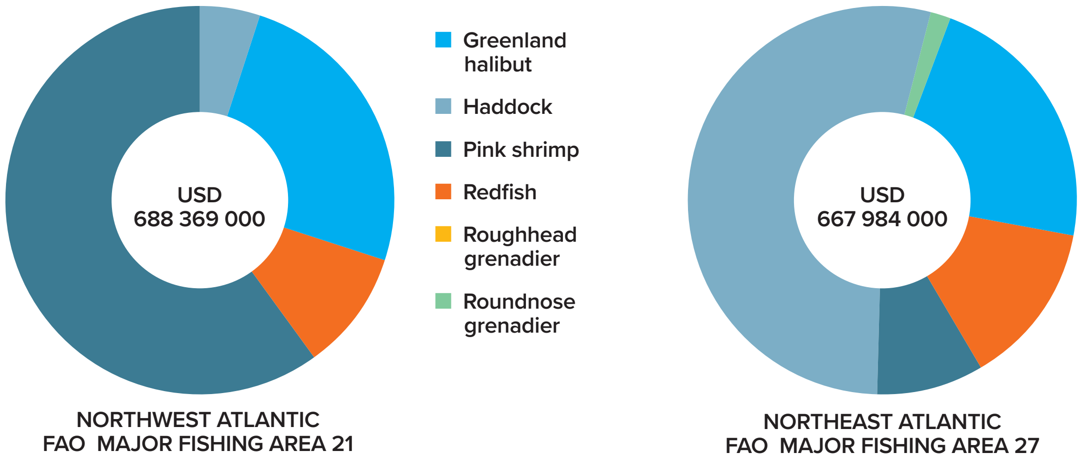
***Geodia* sponge grounds** have a wide distribution in the northern hemisphere, and sponge grounds aggregations **have been mapped in both the Northwest Atlantic** (Murillo *et al*., 2012) **and the Northeast Atlantic** (Klitgaard and Tendal, 2004). The functional role played by *Geodia* sponge grounds on the above-mentioned commercial fish species has not been detailed yet. The role is likely to vary among different species. Sponge grounds rich in invertebrates could be used as feeding grounds, and the three-dimensional structure of sponge grounds could be used as refuge against predators (especially at earlier development stages) or as spawning areas.

A recent FAO study (FAO, 2020b) assessed the economic value of ecosystem services of the deep sea, including the provision of deep-sea fish species in exclusive economic zones as well as in the areas beyond national jurisdiction. The global **economic value of the landings of the six commercial fish species, mentioned above, in the Northeast and Northwest Atlantic was assessed at over USD 1.3 billion/year** (Figure 3).

BOX 4 Why the fisheries sector could suffer an economic loss from the destruction/damage of deep-sea sponge grounds?

- Deep-sea sponge grounds increase the structural diversity of the sea floor, increasing the biodiversity in the deep sea.
- Several commercial fish species have been observed in association with deep-sea sponge grounds.
- Deep-sea sponge grounds could be used as feeding sites, refuges or nurseries by several demersal and pelagic fish species, affecting population recruitment and consequently fisheries landings.
- The economic value of the 2014 fish landings in the North Atlantic of deep-sea fish most reported in association with *Geodia* sponge grounds is estimated at USD 1.3 billion.

FIGURE 3 **Market-value of fish landings in the North Atlantic**



Notes: Estimated market-value refers to 2014 reported fish landings. Roughhead grenadier's contribution too small to be shown on graphs.
Source: FAO, 2020b

Assuming that deep-sea sponge grounds play an important role in the recruitment of these six commercial fish species, the economic repercussions of the damage/destruction of deep-sea sponge grounds on deep-sea fisheries can be easily drawn. As there is not sufficient information to quantify how much deep-sea fish species might rely directly and indirectly on deep-sea sponges, **conserving deep-sea sponge grounds is to be considered, under a precautionary approach, as a strategic long-term vision for the fisheries sector.**

Cultural services

SCIENTIFIC RESEARCH AND EDUCATION

Research on deep-sea sponge grounds started recently, as the first full description of a sponge ground was carried out in 1987 during the inter-Nordic BIOFAR 1 programme around the Faroe Islands (Klitgaard, Tendal and Westerberg, 1997). Conducting investigations in the deep seas requires large and expensive equipment such as specialized research vessels, ROVs, and autonomous underwater vehicles (AUVs). A survey conducted in 2015 (UNESCO, 2017) on 24 countries worldwide recorded technological capacity for deep-sea exploration including 325 research vessels, 226 AUVs and 36 ROVs.

Public investments allocated to scientific research can be considered a proxy of the interest of society in the study and conservation of deep-sea sponges. Funding scientific research on deep-sea sponges indicates recognition of the benefits that they can provide at present and in the future.

At the international level, the European Union, mobilized about USD 35 million between 2010 and 2020 to support and foster deep-sea sponge research in the European Research Area (FAO, 2020a; CORDIS, 2020). This is an important recognition of the economic relevance of deep-sea sponges. However, these investments are to be considered limited in terms of both time and overall amount, considering that research in the deep sea is estimated to cost between USD 46 000/day (FAO, 2020a) and USD 80 000/day (Van Dover *et al.*, 2014).

Scientific research remains a priority as it is fundamental to be able to capitalize current and future high economic benefits derived from deep-sea sponges. It is necessary to make advances in molecular discoveries and biotechnological applications and to increase the capacity to assess threats and impacts of current and future use of the deep sea in an ongoing climate change scenario, in order to progress towards an integrated intersectoral management of the deep-sea ecosystem.

BOX 5 Why investing in scientific research on deep-sea sponges?

- Scientific research on deep-sea sponges is connected to sustainable use of the oceans.
- Funding scientific research on deep-sea sponges means investing into the future and in future economic opportunities.
- The European Union, between 2010 and 2020, has recognized the importance of scientific research on deep-sea sponges by funding USD 35 million in sponge-related projects.
- International funding of deep-sea sponge research is still considered limited, as research in the deep sea is expensive, requires adequate sampling in remote areas and needs specialized equipment.

References

CORDIS. 2020. Projects and results. In: *European Commission* [online]. [Cited 8 September 2020]. https://cordis.europa.eu/search/advanced_en?projects

FAO. 2020a. *Economic valuation of ecosystem services provided by deep-sea sponges.* FAO Fisheries and Aquaculture Circular No. 1217. Rome, FAO.

FAO. 2020b. *Economic valuation of the deep seas and the areas beyond national jurisdiction*. FAO Fisheries and Aquaculture Circular No. 1210. Rome, FAO.

Hawkes, N., Korabik, M., Beazley, L., Rapp, H.T., Xavier, J.R. & Kenchington, E. 2019. Glass sponge grounds on the Scotian Shelf and their associated biodiversity. *Marine Ecology Progress Series*, 614: 91–109.

Klitgaard, A.B. & Tendal, O.S. 2004. Distribution and species composition of mass occurrences of large-sized sponges in the northeast Atlantic. *Progress in Oceanography*, 61: 57-98.

Klitgaard, A., Tendal, O.S., & Westerberg, H. 1997. Mass occurrences of large sized sponges (Porifera) in Faroe Island (NE-Atlantic) shelf and slope areas: characteristics, distribution and possible causes. In Southampton Oceanography Centre. *The responses of marine organisms to their environments*, pp. 129–142. Southampton, UK, University of Southampton.

Leal, M.C., Puga, J., Serôdio, J., Gomes, N.C. & Calado, R. 2012. Trends in the discovery of new marine natural products from invertebrates over the last two decades–where and what are we bioprospecting? *PLoS One*, 7: p.e30580 [online].

Leys, S.P., Kahn, A.S., Fang, J.K.H., Kutti, T. & Bannister, R.J. 2017. Phagocytosis of microbial symbionts balances the carbon and nitrogen budget for the deep-water boreal sponge *Geodia barretti*. *Limnology and Oceanography*, 63: 187–202.

Martins, A., Vieira, H., Gaspar, H. & Santos, S. 2014. Marketed marine natural products in the pharmaceutical and cosmeceutical industries: tips for success. *Marine Drugs*, 12: 1066–1101.

Murillo, F.J., Muñoz, P.D., Cristobo, J., Ríos, P., González, C., Kenchington, E. & Serrano, A. 2012. Deep-sea sponge grounds of the Flemish Cap, Flemish Pass and the Grand Banks of Newfoundland (Northwest Atlantic Ocean): distribution and species composition. *Marine Biology Research*, 8: 842-854.

Pham, C.K., Murillo, F.J., Lirette, C., Maldonado, M., Colaço, A., Ottaviani, D. & Kenchington, E. 2019. Removal of deep-sea sponges by bottom trawling in the Flemish Cap area: conservation, ecology, and economic assessment. *Scientific Reports*, 9: 1–13.

Toronto water. Ashbridges Bay Wastewater treatment Plant 2017. 2016 *Annual Report.* 108 pp.

Van Dover, C., Aronson, J., Pendleton, L., Smith, S., Arnaud-Haond, S., Moreno-Mateos, D., Barbier, E., et al. 2014. Ecological restoration in the deep-sea: desiderata. *Marine Policy*, 44: 98–106.

UNESCO. 2017. *Global ocean science report – the current status of ocean science around the world*, by L. Valdés *et al*., eds. Paris.

Zion Market Research. 2019. Bone grafts and substitutes market by material (natural and synthetic) and by application (spinal fusion, dental, joint reconstruction, craniomaxillofacial, foot and ankle, and long bone): global industry perspective, comprehensive analysis, and forecast, 2018–2026. In: *Zion Market Research* [online]. [Cited 8 September 2020]. www.zionmarketresearch.com/report/bone-grafts-substitutes-market

THIS POLICY BRIEF WAS PREPARED BY: **Daniela Ottaviani, FAO consultant**

CONTACT FOR FURTHER INFORMATION:

Merete Tandstad
Fisheries - Marine and Inland Fisheries Branch (NFIF)
Fi-inquiries@fao.org
fao.org/fisheries
Food and Agriculture Organization of the United Nations
Rome, Italy

info@deepseasponges.org
deepseasponges.org
@DeepSeaSponges
@DeepSea_Sponges

CB2532EN/1/12.20