The Deep Sea Cities of Glass

by Sheila Byers

Glass sponge reefs are ancient unique living structures that have so far only been found in fjords and on the continental shelf off the Pacific Northwest Coast of North America. The first sightings of glass sponge reefs in 1987–1988 in Hecate Strait and Queen Charlotte Sound near Haida Gwaii initiated a series of discoveries along coastal BC. Subsequently reefs were discovered in the Strait of Georgia (SOG), Howe Sound, Lynn Canal north of Juneau Alaska and in Portland Canal (Boundary Reefs) between Alaska and BC. More recently, reefs were discovered in Chatham Sound near Prince Rupert and in Desolation Sound. Closer to home, Glen Dennison of the Marine Life Sanctuaries Society of BC (MLSS) discovered 12 new reefs within Howe Sound (1984–2015).

Glass Sponge Biology and Distribution

Glass sponges belong to the class Hexactinellida, one of four sponge classes within the invertebrate phylum Porifera: the 'pore-bearers'. Close examination of any sponge will reveal its 'holey' appearance. Hexactinellid sponges have a skeleton that is constructed of tiny, six-spined siliceous spicules made of silica (silicon dioxide, SiO_2). The skeleton is as fragile as glass.

Hexactinellid sponges are the first-known multicellular organisms in the Earth's history and have survived several mass extinction events during the last 560 million years. Glass sponges typically grow as individuals on hard substrata and are found throughout the world in deep, dark and cold (<12°C) water, the densest communities occurring at ocean depths around 20 m to 240 m.

Reef-building glass sponges are unique in that the spicules of the skeleton are fused at the tips (not loosely held together) to form an internal, rigid three-dimensional structure. This 3D scaffold comprises greater than 80% of the sponge's biomass and is the basis of the reef formation.

The deep sea reefs of Hecate Strait and Queen Charlotte Sound off Haida Gwaii grow at 165–240 m and the SOG reefs at 69–230 m. The newly discovered Howe Sound reefs are shallower, ranging from 20–122 m.

Glass Sponge Reefs — Ecosystem Structure

There are three species of reef-building sponges in BC: cloud sponge (*Aphrocallistes vastus*), fingered goblet sponge (*Heterochone calyx*), and lace sponge (*Farrea occa*). These three species form the reefs in Hecate Strait and Queen Charlotte Sound. In the SOG and Howe Sound, the cloud sponge (predominantly) and fingered goblet sponge are the reef-builders. Glass sponge reefs benefit from elevated bathymetry whether as exposed glacial seafloor, pinnacles, seamounts or submarine ridges in areas of high silica concentrations

Glen Dennison at Halkett glass sponge reef. Photo by Adam Taylor.

and tidally-driven, near-bottom currents. Fine organic-rich sediments transported by ambient currents are baffled and entrapped by the sponges. As the sponges die the skeletons collapse and with the accumulated sediments, coalesce into a semisolid matrix. New larval sponge recruits settle on exposed dead skeletons of older generations to continue the growth cycle while building the height of the reef.

Sponge reefs can span kilometres of the seafloor and reach up to 25

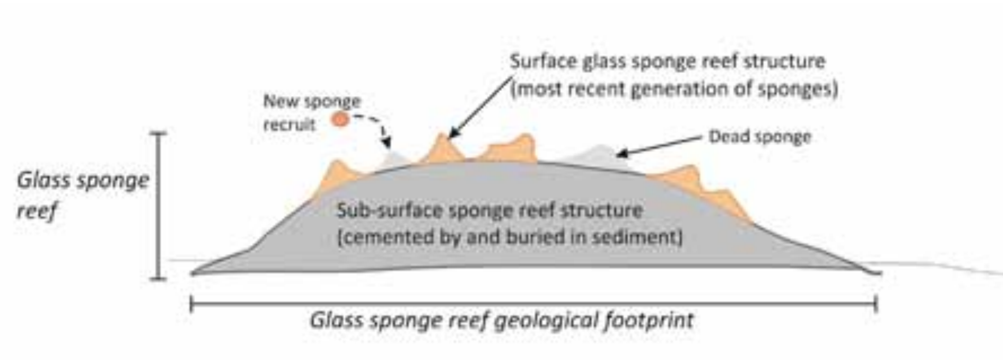

Diagram of glass sponge reef structure (modified from Dunham et al. 2018). By permission of Anya Dunham.

m in height, with the living crowns adding another 1–2 m on top of the reef formation. From an ecosystem perspective, the sponge reefs not only provide habitat for new sponge growth but also support diverse and abundant communities of invertebrates and fishes with 84 taxonomic groups observed. The reefs provide refuge, foraging and nursery grounds for species of commercial, recreational and cultural fisheries such as rockfish, lingcod, crab, shrimp, prawn and sea cucumber.

Ecological Functions and Services

A unique feature of glass sponges is their living tissue. Instead of being formed of single cells (each cell with its own nucleus), it forms one giant cell with many nuclei within. This modified tissue enables both nutrients and communicating electrical signals to travel unimpeded throughout the entire sponge. The so-called syncytial tissue envelops and pervades the silica scaffold much like a cob-web and composes about 75% of the living membrane. The other 25% of the living membrane is composed of cells that perform specific tasks.

All organisms including glass sponges need food to provide energy for growth, repair and reproduction. Glass sponges are suspension feeders that filter food from the overlying water column. Glass sponge reefs have the highest benthic grazing rate (transfer of food from the water column to the bottom-feeders) of any suspension-feeding community measured to date. They have tiny specialized, fine-meshed collar cells that pump massive volumes of water through tiny pores and micro-channels within the skeletal body wall while filtering out 95% of bacteria and other protist picoplankton (<10 µm). Oxygen and silica are extracted from the water during the process.

Glass sponges have a tricky energetic balance to maintain: the energy it costs to pump and filter the water versus the energy gained by ingesting the bacterial food (particulate organic carbon) filtered from the water. How tricky is it? Concentrations of bacteria at the depth of these reefs are about one-tenth of that in surface waters — likely an insufficient supply of food to sustain large sponge reef communities. A recent study suggests that reef communities are supported by several food sources including fresh bacterial food imported by ambient currents from the overlying water column (terrestrial and oceanic) and recycled bacterial food supplied from resuspended sediments entrapped within the reefs. Add the excreted waste (fecal pellets) from the sponges themselves to the entrapped sediments and the result is an enhancement of bacterial growth within the sediments. This unusual interaction between the reef and the sediments baffled by the sponges may explain why the bathymetric elevation of the reef communities is so critical. Tidally-driven currents bring new water for food to replenish that grazed by the sponges, resuspend sediments to cement the reef structure, and increase the food supply from locally resuspended bottom sediments rich with bacteria. Taking advantage of entrapped sediments enables processing of more water (and thus more food) at the same or lower energetic cost.

During the pumping process the sponges release important nitrogenous waste products into the surface waters to contribute towards phytoplankton photosynthesis and productivity. The significant connection of communities of filtering glass sponges on the seafloor affecting properties of the overlying water column is referred to as benthic-pelagic coupling.

How much water is pumped? Calculations made by Fisheries and Oceans Canada scientists estimate that the filtration capacity of nine reefs in Howe Sound would clear over 17 billion liters of water daily. This is equivalent to over 6,500 Olympic-size swimming pools! Add this volume in Howe Sound with the volume of water filtered by the nine known reefs in the SOG and the total daily filtration volume is ~1% of all water in the SOG basin. It would take these 18 sponge reefs just 82 days to filter all water in the SOG and Howe Sound combined (a turnover capacity of 4 times per year).

Or, if the combined reef area of the nine Howe Sound reefs is 60.4 hectares, imagine that these

Squat lobster, *Munida quadrispina*, in Howe Sound glass sponge reefs. Photo by Diane Reid.

nine reefs would take only ~2 hours to pump the equivalent of the waste-water volume generated by the entire population of Metro Vancouver in one day (www.metrovancouver.org; Adam Taylor and Lora McAuley, MLSS, Pers. Comm.).

Vulnerabilities

Glass sponges are sensitive and exceptionally fragile. Reef-building sponges are long-lived but their lifespan is unknown with estimates for a non-reef building sponge suggesting greater than 220 years. They are slow growing with rates estimated at 1–9 cm per year (depending on age). The rate of reef growth is also unknown but an estimate suggests as fast as 12 m vertically in 3000 years. Sponges and reefs are slow to recover from disturbances.

When sponges are exposed to excessive amounts of suspended sediments the tiny pores and micro-channels so important for filtration become clogged. Sponges can be smothered. To prevent clogging, a sponge immediately arrests its filtering in response to rapid electrical signals sent throughout the syncytial tissue. Prolonged clogging causes reduced pumping, reduced feeding and the long term loss of ecosystem function and services. Glass sponges are vulnerable to suspended sediment and contaminant loads associated with bottom-trawling, mines and industrial sites. Mechanical injuries from bottom contact crab, prawn and shrimp traps, downrigger balls and boat anchors cause major cumulative damage in the fragile glass sponge communities. Protecting these ecosystems is critical to the economically important marine fisheries and ecotourism that sponge reefs support.

Top: Pregnant Quillback rockfish, *Sebastes maliger*, in Howe Sound glass sponge reefs. Above: Subadult Yelloweye rockfish, *Sebastes ruberrimus,* in Howe Sound glass sponge reefs. Photos by Diane Reid.

Climate Change: what are the implications on sponge reefs?

The enormous amounts of seawater filtered over time, the heavily silicified skeletons, and sediment entrainment by reef-building sponges suggest the potential for reefs to sequester carbon and silicon as 'sinks' or buried reservoirs. Such reservoirs could provide long-term benefits for ocean primary productivity. Potential for a silicon sink is substantial with several reefs estimated to lock 915 tonnes of silicon into the exposed portion of the reef. Estimates of the amount of carbon removed and processed by reef filtration amount to approximately 1g of carbon per square meter per day. These values are comparable to carbon sequestration rates reported for terrestrial old growth forests and to "blue carbon" sequestration rates by marine vegetation. By example, the productivity of the *Macrocystis* giant kelp forest is estimated at 2.7g carbon per square meter per day. Given these high carbon removal rates, reef-building sponges may act as one of the buffers against ocean acidification.

Ocean acidification may indirectly affect the feeding efficiency of glass sponges if the tissue function and homeostasis of the membrane pumps are detrimentally compromised. The marine life associated with the reefs that are carbonate-dependent (e.g., crustaceans, molluscs), however, will be more directly impacted.

Waters in the SOG and BC fjords (including Howe Sound) are highly productive, well oxygenated due to high tidal mixing, and rich in dissolved silicon from riverine input. Should lower productivity occur, reduced bacterial concentrations below that required for sponge filtration will potentially affect growth and reproduction. Reduced ambient oxygen levels would make extraction by the sponges more difficult and drive up the energy cost of filtration.

Shrimp peering out of glass sponge osculum. Photo by Adam Taylor.

Some fjord sponge populations may face extirpation with warming temperatures and greatly reduced dissolved oxygen levels. Glass sponges are particularly sensitive to temperature change because of their electrical conduction system propagated in the syncytial tissue. With higher temperatures sponges will be less likely to arrest their feeding current making them susceptible to clogging and damage by sediment. Glass sponges do not contract (like other sponges),

Pacific lingcod in Halkett glass sponge reef. Photo by Adam Taylor.

so arresting their filtration current is the only protection they have against ingesting damaging particles.

Glass sponge reefs are fascinating, beautiful, fragile and complex benthic ecosystems that provide refuge, foraging habitat and nursery grounds for a diversity of marine life including those of economic importance. Knowledge of the deep reef habitats and their ecological services is still limited in part due to the technical challenges of accessing these deep and often remote communities. There is much to learn about reproduction, dispersal and recruitment of reef-building sponges. MLSS continues to support DFO by conducting science-based research to broaden the knowledge of Howe Sound glass sponge reefs.

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Select References

1. Canada Department of Fisheries and Oceans. 2018. *Glass Sponge Aggregations in Howe Sound: Locations, Reef Status, and Ecological Significance Assessment.* DFO Canadian Science Advisory Secretariat Response. 2018/032. 43 pp.

2. Chu, J.W.F. and S.P. Leys. 2010. High resolution mapping of community structure in three glass sponge reefs (Porifera, Hexactinellida). Marine Ecology Progress Series 417: 97-113.
3. Chu, J.W.F., M. Maldonado, G. Yahel and S.P. Leys. 2011. Glass sponge reefs as a silicon sink. Marine Ecology Progress Series 441: 1-14.
4. Clayton, L. and G. Dennison. 2017. Inexpensive video drop-camera for surveying sensitive benthic habitats: applications from glass sponge (Hexactinellida) reefs in Howe Sound, BC. Canadian Field-Naturalist 131: 46-54.
5. Conway, K.W., J.V. Barrie, W.C. Austin and J.L. Luternauer. 1991. Holocene sponge bioherms on the western Canadian continental shelf. Continental Shelf Research 11: 771-790.
6. Conway, K.W. , M. Krautter, J.V. Barrie, F. Whitney, R.E. Thomson, H. Reiswig, H. Lehnert, G. Mungov and M. Bertram. 2005. *Sponge reefs in the Queen Charlotte Basin, Canada: controls on distribution, growth and development*. IN: Freiwald A. and J.M. Roberts (eds.) *Cold Water Corals and Ecosystems*. Springer-Verlag.
7. Conway, K.W., F. Whitney, S.P. Leys, J.V. Barrie, and M. Krautter. 2017. *Sponge Reefs of the British Columbia, Canada Coast: Impacts of Climate Change and Ocean Acidification*. Chapter 10 IN: Carballo J.L and J.J. Bell (eds). *Climate Change, Ocean Acidification and Sponges*. Springer International Publishing.
8. Dunham, A., Marine Environmental Research. 2018. https://doi.org/10.1016/j.marenvres.2018.08.002
9. Kahn, A.S., J.W.F. Chu and S.P. Leys. 2018. Trophic ecology of glass sponge reefs in the Strait of Georgia, British Columbia. Scientific Reports 8:756:1–11.
10. Kahn, A.S., G. Yahel, J.W.F. Chu, V. Tunnicliffe and S.P. Leys. 2015. Benthic grazing and carbon sequestration by deep-water glass sponge reefs. Limnology and Oceanography 60: 78-88.
11. Leys, S. P. 2003. The significance of syncytial tissues for the position of the Hexactinellida in the Metazoa. Integrative and Comparative Biology 43: 19-27.
12. Leys, S.P. 2013. *Effects of Sediment on Glass Sponges (Porifera, Hexactinellida) and Projected Effects on Glass Sponge Reefs.* DFO Canadian Science Advisory Secretariat Research Document 074. 23 pp.
13. Marliave, J.B., C.J. Gibbs, D.M. Gibbs, A.O. Lamb and Skip J.F. Young. 2011. *Biodiversity Stability of Shallow Marine Benthos in Strait of Georgia, British Columbia, Canada Through Climate Regimes, Overfishing and Ocean Acidification.* Chapter 3 IN: Grillo O. and G. Venora (eds.) *Biodiversity Loss in a Changing Planet*. InTech Publisher.
14. McAuley, L. 2017. *Howe Sound Glass Sponge Reef Identification*. On behalf of the Marine Life Sanctuaries Society for Department of Fisheries and Oceans Canada. 39pp.
15. Yahel, G. and F. Whitney, H.M. Reiswig, D.I. Eerkes-Medrano and S.P. Leys. 2007. *In situ* feeding and metabolism of glass sponges (Hexactinellida, Porifera) studied in a deep temperate fjord with a remotely operated submersible. Limnology and Oceanography 52(1): 428-440.