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Editorial: Seafloor heterogeneity: Artificial structures and marine ecosystem dynamics - recent advances

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Editorial on the Research Topic
Seafloor heterogeneity: Artificial structures and marine ecosystem dynamics - recent advances

During the past several centuries, marine coastal ecosystems have been altered at alarming rates as a result of ever increasing anthropogenic influences (McCauley et al., 2015; Halpern et al., 2019; Duarte et al., 2020). While impacts of anthropogenic climate change have already been manifested in the form of, for example, decreased ocean productivity, altered food web dynamics, and reduced abundance of habitat-forming species, e.g. corals, seagrass, mangroves, kelp forests (Waycott et al., 2009; Hoegh-Guldberg and Bruno, 2010; Filbee-Dexter and Wernberg, 2018; FAO, 2020; Souter et al., 2021; FAO, 2022), effects of increasing installations of various artificial structures on marine ecosystems are poorly understood. Drawing on the success of the first edition (Fujii et al.), this volume aims to further advance research in the field of human impact on marine life *via* placement of "sub-sea artificial structures". This Research Topic assembles 15 articles investigating relationships between various types of anthropogenic structure and marine ecosystem dynamics. Here we present an overview of these contributions and highlight emerging views and future directions in this field.

Artificial reefs for ecological restoration

To assess the role of artificial reef construction in coastal management, Wang et al. developed trophic models for established and newly deployed artificial oyster reef ecosystems in comparison with non-reef bare substratum located in Bohai Sea, China. Reefs showed more complicated trophic relationships, greater potential to withstand perturbations, and higher carrying capacities of commercial organisms compared to bare

seafloor, demonstrating benefits of constructing artificial oyster reefs for marine ranching. Williams et al. compared growth rates of a shallow-water damselfish in artificial versus natural habitats throughout the Southern California Bight. Adult garibaldi fish (*Hypsypops rubicundus*) are territorial, with limited vagility, linking their growth rates to habitat quality. Garibaldi grew significantly larger on artificial reefs than on natural reefs, a finding consistent with other fishes in the region, providing insights into future reef design and assessments. Williams et al. report on the first restoration rocky reef built on the open coast in California. The Palos Verdes Reef is a series of variable relief rock modules (1-4 m) placed proximate to existing reefs. Due to its novel design, there were rapid recruitment and successional responses. Reef performance quickly exceeded design expectations, including the persistence of giant kelp, fish biomass, and fish density.

Human activities relating to aquaculture and reconstruction of coastal infrastructure

Hashimoto and Sato-Okoshi investigated population dynamics of a capitellid polychaete in Gamo Lagoon (northeast Japan) during restoration works operating in response to the 2011 Tohoku earthquake and tsunami. Daily maximum water level in the inner part of the lagoon, where the capitellid polychaete was most abundant, dropped markedly during the reconstruction of a flow-conducting levee. The maximum water level had a significant effect on maintenance of the polychaete population; sufficiently high water levels enabled dispersion of planktonic larvae, aiding rapid population recovery. Okumura et al. surveyed the coastal environment in Matsushima Bay, northeast Japan, for four years following the 2011 Tohoku tsunami. The lack of differences in nutrient concentrations or eukaryote assemblages between areas with and without aquaculture installations was considered to be a result of efficient seawater exchange, despite the presence of many small islets separating Matsushima Bay from the open ocean. It was concluded that the current aquaculture installations had no major negative impact on the environment in Matsushima Bay.

Continuing importance of archival underwater imagery for ecological assessment of offshore oil and gas installations

Using a remotely operated vehicle (ROV), Biede et al. investigated the response of deep-water benthic megafauna to the installation of a pipeline on the Angolan Margin. While density of megafauna, particularly in mid-slope regions, increased significantly three months after pipeline installation, diversity did not increase consistently. The pipeline appeared to trap organic material and anthropogenic litter, and may have enhanced available food resources locally as well as providing hard substratum. McLean et al. used ROV imagery to assess diversity and abundance of fishery target species on subsea wells and pipelines in relation to structure properties and environmental variables in tropical and temperate Australia. They also used techniques proposed by Smith et al. (2016) to estimate fish production for three species. Many species were associated with these structures, and production estimates were similar to those from other studies of artificial reefs. These data will help inform decommissioning decisions for subsea infrastructure. Sih et al. analyzed industry ROV imagery (2008-2018) at different oil and gas (O&G) structures/pipelines in the Bass Strait, Australia, and compared with fisheries-catch data from the same period. Fish/invertebrate richness, abundance, and diversity were high around O&G platforms, with a different species subset inhabiting pipelines. There was only 10% overlap between species targeted by fishers compared to O&G structures; however, grouped fisheries species data are an under-representation of true diversity. Ierodiaconou et al. reviewed ten years' worth of O&G industry ROV imagery data for wells and flowlines in the Bass Strait, Australia. Sixty-nine taxa were recorded in total, with a higher diversity on flowlines (28 taxa) than wells (19 taxa). High-spatial variability was identified across all sites. Notable protected species were recorded, including Australian fur seal (*Arctocephalus pusillus*).

Variety of techniques for monitoring subsea artificial structures

Boyle et al. used passive acoustic monitoring (PAM) to describe fish sounds in a variety of marine habitats across the Alabama Artificial Reef Zone in the Gulf of Mexico. They showed distinct spatiotemporal sound variation potentially associated with varied species composition and abundance as well as diel and seasonal influences, suggesting soundscape variability may be a consideration for management, as it can provide an acoustic cue for reef location by some fish species. Galaiduk et al. assessed regional patterns in demersal fish assemblages among subsea pipelines and natural habitats across north-west Australia using baited remote underwater video systems (BRUVs). At the regional scale, subsea pipelines showed lower diversity than natural environments, but possessed a higher abundance of piscivorous and herbivorous fish taxa, highlighting a negligible regional influence of subsea pipelines on fish communities, although these structures may be important for some fish species at the local scale. Fernandez-Betelu et al. deployed self-contained, autonomous-underwater-echolocation-click detectors (C-PODs) to investigate presence/foraging of harbor porpoise (*Phocoena phocoena*) around four unmanned oil, gas, and renewable energy installations in the Moray firth, Scotland. Porpoises were encountered on average 17 hrs/day and changed to night-time foraging behavior when the installation was present; foraging activity decreased with distance from structures, highlighting the importance of offshore installations for porpoises.

Theoretical and data-driven approaches for marine habitat assessment and ecosystem-based management

To support ecosystem-based management efforts in the Southeastern US, Steward et al. used multiple data-driven approaches to quantify the amount of seafloor covered by artificial and natural reefs. Artificial reef coverage was several orders of magnitude less than natural reef coverage. While expansive seafloor mapping and characterization efforts are still needed, these results filled critical information gaps and demonstrated an approach applicable to other regions. Pondella et al. synthesized the mechanisms of increasing fish production by maximizing ecological processes. Utilizing structural and ecological theory of artificial reef design based upon physical attributes (i.e., complexity, vertical relief, habitat heterogeneity, and spatial scale), they summarized the mechanisms used to increase secondary fish production and proposed a general theory for optimization of these variables. This theory is applicable to reef assessment and design. Nicolette et al. adapted a Net Environmental Benefit Analysis (NEBA) framework to bolster the comparative assessment (CA) process for decommissioning options of offshore O&G facilities. The NEBA-CA framework is based on integrating ecosystem-service values, site data, and extant scientific information at sites in the North Sea, Australia, Gulf of Thailand, California, Gulf of Mexico, and the Caribbean. A NEBA-CA case study performed on a North Sea offshore installation determined that full removal was the least preferable decommissioning option.

Emerging opinions and future directions

This Research Topic provided further insights into: (1) the importance of considering multiple environmental factors; (2) the scale-dependency of ecological patterns observed on and around sub-sea artificial structures; and (3) the diversity of approaches being developed to investigate impacts of human activities on the marine environment. While many studies reported that sub-sea artificial structures generally have beneficial effects on a range of marine life by providing shelter and/or enhanced food supply (Biede et al.; Fernandez-Betelu et al.; Ierodiaconou et al.; Williams et al.), observed variability in some key ecological properties may also be controlled by other environmental factors such as prevailing hydrodynamics (Hashimoto and Sato-Okoshi; Okumura et al.; Wang et al.), seafloor topography, depth, and sea surface temperature (Galaiduk et al.; Pondella et al.; Williams et al.). Several studies also highlighted that the ecological significance of artificial habitats observed at one spatial scale may become less significant when viewed at another, indicating the importance of scale-dependency when interpreting ecological patterns observed at varying spatiotemporal scales (Galaiduk et al.; Pondella et al.; Steward et al.). An increasing number of studies have also attempted to fill gaps regarding the influence of marine artificial habitats in support of implementing sustainable coastal management, including the ecosystem-based approach (Boyle et al.; Sih et al.; Steward et al.; Wang et al.). With regard to issues surrounding decommissioning, this volume proposes a wealth of approaches in an attempt to facilitate decision-making (Fernandez-Betelu et al.; Ierodiaconou et al.; McLean et al.; Nicolette et al.; Sih et al.). Overall, this Research Topic provided a renewed opportunity to better integrate emerging knowledge and thereby advance our ability to understand, predict, and manage our marine environments and resources.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Conflict of interest

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