GUIDELINES FOR THE DEPLOYMENT AND MONITORING OF ARTIFICIAL REEFS

Introduction

Coastal zones are focal points of human settlement and economic development (De Andres and Muñoz, 2015), however, the rapid expansion of industry, agriculture and aquaculture over the last half-century has exposed these environments under heavy and growing pressure (Naylor et al., 2021). Excess nutrient inputs, chemical pollution, habitat fragmentation and the spread of non-indigenous species are now commonplace, driving eutrophication, biodiversity loss, the decline, and in some instances the collapse, of commercially important fisheries.

These pressures are further intensified by climate-related stressors, including sea-level rise, ocean warming and ocean acidification. Together with human-made pressures, such stressor make it harder for ecosystems to recover and, in severe cases, causing entire coastal systems to fail.(He and Silliman, 2019; Hewitt et al., 2016). Against this backdrop, there is an urgent need for nature-based, scalable interventions that both mitigate ongoing degradation and enhance ecological recovery.

Artificial habitats are multifunctional structures that underpin a wide range of ecosystem services, such as food provision, habitat for marine life, and coastal protection, essential to integrated coastal management. By introducing hard, three-dimensional structures to seabeds, artificial reefs (ARs) can restore lost natural habitats or rehabilitate ecological functions in degraded areas, boost benthic colonisation, facilitate larval settlement, and provide shelter and foraging grounds for diverse taxa (Lemoine et al., 2019; Paxton et al., 2022). Well-designed AR installations enhance secondary production, augment fishery yields, and support recreational diving, scientific research, and other local economic activities, thereby delivering interconnected provisioning, regulating, and cultural benefits (Becker et al., 2018; Seaman, 2007).

Objectives

This document consolidates current evidence and practitioner experience into a practical, step-by-step framework for the **deployment and monitoring** of artificial reefs. It supports practitioners, regulators and other stakeholders in reconciling socio-economic gains with the conservation and rehabilitation of marine ecosystems.

The guideline focuses on:

1. Defining the problem and setting measurable objectives.
2. Selecting reef type, materials, dimensions and spatial layout on an evidence basis.
3. Implementing adaptive monitoring that links observed outcomes to the stated goals.
4. Ensuring full alignment with local regulations and stakeholder expectations.

Best practices for artificial reef design and deployment

1. Defining the problem and setting measurable objectives.

- **Identify the specific ecological or socio-economic issue** (e.g. habitat loss, fishery decline, mitigation of the benthic impact beneath aquaculture farms) that justifies the installation of an AR (Fariñas-Franco and Roberts, 2014; Folpp et al., 2020; Lima et al., 2020; Özgül et al., 2019; Seaman, 2007).
- Summarise existing pressures, baseline habitat condition and any legal or policy drivers.
- **Define SMART** (specific, measurable, achievable, relevant and time-bound) **objectives** (e.g. Achieve a 25% increase in the number of local species colonizing the artificial reef relative to a control site within 24 months (Cadier et al., 2020; Lima et al., 2020)).
- **Stakeholder scoping**: Localise and make a list of affected parties (fishers, local authorities, NGOs, researchers, tourism operators).

It is important to make a clear, documented statement of *why* an AR is needed, *what* it must achieve, and *how* success will be measured.

2. **Evidence-based design and deployment:** Prior to the placement of any module, a comprehensive understanding of the present seabed condition and of the proposed structure design is indispensable.
   - **Baseline data collection:** By collecting four core categories of baseline data, practitioners can subsequently determine whether the artificial reef induces measurable changes: bathymetry, sediment type, hydrodynamics, contaminant status, baseline biodiversity. Always check locally available datasets before commissioning new surveys.
   - **Design criteria:** specify the **target species** and functional groups, identify the level of structural complexity required, ensure durability and manageable maintenance, and justify every design choice with peer-reviewed performance data (Fabi et al., 2015; Lemoine et al., 2019; O'Shaughnessy et al., 2020).
   - **Construction materials:** another key consideration is the selection of **materials**, such as concrete mixes, recycled rock, polymers or biodegradable elements, in accordance with these criteria and relevant environmental guidelines (Talekar et al., 2024; Vivier et al., 2021).
   - **Spatial layout**: carefully plan the orientation of reef modules in relation to prevailing currents and adequate spacing between modules are essential (Fabi et al., 2015).

3. **Implementing adaptive monitoring that links observed outcomes to stated goals**

Prior to deployment, set up a monitoring scheme that is simple, measurable and can be adjusted as results emerge.

- **Define success criteria:** turn every project goal into at least one quantitative indicator, such as abundance, biomass or genetic-connectivity metrics (Cresson et al., 2014; Folpp et al., 2020; Lima et al., 2020). For example, a specific target could be to record ≥ 10 new macrofaunal species colonising the artificial reef within the first two years of deployment.
- **Baseline & BACI:** sampling "before" data at the reef site (Impact) and at a nearby, matched Reference site, then repeat at fixed intervals (e.g. each month; every 6 or every

12 months). The **BACI** design (**B**efore **A**fter **C**ontrol **I**mpact) isolates reef effects from wider environmental variability.

- **What is BACI and what is a *reference site*?** It is a sampling design that compares conditions at the reef site (Impact site) before and after installation with those at a nearby, unaffected site of similar depth and habitat (Reference site). If change is detected only at the Impact site, it can be attributed to the reef, if both sites change in parallel, the driver is likely a broader environmental event rather than the installation itself (Underwood, 1992).

- **Core indicators mapped to key ecological attributes**: choose one or two metrics per attribute, aligned with your objectives and resources (Cadier et al., 2020):

Attribute	Indicator´s examples
Absence of threats	Incidents of illegal trawling, invasive-species cover
Physical conditions	Turbidity (NTU), sedimentation rate (g m^{-2} day^{-1})
Species composition	Biodiversity index, abundance of target species
Ecosystem functionality	Trophic-level structure, benthic respiration (mmol O_2 m^{-2} h^{-1})
Ecosystem connectivity	Larval-settlement rate, acoustic tracking of key species

- **Sampling effort and frequency:** a minimum of three replicate transects per site/date is recommended. Survey quarterly in year 1, then once or twice per year. This balance aligns with European projects and keeps budgets realistic.

  Sampling method: Collect these with sonar surveys, diver/ROV transects, visual census, settlement plates, BRUV fish counts (Fabi et al., 2015)

- **Data management:** archive raw imagery and processed data in an open repository (e.g. EMODnet, Zenodo) to ensure transparency and permit meta-analysis across artificial structures.

4. Ensuring full alignment with local regulations and stakeholder expectations

- **Permit roadmap**: list competent authorities, legal references, typical timelines. Regulatory requirements and the time needed to secure them, vary markedly by jurisdiction. National, regional and even municipal authorities may each issue separate consents for artificial-reef deployment; applicants should therefore identify the competent bodies for their chosen location and build a timetable that reflects local procedures.
  In Galicia (NW Spain), for example, the project dossier must be submitted to the **Consellería do Mar** for installations in internal waters, whereas projects in external waters are authorised by the **Secretaría General de Pesca** (MAPA).
  - **Galicia (regional):** The official portal of the *Consellería do Mar*, where calls, procedures and contact details are published**:** https://mar.xunta.gal
  - **Spain (national)**: MAPA's dedicated page on artificial reefs, which summarises the legal framework (Ley 3/2001, RD 798/1995, technical guidelines) and provides

application templates for projects in external waters: https://www.mapa.gob.es/es/pesca/temas/proteccion-recursos-pesqueros/arrecifes-artificiales/marco-juridico

- **Stakeholder-engagement strategy:** combine public consultation (workshops, online portals, targeted interviews), conflict-resolution measures (e.g. zoning agreements with fishing co-operatives) and clear communication outputs (factsheets, press releases, citizen-science portals).

References

Becker, A., Taylor, M.D., Folpp, H., Lowry, M.B., 2018. Managing the development of artificial reef systems: The need for quantitative goals. Fish Fish. 19, 740–752. https://doi.org/10.1111/faf.12288

Cadier, C., Bayraktarov, E., Piccolo, R., Adame, M.F., 2020. Indicators of Coastal Wetlands Restoration Success: A Systematic Review. Front. Mar. Sci. 7, 600220. https://doi.org/10.3389/fmars.2020.600220

Cresson, P., Ruitton, S., Harmelin-Vivien, M., 2014. Artificial reefs do increase secondary biomass production: mechanisms evidenced by stable isotopes. Mar. Ecol. Prog. Ser. 509, 15–26. https://doi.org/10.3354/meps10866

De Andres, M., Muñoz, J., 2015. Analysis and trends of the world's coastal cities and agglomerations. Ocean Coast. Manag. 114, 11–20. https://doi.org/10.1016/j.ocecoaman.2015.06.004

Fabi, G., Scarcella, G., Spagnolo, A., Bortone, S.A., Charbonnel, E., Goutayer, J.J., Haddad, N., Lök, A., Trommelen, M., 2015. Practical guidelines for the use of artificial reefs in the Mediterranean and the Black Sea. Gen. Fish. Comm. Mediterr. Stud. Rev. I,III,IV,1-74.

Fariñas-Franco, J.M., Roberts, D., 2014. Early faunal successional patterns in artificial reefs used for restoration of impacted biogenic habitats. Hydrobiologia 727, 75–94. https://doi.org/10.1007/s10750-013-1788-y

Folpp, H.R., Schilling, H.T., Clark, G.F., Lowry, M.B., Maslen, B., Gregson, M., Suthers, I.M., 2020. Artificial reefs increase fish abundance in habitat-limited estuaries. J. Appl. Ecol. 57, 1752–1761. https://doi.org/10.1111/1365-2664.13666

He, Q., Silliman, B.R., 2019. Climate Change, Human Impacts, and Coastal Ecosystems in the Anthropocene. Curr. Biol. 29, R1021–R1035. https://doi.org/10.1016/j.cub.2019.08.042

Hewitt, J.E., Ellis, J.I., Thrush, S.F., 2016. Multiple stressors, nonlinear effects and the implications of climate change impacts on marine coastal ecosystems. Glob. Change Biol. 22, 2665–2675. https://doi.org/10.1111/gcb.13176

Lemoine, H.R., Paxton, A.B., Anisfeld, S.C., Rosemond, R.C., Peterson, C.H., 2019. Selecting the optimal artificial reefs to achieve fish habitat enhancement goals. Biol. Conserv. 238, 108200. https://doi.org/10.1016/j.biocon.2019.108200

Lima, J.S., Atalah, J., Sanchez-Jerez, P., Zalmon, I.R., 2020. Evaluating the performance and management of artificial reefs using artificial reef multimetric index (ARMI). Ocean Coast. Manag. 198, 105350. https://doi.org/10.1016/j.ocecoaman.2020.105350

Naylor, R.L., Hardy, R.W., Buschmann, A.H., Bush, S.R., Cao, L., Klinger, D.H., Little, D.C., Lubchenco, J., Shumway, S.E., Troell, M., 2021. A 20-year retrospective review of global aquaculture. Nature 591, 551–563. https://doi.org/10.1038/s41586-021-03308-6

O'Shaughnessy, K.A., Hawkins, S.J., Evans, A.J., Hanley, M.E., Lunt, P., Thompson, R.C., Francis, R.A., Hoggart, S.P.G., Moore, P.J., Iglesias, G., Simmonds, D., Ducker, J., Firth, L.B., 2020. Design catalogue for eco-engineering of coastal artificial structures: a multifunctional

approach for stakeholders and end-users. Urban Ecosyst. 23, 431–443. https://doi.org/10.1007/s11252-019-00924-z
Özgül, A., Lök, A., Tansel Tanrıkul, T., Alós, J., 2019. Home range and residency of Scorpaena porcus and Scorpaena scrofa in artificial reefs revealed by fine-scale acoustic tracking. Fish. Res. 210, 22–30. https://doi.org/10.1016/j.fishres.2018.10.008
Paxton, A.B., Steward, D.N., Harrison, Z.H., Taylor, J.C., 2022. Fitting ecological principles of artificial reefs into the ocean planning puzzle. Ecosphere 13, e3924. https://doi.org/10.1002/ecs2.3924
Seaman, W., 2007. Artificial habitats and the restoration of degraded marine ecosystems and fisheries. Hydrobiologia 580, 143–155. https://doi.org/10.1007/s10750-006-0457-9
Talekar, S., Barrow, C.J., Nguyen, H.C., Zolfagharian, A., Zare, S., Farjana, S.H., Macreadie, P.I., Ashraf, M., Trevathan-Tackett, S.M., 2024. Using waste biomass to produce 3D-printed artificial biodegradable structures for coastal ecosystem restoration. Sci. Total Environ. 925, 171728. https://doi.org/10.1016/j.scitotenv.2024.171728
Underwood, A.J., 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. J. Exp. Mar. Biol. Ecol. 161, 145–178. https://doi.org/10.1016/0022-0981(92)90094-q
Vivier, B., Dauvin, J.-C., Navon, M., Rusig, A.-M., Mussio, I., Orvain, F., Boutouil, M., Claquin, P., 2021. Marine artificial reefs, a meta-analysis of their design, objectives and effectiveness. Glob. Ecol. Conserv. 27, e01538. https://doi.org/10.1016/j.gecco.2021.e01538