

## **Coral reef restoration- a way forward to offset the coastal development impacts on Indian coral reefs.**

**Mandar Nanajkar<sup>1\*</sup>, Kalyan De<sup>1,2</sup>, Baban Ingole<sup>1</sup>**

<sup>1</sup>CSIR-National Institute of Oceanography, Dona Paula, Goa, India.

<sup>2</sup>Department of Marine Sciences, Goa University, Goa, India.

\*Email: mandar@nio.org

### **Highlights**

- Corals in India are stressed by increasing human perturbations and climate change.
- Studies and projections indicate shortfall in traditional conservation practices.
- Scientific restoration techniques to be employed to sustain coral reefs in India.
- Coral translocation can ameliorate possible dire impacts by coastal development.
- Financial commitments of reef restoration projects may be secured from the developer.

### **Abstract**

Globally, coral reefs are degrading rapidly due to the combined impact of wide-scale anthropogenic activities and climate change. Similarly, coral reefs in India are facing an existential threat because of intensified environmental degradation, which challenges reef ecosystem resilience and socio-ecological stability. Recently, Govt. of India has taken up the 'SagarMala Programme' aiming to increase its port capacity by the expansion of existing ports, construction of several new ports and allied infrastructure development by 2025. Synergistic impact of coastal development coupled with the on-going environmental changes is deemed to accelerate coral reef degradation in Indian reefs. Therefore, the present article aims to highlight the urgency of positive intervention and initiation of long-term holistic coral reef restoration program as an active reef management tool. Along with conventional management practices, reef restoration program could curtail further reef degradation and will ensure the persistence of Indian coral reefs and the services they provide.

**Keywords:** Coral reef, Sagarmala programme, ecological engineering, Coral transplantation.

India, the second-most populous country and world's seventh-largest economy, needs to sustain its fast-growing gross domestic production (GDP) to cater to its rising population and to fight poverty, therefore, the government has to rely on industrial development. However, this model of supply, demand and pressure for economic growth hampers the goals of 'sustainability principles', especially the United Nations Sustainable Development Goals (SDG) **13** ("Take urgent action to combat climate change and its impact"), **14** ("Conserve and sustainably use oceans, seas and marine resources for sustainable development") and **15** ("Protect restore and promote sustainable use of terrestrial ecosystem, sustainably manage forest, combat desertification, and halt and reverse land degradation and halt biodiversity loss") (United Nations, 2018). Nevertheless, in the current developmental model, the arms race between industrial development and the pace of collateral ecosystem damage, including global changes is a never-ending escalation. And this contest often ends up in a 'lose-lose' situation when the restoration of the impacted ecosystems is overlooked.

The bruising reality is that the anthropogenic global environmental changes and booming coastal developmental activities have battered the coral reefs worldwide since the past three decades, which are now facing the risk of extinction (Hughes et al. 2014, 2018; Camp et al. 2018). A most recent study revealed that the 'world's biologically diverse marine ecosystem' the Great Barrier Reef has lost about 50% of live corals (Lough et al., 2018) and similarly coral cover has declined by 80% in the Caribbean since the mid-1970s (Gardner et al., 2003). Likewise, coral reefs in India have been witnessing a worrisome degradation and facing local scale extinction threat due to concurrent coral bleaching events, increased disease prevalence, habitat destruction because of accelerated coastal development, pollution, sedimentation, overexploitation, macroalgal dominance, and natural calamities like tsunami (reviewed in De et al., 2017; Datta Majumdar et al. 2018). Moreover, the recent projection has predicted that if the greenhouse gas emission continues by 'business-as-usual scenario,' the global coral cover will further plummet by 70-90% by 2050 relative to their current abundance (Hoegh-Guldberg et al., 2018). Considering the magnitude of present-day perturbation on Indian reefs and the global projection, it can be assumed that coral reefs and reef dependent coastal population in India will suffer greater vulnerabilities and social-ecological uncertainties due to the proposed coastal development program. So, what can be the practical and realistic solution for the denuded and dying coral reefs in the context of developing nations like India? There is an emerging scientific view that immediate intervention using advanced restoration techniques coupled with pragmatic conservation approach is imperative to offset the degradation of this valuable ecosystem.

India has set a development plan to increase the Indian port capacity to 3500+ MMTPA by 2025 to cater to the growing traffic as 90% of India's trade is by maritime route (GOI, 2018). Recent studies

have provided striking evidence that the port activities and associated dredging operations pose a grave threat to corals due to exacerbated sedimentation and has resulted in mass coral mortality ranges from thousands to millions of coral colonies (reviewed in Erftemeijer et al. 2012; Cunning et al. 2019). A recent finding from Lakshadweep islands (Ravindran et al. 2014) revealed that even small-scale coastal development activity could result in significant coral mortality, habitat degradation, and increased vulnerability. Moreover, the ecological cost of these coastal development projects could far exceed the economic benefit accrued unless environmental sustainability policies sincerely implemented. However, impending expansion and construction of new infrastructure (port, jetty, bridge, roadways, dredging, drainage) in combination with ongoing climate change will continue to cause adverse impact to sensitive coral reef habitats along the Indian coastline especially on the West coast of India where many coral reefs are already damaged (Zacharia et al. 2008; Hussain et al. 2016 a, b; De et al., 2017). Considering the facts as mentioned above, we suggest the compensatory mitigation approach to curtail the unavoidable direct and indirect impact of this coastal developmental activity by restoration, relocation, and translocation of corals at identified suitable sites.

Although efforts are being made at different stakeholder level to study, conserve, and monitor corals which are already under legal protection, the question is 'is that enough?' Restorative activities at a similar pace must compensate for the speed of global change and industrial development; else, traditional conservation methods might fall short of the required efforts (Rinkevich, 2008). In several countries including India, restoration is mandatory for the terrestrial mining sites and compensatory plantation for development on forest land. Unfortunately, there is a lacuna in implementation strategies with co-ordinated positive intervention for the disappearing coral cover probably because the coral reefs do not fall under the purview of any lease or ownership. However, these sensitive and long-lived biotic communities should also receive the privilege of restoration as they are arguably the most important, diverse, and highly functional ecosystems, and disappearing at a rapid pace. Therefore, this alarming situation raises the critical question: if the mined-out areas can be re-vegetated, barren scrublands can be cultivated; lakes can be restored then can coral reefs be restored? And the answer is yes, the improved environmentally sound reef restoration tools, better management, and legislation can rejuvenate degraded coral habitats and develop new reef areas. Several studies have demonstrated that restoration of damaged and degraded coral reef is possible by employing different 'ecological engineering tools' like translocation and transplantation of whole coral colonies, setting up of coral nurseries, coral fragging or reef gardening, and deployment of artificial substrates for reef development (Rinkevich, 2015; see Horoszowski-Fridman et al. 2015 and references therein; Rachmilovitz, and Rinkevich, 2017).

Coral transplantation projects also resulted in enhance the coral cover, and concomitantly could buffer the mass coral mortality while re-establishing the functional communities and the ecosystem services (Rinkevich, 2015). Therefore, the viewpoint is that the incorporation, implementation, and prioritization of ‘ecological engineering’ approaches in mainstream coral reef conservation and management practices could result in tangible output rather than just monitoring the disappearance of coral cover in the wake of local and global stressors. Considering the ecological services, and economic reliance of coastal population on coral reefs in India (for example coral reefs contribute to 28 % of the total fish catch in India; Raghuraman et al. 2013), we suggest that identification of suitable sites for relocation and transplantation of live corals from a proposed coastal development site with monitored protection scheme could support the persistence of coral reefs in Indian water.

Nevertheless, it is always best to take a proactive route and start conditioning new habitats for revitalizing and recovering affected coral reefs (Rinkevich, 2015). Upon realization, many government agencies and stakeholders around the world have already made a mandate to translocate and transplant corals from an ineluctable industrial development site to a new location (Keenleyside et al. 2012; USCRTE, 2016). Experimental coral restoration programs in the Middle East Asia, Singapore, Philippines, Thailand, Israel, have been successful in the rehabilitation of corals and associated biodiversity within a short span, making it a functional and resilient ecosystem. Very few coral restoration experiments have been carried out in India although with some success (e.g., Kumar et al. 2017 in the Gulf of Kachchh), however, the active reef restoration approach is still in its nascent state. A successful coral restoration program at a large scale can have a positive regional impact on coastal protection, fisheries, tourism, and overall ecosystem services. Such programs can be efficiently executed through a sound scientific understanding of reef ecology, local hydrodynamics, seafloor morphology best suited for reef formation and the water column chemistry along with meticulous planning and pairing long-term monitoring of restored reef’s health, survival, and resilience. Even though such ventures are expensive, but certainly are more cost-effective than the consequences of not doing them. Nevertheless, cautious execution is to be warranted as some well-intentioned programs have also resulted in failure to accomplish desired outcome (Ferse et al., 2013) due to lack of scientific understanding, and un-solicitous planning.

Initiatives and participation from long-term beneficiaries and large corporate houses are required rather than just government agencies taking the burden to mitigate these irreversible losses. ‘Polluters pay’ principle applies here and strictly implementing this policy will generate funds for coral reef conservation and restoration while reducing a lot of stress on the state’s fiscal funds. The restoration activities can be accounted as corporate social/environmental responsibility and will serve ecological

justice. Hope this opens a conscious debate to reach a consensus within experts, corporates, policymakers, and managers in India as well as in other developing nations to set appropriate reef restoration targets considering their resources and indigenous capabilities.

## **Acknowledgments**

Authors are thankful to the Directors, CSIR-NIO for the facilities. KD acknowledge DST-INSPIRE fellowship and Fulbright-Kalam Climate fellowship for his doctoral program. We are grateful to the anonymous reviewers for their suggestions to improve this article. This is CSIR-NIO's contribution no: #####.

## **References**

1. Camp, E.F., Schoepf, V., Mumby, P.J., Hardtke, L.A., Rodolfo-Metalpa, R., Smith, D.J., Suggett, D.J., 2018. The future of coral reefs subject to rapid climate change: Lessons from natural extreme environments. *Front. Mar. Sci.* 5:4. <https://doi.org/10.3389/fmars.2018.00004>
2. Cunning, R., Silverstein, R., Barnes, B., Baker, A., 2019. Extensive coral mortality and critical habitat loss following dredging and their association with remotely-sensed sediment plumes. *Mar. Poll. Bull.* 145:185-199. <https://doi.org/10.1016/j.marpolbul.2019.05.027>
3. Datta Majumdar, S., Hazra, S., Giri, S., Chanda, A., Gupta, K., Mukhopadhyaya, A., S. Dam Roy, S., 2018. Threats to coral reef diversity of Andaman Islands, India: A review. *Reg. Stud. Mar. Sci.*, 24, 237-250. <https://doi.org/10.1016/j.rsma.2018.08.011>
4. De, K., Venkataraman, K., Ingole, B., 2017. Current status and scope of coral reef research in India: a bio-ecological perspective. *Ind. J. Geo-Mar. Sci.* 46:647-662
5. Erftemeijer, P.L.A., Riegl, B., Bert W. Hoeksema, B.W., Todd, P.A., 2012. Environmental impacts of dredging and other sediment disturbances on corals: A review. *Mar. Poll. Bull.* 64 (2012) 1737–1765. <http://dx.doi.org/10.1016/j.marpolbul.2012.05.008>
6. Ferse, S.C.A., Nugues, M.M., Romatzki, S.B.C., Kunzmann, A., 2013. Examining the use of mass transplantation of brooding and spawning corals to support natural coral recruitment in Sulawesi/Indonesia. *Restoration Ecol.* 21(6):745-754. <https://doi.org/10.1111/rec.12004>
7. Gardner, T.A., Côté, I.M., Gill, J.A., Grant, A., Watkinson, A.R., 2003. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. *Science* 265(5178): 1547–1551. <https://doi.org/10.1126/science.265.5178.1547><https://doi.org/10.1126/science.265.5178.1547>
8. GOI 2018. About Sagarmala. Retrieved from Sagarmala: <http://sagarmala.gov.in/about-sagarmala/vision>.
9. Hoegh-Guldberg, O., Kennedy, E.V., Beyer, H.L., McClennen, C., Possingham, H.P., 2018. Securing a long-term future for coral reefs. *Trends Ecol. Evol.* 33(12):936–944. <https://doi.org/10.1016/J.TREE.2018.09.006><https://doi.org/10.1016/J.TREE.2018.09.006>

10. Horoszowski-Fridman, Y., Brêthes, J., Rahmani, N., Rinkevich, B., 2015. Marine silviculture: Incorporating ecosystem engineering properties into reef restoration acts. *Ecol. Eng.* 82:201-213. <https://doi.org/10.1016/j.ecoleng.2015.04.104>
11. Hughes, T. P., Anderson, K.D., Connolly, S.R., Heron, S.F., Kerry, J.T., Lough, J.M., Baird, A.H., Baum, J.K., Berumen, M.L., Bridge, T.C., Claar, D.C., Eakin, M.C., Gilmour, J.P., Graham, N.A.J., Harrison, H., Hobbs, J.P.A., Hoey, A.S., Hoogenboom, M., Lowe, R.J., McCulloch, M.T., Pandolfi, J.M., Pratchett, M., Schoepf, V., Torda, G., Wilson, S.K., 2018. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science*. 359, 80–83.
12. Hughes, T.P., Bellwood, D.R., Connolly, S.R., Cornell, H.V., Karlson, R.H., 2014. Double jeopardy and global extinction risk in corals and reef fishes. *Curr. Biol.* 24, 2946-2951. <http://dx.doi.org/10.1016/j.cub.2014.10.037>
13. Hussain, A., De, K., Thomas, L., Nagesh, R., Mote, S., Ingole, B.S., 2016a. Prevalence of skeletal tissue growth anomalies in Scleractinian coral: *Turbinaria mesenterina* of Malvan Marine Sanctuary, Eastern Arabian Sea. *Dis. Aquat. Org.* <https://doi.org/10.3354/dao03038>
14. Hussain, A., Thomas, L., Nagesh, R., Mote, S., Patil, A., Pujari, L., De, K., Ingole, B., 2016b. Coral reef at risk: Anthropogenic stressors in Grande Island, Goa. Proceeding of the National seminar on approaches to clean and sustainable development in coastal zones of India- Present status and future need. At CSIR-National Institute of Oceanography, Mumbai. <https://doi.org/10.13140/RG.2.2.34478.51527>
15. Keenleyside, K.A., Dudley, N., Cairns, S., Hall, C.M., Stolton, S., 2012. Ecological restoration for protected areas: Principles, guidelines and best practices. Gland, Switzerland: IUCN.
16. Kumar, J.S.Y., Satyanarayana, C., Venkataraman, K., Beleem, I.B., Arun, G., Chandran, R., Ramkumar, K., Kamboj, R.D., 2017. Coral reefs transplantation and restoration experience in Pirotan Island, Marine National Park, Gulf of Kachchh, India. *Ind. J. Mar. Sci.* 46(02):299-303.
17. Lough, J.M., Anderson, K.D., Hughes, T.P., 2018. Increasing thermal stress for tropical coral reefs: 1871–2017. *Sci. Rep.* 8(1): 6079. <https://doi.org/10.1038/s41598-018-24530-9>
18. Rachmilovitz, E.N., Rinkevich, B., 2017. Tiling the reef – exploring the first step of an ecological engineering tool that may promote phase-shift reversals in coral reefs. *Ecol. Eng.* 105:150-161. <https://doi.org/10.1016/j.ecoleng.2017.04.038>
19. Raghuraman, R., Raghunathan, C., Venkataraman, K., 2013. Present Status of Coral Reefs in India. In *Ecology and conservation of tropical marine faunal communities* (Eds. Venkataraman, K., Sivaperuman, C., Raghunathan, C.). Springer, Berlin. pp 351-379. <https://doi.org/10.1007/978-3-642-38200-0>
20. Ravindran, J., Manikandan, B., Venkatesh, M., Mani Murali, R., Marimuthu, N., Wafar, M.V.M., 2004. Repercussions of embarkation wharves in Lakshadweep Islands on coral communities and their ecology. *Ind. J. Mar. Sci.* 43(7):1391-1400.

21. Rinkevich, B., 2008. Management of coral reefs: We have gone wrong when neglecting active reef restoration. *Mar. Poll. Bull.* 56:1821–1824. <https://doi.org/doi:10.1016/j.marpolbul.2008.08.014>
22. Rinkevich, B., 2015. Climate change and active reef restoration-ways of constructing the “Reefs of Tomorrow”. *J. Mar. Sci. Eng.* 3: 111-127. <https://doi.org/doi:10.3390/jmse3010111>
23. United Nations 2018. Sustainable Development Goals. Accessed from: <https://www.un.org/sustainabledevelopment/sustainable-development-goals/> on 06.06.2019.
24. USCRTF 2016. Handbook on coral reef impacts: Avoidance, minimization, compensatory mitigation, and restoration. Accessed from [https://www.epa.gov/sites/production/files/2017-02/documents/mitigation\\_handbook\\_final\\_full\\_featured.pdf](https://www.epa.gov/sites/production/files/2017-02/documents/mitigation_handbook_final_full_featured.pdf) on 25/07/2019
25. Zacharia, P.U., Krishnakumar, P.K., Dineshababu, A.P., Vijayakumaran, K., Rohit, P., Thomas, S., Sasikumar, G., Kaladharan, P., Durgekar, R.N., Mohamed, K.S., 2008. Species assemblage in the coral reef ecosystem of Netrani Island off Karnataka along the southwest coast of India. *J. Mar. Biol. Ass. Ind.* 50(1), 87- 97.



new site near Musandam in the Sea of Oman during March 2014 (Photo: Mandar Nanajkar Monitored corals (tagged) showed 100% survival success after one month of mass translocation at a).