NOTE
BRAZILIAN JOURNAL OF OCEANOGRAPHY, 61(1):77-81, 2013

ARTIFICIAL REEFS: FROM ECOLOGICAL PROCESSES TO FISHING ENHANCEMENT TOOLS

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Descriptors: Artificial reef functioning; Habitat quality, Chemical-physical and biological processes, Reef production.
Descritores: Funcionamento dos recifes artificiais; Qualidade de habitat; Processos físicos, Químicos e biológicos, Produtividade dos recifes.

Polovina published the article *"Artificial reefs: nothing more than benthic fish attractors"* in 1990 and in it debated the potential for artificial reefs to substantially increase standing stock of marine resources. Artificial Reef (AR) technology was strictly oriented towards improving commercial fishing (STONE et al., 1991) from the 1930s, when the Japanese government invested in large scale artificial reefs, until the 1990´s. The first three International Conferences on Artificial Reefs and Related Aquatic Habitats (CARAH) focused on the improvement of fisheries around the world (SEAMAN; SPRAGUE, 1991; GROVE; WILSON, 1994). However, over the last twenty years, the expansion and diversification of AR use has resulted in a shift in the focus of AR-based research towards a more ecosystematic approach (largely due to advances in SCUBA), focusing on a better understanding of the AR's ecological function and its effect on marine benthic and fish communities (JENSEN, 2002; BORTONE et al., 2011).

Questions concerning the AR's function address the interactions between the artificial and natural environments, and understanding how benthic and fish species (mostly commercial species) benefit from the presence of artificial habitats. Production at higher trophic levels (usually of commercial species) normally depends on production at lower levels (bottom-up control). Production levels can be modulated by physical forcing and the structure of the marine food webs (top-down control), with environmental constraints determining the community structure of the fauna and flora (SNELGROVE; BUTMAN, 1994). Physical factors (e.g. currents) and chemical bottom sediment components (in particular phosphorous) are therefore vital for reef production. An alternative approach for assessing the ecological implications of reef structures is the use of a bottom-up approach, i.e. assessing the role of ARs in enhancing primary production and energy transfer to the lower trophic levels of the benthic food web. ARs are normally deployed in areas where sandy habitats predominate. The presence of these man-made reef structures will affect: i) nearby sandy areas and also ii) water column processes in the vicinity of ARs. Habitat linkages among distinct reef compartments are driven by hydrological processes (changes in water flow patterns), sediment type, geomorphological, chemical-physical and biological processes (FABI et al., 2002; KIRKE, 2003; DEDIEU et al., 2007; FALCÃO et al., 2007, 2009) and also biotic processes (YANAGI; NAKAJIMA, 1991; LINDQUIST et al., 1994; PEPE et al., 1998; SHENG, 2000; DALE; PREGO, 2002; WILLIAMS; POLUNIN, 2001; FABI et al. 2006; EINBINDER et al., 2006). AR structures can affect biological processes differently within different reef compartments. The understanding of the different mechanisms behind these processes is essential for evaluating community responses to man-made perturbations, including fishing.

ARs are known to affect nearby sandy benthic sediments and their communities (BULLERI, 2005). When an AR obstructs current flow, a lee wave or stationary wave is formed, which can trap drifting larvae and seaweeds (SHENG, 2000). Moreover, fish attracted to ARs can significantly increase nutrient production in the water column - by excreting ammonium, urea and faeces - which is then incorporated into the reef food web. This process contributes to the organic enrichment of sediments due to entrapped drift algae and other organic materials driven from reef biological activities and deaths of reef associated organisms. Deposition of biomass in the lee of the reefs favours benthic remineralization, promoting nutrient regeneration in pore water (FABI et al., 2002; DEDIEU et al., 2007). Sediment nutrient enhancement from deposited organic material can be incorporated into the reef food web, enhancing sandy benthic production which contributes to the rehabilitation of sandy coastal areas via sediment chemical trophic chain pull-out (FALCÃO et al., 2007, 2009). The biochemical role of ARs in this respect is particularly important in shallow coastal areas (less than 50 m deep), where productivity in the overlying water column is heavily reliant on the sediment system, with up to 80% of phytoplanktonic nitrogen requirements coming from bacterial regeneration of organic matter within the seabed (DALE; PREGO, 2002). However, few studies have quantified how this primary production is transformed into meiofaunal and macrofaunal productivity, e.g. biomass or abundance (SOYER, 1985; DANOVARO, 1996; FABI et al., 2002). Nevertheless, sandy benthic communities have an important role in coastal food webs since they are an important food/energy source and a crucial link between lower and higher trophic levels (DALE; PREGO, 2002), such as commercial fish feeding on benthic ARs resources (LINDQUIST et al., 1994; PEPE et al., 1998; FABI et al., 2006).

ARs deployed on the bottom in coastal areas can also act as physical barriers, inducing changes in bottom current intensity and direction, water flow and turbulence patterns (SHENG 2000). This promotes upwelling (YANAGI; NAKAJIMA, 1991; KIRKE, 2003; MARUYAMA, 2004), bringing nutrient rich AR bottom benthic waters (compared to control areas, see: HAROUN et al., 1994; AMBROSE; ANDERSON, 1990; FALCÃO et al., 2007, 2009) into the water column, thereby enhancing biological production (RELINI et al., 1994; PERKOL-FINKEL; BENAYAHU, 2005). Planktonic community development in the areas surrounding ARs has been found to be in accordance with nutrients (ammonium, organic nitrogen) and particulate organic matter (POM) time evolution series (YANAGI; NAKAJIMA, 1991; FALCÃO et al., 2007, 2009). There is also evidence suggesting that increased phytoplankton production and diversity promote microzooplankton diversity (HUTCHINSON, 1961). Thus, AR rich bottom-up pulses can directly influence phytoplanktonic growth and diversity which can act as a trigger for increasing zooplanktonic assemblage diversity. Several studies (LEITÃO et al., 2008b; SANTOS et al., 2011b) advocate that demersal filter-feeding species, such as juvenile *Boops boops*, *Pagellus acarne*, *Trachurus trachurus* and *Scomber japonicus* (DOMANEVSKAYA; PATOKINA, 1984; CABRAL; MURTA, 2002; SANTIC et al., 2005) directly benefit from the demersal/pelagic zooplankton production in the water column due to the presence of ARs (DONALDSON; CLAVIJO, 1994; RELINI et al., 2002). This phenomenon is of particular importance to young-of-the-year juvenile demersal commercial species, providing a trophic energy link between secondary production and commercial and recreational species at higher trophic levels (LEITÃO et al., 2008b; LEITÃO et al., 2009).

In addition, it is important to understand the value of artificial habitats *per se*, that is as ecological promoters of marine life. The hard substrate of AR provides a solid surface and recruitment habitat for the settlement of larvae of marine plants and animals that would otherwise be lost from the population. This contributes to the creation of new feeding areas, increasing trophic efficiency (BOMBACE, 1989) in areas that formerly had sandy bottoms with low levels of productivity (LEEWIS et al., 1997; STEIMLE et al., 2002). Consequently, due to fish-ARs trophic transference, AR benthic fauna will contribute to an overall increase in fish biomass LINDQUIST et al., 1994; PEPE et al., 1998; WILLIAMS; POLUNIN, 2001; EINBINDER et al., 2006; LEITÃO et al., 2007). In summary, the physical presence of ARs promotes biological colonisation and enhances species richness in local ecological niches and food webs (RELINI et al., 1994; SNELGROVE; BUTMAN, 1994) by increasing biotic and abiotic habitat complexity (AMBROSE; ANDERSON, 1990; BULLERI, 2005), productivity and diversity on a local scale (STEIMLE et al., 2002).

It is recognised that mechanisms for increasing fish production also provide additional food (BOMBACE, 1989; RELINI et al., 2002) and that documenting food web relationships (from biochemical evidence of energy transfer from the lower sections to the upper apex of the AR trophic chain) could demonstrate the potential of ARs to increase production and consequently enhance coastal fisheries. However, AR fish production is species-specific. That is, fish species that do not benefit directly from ARs' trophic production could still benefit from the other ecological functions provided by the presence of the reef, such as shelter against currents or predators, spawning structures, and possible mating areas. For instance, fish species' ontogeny might provide access to ARs for food or shelter, but grown adult fish may still use reef structures to spawn, feed or as refuges (LEITÃO et al., 2007, 2009). A synergy of AR uses (feeding, growth) or a single use (spawning) by fish might be detrimental for the local population's scale enhancement.

ARs and their deployment can, in an oversimplified stock assessment management approach, be regarded as fishing production units. Several studies have shown that AR areas have larger fishing catches (yields) and economic incomes than do natural control areas (FABI; FIORENTINI, 1994; SANTOS; MONTEIRO, 1998; WHITMARSH et al., 2008; BORTONE et al., 2011). Nevertheless, the experimental design of many of these studies has been criticized, because, for example, of the lack of before deployment reference conditions (BRICKHILL et al., 2005). Independent of the attraction-production controversy surrounding ARs, much AR focused research does not recognize the fundamental ecological importance of AR benthic habitats as high quality habitats (LEITÃO et al., 2007; SANTOS et al., 2011a,b) and that scientists should recognise the intrinsic value of the habitat *per se* and identify the types of habitat used by fish species.

Fisheries biologists need to recognise that increases in catches due to services provided by reefs will depend on species-specific biological life cycles, fish adaptation to the reef environment and to fishing/exploitation strategies rather than on evaluating fishes associated with artificial reefs using novel approaches (BRICKHILL et al., 2005; BAINE, 2001; WHITMARSH et al., 2008; BORTONE et al., 2011). The lack of a suitable area with a full complement of habitats and structural complexity in the sandy fishing grounds off southern Portugal was the justification for the establishment of ARs, that might provide at least some of the necessary habitat requirements for future implementation of marine protected areas in the region (LEITÃO et al., 2009) due to their accepted role in the ecology of marine life and habitat fish quality (SANTOS et al., 2011a,b). Consequently, increases in fish catches cannot be regarded only in terms of quantification of the catches, but must also evaluate the biological and ecological value of ARs for fish assemblages. This requires the identification of habitat use by target species, fish-AR relationships (e.g. spawning, feeding and attraction), in order to predict long-term fishery enhancement measures. Increased exploitable fishery biomass depends on recruitment and fish growth which influences the sustainable catch that can be taken from a stock (KING, 1995). Hence, ARs provide the necessary habitats for the biological cycle of marine fish populations and have been recently classified as Essential Fish Habitats (see LEITÃO et al., 2009), defined as substrates necessary for fish for spawning, feeding or growth to maturity by Benaka (1999); ARs also have an indirect role in fishing enhancement by increasing environment quality (multi-use reefs). For example, the production of filtering organisms such as mussels to clean offshore fish production structures (ANTSULEVICH et al., 2000), is economically profitable and recycles nutrients in the marine environment. An important argument that highlights the necessity of conservation of high quality habitats such as ARs, is the recognition of the value of different habitats for determining management strategies for exploited fish assemblages, via awareness of reef ecological processes such as the role of coastal habitats in order to advance fisheries enhancement due to ARs.

ACKNOWLEDGEMENTS

I would like to acknowledge Samantha Hughes' (researcher at UTAD/CITAB) comments on and editing of parts of this study, as they improved its quality considerably.

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(Manuscript received 02 October 2012; revised 16 February 2012; accepted 05 March 2013)