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Transition of artificial reefs (ARs) research and its prospects

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ABSTRACT

This literature review encompasses more than one-hundred and sixty worldwide studies on artificial reefs (ARs) in terms of their design, application, performance and management. Over the past three decades, research on ARs has increased remarkably, suggesting an increase in social and economic aspects of ARs. The scope of AR research has largely expanded from early AR design and deployment to improve fisheries to various additional purposes. In particular, recent research on ARs has had a tendency to focus on variations in the community structure or composition of ARs, suggesting that the purpose of AR research has shifted from improving fisheries as a resource to rehabilitation of marine ecosystems. Most countries are expected to make active use of AR functions, even if the objective of deployment might be different for each case. Consequently, AR research will most likely expand and evolve to span multiple purposes in the future.

1. Introduction

Artificial reefs (ARs) are structures constructed at sea to attract and concentrate fish and to potentially improve and rehabilitate coastal ecosystems (Pickering, 1996). Today, ARs are being constructed in coastal areas around the world for various purposes, including to improve fishery production and management, preserve biodiversity, rehabilitate habitats, create sea afforestation, protect habitats, mariculture, prevent illegal fishing, sports such as diving, recreational fishing, coastline protection, and tourism.

The first record of ARs being used by humans is in Japan. Ogawa (1968) described a warrior who had made a fishing ground at sea using stones from a mountain in Kochi Prefecture in the 1640s. Another record describes an angler in Awaji province in 1795 who had caught a yellow-spotted grunt with a net in a sunken ship (Pickering, 1996). In 1916, Japan started to use scrapped naval ships as ARs, and by 1952, a 5-year plan was introduced to assist in the construction of reefs built with concrete blocks. Japan is still attempting to maximize fishing efficiency by providing habitats, spawning areas, and shelters based on special AR designs. From this point of view, Japan is considered to be a world leader in the field of AR design and deployment (Ito, 2011; Lee et al., 2017).

The first record of AR use in the USA appears to be in the 1880s, when anglers used long huts sunken off the coast of South Carolina as a fishing reef. Sunken vessels were also used for recreational fishing in 1935 off the coast of New Jersey, and designed ARs were first constructed in the Gulf of Mexico in 1954. In 1958, the California Department of Fish and Game started a pilot study monitoring ARs off the coast of Southern California (Stone et al., 1991).

In Europe, ARs have been mainly utilized around the Mediterranean Sea, with AR experiments beginning in France in the 1960s on the coast of the Mediterranean. A test development of an AR system was initiated in Portugal in 1989 (Santos and Monteiro, 1997). ARs were also implemented in Australia in Port Phillip Bay in 1965 (Sutton and Bushnell, 2007), China in Penghu Bay in 1974 (Chen et al., 2013), and Korea in 1971 (Lee et al., 2017). In Eastern Asia, ARs projects have not been fully developed, but some countries have promoted AR installation as national projects, such as Cambodia in 1991, Malaysia in 1975, the Philippines in 1981, Singapore in the late 1980s, and Thailand in the 1970s (Lee et al., 2016).

Regarding the materials used in ARs, stones, rocks, riprap or wood, trees, and bamboo stalks were mainly used in early AR development, but now concrete has become a major AR material. In addition, fish aggregating devices (FADs), offshore platforms, tires, stabilized ash waste, plastics, PVC, vessels, barges, shipwrecks, breakwaters, coastal structures, steel, metal, rope, netting, automobiles, train, cars, and oyster shells are being used as AR materials (Grove and Sonu, 1991; Baine, 2001; Lee et al., 2016).

The history of AR development and their use cases can differ somewhat among countries, so we hypothesized that the themes or objectives of AR projects among countries would also differ and that the main issues pertaining to AR research would change over time. We reviewed AR research over the past three decades to investigate our hypothesis and attempted to understand the characteristics of AR

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research in each country with respect to their themes. Finally, we state the prospects for AR research in the future.

2. Materials and methods

First, we define ARs as all types of structures deployed at sea by humans to attract fish or to create sea afforestation. Thus, ARs include FADs, artificial habitats, artificial substrates, artificial structures such as groynes, breakwaters, seawalls, marina facilities, surf reefs, sills, wrecked or sunken ships, wind farm foundations, wave energy devices, recycling oil/gas development rigs, tires, and etc. Based on this definition, we reviewed twenty-six studies of AR research presented at international conferences such as the (5th World Council of Fisheries Societies, 2008), symposiums (Stone et al., 1991; Nakamura et al., 1991), and workshops (Seaman, 2001), as well as in reports including those issued by the National Research Institute of Fisheries Engineering, Japan, http://nrife.fra.affrc.go.jp and in books (Seaman, 2000; Bortone et al., 2011) published from 1991 to 2015. In addition, we reviewed one-hundred and forty Science Citation Index (SCI) articles on ARs issued for twenty years from 1996 to 2017 (for example Science Direct papers published by Elsevier), while excluding articles on coral reefs because these are present in limited areas. Based on a review of these papers, we examined the transition of AR research and describe the prospects of AR research in the future.

3. Results and discussions

3.1. Variation of the number of ARs research papers

Fig. 1 presents the number of research papers on AR issued each year. We noticed that AR research remarkably increased over the past two to three years, and this reflects an increased demand for ARs. In addition, for the past thirty years, papers on ARs have been presented in 25 countries, with the majority in the USA (nineteen). China and Australia followed the USA with ten papers each. Beside, Portugal, UK, Japan, Brazil, France, Taiwan, Korea, and Italy have presented more than six papers. However, Belgium, Germany, Spain, Netherland, and Sweden presented only one to three papers, in contrast with other EU countries such as Portugal, UK, France, and Italy.

According to the number of papers that have been published in each country each year, the USA has continuously published the most while the number of papers published in Japan has decreased, particularly in a few recent years. In contrast, the number of papers on ARs published in China, Korea, Brazil, and Australia appear to have increased, implying that these countries are actively implementing AR projects.

Grove and Sonu (1991) examined publications (papers or abstracts) presented at international conferences on ARs in 1974, 1983, 1987, and 1991. They found that conferences were attended in only four countries

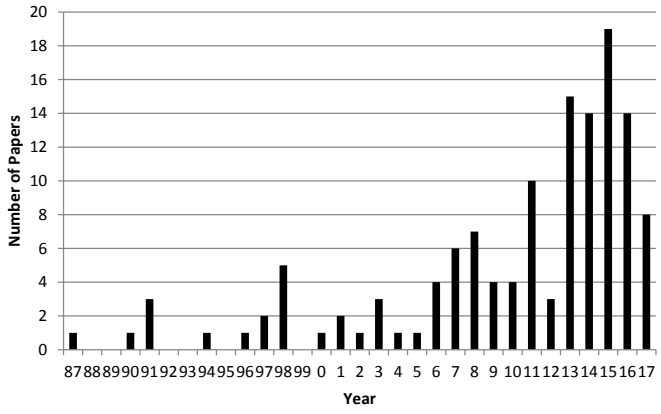

Fig. 1. Number of ARs research papers issued each year.

in 1974, but were attended in twenty-five countries in 1991. Moreover, the 328 total presentations were accumulated during the four conferences (118 outside of the USA). Baine (2001) also conducted a comprehensive review on abstracts form 249 studies related to the design, application, management, and performance of ARs. According to his results, the geographical distribution of the abstracts that were reviewed revealed that 38% of papers were presented in North America (the majority of which are from the USA), while 29% and 18% had been presented in Europe and Asia (the majority of which are from Japan), respectively. He also evaluated the degree to which ARs meet the objectives for their deployment in terms of a reef performance scale that he developed. He found that only two of thirty case studies appeared to successfully meet all objectives. In particular, fisheries ecology and management appeared to be a general theme during his investigation.

In contrast, the present survey shows that in a total of 136 reviewed papers as of 2017, 22% were presented in the USA while 32%, 29%, and 10% were presented in Europe, Asia, and Australia, respectively. Thus, we conclude that the number of AR research papers presented in the USA relatively decreased while those in Europe and Asia (in particular, Far East such as China, Japan, Korea, and Taiwan) increased significantly, suggesting that these countries develop and make diverse uses of AR from socio-economic and ecological aspects. Moreover, AR research today seems to be more globally widespread, including in Australia, Brazil, and India compared to the past. This also suggests that people in more countries are now aware of the positive effects of ARs.

On the other hand, it is not clear when island nations, for example, such as Jamaica, Kiribati, Tuvalu, Marshall islands, Hawaii and Maldives in the Caribbean, Pacific and Indian Oceans started AR projects. For example, Jamaica, an island nation in the Caribbean, started AR construction since 1973 using motor vehicles tyres (Haughton and Aiken, 1989). These island nations are geologically located at the same tropical or subtropical zones as Southeast Asian countries such as Malaysia, Cambodia, the Philippines, Thailand and Singapore. Accordingly, ARs seem to be comprised of similar materials such as tyres, wood, bamboo, aging ships and old motor vehicles, and even concrete recently (Pickering et al., 1998). However, their ARs contrast with decommissioned oil and gas development rigs, so-called rigs-to-reefs, as seen in the USA and Europe (Wright et al., 1998; Kaiser, 2006), eco-friendly-reefs (Pickering, 1996; Vose and Nelson, 1998; Cuadrado et al., 2015; Sawyer et al., 2015), and high-rise steel reefs in Japan as well as in Korea (Lee et al., 2016, 2017).

However, the most important issue distinguishing these island nations from other countries, such as the USA, Europe and Asia, are coastal erosion and the loss of coral reef ecosystems due to rising sea levels. Of course, although coastal erosion occurs not only in these island nations but also all around the world, these island nations suffer more seriously. For example, in Kiribati, an artificial island was proposed to cope with rising sea levels (Lister and Ema, 2015). In addition, rapidly subsiding margins in Hawaii have been investigated to understand the morphology of drowned reefs due to a rise in sea level (Faichney et al., 2009).

3.2. Transition of AR research themes

Table 1 indicates all of the themes that have been addressed in AR research for the last three decades. Most ARs have been installed with a secondary objective along with a major objective, so it is not easy to clearly distinguish themes from one to the next. Here we have clarify the themes of AR research in terms of their primary deployment. For convenience, we divided the period of AR research into three phases: the first in 1987–1997, the second in 1998–2007, and the third in 2008–2017 as themes have become diverse and the number of papers has also increased remarkably over time.

3.2.1. Reef materials of ARs

Three papers of eight explored AR materials in the first phase while