Ocean & Coastal Management 128 (2016) 1–9

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Ecological rehabilitation prediction of enhanced key-food-web offshore restoration technique by wall roughening

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ARTICLE INFO

Article history:
Received 26 January 2015
Received in revised form
8 April 2016
Accepted 14 April 2016
Available online 23 April 2016

Keywords:
Ecological restoration
Artificial reefs
Hard slope roughing
Ecopath model
Ocean health index

ABSTRACT

The enhanced key-food-web offshore restoration technique by wall roughening is proposed in this approach. Three kinds of wall roughening, i.e. artificial reefs, hard slope roughing and the integration of artificial reefs and hard slope roughing are applied to enhance the original key-food-web offshore restoration technique. The effects of ecological rehabilitation of the proposed enhanced key-food-web offshore restoration technique are predicted by the models of Ecopath model and ocean health index. The results indicate that the ecological rehabilitation of the enhanced key-food-web offshore restoration technique with different wall roughening is better than that of the original one. Among them, the enhanced key-food-web offshore restoration technique with the integration of artificial reefs and hard slope roughing is the best. After using it, the restored offshore ecosystem is the most mature, and the ocean health index is increased to 87.1 or 87.3 with respect to the case of 2% or 0.57% artificial reef for the conservative or optimistic analysis.

1. Introduction

Marine ecosystem is one of the most valuable human resources supplying a variety of benefit and servicing for human and other species (Shi et al., 2008). However, with expanding industrialization and urbanization such as wanton discharge of sewage from plants have caused water resources deterioration along vast coastline since late 1950s, and consequently marine ecosystems have been destroyed and degraded seriously (Chen and Uitto, 2003; Chen et al., 2012; Sun et al., 2013). The inshore ecosystem of Bohai Bay is no exception, and it is one of China's most pollution waters (Zhou et al., 2012). Therefore, it is urgent and significant to mitigate the degradation of Bohai Bay inshore ecosystem and make its structure and function recovered.

Previous ecological restoration methods are primarily classified into two categories. One is mainly ecological environment restoration, such as shoreline design technique, hard slope roughing (Moschella et al., 2005) and artificial reefs technique (Pitcher et al., 2002), to construct biological habitat and improve biotic living environment. These techniques contribute to an increment in the maturity of degraded ecosystem gradually. The other is biological population restoration, such as the quantitative biological food web proliferation technique (Zheng and You, 2014) and alien species introduction technique (Borsje et al., 2011), to enhance marine bioresource and food web. These techniques help the restoration ecosystem achieve ecological balance and stability. However, these ecological restoration techniques only focus on one aspect of improving the biotic living environment or enhancing marine bioresource and food web. In this paper, the original key food web technique is further enhanced by introducing wall surface roughening, which is an integration of increasing both biotic living environment and the species richness in restoration. The proposed method is benefit of both biotic living environment and species richness to improve the maturity and health of ecosystem comprehensively.

The key food web technique is to rebuild the key food web of restoration ecosystem by quantifying the trophic relationships of screening key species from the reference ecosystem. It is an effective restoration method, which avoids the risk of alien species invasion. The wall surface roughening technique is to increase roughness of onshore walls or revetments through engineering methods to provide artificial habitats for species spawning and feeding, similarly, to improve associated biota and water quality. Wall surface roughening is artificial reefs (ARs), hard slope

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http://dx.doi.org/10.1016/j.ocecoaman.2016.04.008
0964-5691/

roughing (HSR) and the integration of artificial reefs and hard slope roughing (ARHSR).

ARs are underwater structures which are deployed in underwater intentionally to imitate the features of natural reefs (Baine, 2001). The initial purpose of ARs is commercial fishing. With the pollution and degeneration of marine ecosystem, ARs has become been an important technique to rehabilitate degraded habitats and rich marine resources (Woo et al., 2014). ARs have achieved positive effect in restoring and rebuilding marine ecosystem (Rilov and Benayahu, 2000). ARs influences the environment over a spatial scale of tens to hundreds meters near the reef (Wilding and Sayer, 2002). The influences are the variations in nutrient cycling and transport (Falcao et al., 2007; Vicente et al., 2008) and sediment biogeochemistry (Alongi et al., 2008). This lead to the changes in the structures and richness of associated infaunal organisms (Langlois et al., 2006).

HSR is used to increase surface roughness through engineering methods. Roughness is peak-valley geometric shapes on offshore slope surface. Roughness is also important for sediment dynamics (Guillén et al., 2008). Rough surface performs as a wave dissipater to reduce the impacts on building infrastructure, and provides refuges for epibiotic species similarly (Nordstrom, 2014). HSR is obtained by engineering methods of making surface unevenness and planting vegetation on offshore slopes. The hybrid approach of combining unevenness or porous structure with ecological revetment is becoming popular.

In this study, three wall surface roughening techniques (ARs, HSR and ARHSR) are applied to enhance the restoration effect of key food web technique. The Ecopath model and ocean health index are used to analysis the maturity and health of the restoration ecosystem, respectively. The restoration effect and technical feasibility of the proposed enhanced technique is evaluated in the restoration of inshore marine ecosystem.

2. Method

2.1. Study site and data sources

The restoration project is a part of a covered harbor, which is located at the first harbor of Tianjin Lin Gang Economic Zone (38°34′–40°15′N, 116°43′–118°04′E) of China (Fig. 1). The restored area is about 5 m in depth and 200 m along the shoreline and 60 m away from the land in horizontal plane.

The key food web technique enhanced by ARs, HSR and ARHSR is applied to restore the inshore marine ecosystem. Besides applying the ecological key food web restoration technique, the wall surface roughening techniques are also adopted to improve biological habitats. The data sources, functional groups assigned and the parameters of functional groups are obtained from the study of Zheng and You (2014).

2.2. Key food web

The Bohai ecosystem of 1982 less disturbed by the human is taken as the reference ecosystem. The key food web technique is to rebuild food web of restoration area by quantifying the trophic relationships of screening key species of the reference ecosystem. Based on the screening species principles, the screening species of the target ecosystem is obtained. For our case, the key food web composes of 13 functional groups and the species of each functional group have similar habitats and diets (Zheng and You, 2014). In this system, the producer is Phytoplankton. The grazers are Zooplankton, *Portunus trituberculatus*, *Fenneropenaeus chinensis* and *Scapharca subcrenata*. The carnivores are *Oratosquilla oratoria*, *Mugil so-iuy*, *Pampus argenteus*, *Setipinna taty*, *Thryssa kammalensis*, *Harengula zunasi*, *Eupleurogrammcus muticus* and *Clupanodon punctatus*. The secondary carnivores are *Lateolabrax japonicus*, *Johnius belangerii* and *Scanberanorus niphonius*. The ecosystem before ecological restoration is referred to the existing ecosystem, and that after ecological restoration is called the target ecosystem. Zheng and You (2014) showed the key food web technique is an effective restoration method since the restored (target) ecosystem is more mature and healthier than the existing ecosystem. What's more, it avoids the ecological risk of alien species invasion. However, in their approach, the living environment and associated biological characteristic properties of species are neglected. The ARs, HRS and ARHRS are applied to solve the problems. The target ecosystem of Zheng and You (2014) is the initial ecosystem of our approach and it is called as the starting ecosystem (SE).

2.3. Artificial reefs (ARs)

The aim of this ecological restoration is to increase 30% primary productivity in the restored area. Referred to the biomass ratio of the Bohai ecosystem, each trophic level of 1982 is: Producer: grazers: carnivores: secondary carnivores = 100: 40.5: 19.9: 8.0 (Su, 2002). The 30% increase of primary productivity means that the total biomass of the ecosystem also increases 30%.

Claudet and Pelletier (2004) and Lowry et al. (2011) reported that the biomass of the reef area is higher than that without reef and the reef area supports large numbers of fish. Pitcher et al. (2002) utilized Ecopath model to simulate the marine ecosystem of Hong Kong to investigate the relation of the reef fish biomass to the area rate of the layout artificial reefs and the protected marine (AR/PM). They concluded that the total biomass of reef fishes (initial approximately 190t) is increased by 30% (about 247t) for 2% AR/PM after 10 years.

Liu (2013) indicated the number of species increases distinctly from the temperate climate zones to the tropical ones. Because the biomass data of local deployed artificial reefs is very limited, the data of Hong Kong can be only used to estimate the biomass of artificial reefs (AR) shelter and breeding habitats for species. In this approach, we assumed that the biomass of AR shelter and breeding habitats for species is independent on the temperate climate zones and the tropical ones. The effect of latitude is mainly reflected in the growth rate of biomass. For the same biomass growth, the biomass of low latitude needs for a long time. Therefore, the biomass of artificial reefs (AR) shelter and breeding habitats for species in Hong Kong can be also obtained in our restoration area.

Two patterns are used to analysis the influence of AR on the growth of the biomass in the restored area, namely the conservative and optimistic analysis. When the primary productivity is increased by 30% in restored area, similar to the case of Hong Kong, AR is required to be deployed by 2% of the restored area for a conservative analysis. The biomass of reef fishes is lower than that of Hong Kong because the initial biomass (70.99 t/km^2) (Pitcher et al., 2000, 2002) of the Hong Kong marine ecosystem is 3.5 times more than that (20.295 t/km^2) of the existing ecosystem (Zheng and You, 2014) of the restored area due to the big difference of latitude. Optimistically, it is assumed that the same high biomass in ARs of Hong Kong can also grow in those of the restored area. Therefore, the relative size of AR/PM can be 1/3.5 of that of Hong Kong to keep the same biomass in AR of both places. When the primary productivity is increased by 30% in the restored area, AR should be deployed in 0.57% (2%÷3.5 ≈ 0.57%) of the restored area in Tianjin for an optimistic analysis.

To provide shelter and breeding habitats for species before the main breeding season (the main breeding of Bohai Bay is in summer), the artificial reefs should be deployed in spring (Loya, 1990), and the reef module of every location area is defined as a reef unit.