Technical Methodologies for The Assessment of the Impacts of Reclamation Projects on Marine Ecology

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Research Article

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Abstract

The present article introduces the concept of ecological assessment of reclamation projects. In addition, considering the impact of reclamation projects on marine ecosystems, we built a framework that takes into account structure, function, and ecosystem services for the assessment of the impact of reclamation projects on marine ecology. Moreover, this study explored different technical methods for ecological assessment of reclamation projects, with an emphasis on those that evaluate the impacts of reclamation on the structure of marine ecosystems. The present research provides technical support for the recognition and diagnosis of marine ecology problems that are the result of reclamation projects, introduces a guideline for the development of ecological restoration projects, assists in protecting coastal wetland ecosystems, promotes the scientific and reasonable management and control of reclamation, and helps maintaining the regional marine ecological security pattern.

Introduction

Coastal areas are transition zones between ocean and land. Apart from natural geographical features such as rich resources and ecological fragility, coastal zones display unique social and economic characteristics. These regions present intensive human activities including industrial, commercial, residential, tourism, military, fisheries, and transportation. The coastal economy has been playing a pivotal role in the economic growth and modernization in China. In 2019, the national marine product was 8,941.5 billion yuan, accounting for 9.0% of the gross domestic product (GDP) and 17.1% of the coastal area's GDP(Beijing: Department of Marine Strategy, Planning and Economy, Ministry of Natural Resources 2020). The rapid development of the marine economy, the acceleration of the urbanization process, and the rapid population growth have greatly stimulated infrastructure construction and the development of coastal industries, and at the same time have aggravated the shortages of land resources in coastal areas. In this context, the primary solution to relieve this situation is land reclamation(Wang 2010; Ma et al. 2015). Since 2002, China has gained 163,000 hm^2 reclamation lands with warrants, with a peak period in 2005-2015 at a rate of approximately 10,000 hm^2 per year, and a peak value of 18,000 hm^2 in 2009. The reclamation lands are mainly used for port projects, coastal industries, and urban construction, activities that accounted for approximately 90% of the total reclamation lands(Yu et al. 2019).

Human beings greatly benefit from reclamation projects since they result in the protection of arable lands that increases food supply(Peng et al. 2005). In addition, economic aggregates increase, providing proper space and ensuring the implementation of strategic plans for major development of coastal urban areas and industries(Chinese Academy of Sciences 2016). However, reclamation has also caused permanent changes in the natural characteristics of sea areas(Hou et al. 2018). Unreasonable reclamation projects have also introduced a series of ecological and environmental problems, resulting in reduced coastal wetlands and declined natural purification capacity of seawater. As a consequence, marine ecosystems have been threatened because of a decreased repairability, reduced stability or even loss of islands. Most land reclamation projects have transformed the natural coastlines into artificial ones, changed the natural characteristics of the coastline, blocked the exchange of material and energy between the sea and land,

altered the ecosystem structure of the reclamation areas, damaged the ecosystem stability, reduced the ecological service, and also increased the risk of alien species invasion. In order to solve these ecological problems, coastal areas have engaged with some success in active ecological restoration projects including the construction of ecological seawalls, reverse reclamation, coastal wetlands restoration, and marine breeding and releasing, among others.

Currently, there is a significant amount of research about the ecological impacts of reclamation(Ma et al. 2009; Mu et al. 2011; R.M.Muller et al. 2020; Xiaojing et al. 2020), ecological damage assessment of reclamation(Peng et al. 2005; Li 2010; Li and Liu 2012; Li et al. 2014; Yu et al. 2015; Li and Wang 2016; Yu et al. 2019; Zhang et al. 2020), and ecosystem service losses from reclamation(Wang et al. 2010; Sui et al. 2013; Liu et al. 2014; Jiang et al. 2017; Liu et al. 2020; Su and Li 2020). These studies have determined the impacts of reclamation on different environmental, ecological, and socio-economic factors, and have also evaluated the feasibility of carrying out those reclamation projects. Other investigations have studied different methods used to assess the ecological loss or ecosystem service loss to provide references for quantitative eco-compensations. However, only few studies have focused on the assessment of ecological damages in the reclamation area for the purpose of ecological restoration, that is, ecological assessment. Ecological assessment is the basis for scientifically setting up ecological restoration goals and performing ecological restoration plans, and it plays an essential role in ecological restoration processes. Based on the composition of the marine ecosystem and taking the reference system as the goal, the present study established an ecological assessment method for reclamation projects and achieved the goal of problem-oriented and scientific implementation of ecological restoration in the reclamation areas.

1 Concepts Of Marine Ecological Assessment For Reclamation Projects

1.1 Concepts related to ecological assessment

At present, there is no specific definition for ecological assessment. Common related concepts include ecosystem assessment, ecological impact assessment, ecological damage assessment, and others. However, most them are formulated from a management perspective and are useful in assisting relevant management departments for decision-making purposes. Reported studies have focused on solving scientific questions related to ecosystem structure, dynamics, processes, services, and sustainability management, as well as ecological diversity, ecosystem management, ecological risk and security, ecological response, and the effects of global change(Fu 2010).

On June 5th, 2001, at the World Environment Day, the United Nations Secretary General Kofi Annan officially announced the launch of the Millennium Ecosystem Assessment(Zhao and Zhang 2004; Millennium Ecosystem Assessment (Program) 2005; Zhang and Guo-Pei 2006). This was the first worldwide scientific assessment plan regarding the impacts of ecosystem change on human well-being. Considering the relationship between ecosystem functions and services and human well-being, the

central task of the ecosystem assessment was to evaluate the current status of the ecosystem, predict possible changes in the future, and propose countermeasures to improve its management(Zhao 2001). The ecosystem assessment framework included ecosystems and their functions and services, human well-being and poverty alleviation, drivers of changes in ecosystems and their services, the interactions and evaluations of ecosystems at different scales, and the value and evaluation of ecosystems, among others(Zhao and Zhang 2004).

Ecological impact refers to any harmful or beneficial effects of economic and social activities on the ecosystem and its biotic and abiotic factors. Impacts can be divided into: (a) adverse and beneficial; (b) direct, indirect, and cumulative; and (c) reversible and irreversible(Center for environmental engineering assessment 2011)

. Ecological impact focuses on evaluating the scope and extent of the impact of the construction project on the ecosystem and its constituents in order to provide conclusions and suggestions about the feasibility of project construction.

Marine ecological destruction refers to the harmful effects on marine ecosystem and its biotic and abiotic factors caused by changes in marine natural conditions or contaminated material and energy released into the sea due to direct and indirect human activities(The third Institute of Oceanography et al. 2017). The assessment of marine ecological destruction is primarily focused on the harmful effects on marine ecosystem and its constituents caused by marine ecological destruction events (marine resource exploitation and marine environmental emergencies).

Thus, the concepts previously presented differ from those related to ecological assessment in terms of assessment purpose, assessment objectives, assessment scope, and assessment methods. Thus, in order to provide support for different assessment purposes, the targeting assessment objects and scopes will be different, and the adopted assessment methods will also be different. Therefore, how to define the concepts and contents of marine ecological assessment of reclamation projects and how to construct or select a scientific and reasonable ecological assessment framework has become the key to marine ecological assessment in reclamation projects.

1.2 Defining the concepts for marine ecological assessment for reclamation projects

In order to properly define the concepts, we must first clarify the purpose of marine ecological assessment of reclamation projects. Generally, the marine ecosystem is present in a stable equilibrium state, which is the normal ecosystem. It is a self-sustaining system with biological communities and natural environment in a state of equilibrium(Li and Ju 2005). When various components are disturbed, they follow certain rules and fluctuate around the position of equilibrium, reaching a state of dynamic equilibrium. After the implementation of reclamation projects, the normal ecosystem may be degraded due to disturbance, and become a degraded marine ecosystem. In other words, a marine ecosystem formed under natural and/or human disturbance deviates from its original state(Li and Tang 2016). Therefore, the purpose of marine ecological assessment of reclamation projects is to assess the extent to

which the marine ecosystem deviates from the normal ecosystem as a consequence of reclamation, and to take corresponding ecological restoration measures to restore the degraded marine ecosystem.

The reference object of the marine ecological assessment of reclamation projects is the original ecosystem before degradation or the undamaged natural ecosystem. He Nianpeng et al.(He et al. 2020) proposed that the ideal reference frame is that composed of specific values of a series of key indicators, which provide information about the quality of the ecosystem under specific conditions for suitable environments and with no or few human activities. It can also be called an authentic reference frame.

Therefore, the concept of marine ecological assessment of reclamation projects refers to the assessment of damaging pathways, damaging processes, and the degree of damage in marine ecosystems that are under the impact of reclamation with respect to the reference ecosystem.

Marine ecological assessment of reclamation projects should consider: (a) the degraded marine ecosystem affected by the already implemented reclamation projects; and (b) the marine ecosystem that might be degraded because of the planned reclamation projects.

The main objective of a marine ecological assessment of reclamation projects is to study the degradation/damage process and impact mechanism on marine ecosystems under various disturbance conditions (reclamation scale, location, construction time, construction methods, etc.), as well as to analyze the degradation status and degradation degree of the systems.

2 Design Of The Framework For Marine Ecological Assessment Of Reclamation Projects

Ecosystem refers to an interconnected and interacting natural entirety with an automatic adjustment mechanism that is the result of energy flow and material circulation between organisms (one or more biological communities) and abiotic environment within a certain time and space(Shen and Shi 2002). The marine ecosystem is a natural organic entirety that is interdependent, interrelated, and displays an automatic mechanism of adjustment. This ecosystem is formed by the marine biological community (marine plants, marine animals, and marine microbial communities) and the marine abiotic inorganic environment that interact through energy flow and material circulation(Wang et al. 2011). Depending on the concept of ecological assessment of reclamation projects and the definition of marine ecosystem, ecological assessment needs to consider the direct impacts of reclamation on marine abiotic environments and marine communities in the marine ecosystem, as well as the indirect impacts of changes in marine abiotic environments on marine biological communities (Figure 1).

Marine Ecosystems display a specific structure and function, and provide a variety of services to human beings. Reclamation affects the structure of the marine ecosystem, which in turn affects functions and services causing different types of damages to the entire marine ecosystem. When the damage exceeds a certain level, it causes the degradation of the marine ecosystem. Therefore, reclamation projects should be evaluated taking into account the following three aspects: (a) the structure; (b) function; and (c)

services of the marine ecosystem. Among them, the impact on the structure of marine ecosystem plays a key role, since it determines the degree of damage to function and services. Thus, evaluating the impact of reclamation on marine system structure should be the focus of the assessment. The ecological assessment framework of reclamation projects is shown in Figure 2.

3 Methods Of Marine Ecological Assessment In Reclamation Projects

3.1 Assessment regarding the changes in marine ecosystem structure

3.1.1 Marine hydrodynamics

Regarding the planned reclamation projects, the hydrodynamic environmental ecological assessment may be conducted through digital and physical prediction models. For the previously implemented reclamation projects, the hydrodynamic environmental ecological assessment should include a before-and-after comparative analysis of the actual measurements in addition to the digital model comparison(Wang 2010; Sun 2014).

Indirect effects of hydrodynamic changes on marine biological communities, with emphasis on targets that are especially sensitive. Feature points for prediction or comparative analysis should be selected at the protected area border around the construction site, and at the borders of important ecosystems. For example, in high flow velocities, coral reef ecosystems and coral larvae would fail to attach to the reef and reduce their ability to survive from predators. In contrast, too slow flow velocities would reduce the exchange rate of dissolved oxygen and nutrients in the water body diminishing favorable conditions for the growth of coral reefs. In mangrove forests impacted by tidal scouring and sea tides, the mangrove foundations are prone to erosion and collapse. Therefore, for ecological assessment purposes after the implementation of a reclamation project, the changes in water flow velocity (the maximum change in flow velocity and the range of flow velocity change) at the boundaries of the coral reef and the mangrove distributed area should be considered.

3.1.2 Marine geomorphology and deposition-erosion

The ecological assessment of the ocean surface topography is usually carried out through on-site field survey, remote sensing, and unmanned aerial methods. For planned reclamation projects, numerical simulations predicting the scouring and silting degree of seabed and/or shore will be carried out. For the already implemented reclamation projects, in addition to numerical simulations, a before-and-after comparative analysis for water depth from field measurements will also be conducted.

Changes in ocean surface topography and scouring and silting environment, and indirect impacts on marine biological communities caused by reclamation projects will be investigated. For this purpose, the prediction results obtained for the scouring and silting of the shore and seabed will be considered. Using spatial analysis methods including Kriging interpolation and Tyson polygon construction, the spatial

distribution data of the scouring and silting of the shore and seabed in the whole sea area will be generated. Later, including data on the regional water depth and terrain and the distribution and characteristics of sensitive objects, the impacts of the reclamation project on the seabed topography, shoreline, and surrounding ecologically sensitive objects will be quantified. The assessment plan is shown in Figure 3.

Taking into account our results for changes in hydrodynamic conditions, and combining them with the analysis of sedimentation process and sediment source, changes in the sedimentary environment will be explored. Finally, the indirect impacts of changes in the sedimentary environment on marine biological communities, primarily the benthos changes will be further studied.

3.1.3 Marine water quality

During marine ecological assessment of reclamation projects, the impacts of reclamation projects on marine water quality were evaluated considering two aspects. The first aspect focuses on the impact of suspended sediments originated from construction activities on seawater quality. Analyses were performed to determine indirect impacts on marine biological communities including plankton, benthos, and fishery resources, as well as the impacts on sensitive objects such as coral reefs and lancelets. The second aspect considers changes in the pollution carrying capacity of the area (especially the bay) caused by the reclamation project. Using predictive modeling, changes in the environmental carrying capacity can be analyzed. Results were used to determine the indirect impacts on the marine biological community, primarily focusing on the impacts on pollution-sensitive organisms. Moreover, the status of marine ecology and sensitive object surveys may be combined to conduct qualitative analysis of changes in biological species (such as pollution-tolerant species and invasive species).

3.1.4 Marine sediments

The marine ecological assessment of reclamation projects should consider the coverage of suspended sediments originated from construction activities on the seabed. Results may be used to further explore the indirect impacts of the quality change of sediments on marine biological communities, particularly the benthos.

3.1.5 Marine ecological environment

The direct impact of reclamation on the marine environment occurs on benthic habitats, significantly affecting the benthos component. In addition, the impacts of reclamation projects on the hydrodynamic environment, ocean surface topography, and scouring and silting environment, indirectly affect marine communities, especially their habitats, causing changes in marine biological species, resources, and biodiversity.

3.1.6 Marine ecological sensitive objects

The impacts of reclamation projects on marine ecological sensitive objects should be assessed considering important coastal wetlands (including estuaries, mangroves, coral reefs, etc.), marine protected areas, concentrated areas for rare and endangered marine species, important fishery waters (spawning grounds, feeding grounds, wintering grounds, and migratory passages for commercially important fishes), marine natural historical artifacts, and natural landscapes.

For reclamation projects involving migratory and foraging grounds for birds, the assessment of impacts on birds should also be carried out, identifying the changes in the number, species, and bird distribution areas.

3.2 Assessment regarding changes in marine ecosystem functions

To the best of our knowledge, only few studies regarding the impact of reclamation projects on marine ecosystems have been reported. The three major functions of ecosystem are energy flow, materials circulation, and information transmission(Shen and Shi 2002). The main impacts of reclamation projects on the energy flow of marine ecosystems result in the transformation of natural ecosystems into artificial ecosystems, reducing trophic levels, and reducing energy utilization efficiency. At the same time, material circulation and information transmission may be hindered. Thus, it is extremely important to investigate further changes in ecosystem functions caused by reclamation projects. These modifications can be analyzed considering primary productivity before-and-after the implementation of a reclamation project, as well as variations in the stability of marine ecosystems(Gray 1977; Vallina et al. 2017; Valdivia et al. 2020). However, there are limited studies on this topic.

3.3Assessing changes in marine ecosystem services

Currently, there is a significant amount of data on the impact of reclamation projects on marine ecosystem services. In addition, assessment methods are reasonably mature. Marine ecosystems provide a wide range of services to human society. Costanza et al.(Costanza et al. 1997) divided the services into 17 types, while Wang Qixiang et al.(Wang and Tang 2009) categorized them into 15 types. Taking into account the United Nations Millennium Ecosystem Assessment framework, these services were classified into four categories: (a) provisioning; (b) regulating; (c) cultural; and (d) supporting services(Millennium Ecosystem Assessment 2005). The marine ecological assessment of reclamation projects also considers these four service functions. Market price, shadow engineering, alternative market, and result-based reference, are among the commonly used assessment methods. However, they are not discussed in detail in this article.

4. Conclusions

Considering the significance and purpose of the ecological assessment of reclamation projects, the present paper introduced the concept of ecological assessment of reclamation projects, and proposed a marine ecological assessment framework that includes structure, function and ecosystem services. In addition, we elucidated the means and methods to determine the effects of different marine abiotic

environments on marine biological communities via biotic factors. Furthermore, we explored different technical methods for the ecological assessment of reclamation projects, with a focus on the impacts of reclamation on the structure of marine ecosystems. The present document briefly introduced the methods that can be used to evaluate the impacts of reclamation on ecosystem functions and service values. This study may be able to provide technical support for the recognition and diagnosis of marine ecological problems in reclamation projects. In addition, it may also be helpful for the subsequent development of problem-oriented and goal-led marine ecological restoration projects that may reduce the negative impacts of reclamation. The present research may stimulate the protection of coastal wetland ecosystems, strengthen the scientific and reasonable management and control of reclamation, and assist in maintaining regional marine ecological security patterns.

The current ecological assessment of reclamation projects focuses on the marine ecosystem structure and ecosystem service values. In the future, we should pay more attention to other technical methods that may be used for the evaluation of marine ecosystem functions, in order to further improve the technical method system used in this area. In addition, current studies are mostly conducted on single reclamation projects. However, in specific regions, particularly in estuaries and bays, the cumulative effect of multiple reclamation projects has drawn increasing attention to the scholars and will become the focus of future research. Moreover, for planned reclamation projects that will be carried out in the future, it is suggested that the positive benefits of ecological restoration projects are taken into account, and that the corresponding scenario design is added to the ecological assessment plan.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Competing interests

The authors declare that they have no competing interests

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Author's contributions

OYY defined the concept of marine ecological assessment for reclamation projects and designed an ecological assessment framework. LW discussed current domestic and international research status, as well as existing problems of marine ecological assessment for reclamation projects. JD participated in the marine ecological assessment framework for reclamation projects. He designed and studied the evaluation of changes in marine ecosystem functions. YW studied the impact assessment of sea reclamation projects on marine ecologically sensitive targets. LC investigated marine ecological environment assessment methods. QL conducted research about sea water quality environmental assessment methods. JW studied Marine landforms and scouring and silting environment assessment methods. SJ studied hydrodynamic environment assessment methods.

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Figures

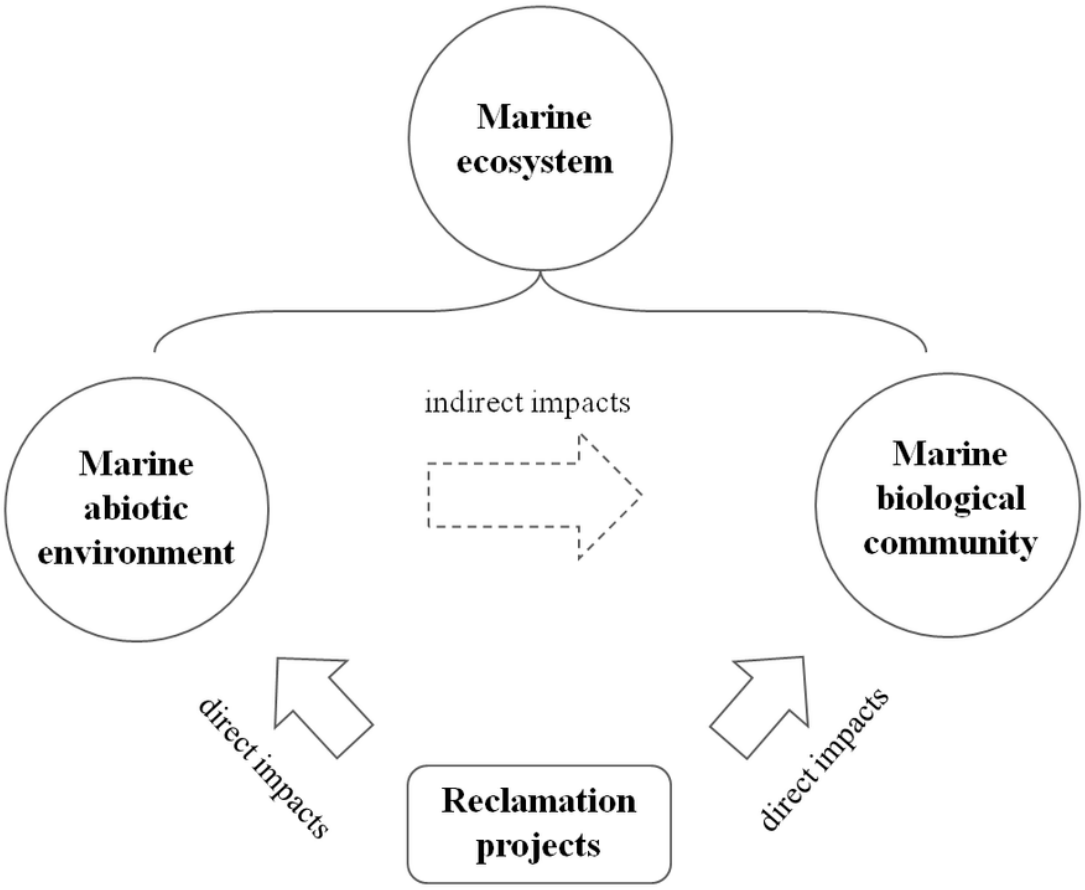

Figure 1

Impact of reclamation on marine ecosystems.

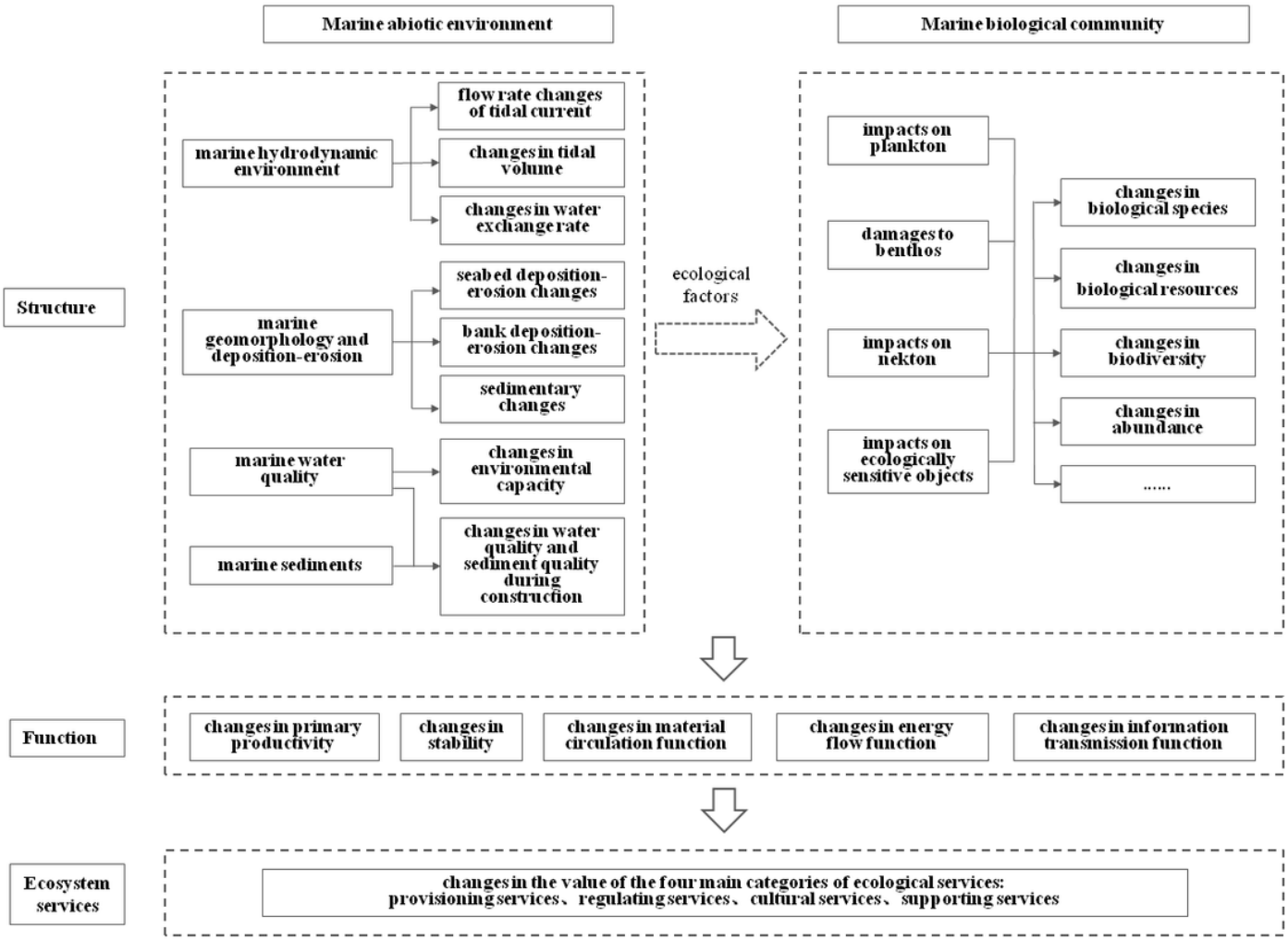

Figure 2

Ecological assessment framework in reclamation projects.

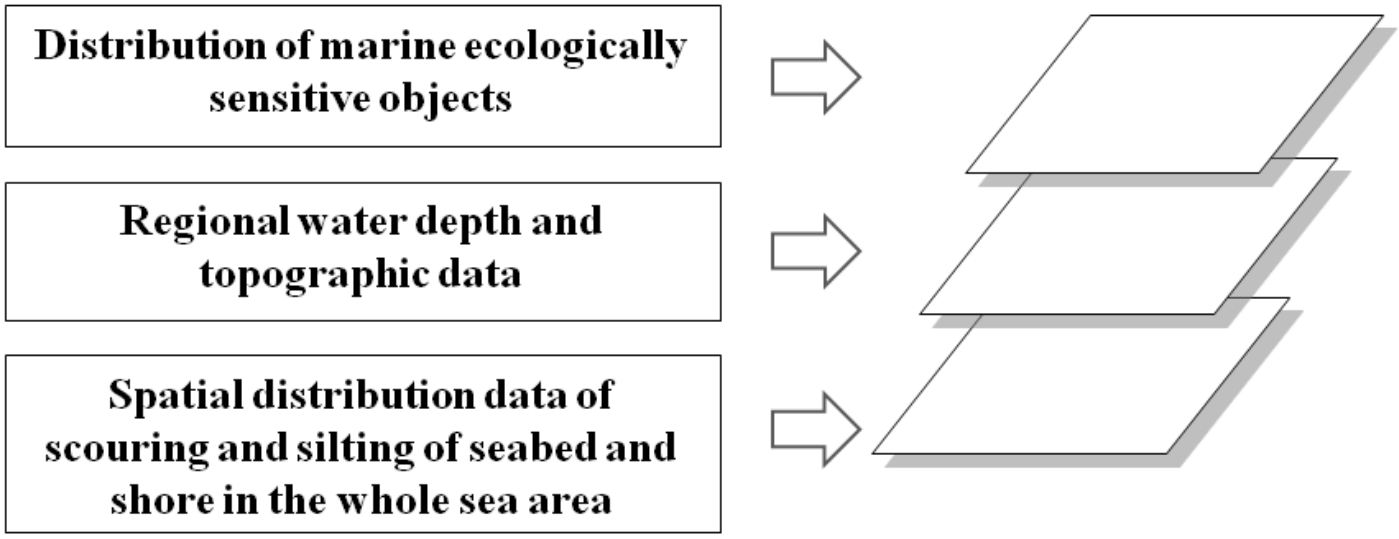

Figure 3

An assessment plan of the indirect impacts of changes in ocean surface topography and scouring and silting environment on marine biological communities.