



Transdisciplinary, Co-Designed and Adaptive Management for the Sustainable Development of Rongcheng, a Coastal City in China in the Context of Human Activities and Climate Change

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Half the population of China live in coastal zones where 70% of large cities are also located. Intensive human activities pose significant environmental and ecological hazards to these cities that are already vulnerable to natural hazards and climate change. The sustainable development of coastal cities is thus both a national and international issue. Rongcheng is a typical coastal city in east China. It is a national marine ranch demonstration area that is subjected to multi-stressors from human activities and climate change. The dominant economic sectors include aquaculture and fisheries, agriculture, shipping and tourism. A multitude of resulting pressures come mainly from intensified human activities, such as intensive aquaculture, overfishing, industrial pollutants, agricultural runoff, land reclamation and port expansion. In addition, Rongcheng is also facing exogenic pressures from extreme climate events such as intensified storms, storm surges, droughts and sea ice. A growing awareness of these problems brought together a trans-disciplinary group from local government, research institutions, local practitioners and coastal representatives to jointly explore and co-design adaptive coastal management options. In this transdisciplinary study, a social-ecological analysis based on a combination of the Systems Approach Framework and the Drivers-Pressures-States-Impacts-Responses framework was used to analyze and formulate an adaptive management plan for the sustainability of Rongcheng. More than 40 stakeholders including government, companies, civil society and institutions participated in the study through questionnaires and on-site meetings. A statistical analysis of the results identified urgent issues impeding the sustainable development of Rongcheng. The issues identified were poorly regulated aquaculture, loss of shoreline, and the decline of seagrass and cultural heritage. The study identified management options and measures, some of which were adopted by the local government in a co-designed

management plan. The measures included upgrading of aquaculture industry, habitat conservation and restoration, and the development of cultural tourism. Another outcome was the increased knowledge exchange between stakeholders to inform management, policy, and decision making, as well as raised awareness of vulnerability to natural hazards and climate change. The success of this case study provides a reference for the adaptive management of other coastal cities and their sustainable development in a changing climate.

Keywords: coastal city, human activity, DPSIR, climate change, sustainable development, transdisciplinary adaptive management, social-ecological systems

INTRODUCTION

One-third of the world's population lives within 100 km of the coastline, and 62% of cities with a population of more than 8 million are in coastal areas (Stephenson et al., 2010). In China, more than 70% of large cities and 50% of the population are concentrated in the eastern and southern coastal areas (Wang et al., 2012; You, 2019). Since the industrial revolution when Greenhouse Gas (GHG) emissions increased dramatically, the global climate system has been experiencing significant changes characterized by global warming. An increase in temperature is posing huge challenges such as sea level rise (SLR), sea surface temperature (SST) rise, storm surges, sea water intrusion and coastal erosion to the coastal cities. Moreover, climate change is compounded by past and present patterns of unsustainable development that have degraded coastal ecosystems and increased social vulnerability. Furthermore, climate change impacts like SLR are increasing the intensity and frequency of some hydro-meteorological events, such as extreme sea-level-related events. Recently, the WGI report of IPCC (2021) outlined the physical scientific basis of climate change, including the latest projections about SLR. The IPCC SROCC report outlined details of the challenges faced by coastal cities (Oppenheimer et al., 2019). In this climate change context, the pressures originating from high-intensity human activities such as industrialization, agricultural intensification, coastal land reclamation, and rapid urbanization are changing the coastal ecosystems, especially in developing countries (Major et al., 2018), such as China.

The global scientific community recognizes the importance of the sustainability of the oceans and the United Nations Educational, Scientific and Cultural Organization (UNESCO) has launched the initiative "The Decade of Ocean Science for Sustainable Development (2021–2030)". There is also global awareness of threats and risks to coastal cities due to climate change and human activities. Future Earth Coasts¹ is undertaking coastal zone research focusing on trans-disciplinary adaptive strategies that integrate excellent science, effective governance, social and cultural adaptations, and raising public awareness of coastal risks (Future Earth Coasts, 2018a; Future Earth Coasts,

2018b). Future Earth Coasts brings together an international group of scholars, including the co-authors of this article, who explore how to translate the above aspirations into practical reality through a series of case studies.

Coastal city responses to climate change and anthropogenic stressors have been extensively studied to explore various approaches to support sustainable development (Newton et al., 2016; de Alencar et al., 2020). Adaptation strategies to climate change rely on excellent science, as well as local culture, social networks, economic and political systems (Mea et al., 2016; Sorensen et al., 2018). A transdisciplinary, co-designed, adaptive management framework can contribute positively to the sustainable development of a coastal city, in the context of climate change and human activities, by addressing stakeholder issues and perspectives (Semeoshenkova et al., 2017; Berninsone et al., 2018).

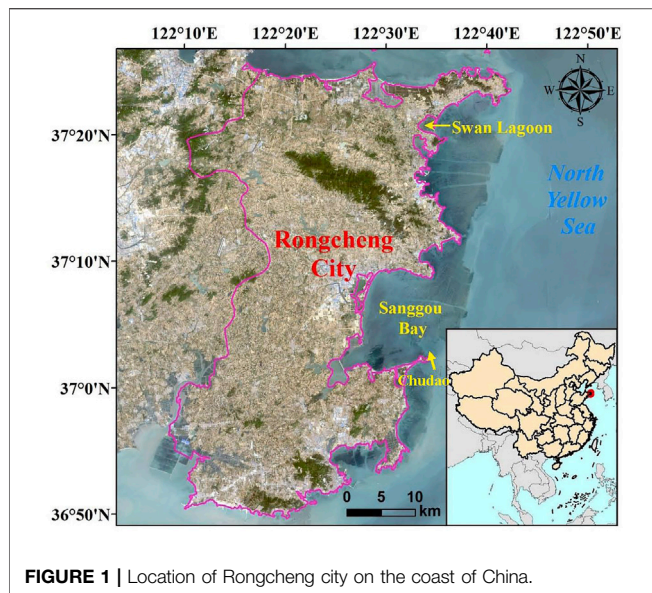
Adaptive-management frameworks can be used to analyze prominent local issues of coastal social-ecological systems (Binder et al., 2013). They depend on a co-learning process that begins with stakeholder engagement and concludes with the implementation of practical management actions (Frohlich et al., 2019). Various studies and research approaches have developed trans-disciplinary adaptive strategies (Chiang et al., 2014; Mansur et al., 2018; de Alencar et al., 2020). However, transdisciplinary, co-designed, adaptive management is a relatively new approach, with few examples in China.

In this study, Rongcheng, a typical coastal city in East China was selected as a case study, to explore how transdisciplinary, co-designed and adaptive management could support sustainable development, especially the response to coastal hazards in the context of human activities and climate change. Two adaptive management frameworks, Systems Approach Framework (SAF) and Drivers-Pressures-States-Impacts-Responses (DPSIR) were used in combination to 1) map the stakeholders engaged in the study; 2) identify and analyze the key issues impeding the sustainable development of Rongcheng; 3) formulate an adaptive management plan for Rongcheng City. This provides a reference case study on the adaptive management and sustainable development efforts by other coastal cities in a changing climate.

This study addressed the following research questions:

- (i) What are the main hazards for the sustainable development of Rongcheng from the perspective of scientists?

¹Formally the Land-Ocean Interactions in the Coastal Zone (LOICZ) project of the former International Geosphere Biosphere Programme (IGBP) and the International Human Dimensions Programme (IHDP).



- (ii) Who are the interested parties with respect to the sustainable development of Rongcheng?
- (iii) What are the main issues for the sustainable development of Rongcheng from the perspective of the local, interested parties?
- (iv) What is the willingness to engage in participatory processes as a stakeholder?
- (v) Who are relevant stakeholders corresponding to the main identified issues?
- (vi) What are the management options to address these issues?
- (vii) Does the transdisciplinary approach contribute knowledge that is useful to decision-makers?
- (viii) Does the approach raise awareness of vulnerability to natural hazards and climate change?
- (ix) Can this approach be useful for future-proofing coastal cities in China?

MATERIALS AND METHODS

Study Area

Rongcheng City² district is located on the easternmost tip of Shandong Peninsula, China (see **Figure 1**), facing the Yellow Sea on its north, east and south sides with a coastline of 500 km. The city district has a land area of 1,526 km², with the jurisdiction over 26 towns, 920 administrative villages, and a total population of 660,000. The terrain slopes from northwest to southeast, with an average elevation of 25 m. There are 102 rivers in the city, all of which have intermittent flows, following seasonal rains. The climate here is warm, humid, and influenced by monsoons. Surrounded by the sea on three sides, the city climate is significantly regulated by the ocean, with the characteristics of maritime climate. There are 10 bays, 10 natural bathing beaches,

115 islands and 100 km² of tidal flat along the shoreline. Rongcheng possesses numerous natural and cultural landscapes, including the typical coastal habitats of lagoons and seagrass meadows. Moreover, Rongcheng has rich biodiversity and fishery resources including swans, prawns, eagle claw shrimp, yellow croaker, flounder, scallops, kelp and wakame.

The economic development of Rongcheng is mainly driven by the marine or “blue” economy, and the value of the marine fishery and aquaculture dominates the whole industrial food-system. After decades of aquaculture and urbanization, Rongcheng has developed as a National Marine Ranch Demonstration Area where the dominant economic sectors are aquaculture and fisheries. Rongcheng includes a breeding area of 388 km², 5 national marine ranches and 11 national, leisure-fishery demonstration areas. The output of aquatic products (1.25 million metric tons) and the total fishery income (15.0 billion USD in 2020) have been ranked first, at the national level, for 39 years. This accounts for a substantial contribution to the total annual aquaculture production in China, for example kelp (31%), sea cucumber (14%) and abalone (5%).³ Rongcheng has 2, first-class open ports and 10 first-class open harbors, with the cargo throughput capacity over 25 million metric tons. Rongcheng possesses 317 professional, ocean-going fishing vessels, accounting for 70% of the Shandong Province pelagic fishing fleet. Rongcheng has more than 260 marine food companies, with an annual income from sales reaching 20 billion USD, according to the official website of the local government. Rongcheng is the largest production base for frozen prepared food, kelp, seafood and canned food in China. The tourism industry in Rongcheng is also very developed, with about 12 million domestic and foreign tourists annually. Other important economic sectors include agriculture, shipping and urbanization.

A multitude of resulting pressures come mainly from human activities including intensive aquaculture, overfishing, industry pollutant discharge, agriculture runoff, coastal land reclamation and port construction (Ni et al., 2017; Shao et al., 2019). These have led to changes in the state of the environment and ecology, such as pollution by heavy metals and persistent organic pollutants (POPs), marine debris and microplastics, eutrophication, seagrass meadow degradation, and shoreline recession (Wang F. et al., 2017; Sui et al., 2020). This environmental degradation has resulted in a reduction in the delivery of valuable ecosystem services, such as the provision of quality seafood, cultural heritage, which also impacts on human welfare, human health and the sustainable development of the local economy. In addition, Rongcheng is also facing exogenic pressures from the extreme climate events, such as intensified coastal storms, storm surges, beach erosion, droughts and sea ice. These have resulted into the erosion of the natural shoreline, the decline of coastal

²<http://www.rongcheng.gov.cn/col/col61812/index.html>

³<http://tjj.weihai.gov.cn/col/col12005/index.html>

TABLE 1 | Stakeholders related to the Rongcheng City coastal development.

Sector	Governance	Private company	Civil society/community and research institutions
Aquaculture/fishery	North China Sea Branch of State Oceanic Administration China Fisheries Law Enforcement (in Yellow Sea and Bohai Sea) Rongcheng Municipal Ocean and Fishery Affairs Bureau Shandong Ocean Bureau Shandong Hydrobios Resources Conservation and Management Center Rongcheng Station for Popularizing Fishery Technique	Xunshan Group Co., Ltd. Shandong Homey Aquatic Development Co., Ltd. Chudao Fishery Co., Ltd. of Rongcheng Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	Rongcheng fishery Association Yellow Sea Fisheries Research Institute (YSFRI), Chinese Academy of Fishery Sciences Ocean University of China (OUC) Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS) Marine Biology Institute of Shandong Province Ludong University Institute of Oceanology, Chinese Academy of Sciences (IOCAS)
Agriculture	Rongcheng Municipal Agriculture Bureau Rongcheng Food and drug Administration	-	-
Maritime Navigation and Transport	Weihai Maritime Safety Administration Weihai Port and Shipping Administration Bureau Rongcheng Transport Administration Bureau (Port and Shipping Administration Bureau)	Xunshan Group Co., Ltd. (Lijiang Harbor) Chudao Shipyard Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	-
Industry (mining, Petrochemical, salt ...)	Weihai Municipal Bureau of Land and Resources Weihai Bureau of Salt Industry	-	Ludong University
Leisure (Tourism)	Rongcheng Station for Popularizing Fishery Technique	Weihai China Travel Service Co., Ltd. The Base for Recreational Fishing The Museum of Traditional Culture and Seagrass House	Shandong Tourism Trade Association
Sewage treatment	Weihai Municipal Environmental Protection Bureau Weihai Municipal Ocean and Fishery Affairs Bureau	Rongcheng Sewage Treatment Plants	Ocean University of China (OUC) Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS)
Coastal engineering	Weihai Municipal Bureau of Land and Resources Shandong Provincial Cultural Relics Bureau The National Cultural Relics Bureau	Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	Yellow Sea Fisheries Research Institute (YSFRI), Chinese Academy of Fishery Sciences Ocean University of China (OUC) Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS) Ludong University

habitat and an increased vulnerability of the population to natural hazards.

Data Sources

The information and data used were obtained from the following resources:

- (1) Bibliographical survey: The sources include published reviews and research articles, books and book chapters, master/doctoral degree theses, government reports.
- (2) Field and monitoring data: Field investigation and sampling to determine state variables, such as rates of erosion, condition of seagrass meadows;
- (3) Multi-temporal remote sensing images: Mapping and assessing areas devoted to aquaculture and the extent of seagrass meadows;
- (4) Outcomes of participatory processes: These included minutes of face-to-face interviews, meetings with stakeholders, oral presentation slides from the local representatives during the stakeholders' meeting, project deliverables. The participatory

process is summarized in **Tables 1** and **2** and in *Participatory Process*.

Participatory Process

The transdisciplinary approach had not been used previously for studies in coastal sustainability in China. The Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences (YICCAS), initiated the work was supported by the CAS President's International Fellowship Initiative (PIFI), to involve international experts to help with the initiation of the process. A variety of stakeholder engagement tools was used in the work including questionnaires, meetings and presentations.

Step 1 Identification of stakeholders: The researchers from YIC-CAS carried out a mapping exercise that identified 40 potential stakeholders. These were categorized by sectors (e.g., fisheries/aquaculture/shipping) and then allocated to the following four groups: government, private companies, civil society/community and research institutions (**Table 1**), to ensure balance and cross-sectoral representation.

TABLE 2 | Stakeholder participation and the level of engagement.

Stakeholder identification		Issue 1 Poorly regulated aquaculture	Issue 2 Loss of shoreline	Issue 3 Decline seagrass bed and seagrass house	Online questionnaires	Responses (measures)	Meetings and on-going forum
Set One	Shandong Ocean Bureau	yes	yes	yes	yes	yes	yes
	Shandong Hydrobios Resources Conservation and Management Center	yes	yes	yes	yes	yes	yes
	Chudao Fishery Co., Ltd. of Rongcheng	yes	yes	yes	yes	yes	yes
	Yantai Institute of Coastal Zone Research, Chinese Academy of Sciences	yes	yes	yes	no	yes	yes
	Rongcheng Station for Popularizing Fishery Technique	yes	yes	yes	yes	yes	yes
	Rongcheng Fishery Association	yes	no	yes	yes	no	yes
	Chudao Shipyard	yes	yes	yes	yes	no	no
Set Two	The People's Government of Rongcheng Municipality	yes	yes	yes	no	yes	yes
	Shandong Homey Aquatic Development Co., Ltd.	yes	no	no	no	yes	no
	Rongcheng Municipal Ocean and Fishery Affairs Bureau	yes	no	no	no	yes	yes
	Weihai Municipal Ocean and Fishery Affairs Bureau	yes	no	no	no	yes	yes
	Ludong University	no	yes	no	no	yes	yes
	Yantai Sanhang Radar Service Technology Research Institute Co., Ltd.	no	yes	no	no	yes	yes
	Institute of Oceanology, Chinese Academy of Sciences (IOCAS)	no	no	yes	no	yes	yes
	Mashan Group Co., Ltd.	no	no	yes	no	yes	no
	Yellow Sea Fisheries Research Institute (YSFRI)	no	no	yes	no	yes	yes
	Chinese Academy of Fishery Sciences						
	Ocean University of China (OUC)	no	no	yes	no	yes	yes
	China Foundation For Cultural Heritage Conservation	no	no	yes	no	yes	no
	Shandong Provincial Cultural Relics Bureau	no	no	yes	no	yes	no

Step 2 Invitation to participate: All the potential stakeholders were then contacted and invited to participate by YICCAS and the local government. Contacts were made through various means, including meetings, emails, and phone calls. The initial contacts were followed up to confirm if they were interested in participating in the study and to encourage them to do so.

Step 3 Issues questionnaire: The stakeholders who engaged then participated in a questionnaire survey to identify their perception of the main issues for coastal sustainability under climate change, as explained in detail in *Issue Identification*.

Step 4 Introduction to transdisciplinary adaptive management: The stakeholders were invited to attend presentations about the purpose of adaptive management frameworks and transdisciplinary co-design. The subsequent process and their involvement were explained to encourage continued participation.

Step 5 Issue identification: The stakeholders who were brought together in a meeting to interact and deliberate reached a consensus on the main issues related to sustainable development in Rongcheng City based on the results of the questionnaire (step 3).

Step 6 Engagement of additional stakeholders: Further stakeholders were invited and encouraged to participate as

interested parties, based on the identified issues. The adaptive management framework, the subsequent process and their involvement were explained.

Step 7 Parallel stakeholder sessions: The stakeholder process continued in parallel between stakeholders grouped according to the different issues. The stakeholders used the adaptive framework to analyze each of the main issues and arrive at management options.

Step 8 Joint stakeholder meeting: A series of meetings was held to analyze the possible responses and measures identified for each issue in Step 7.

Step 9 Management plan: The stakeholders co-designed an adaptive management plan.

Adaptive Management Frameworks

Binder et al. (2013) compared the advantages of 10 different frameworks finding that some frameworks are more suitable in a coastal, social-ecological analysis. For example, the Systems Approach Framework (SAF) is a methodological framework for the transition to sustainable development in coastal zones (Newton, 2012). The SAF was developed for providing multidisciplinary and trans-disciplinary advice to environmental managers and policy-makers concerning environmental problems in the coastal zone (Baltranait et al.,

2020). The key parts of the SAF approach - System Definition, Stakeholder Mapping, and Issue Identification are fundamental steps of the adaptive management framework.

The Drivers-Pressures-States-Impacts-Responses (DPSIR) is another framework initially developed by the Organization of Economic Cooperation and Development (OECD, 1993) and then adopted by the European Environment Agency (EEA, 1995). It has been widely used to analyze issues of sustainable development and in Integrated Environmental Assessment, especially in coastal zones (Gari et al., 2015) and the recent UN World Ocean Assessment.⁴ This framework has evolved (Elliott et al., 2017) to eliminate confusion in terminology (Patricio et al., 2016).

Adaptive management frameworks also need to be adapted to the local situation. Different frameworks offer different approaches and some omit aspects that others include. Contributions from the frameworks were combined and used in the Rongcheng case study. The SAF approach was applied in this study to ensure full participation of appropriate stakeholders from government, scientists and communities. Based on the SAF, three main issues impeding the sustainable development of Rongcheng City under the co-influences of climate change and human activities were identified. Once the issues, corresponding system and stakeholders were defined, an adapted DPSIR framework (Elliott et al., 2017) was used to analyse each issue and identify suitable measures as a response. Combining features of the different frameworks, adapting them to the local issues and situation has been successful in several different settings and for different issues (Semeoshenkova et al., 2017; Berninsone et al., 2018; Tseng et al., 2018; El Mahrad et al., 2020; Abalansa et al., 2020).

RESULTS

System Definition and Stakeholder Mapping

The social-ecological system defined in this study is the land area of Rongcheng City and its adjacent sea area. Rongcheng City is the most prominent county-level city of traditional aquaculture and fisheries in China, which has a long history of integrated multi-trophic aquaculture. With the development of marine fishery and urbanization, coupled with extreme weather, such as storm surges, the problems and contradictions of the aquaculture environment, offshore ecosystem and folk culture are most prominent in this social-ecological system.

For the stakeholder mapping, according to their chronological order of participation in the research, the stakeholder candidates were classified into two sets, Set One and Set Two (Table 2). Most of the stakeholders in Set One have been involved in the entire work from 2014 to 2019. The second set of stakeholders were further chosen by the government to engage and implement responses and measures, according the management plans of different issues already identified. The result of the stakeholder mapping is summarised in Table 2.

Chudao Fishery Co., Ltd. of Rongcheng is a typical representative of fishery companies and one of the main stakeholders from the commercial sector. It is a comprehensive company integrating seafood breeding, nursery, freezing, processing, as well as tourism and sightseeing. The company has cooperated with the Chinese Academy of Sciences, the Chinese Academy of Fishery Sciences and Universities. They are established as a science and education experimental base for Ecological Farming and Marine Science. The company is organized on the basis of a local administrative village and also represents the local residents. With the dual identity of local administrator and fishery company, as well as one of the initiators of the research, the company played an important role in the transdisciplinary, co-designed process throughout this study.

Shandong Ocean Bureau (former Shandong Provincial Department of Ocean and Fisheries) is a typical stakeholder from provincial authority. It is responsible for formulating plans for the development of marine industry, industrial layout and efficient use of marine resources, drawing up and organizing the implementation of plans for marine technology development, the allocation and use of marine areas, island protection and utilization management. It provided research funding and promoted the implementation of several response measures of this study.

The Peoples' Government of Rongcheng Municipality is the local government, responsible for organizing and managing various administrative affairs in the administrative area of Rongcheng. It adopts the consulting suggestions from scientists on the sustainable development of Rongcheng, and formulates and promulgates the corresponding planning and management regulations. This science-policy link guaranteed the implementation of the adaptive management plan.

Another stakeholder representing local authority is the Rongcheng Station for Popularizing Fishery Technique, which is a unit directly under the Rongcheng Ocean and Fishery Bureau. It is responsible for promoting fishery technology and development. In this study, it participated in scientific research, especially in the fisheries planning and habitat restoration.

Several important stakeholders representing the scientific community come from Chinese Academy of Sciences, the Ministry of Agriculture and Rural Affairs, universities and provincial research institutions. In addition, Rongcheng Fishery Association and China Foundation for Cultural Heritage Conservation were identified as the NGOs in this study, who provided important advice and response measures in the transdisciplinary participatory process.

Issue Identification

A list of five locally contextualized issues, including (A) Aquaculture pressures; (B) Loss of seagrass meadows; (C) Shoreline erosion; (D) Reduction of fish stock; (E) Lack of job opportunities were identified through the analysis of literature. Based on the above, a questionnaire on the main issues of Rongcheng's sustainable development was designed. All the stakeholders were engaged to rank the importance of the main

⁴<https://www.worldoceanobservatory.org/content/un-world-ocean-assessment>

TABLE 3 | Ranking and integrating of issues.

No.	Issue	Means of identification	Ranking	Inter-related issues
A	Aquaculture pressures	Literature survey	1	1
B	Loss of seagrass meadows		4	3
C	Shoreline erosion		3	2
D	Reduction of fish stock		2	1
E	Lack of job opportunities		5	3
F	Poor governance and management of aquaculture licenses and activities	Open answers from Questionnaire		1
G	Degradation of cultural heritage and especially the traditional of the seagrass thatched houses			3
H	Unsustainable fishery practices			1

Results of Stakeholder analysis of issues

Rank	Issue	
1	Poorly regulated aquaculture	A + D + F + H
2	Loss of shoreline	C
3	The decline of seagrass and decline of cultural heritage	B + E + G

issues listed in this questionnaire, add further issues and give their feedback through emails, telephone and on-site meetings.

The statistical analysis of the responses to the questionnaires, together with face-to-face interviews and meetings, ranked the issues in order of importance, and the result was A-D-C-B-E. Three other issues were raised by the stakeholders besides the five initially identified. These were (F) poor governance and management of aquaculture licenses and activities; (G) degradation of cultural heritage and especially the traditional of the seagrass thatched houses; (H) unsustainable fishery practices. In view of the connection between the eight issues and their prominence, these issues were integrated, summarized and analyzed by the first sets of stakeholders. A, D, F and H were combined as the most prominent aquaculture issue, C as the most urgent shoreline issue, then B and G combined as the most concerning issue about seagrass and seagrass houses. E was considered as a negative effect resulting from some of these issues. Finally, three issues urgently related to the sustainable development of Rongcheng were focused on. They were 1) poorly regulated aquaculture; 2) loss of shoreline; and 3) the decline of seagrass and decline of cultural heritage (Table 3).

DPSIR Analysis for Sustainability of Rongcheng City

In this section, three main issues and their DPSIR analysis are explained in detail and are summarized in Table 4. Some issues share the same drivers and pressures, and the others require similar responses. Moreover, the response to one issue can produce a pressure on another issue or even introduce a new issue (Berninson et al., 2018). The response discussed below indicates the possible measures based on the analysis of DPSI of each issue.

DPSIR Analysis of Unregulated Aquaculture

Rongcheng was a traditional seaweed farming village. Due to its unique geographical location, the coastal area of Rongcheng is

one of the best places to farm kelp (*Saccharina japonica*). More than 80% of China's total kelp production came from Rongcheng in 2016, earning it the title of "home of kelp". At present, there are 260 kelp nursery and breeding enterprises, with a breeding area of 40,000 hectare, an annual output of more than 500,000 metric tons of kelp, and an output value of more than 300 million USD (Rongcheng Fishery Technology Extension Station, 2017). The other main cultured species are the oyster *Crassostrea gigas*, the scallops *Chlamys farreri* and *Patinopecten yessoensis*, and sea cucumber *Apostichopus japonicus*. The production of oyster and scallop was 66,200 and 13,500 t yr⁻¹, respectively, in 2016 (Rongcheng Fishery Technology Extension Station, 2017). All the species are grown in suspended culture, by placing the kelp seedlings or oyster seed on a rope or scallop in suspended cages (Gao et al., 2020). In 2017, the area of sea cucumber cultivation exceeded 1,000 ha and the production accounted for 16% of the national total production.⁵

The *pressures* from the development of aquaculture and fisheries are the disordered structure and layout of aquaculture, overstocking and the increasing wastewater discharge. As a result, the *state change* of the ecosystem is loss of biodiversity and bio-resources, and environmental degradation. The dissolved nitrogen concentrations increased significantly and the average nitrogen/phosphorus ratio increased after 2010 approximately three to four times more than the 2006 value due to rapid expansion of mariculture (Li et al., 2017). Consequently, the proportion of dinoflagellates in phytoplankton increased from 4 to 9% between 2011 and 2014 and the pH also presented a potential declining trend since 2011 (Li et al., 2017). Both kelp and bivalve farming induced significant spatiotemporal variations in the carbonate system within the Sanggou bay (Li et al., 2021). Moreover, the abundance of microplastics in the surface sediments was at high level with

⁵http://www.shuichan.cc/news_view-343617.html

TABLE 4 | Results of DPSIR analysis: Issues-Drivers-Pressures-States-Impacts-Responses.

Issues	Drivers	Pressure	States	Impacts	Responses
Unregulated aquaculture	<ul style="list-style-type: none"> • Fisheries activities 	<ul style="list-style-type: none"> • Aquaculture layout • Overfishing 	<ul style="list-style-type: none"> • Increased pollution by antibiotics, toxic metals, microplastics and others • Changes in nutrient conditions and decline in the quality of aquaculture and seafood 	<ul style="list-style-type: none"> • Health risk to inhabitants • Loss of income and jobs 	<ul style="list-style-type: none"> • Scientific research on pollutants • Reasonable breeding layout • Breeding standards and norms • Employment Guidance • Healthy aquaculture pattern
Loss of shoreline	<ul style="list-style-type: none"> • Urbanization • Fisheries Activities • Nature processes (storm surge, etc) 	<ul style="list-style-type: none"> • Pollutant discharge • Shoreline change 	<ul style="list-style-type: none"> • Shoreline change • Shoreline erosion 	<ul style="list-style-type: none"> • Production reduction in aquaculture • Loss of income 	<ul style="list-style-type: none"> • Scientific research • Conservation measures • Restoration projects
Decline of seagrass and cultural heritage	<ul style="list-style-type: none"> • Urbanization • Fisheries Activities • Lifestyle changes 	<ul style="list-style-type: none"> • Space encroachment • Pollutant discharge • Subjective willingness to protect folk culture 	<ul style="list-style-type: none"> • Loss of seagrass meadows • Damaged and abandoned traditional, thatched houses 	<ul style="list-style-type: none"> • Loss of Ecosystem services • Loss of income, jobs • Loss of culture value 	<ul style="list-style-type: none"> • Scientific research • Conservation measures • Restoration projects • Planning, conservation and marketing of cultural tourism

1,674 ± 526 items/kg dry weight, of which approximately 57.7% of the microplastics originated from the plastic mariculture facilities (Sui et al., 2020).

The direct **impact** on human welfare is the loss of income due to unregulated behavior by individual aquaculture farmers and the subsequent decline of market price. Another **impact** is the increasing risk to food safety due to environmental pollution caused by the wastewater from aquaculture. The latter not only poses a threat to the human health, but also results in a decrease in the income for farmers because of cheaper price from decline in quality. Therefore, it is necessary for all the stakeholders to co-design an adaptive management plan.

The first urgent **response** to this issue is aquacultural planning, which can strictly delimit non-aquaculture areas such as ecological protection areas and aquaculture areas. It is beneficial to protect coastal habitats and facilitate the subsequent management and research of aquaculture. Secondly, scientific monitoring and impact assessment of the aquacultural environment are crucial to the better understanding of the environmental and ecological quality of Rongcheng. Thus, a sound management regulation system is vital to regulate the random behaviors by individual aquaculture farmers. Finally, the stakeholders will jointly probe healthy aquaculture patterns and technologies, such as “Integrated Multi-Trophic Aquaculture (IMTA)” and “Modern Marine Ranching,” explore its characteristic industry chain, such as “Recreational fishery” and “Aquatic products processing industry,” and ultimately realize the sustainable development of aquaculture in Rongcheng. The formulation and implementing of the transdisciplinary, co-designed and adaptive management plan will be explained in *Transdisciplinary, Co-Designed and Adaptive Management Plan*.

DPSIR Analysis of Loss of Shoreline

Rongcheng city has a long, sandy, coastline with a total length of 62.6 km and mean beach width of 37.2 m (Li et al., 2013). Natural hazards such as storm surge, large storm waves and sea level rise are important natural drivers of loss of shoreline. The main **activities** along the shoreline are thousands of aquaculture ponds of different sizes, as well as the beach tourism that attracts 11.5 million every year, supporting the City’s GDP by 8.6 billion RMB (Yearbook Compilation Committee of Rongcheng, 2017).

The habitats are facing significant pressures due to shoreline modification. Since 1988, artificial or modified shoreline by dams or aquaculture activities now account for 39.44% of the total shoreline in Weihai City, including Lidao Bay and Shidao Bay of Rongcheng City (Sun et al., 2019). The **change of state** of the coastline is its dramatic degradation by both natural hazards and human activities resulting in sediment deficit. Coastal erosion, caused by natural hazards and human activities, such as sand excavation and coastal engineering, significantly threatens the sandy beaches in Dongchudao Village of Rongcheng City (e.g., **Figure 2A**). Beaches in Jingzi Bay and Yulong Bay have disappeared completely, while the sand dunes of Daxizhuang have retreated tens of meters in the last decades, resulting from large area of pine forests collapsed into the sea (Li et al., 2013).

This degraded coastline has **impacts** on human welfare. Coastline erosion and suspended particles in the water column increase turbidity, affecting primary production (such as kelp) and other seafood resources in offshore breeding pond. This leads to the loss of the income for local fishers with lower catch and lower value of the catches. Moreover, conversion to artificial shorelines decreases beach tourism in Rongcheng, decreasing



FIGURE 2 | Shoreline recession before (A) and after (B) ecological restoration was undertaken in Dongchudao village, Rongcheng.

both the number of tourists and the income of the tourism industry.

Thus, the main **response** to the loss of shoreline is to clarify the reasons and mechanisms of shoreline loss, and to design and conduct corresponding shoreline restoration projects. The formulation and implementing of the transdisciplinary, co-designed and adaptive management plan will be explained in *Transdisciplinary, Co-Designed and Adaptive Management Plan*.

DPSIR Analysis for Decline of Seagrass and Cultural Heritage

Another kind of well-known habitat in Rongcheng is seagrass meadows, mainly of *Zostera marina* and *Zostera japonica*, covering 553.84 ha mostly in Swan Lagoon, Sanggou Bay, Lidao Bay and Moye Bay of the City (Zheng et al., 2013; Li et al., 2019). However, decades of aquaculture and urbanization activities have encroached on seagrass meadows. The **pressure** on seagrass meadows comes from the space encroachment caused by expanding aquaculture and urbanization, and the environmental pollution releasing from the aquaculture farms and onshore areas. From 2000 to 2018, the marine aquaculture area in Rongcheng expanded from 153 to 381 km², an increase of 150%, and the annual output of marine fisheries (including marine fishing) increased by 31%; in the context of urbanization, the proportion of agricultural population in Rongcheng City dropped from 70% of 2000 to less than 44% of 2018.⁶ These pressures are changing the **state** and causing a decline of seagrass and 90% of the seagrass habitats in Rongcheng have been lost in the last 30 years (Zheng et al., 2013; Fu et al., 2021). These blue carbon habitats, with carbon burial rates of 121–976 g C m⁻² yr⁻¹ and sediment accretion rates of 11.6–40 mm, are acting as efficient regional carbon sinks, as well as buffers of the rising sea level (Fu et al., 2021). Following disturbance or conversion of the seagrass meadows, a portion of the organic carbon preserved in the top meter soils becomes exposed to oxic conditions, which discharge approximately 0.72 Tg CO₂ into the atmosphere, resulting in negative effects on climate change mitigation. The seagrass habitats also provide significant additional ecosystem services and benefits such as juvenile fish nurseries and pollution

filtering. Moreover, the seagrass harvested in Rongcheng is a culturally important heritage as a traditional thatching material of the distinctive seagrass roof houses that are characteristic of the city.

The decline of seagrass ecosystem services resulted in **impacts** on human welfare. The limited supply of roof seagrass material also affects the maintenance of traditional seagrass houses threatening the distinct culture heritage of the city and the tourism linked to it. Seagrass-thatched houses have great value in historical, cultural and architectural aesthetics and research on traditional lifestyles and crafts (Wang, 2011; Li et al., 2020). They are crafted by skilled fishermen on the Jiaodong Peninsula and a model of harmony between natural and artificial. However, the decrease in the supply of seagrass has led to the decline of the traditional seagrass market and the seagrass house construction industry and the loss of seagrass house craftsmen. There has been an increase in market prices of seagrass from a few cents to a few USD per kilogram. The price of seagrass thatched roofs is almost 10 times more expensive than brick-tile, so the villagers cannot afford to build or repair their seagrass houses (Ma et al., 2019). More than 58% of the traditional villages of seagrass houses are currently in a state a poor state and most of the existing seagrass houses have shown varying degrees of damage and even their gradual disappearance. This has led to a decline in the number of seagrass houses (Wang S. G. et al., 2017). In the 2006 census survey, there were 95,000 seagrass houses in Rongcheng, but in 2016, there were less than 10,000 seagrass houses, a loss of 10,000 seagrass houses per year (Jin and Wang, 2016; Li et al., 2020). Of course, the decline of traditional seagrass houses is not only caused by the loss of seagrass habitat, but has also resulted from changing concepts about housing and the processes of coastal urbanization. Nevertheless, the decline of this kind of cultural heritage is an unfortunate consequence.

The decline of seagrass meadows directly leads to the lack of raw materials for seagrass houses. Therefore, the primary response is to implement the restoration of seagrass meadows. Meanwhile, strict management regulations are also needed to prohibit the encroachment from aquaculture and urbanization. Regarding the decline of traditional seagrass houses, responses need to be initiated by the governors to develop and implement conservative remediation plans, to seek remediation funds, and to explore sustainable cultural industry together with

⁶<http://tjj.weihai.gov.cn/col/col12005/index.html>

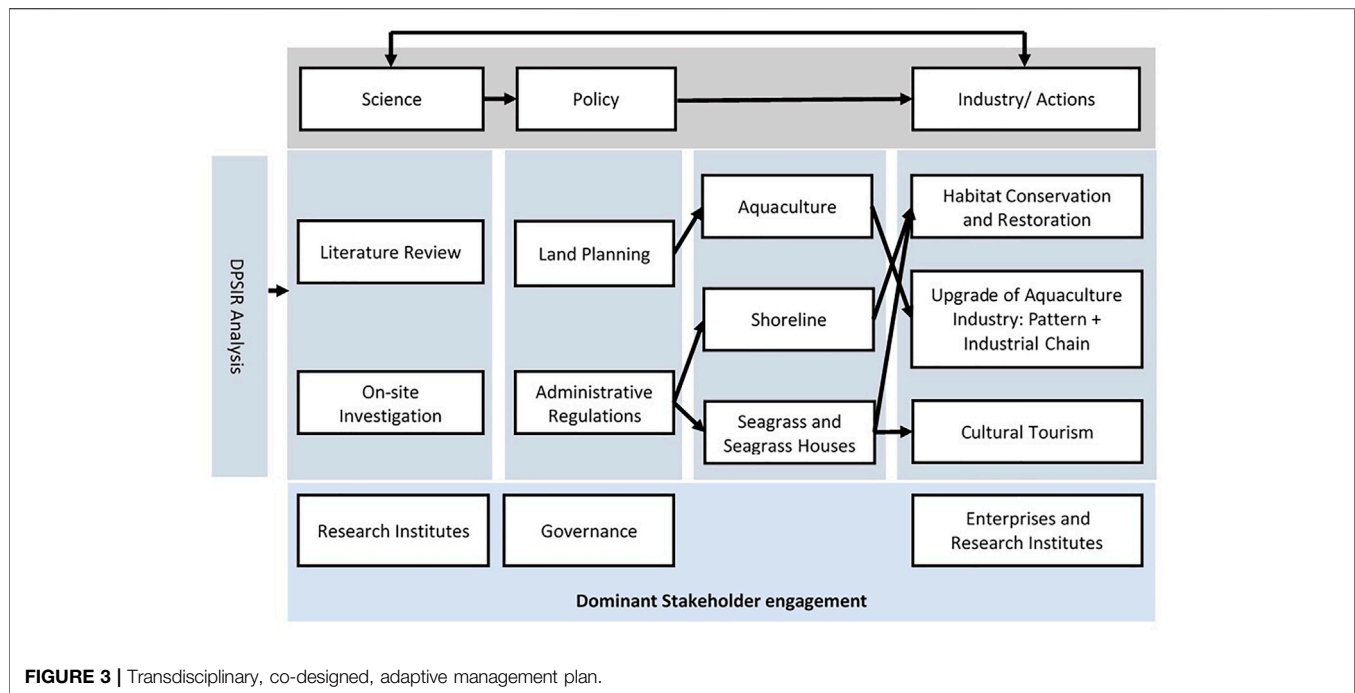


FIGURE 3 | Transdisciplinary, co-designed, adaptive management plan.

representatives from institutes or universities, industries, associations, NGOs and local residents. The formulation and implementing of the transdisciplinary, co-designed and adaptive management plan will be explained in *Transdisciplinary, Co-Designed and Adaptive Management Plan*.

Transdisciplinary, Co-Designed and Adaptive Management Plan

Based on the DPSIR analysis of three main issues, a transdisciplinary, co-designed and adaptive management plan was proposed and submitted to the two levels of government, both Rongcheng City and Dongchudao Village. Some of the suggestions proposed by this study have been adopted and implemented by the government.

Content of Management Plan

The first set of stakeholders discussed the three main issues about the sustainable development in Rongcheng to reach a consensus about potential responses to **Table 4**. They ranked the management options, in terms of urgency, as follows: 1) Reasonable breeding layout and standards; 2) Measures of conservation and restoration for vulnerable habitats; 3) Healthy aquaculture pattern; 4) Cultural conservation and marketing; with 5) Scientific research necessary throughout. They subsequently drafted a co-designed, adaptive management plan (**Figure 3**) based on the analysis.

Three aspects were considered in the plan, Science, Policy and Industry/Action. Research institutions and universities together led the implementation of scientific research with inputs from the community. They carried out literature reviews, field investigation and sampling, to monitor and assess the

ecological and environmental state. They advised the policy makers on how to implement specific measures, such as upgrading the aquaculture industry upgrading and shoreline resource restoration. The role of the government and administration is spatial planning, regulation, management and supervising the implementation of the response measures. The spatial planning includes land and coastal zoning, breeding areas and protected areas. Regulations include industry regulations, regulations for the protection of the coastline and seagrass meadows. They also include management and restoration, for example of seagrass houses. Representative enterprises/companies, research institutes/universities and community cooperate and are responsible for actions to implement the measures that are approved by the policy makers.

Implementation Progress

Aquaculture Planning: At present, based on but not limited to this study, the "Tidal Flat Planning for Aquaculture Waters in Weihai City (2018–2030) has been implemented, delimiting the tidal flat space for the aquaculture area (http://www.weihai.gov.cn/art/2020/2/25/art_51907_2277601.html)". The traditional aquaculture is shifting to green and sustainable aquaculture by successively enacted policies on Green Development, reflecting the great importance attached by the government at all levels to the construction of national modern marine ranches and the integrated multi-trophic aquaculture (IMTA) as the main management *response*. In Sanggou Bay, the ecosystem production was much more than the circulation of matter and flow of energy and the social benefits are higher than the private benefits after the application of IMTA, which is a promising way to minimize the disturbance of aquaculture to protect the ecosystem and improve economic benefits for stakeholders (Yu

et al., 2017; Sun et al., 2020). The aquaculture is going through an evolution from an extensive, traditional aquaculture to the current intensive, 3D farming method. Authorities in Rongcheng have been touting “China’s first 5G fish farm,” equipped with real-time camera technology provided by Huawei helping assist with feed management (Godfrey, 2019). Research institutions such as the Institute of Oceanology, Chinese Academy of Sciences, universities such as the Ocean University of China and aquaculture associations have provided scientific guidance to aquaculture producers and enterprises in areas such as stocking density, choice of which species to raise, and the most economic breeding method to follow (Wang et al., 2020). Aquaculture enterprises such as Shandong Homey Aquatic Development Co. Ltd. have promoted new aquaculture technology and trained local farmers in Rongcheng for sea cucumber breeding. As a result, the company has become one of the 10 biggest aquaculture companies in China, and Rongcheng has become the “National Sea Cucumber Breeding Standardization Demonstration Zone”.

Shoreline Restoration: The local and provincial governments have set up a series of stipulations and projects to protect and restore coastal habitats. In 2017, the city issued the local coastal ecological protection regulations, prohibiting coastal land reclamation and sand extraction in the coastal zone (http://www.rongcheng.gov.cn/art/2017/7/31/art_40961_1107178.html). Collaboration between research institutions, local governments and relevant enterprises has been initiated, and some engineering and ecological restoration projects have been conducted to protect the shoreline from further retreating (**Figure 2B**). The height of the revetment in the project was designed based on the maximum wave runup under the extreme climate conditions such as typhoons and storm surges. In 2019, the completed revetment successfully withstood the damage of Typhoon Lekima and prevented the erosion of the shoreline.

Seagrass Meadows and Seagrass Houses Conservation: Research institutions, local governments and relevant enterprises have jointly launched the ecosystem reconstruction project to implement the restoration and conservation measures, such as the seagrass seeds and seedling cultivation, and adult seedling transplantation in Swan Lake and Sanggou Bay of Rongcheng (<Http://www.ysfri.ac.cn/info/1756/35894.htm>). While restoring the seagrass bed habitat, it also improved the aquaculture ecological environment and developed an ecological farming pattern⁷ (Yang, et al., 2016; CAS STPDP, 2018). For the seagrass houses, the local government promoted the “Trial Measures for the Protection of Seagrass Houses in Rongcheng City” as early as 2006 (Ma, 2018) and set up tourist resorts and the village memory museums themed as seagrass houses. The Provincial Cultural Relics Bureau and the National Cultural Relics Bureau have successively funded and implemented two

phases of seagrass house restoration projects in the Dongchudao Village. These measures will contribute to the restoration of seagrass habitats and the protection of cultural heritage. Further research and practice of adaptive policies are vitally necessary to maintain the habitats and ecosystem services of seagrass meadows.

DISCUSSION

Stakeholder Engagement

In this study, transdisciplinary, stakeholder engagement ensured effective communications between administration, enterprise and scientists. The first set of stakeholders were invited or recruited by the initiator of this project, YIC-CAS, together with the Chudao Fishery Co., Ltd. of Rongcheng, and subsequently enlarged to include other relevant enterprises, scientific research institutes, local governments and industrial administrators. These stakeholders participated in the co-design of the adaptive management plan. The categories of stakeholders in this study were devised prior according to the typology of inputters, extractor, beneficiaries, affectees, influencers, and regulators (Newton and Elliott, 2016). Nevertheless, in retrospect, all these types are included. However, there is always a room for improvement, for the better engagement in transdisciplinary, participatory processes. For example, more face-to-face meetings and online forums should be consciously organized, and further stakeholders should be identified to ensure a balanced, equitable outcome.

As a result of the active stakeholder engagement, many successful measures or actions have been implemented as an outcome of this study. These include the restoration of the shoreline, the conservation of seagrass meadows and seagrass houses. This may be ascribed to the nested governance at all levels in China, from local to National and the strategic consulting role of scientists. This helps to advise decisions makers and informs industry. There is a deep trust of science that fosters strong links and cooperation among science, policy-makers and industry.

DPSIR Analysis for the Three Issues

The three issues were analyzed separately using the DPSIR framework (**Table 4**). However, they are not separate, as there are multiple interactions that became apparent in the issue definition process. The main *driver* of one issue may exacerbate the emergence of other issues, which in turn may produce the same *pressure* and *impact*. In this study, the development of aquaculture as the pillar industry of Rongcheng City is the dominant driving force for unregulated aquaculture. At the same time, the natural shoreline could be destroyed by the development of aquaculture ponds, and coastal seagrass habitats and traditional village are occupied, resulting in the other two issues. Furthermore, these issues share the same pressure and impact, such as waste water discharge and loss of income.

Some responses are appropriate for several issues, yet sometimes the response to one issue may have pressure or impact on another issue. Usually, scientific research is required for all issues. Strict aquaculture planning is also positive for aquaculture health and the

⁷The ecological farming pattern is a new model to achieve the goal of protection and sustainable utilization. In the text here it refers to the coastal ecological farms and ranches, which are designed and constructed based on ecological principles and modern engineering technologies (Yang, 2017).

protection of natural shoreline and seagrass meadows. However, shoreline or seagrass restoration projects will affect the aquaculture environment and fishery production.

Given the complexity above, the similarities and differences of DPSIR for the three issues were analyzed in detail by all the stakeholders involved in this study, opinions and suggestions from each group of the stakeholders were fully considered, and the priority of potential response (measures) were discussed together. These were vital to the formulation of the co-designed adaptive management plan.

The Adaptive Management Plan

As a model and epitome of coastal cities in China, Rongcheng city is being significantly affected by global climate change and human activities. An adaptive management plan is urgent to reduce the vulnerability and to support the sustainable development of Rongcheng city.

The transdisciplinary and adaptive management plan based on the integrative responses obtained from the DPSIR analysis has been co-designed by the scientists, representatives from the industrial association, and decision makers from the local government. The proposed responses are supposed to address the issues arising from human, natural and cultural factors on the whole. The delineation of aquaculture and protection zones could not only protect many habitats such as natural shorelines and seagrass meadows, but also regulate aquaculture behavior. The upgrading of the aquaculture industry and the development of cultural tourism could improve the breeding environment, increase the income of residents, as well as protect folk culture. The plan aims to address the local issues concerning sustainable development, providing an appropriate approach for the management of social-ecological systems of Rongcheng. The plan resulted from a two-phase learning process: 1) local managers and other stakeholders were engaged; 2) the practical actions were implemented, the management effectiveness were monitored, and the feedback knowledge were achieved. The plan framework is trans-disciplinary and co-designed. In an academic sense, it integrates the professional guidance of scientists from multiple disciplines such as biology, physics, and geology. Above all, it is transdisciplinary, with actors from research, government, local communities and industry entities. All the results of the analysis are not directly translatable into the plan but do make a contribution that is used by the local regulators in their plans and regulations, for example, Tidal Flat Planning for Aquaculture Waters in Weihai City (2018–2030), Coastal Zone Ecological Protection Regulations in Rongcheng City.

As the main management response, the construction of modern marine ranches is one of the most important measures for the upgrading of aquaculture and fishery industries in Rongcheng City. The adaptive management plan should have an effect through the “full chain design” at three different levels: Stakeholder cooperation; capacity building and appropriate governance. It is fundamental that the stakeholders were engaged to overcome the challenges in coastal environmental monitoring, remediation, and seagrass habitat restoration. The first priority is to agree on and co-develop the theoretical and engineering technology frameworks of

coastal protection and sustainable utilization. Capacity building is the next priority. Biologists working together with experienced workers from fisheries and aquacultures are urgently needed to co-develop selective breeding, resource conservation and processing of high output, value-added products. Finally, the science-policy-industry nexus should inform policy makers from national, provincial and local government. Together they will provide the knowledge basis to draft and enact policies and regulations that provide ecological environmental protection and remediation. These joint responses and measures will prevent shoreline erosion and coastal degradation, support seafood provision, revitalize traditional cultural heritage and stimulate the tourism economy. The integration of government, industry, scientific community and the public citizens will implement the transdisciplinary, co-designed and adaptive management plan for the sustainable development of Rongcheng city, in the context of climate change and human activities.

CONCLUSION AND FUTURE PROSPECTS

In this study, clear scientific questions were proposed, which were the three main issues regarding the sustainable development of Rongcheng city from the SAF analysis. Moreover, scientific methods and models were used, namely SAF procedure, DPSIR framework, and trans-disciplinary participation models from community, researchers, government and other stakeholders. Above all, detailed findings led to practical actions. The adaptive management plan was developed and some of the recommendations were adopted and enacted by the local government.

The frameworks of SAF and DPSIR complement each other and if used together can provide a better understanding of the social-ecological systems especially in coastal zone. This case study is a significant experiment to analyze the typical social-ecological systems in China, including stakeholder mapping (two groups), stakeholder participation, issues identification, DPSIR analysis, the formulating of the management plan, and the implementation of some responses (measures). Prior to the study, knowledge was fragmented by economic sector, sub-regions of Rongcheng, administrative departments and scientific expertise (environmental/social). The transdisciplinary approach resulted in more integrated knowledge of the issues and their interrelations. This knowledge synthesis contributed to a plan to solve these problems. The United Nations is currently initiating “The Decade of Ocean Science for Sustainable Development (2021–2030),” which aims at providing a common framework to ensure that ocean science can fully support marine nations to sustainably manage their Oceans. Stakeholders engaged in the study focused on the United Nations Sustainable Development Goals (SDG), especially in SDG 8.9, SDG 12.8, SDG13 and SDG14, for sustainable economic growth, full employment opportunities, and conserve and sustainably use of the coastal resources. In this context, the “Our Coastal Futures” strategy of Future Earth Coasts (FEC) promotes action towards the sustainable development of coasts

and is initiating a “Global Coastal Assessment” project. Chinese coastal cities are vulnerable in the context of climate change and intensified high-intensity human activities. The case study of Rongcheng is an ideal demonstration study site and a comprehensive paradigm for the global coastal assessment, which may contribute to the achievement of the 2030 UN Sustainable Development Goals at a local level. If successful, it can be scaled up to the provincial level (Shandong) and national level (PR China).

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

CT, HM, Z-JY, AN, and YoL designed the case study and analyzed the data. CT, HM, YuL, CF, and YoL wrote the manuscript. Z-JY, AN, and YoL provided invaluable scientific

comments and language editing. All authors read and approved the final version of the manuscript.

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