Vacancy analysis and layout optimization of Changdao natural protected area from the perspective of multi-objective collaboration

Shuai He[1], Tao Xia[1], Meixue Luo[2], Wenwen Li[1], Junxin Zhang[3], Yanxiang Li[3] and Shang Chen[1*]

[1]First Institute of Oceanography, Ministry of Natural Resources, Qingdao, China, [2]Fujian Provincial Key Laboratory of Coast and Island Management Technology Study, Fujian Institute of Oceanography, Xiamen, China, [3]Changdao National Marine Park Management Center, Marine Ecological Civilization Comprehensive Experimental Area of Changdao, Yantai, China

Research on vacancy analysis and spatial layout of protected natural areas has been carried out for many years around the world, but most of the research objects are land-type protected natural areas, while studies on Marine protected natural areas are relatively rare, and there are few cases to carry out integrated optimization research on spatial layout of protected natural areas. This study will take Changdao in Yantai, Shandong Province, China as an example, from the protection of how much? How representative? Where is it protected? Starting from the three problems, the vacancy analysis is carried out, and the integrated optimization research is carried out based on the existing spatial layout, aiming at the rescue protection, coordinated protection and forward-looking protection. The results show that the integrated and optimized Changdao protected area eliminates the protection vacancy, integrates the overlapping protected areas, optimizes the unreasonable protected space, alleviates the contradiction between protection and development, promotes the coordinated development of ecology and economy and society, and can provide a scientific reference for the integrated and optimized spatial layout of Marine protected areas.

KEYWORDS

marine, natural protected area, integration, optimization, spatial arrangement

1 Introduction

In recent years, under the combined impact of global climate change intensifying human activities, the ecological effects of unhealthy succession of natural ecosystems have negatively affected the quality of human life. It is therefore imperative to implement complete protection of natural ecosystems. Identifying a natural protected areas on a scientific basis would help
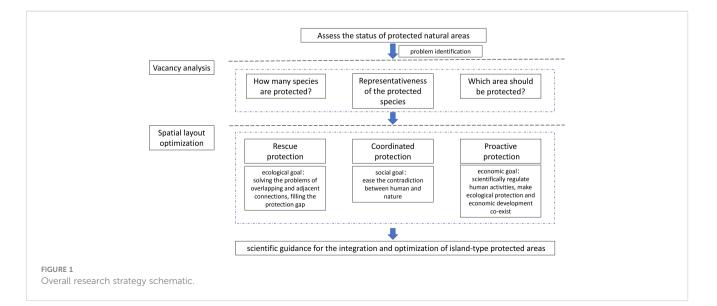
prevent the disorderly expansion of human exploitation (McNeill, 1994; Montesino Pouzols et al., 2014; Tittensor et al., 2019). China has established a system of natural protected areas mainly comprising of national parks in an aim to protect biodiversity, preserve natural heritage, improve ecological environment quality, and strengthen national ecological security. At the same time, these natural protected areas collectively play a key role in the supply of high-quality ecological products and the provision of public services such as science, education and recreation to the whole society (General Offices of the CPC Central Committee and The State Council, 2019; Tang et al., 2019; Tang et al., 2020). As the core area of marine protected areas (Hamid et al., 2021), islands sustain a mixed terrestrial and marine ecosystems (Shi et al., 2009), playing a basic role in maintaining biodiversity (Correia et al., 2021), regulating the productivity and material cycle of the island ecosystem, and are of high conservation value (Tilman et al., 1997; Hooper et al., 2004; Cardinale et al., 2006; Wei et al., 2008). Previous works on spatial layout of natural protected areas, however, are problematic (e.g. some biologic species together with their habitats were not included) due to the lack of scientific evidence.

The analysis of protected areas in both terrestrial and marine ecosystems (forests (Wang et al., 2010; Huang et al., 2014; Wang et al., 2018; Zhang, 2022), wetland (Wang et al., 2010; Huang et al., 2014; Wang et al., 2018; Zhang, 2022; Hong et al., 2023), desert (Lu et al., 2019), grassland (Liu et al., 2014), etc.), has been intensively studied over the past several decades (Huang et al., 2022). The protected areas in islands, however, have been rarely studied. Moreover, most of the existing studies are policy-oriented guidance, instead of detailed optimization scheme for spatial layout. China is promoting the integration and optimization of protected natural areas across the country, and relevant studies have emerged, mainly covering: (1) classification system and selection index system of protected areas (Gao et al., 2019; Hou et al., 2019; Ma et al., 2019; Qu et al., 2019; Tang et al., 2019; Chen and Jiao, 2020; Li et al., 2020; Ouyang et al., 2020; Tang et al., 2020a; Zhao et al., 2020); (2) basic ecological theory of integrated optimization of protected areas (Tang and Luan, 2017; He and Su, 2019; Lin and Zhou, 2019; Jiang et al., 2021; Tang, 2021);

(3) rules and procedures of integrated optimization (Ma et al., 2019; Qu et al., 2019; Huang et al., 2020; Li et al., 2020; Tang et al., 2020b; Gao et al., 2021; Liu et al., 2022);and (4) practice of integrated optimization (Shang and Wang, 2019; Liu et al., 2020; Liu et al., 2021; Luo et al., 2021; Weng et al., 2021; Zeng et al., 2021). Two shortcomings exis: (1) marine protected areas are less studied, in comparison with those on land. The boundaries of landscape units, such as mountains and forests, within the terrestrial ecosystem are clearly defined. In order to establish protected areas, the outer edge line of each landscape unit can be directly adopted. Comparing with those in island protected areas where most of the landscapes and protected items are under sea level.In order to facilitate the management and positioning of boundary point buoys, the outer boundary of the island protected area is predominantly linear. Some of the protected marine animals have long-distance migrating pathways, making it difficult to protect the whole area. Due to the inherent differences between marine and terrestrial ecosystems, the vacancy analysis and layout optimization methods of land-type protected areas may not be applicable to island protected areas; (2) There has been limited connection between vacancy analysis and layout optimization studies.

In this study, we conducted vacancy analysis to natural protected areas in the Changdao Island on three issues (Zhang and Sun, 2019): "how many species are protected", "representativeness of the protected species" and "which areas should be protected". We further optimize the existing spatial layout of protected areas by combining protection objectives at different levels, with a view to building an integrated optimization rule system applicable to protected areas on islands (Figure 1). Our results can provide new guidance for the integration and optimization of national marine protected areas.

2 Study area profile

Located between Liaodong Peninsula and Jiaodong Peninsula, the Changdao Island chain consists of 151 islands, spanning over 56.41 km from south to north and 30.81 km from east to west. The

FIGURE 1
Overall research strategy schematic.

total administrative area of Changdao Island is 3,301.97 km^2, including a land area of 59.25 km^2 and a sea area 3,242.71 km^2 (Figure 2). The Changdao Island chain is located on the East Asia-Australasia international bird migration route, providing a valuable resting place for migratory birds and migratory animals such as harbor seals and East Asian finless porpoises, This area therefore serves as a key "pump station" for the ecosystems in the Yellow Sea and Bohai Sea. The ecological importance of this area leads to the establishment of 9 different types of natural protected area (Figure 3; Table 1). However, there is a massive overlap in spatial layout among the 9 protected areas. For instance, one protected area was repeatedly claimed by the other 5 protected area (Wang et al., 2019). The sum of approved area of each protected area is 2,472.96 km^2, far exceeding its actual protected area is 1,894.65 km^2.

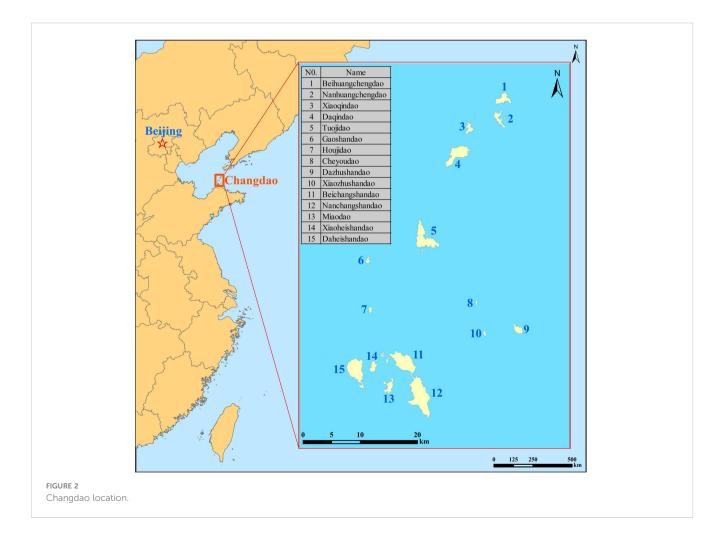## 3 Analysis of vacancies in protected area
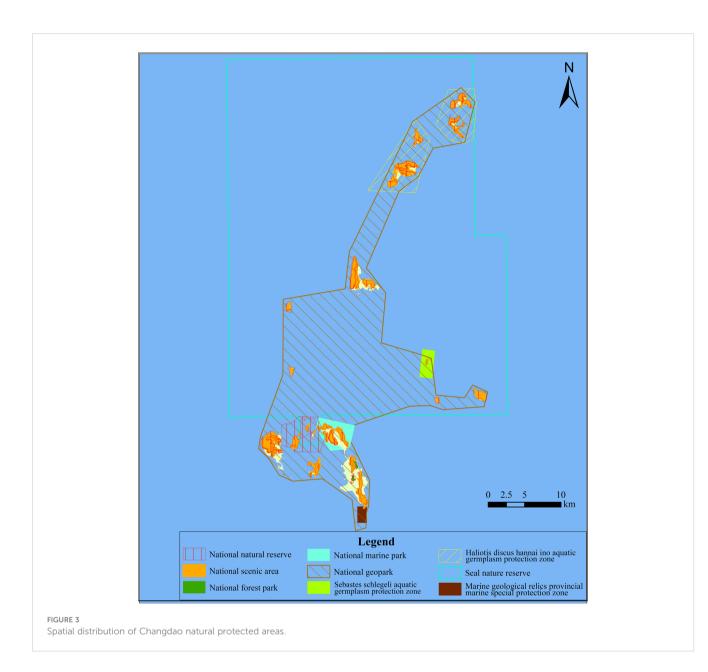
3.1 How many species are protected?

The Changdao Island chain is biological diverse. During the observation from May 2019 to October 2021, up to 3,543 biological species were found, including 1,541 species of plants and 2002

species of animals. Although there are many protected areas in this area, only the national nature reserve has been scientifically investigated. According to the historical statistics (listed in Table 2), most of the animals on land (excluding birds), birds, and marine animals discovered in Changdao have been protected by the Changdao National Nature Reserve, but less than half of the plant species have been protected, creating an apparent protection vacancy. This is possibly because the field investigation in 2016 had a small spatial coverage of the whole area. If all the existing protected areas are integrated as one in the future, it is necessary to update the protection list based on the latest scientific data and fill the protection vacancy. In addition, Changdao has abundant geological and cultural landscapes (Table 3) that have been formally protected.

3.2 Representativeness of the protected species

According to the latest "National Key Protected Wildlife List" issued in 2021, a total of 96 species of wildlife under national key protection have been found in Changdao, including 90 species of birds and 6 species of marine animals. Among these 90 species of birds, there are: (1) 21 Class I national key protected species

FIGURE 2
Changdao location.

FIGURE 3
Spatial distribution of Changdao natural protected areas.

including *Aythya baeri*, *Mergus squamatus*, *Otis tarda*, *Grus leucogeranus*, *Grus japonensis*, *Saundersilarus saundersi*, *Phoebastria albatrus*, *Ciconia nigra*, *Ciconia boyciana*, *Platalea minor*, *Egretta eulophotes*, *Aegypius monachus*, *Clanga clanga*, *Aquila nipalensis*, *Aquila heliaca*, *Aquila chrysaetos*, *Haliaeetus albicilla*, *Falco cherrug*, *Emberiza aureola*, *Grus vipio*, *Grus monacha*; (2) Class II national key protected 69 species, including *Anser albifrons*, *Cygnus olor*, *Cygnus columbianus*, *Cygnus cygnus*, *Aix galericulata*, *Podiceps auratus* and etc. Among the marine animals under national key protection, there are two Class I national protected species, namely *Phoca largha*, Western Pacific harbor seal, and *Balaenoptera acutorostrata*, minke whale. Class II national protected species: include East Asian finless porpoises (*Neophocaena sunameri*), killer whales (*Orcinus orca*), false killer whales (*Pseudorca crassidens*), and North Sea lions (*Eumetopias*

jubatus). In addition, a considerable number of *Gloydius changdaoensis*, a vulnerable species on the IUCN Red List of Endangered Species, has been found in the the Changdao Island chain. There are also some native populations of sea curiotica found in this area, such as *Haliotis discus hannai Ino*, *Strongylocentrotus nudus*, *Stichopus japonicus*, Besides, it is also an important habitat for important economic fish such as *Sebastes schlegelii*. According to the latest List of Key Protected Wild Plants issued in 2021, excluding cultivated plants, there are three species of wild vascular plants under national Class II protection namely *Zoysia sinica*, *Glycine soja* and *Glehnia littoralis*. In addition, several geologically and historically important landscapes are located in this area, including the sandbank that separates the Yellow Sea and Bohai Sea, the rarely-found island loess, coastline progradation and retreat, ancient societal relics and Mazu culture. According to the

TABLE 1 Information of Changdao natural protected areas.

	Name	Area (hm^2)	Main protected object
1	National natural reserve	5591.0	Eagles, falcons and other birds of prey
2	National scenic area	3542.0	Geological and geomorphic landscape (marine erosion and accumulation) Human landscape(Northern Mazu culture, Beizhuang ruins)
3	National geological park	54640.0	Geological geomorphology and geological structure landscape(marine erosion and accumulation, volcanic, geological hazard of collapse, island loess, natural stone painting, colored sphaerite) Ancient human cultural ruins
4	National forest park	5700.0	Forest vegetation, birds, snakes and other wildlife resources and other landscapes
5	National Marine park	1126.47	Pristine natural shoreline, Harbor seals and their important habitats, Jiuzhangya sea erosion landform, Crescent Bay pebble Beach
6	Haliotis discus hannai ino and strongylocentrotus nudus national aquatic germplasm resources reserve	2600.0	Haliotis discus hannai ino, Strongylocentrotus nudus, Stichopus japonicus and their key habitats
7	Sebastes schlegeli national aquatic germplasm resources reserve	700.0	Sebastes schlegeli and their key habitats
8	Provincial seal nature reserve	173100.0	Harbor seals and their important habitats
9	Changshanwei provincial marine geological heritage reserve	297.0	Changshanwei marine geological resources and marine ecological resources

main objectives of the existing protected areas, most birds, choice rare sea food, important economic fish, land animals, plants, geological heritage landscape and cultural landscape with important protection value have been included in the protection list, but among the marine animals under key national protection, only the Western Pacific harbor seal has been included in this list. Minke whales, East Asian finless porpoises, killer whales, false killer whales, and North Sea lions are still unprotected.

3.3 Which area should be protected?

As shown in Figure 2, long-distance migratory species such as birds and harbor seals, key protected plants, and coastal erosion landscapes are distributed in each island and its surrounding waters. The main protection areas for the native populations of sea treasures such as sea cucumber are Daqin Island, Xiaoqin Island, South Huangcheng Island and North Huangcheng Island. The protection area of the Sebastes is located in Cheyou Island. The main protection areas of Miaodao Gloydius are located in Nanchangshan Island, Beichangshan Island, Daheishan Island, Xiaoheishan Island and Miaodao Island. The boundary sandbank separating the Yellow Sea and Bohai Sea is located at the tail of Changshan Mountain in the south of Nanchangshan Island. The loess is mainly distributed in Daheishan Island and Tuoji Island. Beizhuang site is located on Daheishan Island; The main protection area of Mazu culture is located on the Miao Island.

At present, minke whales, East Asian finless porpoises, killer whales, pseudo-killer whales, and northern sea lions are still un-protected, and their living domains remain unclear. Surveys performed from 2019 to 2020 reveal that the East Asian finless porpoise appeared mainly in the waters to the east and west of the Changdao Island chain, demonstrating that there is still a total area of 575 km^2 uncovered by the existing protected areas. The living domains of Minke whales, orcas, pseudo-orcas, and Beihai lions remain poorly determined. Existing evidence only comes from fisherman's occasional witness. For example, minke whales have appeared in the northern waters of Beichangshan Island, orcas appeared in the northern waters of Beichang Island and the eastern waters of Tuoji Island, pseudo-orcas appeared in the eastern waters of Changdao Island, and Beihai lions appeared in the waters around Daqin Island and Nanhuangcheng Island.

TABLE 2 Changdao scientific survey data over the years.

		Time	2016	2019~2021	Proportion
		Scope	National natural reserve	Changdao	Proportion
Species Number		botany	730	1541	47%
	Animal	Land animals (excluding birds)	675	790	85%
		Birds	330	346	95%
		Marine animal	650	866	75%

TABLE 3 Conservation status of representative species and landscapes.

Representative protected target				Species/ Landscape	Protection State	Protected Area	Vacancy
Important species	animal		Birds	90	90	National natural reserve National forest park	\
		marine animal	national key protected species	6	1	National marine park Provincial seal nature reserve	5
			choice rare sea food	3	3	Haliotis discus hannai ino and strongylocentrotus nudus national aquatic	\
			Economically fish	1	1	Sebastes schlegeli national aquatic germplasm resources reserve	\
		terrestrial animal		1	1	National forest park	\
	botany			3	3	National natural reserve National forest park	\
Representative landscape	Geological heritage landscape		Yellow Bohai Sea boundary bar	√		National scenic area National geological park Changshanwei provincial marine geological heritage reserve	\
			Island loess	√		National geological park	\
			Marine deposition and erosion landscape	√		National scenic area National geological park National marine park	\
	human landscape		Beizhuang ruins	√		National scenic area	\
			Mazu culture	√		National scenic area	\

4 Optimization of protected area's spatial layout

In this study, the spatial layout of natural protected areas in Changdao will be optimized with the goals of "rescue protection", "coordinated protection", and "forward-looking protection". The goal of "rescue protection" is an ecological goal, which aims to integrate the overlapping of space and fill the protection gap. The goal of "coordinated protection" is a social goal, which aims to ease the contradiction between the protected areas and their surrounding residential communities, and promote the coexistence of ecology and society. "Forward-looking protection" is an economic goal, that aims to explore the economic benefit provided by these natural protected areas.
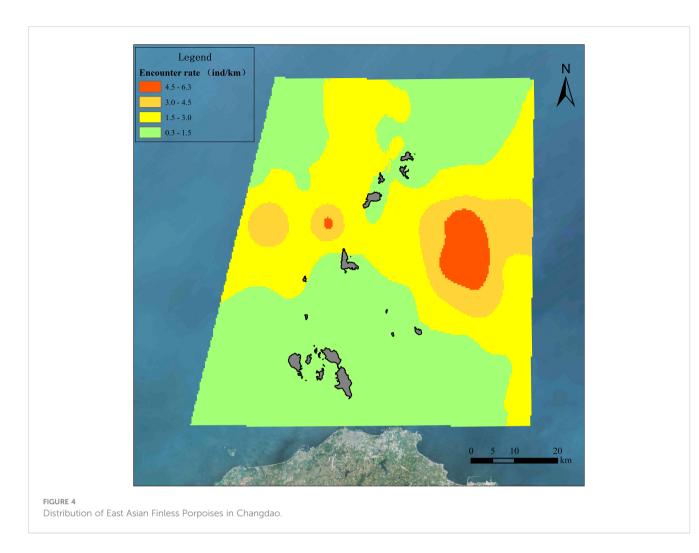
4.1 "Rescue protection" optimization

The "rescue protection" optimization aims to solve the problems of overlapping and adjacent connections, and to fill the protection gap. Following the guidance of relevant documents (Ministry of Natural Resources and National Forestry and Grassland Administration, 2020; He et al., 2021), the national nature reserve is treated as the main body, with the other 8 protected areas included, transforming the core protected areas and buffer areas of national nature reserve and provincial seal nature reserve into core protected areas, and the remaining areas are transformed into general control areas. The "protection gap"

area included in the protected area mainly considers the spatial coverage of waters where the East Asian finless porpoise appear most, which is located in the east and west sea areas in the middle of the Changdao Island chain (Figure 4) (Wang et al., 2019). This area is little disturbed by human activities, owing to the non-existing aquaculture or submarine pipelines, minor fishing activity that is concentrated mostly in September-April, and less shipping. This area, if protected, will largely improve the habitat for the East Asian finless porpoise (Figure 5).

4.2 "Coordinated protection" optimization

The optimization of "coordinated protection" aims to ease the contradiction between human and nature by adjusting the spatial layout of protected land. The Regulations of the People's Republic of China on Nature Reserves expressly stipulate that "only scientific research and observation activities are allowed in the buffer zone of nature reserves" and "tourism, production and business activities are prohibited in the buffer zone of nature reserves". However, the buffer zone of Changdao National Nature Reserve is filled with many human activities such as aquaculture and shipping (Figure 4). Due to the lack of overall consideration, the national geology park, the Miaodao Islands Provincial Seal Nature Reserve and other protected areas were incorporated into the protected areas at the beginning of their establishment. In particular, the Miaodao Bay area, which is surrounded by the five islands in the south, is intensively disturbed by human activities including raft, bottom seeding, cage farming, shipping, submarine pipeline maintenance, port channel dredging,

FIGURE 4
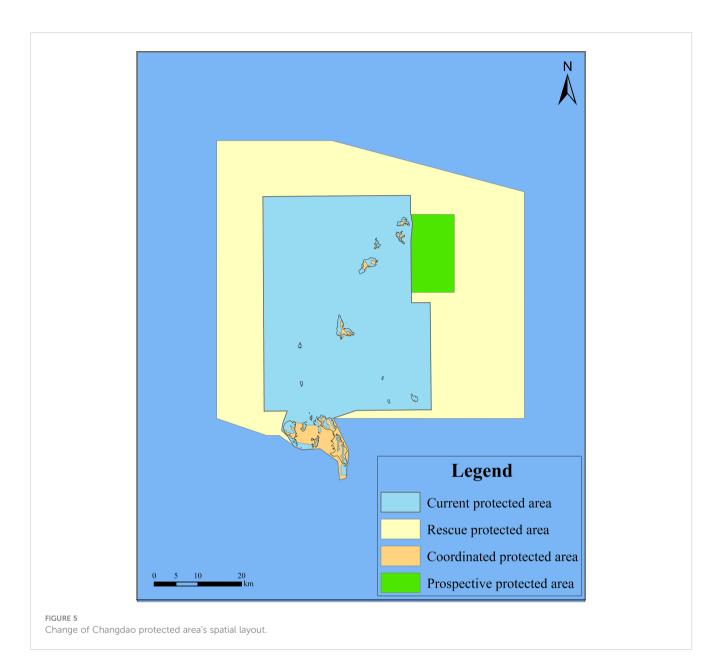Distribution of East Asian Finless Porpoises in Changdao.

urbanization, and etc. These sea waters have low protection value due to the substantial alteration from their original state, and will be a wasted of money if listed as a protected area. Moreover, the sea area is not the habitat for harbor seals, East Asian finless porpoises, and other economic sea production. Excluding it from the protected areas will not affect the inherent ecological connectivity of the sea area. It not cut off the migration route, and destroy the habitats for the key protected species. At the same time, excluding those human-dominated lands from the protected areas, (e.g., agriculture and fishery land, residential land, public facility service land, commercial service land), will not impact the protected targets but will help alleviate the contradiction between protected land and surrounding communities.

After the boundary of the protected area is determined, the internal partition is optimized. The core protected area is a key area to maintain the normal reproduction, and migration of rare animal populations. It is also an important area to realize the complete protection of the island land-intertidal and shallow sea ecosystem, and also an area to adopt the strictest control measures. In order to achieve effective protection of the main conservation objectives, the core areas and buffer areas of existing nature reserves shall be transformed. And original genuine, higher sensitivity to human activities, the forest park of ecological conservation area, the leopard seal, east Asia finless porpoises and active region of rare

and endangered Marine life and migration routes, trepang and wrinkles dish bao, light spines ball sea urchins and other marine products native populations the main distribution area of priority to delimit core protection area. All areas outside the core protected areas are included in the general control areas. This area also has high ecosystem authenticity and greater protection value, but it is difficult to implement the strictest control because of the high human disturbance, so it is included in the general control area control.

4.3 "Proactive protection" optimization

The "forward-looking protection" optimization aims to scientifically regulate human activities by adjusting the spatial layout of protected areas and using the management and control measures of protected areas, so that ecological protection and economic development can co-exist. Aquaculture and tourism are the two biggest contributors to the economy of Changdao. If all the aquaculture and tourism areas are excluded from the protected areas, the lack of control measures of the protected areas may lead to a protection crisis due to disorderly breeding and the surge in the number of tourists, and reduce the effectiveness of protection (in the history of Changdao, a large number of scallops died and a decrease in production in successive years due to the disorderly expansion of

FIGURE 5
Change of Changdao protected area's spatial layout.

aquaculture). Therefore, the concentrated distribution sea area (Figures 5, 6) located in the eastern part of the four islands in the north is included in the general control area of the protected area. The sea area is relatively open, with high flow velocity, and the aquaculture areas are in an open farming mode. This openness will not block the of migratory route for species such as harbor seals and East Asian finless porpoises. Moreover, this will not threaten the ecological environment. At the same time, the control measures of protected areas are used to scientifically control the scale and intensity of aquaculture and tourism based on the ecological environmental carrying capacity, to improve the aquaculture production and tourism services. At the same time, it can also rely on the brand effect and publicity advantages of the integrated national nature reserves or even national parks to provide more high-quality ecological products for the society.

After the above integration and optimization, nine nature protected areas in Changdao were merged into Changdao National Nature Reserve (Figure 7; Table 4), with a total area of 4,269.68 km^2, This area is 2375.03 km^2 larger than the previous one, with the core protected areas and general control areas respectively increased by 1723.1 km^2 and 651.93 km^2. The percentage of core protected areas increased from 17% to 48%, which will be favorable to sustain the authenticity and integrity of the ecosystem. After superposing the development and utilization status of the integrated and optimized protected area spatial layout, the cross-overlap in protected area space and the derived multiple management problems have been eliminated through the integrated optimization, the protection vacancy space of the important habitat of the East Asian finless porpoise has been filled, and the residential area with high human interference and low protection value has been transferred. It will be transferred into the concentrated distribution of marine pastures that will be an important production area of high-quality ecological products to promote development through protection, which can promote the

FIGURE 6
Development and utilization status of Changdao.

coordinated development of ecology, society and economy in Changdao.

5 Outlook

The purpose of this study is to explore an integrated optimization method applicable to natural protected areas on islands. This method can jointly protect the key protection objectives, promote the coordinated improvement of the social and economic development of the surrounding communities, and enable the local residents to benefit from ecological protection. Our method used in this study can provide scientific guidance for the integration and optimization of island-type protected areas in China and even in the world. In the future, there is still a high necessity to strengthen the following research directions: (1) At

present, China's system of natural protected areas are mainly divided into three types: national parks, nature reserves, and nature parks. Among them, national parks and nature reserves are further divided into core protected areas and general control areas, while the entire area of nature parks is general control area. In order to achieve fine management of natural protected areas, differentiated management strategies, such as time-sharing and zoning, can be explored based on the life history of the main protected objects and their sensitivity to human activities; (2) the habitats of marine organisms are not generally limited to a single natural protected area, especially for those long-distance migratory species. In order to protect the targeted species throughout their lives, further research on ecological corridors and network connectivity of protected areas should be strengthened; (3) In order to enhance the integrated optimization of protected areas on a scientific basis and explore more detailed methods, it is
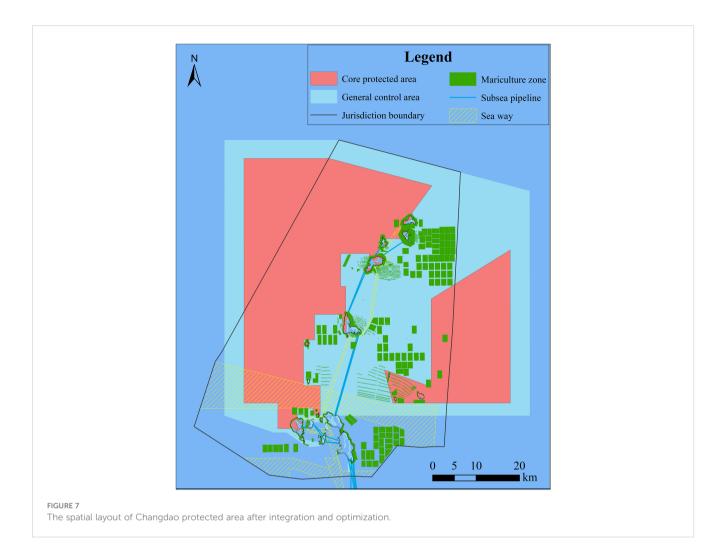
FIGURE 7
The spatial layout of Changdao protected area after integration and optimization.

TABLE 4 The area changes of Changdao protected areas before and after integration and optimization (km^2).

	Total	Core protected area		General control area	
		Area	proportion	Area	proportion
before	1894.65	328.09	17%	1566.56	83%
after	4269.68	2051.19	48%	2218.49	52%

necessary to improve the evaluation framework of ecosystem integrity and authenticity of protected areas; (4) In order to fully demonstrate and continuously track all aspects of the impact brought by the integration and optimization of protected areas, it is necessary to carry out studies on socio-economic impact assessment and performance evaluation of protected areas.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

SH: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft. TX: Data curation. ML: Methodology, Resources, Validation, Writing – review & editing. WL: Conceptualization. JZ: Data curation. YL: Investigation, Data curation. SC: Project administration, Investigation.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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