Landsc Ecol (2024) 39:4
https://doi.org/10.1007/s10980-024-01801-7

RESEARCH ARTICLE

Implications of policy changes for coastal landscape patterns and sustainability in Eastern China

Yafei Wang · Jinfeng Liao · Yuxuan Ye · David O'Byrne · Murray W. Scown

Received: 24 July 2023 / Accepted: 27 December 2023 / Published online: 18 January 2024

Abstract

Context The capacity of a landscape to maintain multifunctionality through ongoing pressures relates to its sustainability and is affected by land use policy and environmental changes. In coastal zones, limited empirical evidence exists regarding the impact of macro-level policy changes on local landscapes and their resulting temporal and spatial responses.

Objectives This paper investigates the impact of national and provincial policies on local landscape patterns in China's Zhejiang coastal zone, encompassing human expansion and ecological restoration in terms of landscape sustainability.

Methods A cluster-based landscape pattern mining is conducted from 1990 to 2020 using Google Earth Engine, which is coupled with a historical policy classification analysis.

Results Coastal zone policies evolved in three stages: development-oriented (1990–2010), conservation turning (2010–2017), and land-sea coordination (2017-present). Consequently, significant temporal and spatial differences in local landscape changes are observed. Artificial surface expansion aligned with these stages, especially in Hangzhou Bay, Xiangshan Bay, and Sanmen Bay. Expansion responded more swiftly to development-stimulating policies, exhibiting longer-lasting effects. Conservation policies faced delays due to conflicting interests, varied implementation entities, unsynchronized cycles, and a lack of coordinated conservation priorities across terrestrial and marine domains.

Conclusions This study provides insights into the processes and patterns of human expansion and ecological restoration in coastal zones, offering implications for coastal policies and landscape sustainability. It facilitates an evaluation of the effectiveness of coastal zone policy implementation and suggests differentiated sustainable transformation plans. Moreover, it underscores the need to strengthen

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10980-024-01801-7.

Y. Wang · J. Liao · Y. Ye
Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
e-mail: wangyafei@igsnrr.ac.cn

Y. Wang
Key Laboratory of Ocean Space Resource Management Technology, MNR, Hangzhou 310012, China

Y. Wang · J. Liao · Y. Ye
College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

Y. Wang · D. O'Byrne · M. W. Scown
Lund University Centre for Sustainability Studies (LUCSUS), Lund University, Lund 22362, Sweden

Y. Wang (✉) · D. O'Byrne · M. W. Scown
Lund, Sweden

coordination between sea and land development for effective coastal zone management and sustainability.

Keywords Coastal zone · Policy evaluation · Landscape pattern · Time series · Land-sea coordination · SDGs

Introduction

Coastal landscapes are important and complex places for sustainability in a changing world (Nicholls and Cazenave 2010; Von Glasow et al. 2013; Scown et al. 2023b). Coastal zones are characterized by high population density and rapid economic growth, with more than 50% of the population and over 80% of metropolitan areas, globally, located within 100 km of the coastline (Halpern et al. 2019; Tu et al. 2022); the flat, fertile plains of coastal landscapes are highly important for food production; and coastal ports create hubs for global trade through shipping. In recent decades, however, global climate change and human activities have led to significant changes in the land use (LU) function and structure of coastal landscapes as well as in the hazards they face (e.g., sea-level rise, cyclones, etc.). These changes have resulted in issues such as nearshore water pollution, salinization, loss of ecological diversity, wetland degradation, land subsidence, and coastal inundation and erosion (Nicholls and Cazenave 2010; Mentaschi et al. 2018; Goldberg et al. 2020; Murray et al. 2022; Lincke et al. 2022). These dynamics play out through spatial patterns in coastal landscapes and the challenge of maintaining critical landscape functions in the face of high exposure to hazards and rapid socio-economic and environmental change (i.e., coastal landscape sustainability) requires prudent spatial landscape planning and coastal zone policies (Loizou et al. 2014; Fan et al. 2018; Gussmann and Hinkel 2021; Bazant-Fabre et al. 2022). Understanding the impacts of coastal zone policies on landscape patterns, and how these patterns might affect future risk and sustainability, are important steps towards guiding sustainable governance of coastal zones.

Previous research has yielded rich information on the effects of coastal zone policies around the world, yet has been limited in two ways that we advance in this study: (1) limited consideration of multiple interacting policies and multiple social and ecological outcomes in coastal landscape patterns; and (2) lack of spatially-explicit insights into landscape patterns and structure, multifunctionality, and consequently hazard exposure. To explain the first limitation, the relationship between coastal zone policies and their impacts can be classified into four types: one-to-one, one-to-many, many-to-one, and many-to-many. Existing studies mostly focus on the first two types, assessing the impact of specific coastal zone policies on one or more objects, such as the impact of marine protected area policies on biodiversity or land use functions (Cheng et al. 2021; Wang et al. 2022a). Many-to-one studies typically analyze the impact of multiple policies on a particular phenomenon, such as the expansion of aquaculture ponds or the restoration of wetlands (Vélez et al. 2018; Lou et al., 2022). The many-to-many type involves assessing the impact of multiple regional policies on multiple historical observations, often considering different types of coastal zones that aim to balance development and protection (Loizou et al. 2014). As coastal zone policies encompass multiple aspects of socio-ecological systems, many-to-many research often holds greater policy guidance value, which is often overlooked in previous studies. Existing methods for assessing the impact of coastal zone policies fall into three main categories: econometric models, scenario simulations, and coupling analysis. Commonly used econometric models include input-output models (Loizou et al. 2014), structural equation models (SEM) (Wang et al. 2022a), and the double-difference method (DID) (Cheng et al. 2021). While these models are frequently employed to assess the impact of coastal zone policies, they often overlook spatial differences and are limited to one-to-one or one-to-many policy analyses. Scenario simulations are useful for analyzing the impact of dominant policies or specific policies, but they are often highly uncertain, challenging to apply to many-to-many policy analyses, and fail to capture the coupling effect between policies (Guo et al. 2015; Strokal et al. 2017; Shih et al. 2022).

While it is crucial to monitor and evaluate the long-term implementation effects of coastal zone policies, few studies have utilized long time-series analysis methods to assess the historical evolution of multiple policies on multiple LU functions (i.e., many-to-many) in a spatially-explicit framework to analyse their impact on landscape patterns. This knowledge gap is mainly due to limitations in

long time-series data, spatio-temporal mining techniques, and platforms. However, the availability of remote sensing big data platforms such as Google Earth Engine (GEE) has made it possible to monitor and analyze human expansion and ecosystem changes in coastal zones over an extended period. Based on this capability, evaluating the effectiveness of different types of coastal zone policies implemented in different historical periods becomes feasible (Duan et al. 2020). Policy coupling analysis also provides an approach for evaluating historical policies and can analyze the impact of multiple policy types from multiple dimensions. This analysis is typically conducted through time-stage division or by extracting key time nodes for comparison with alterations in specific goals or outcomes. It helps decision-makers learn from existing policies and understand the objective laws that exist during policy implementation (Bao et al. 2019; Wang et al. 2021a).

In this study, the coastal zone of Zhejiang Province, China, is selected as a representative case study area that epitomizes the historical development and protection of coastal zones in China. This area has undergone three distinct stages, transitioning from encouraging coastal zone development in the past to implementing protection policies to prevent ecological degradation, and eventually striving for a balance between development and protection. Following an extensive process of policy collection and review, we meticulously categorized the selected policies based on expert discussions. Then, a long-term LU classification data spanning a 30-year period from 1990 to 2020 was used to identify landscape functions and delve into landscape pattern mining analysis. Furthermore, the study integrates the obtained findings with the spatiotemporal landscape patterns and evolution of coastal zone policies to assess their interaction on human expansion and ecological degradation. The research examines different coastal zone policies, with a particular focus on the impact of sea-land incoherence on the effectiveness of policy implementation. We aim to answer the following scientific questions and frame the paper accordingly: (1) How can we categorize and phase coastal zone policies with a focus on sustainability, (2) Have distinct spatial and temporal patterns emerged in coastal landscape changes, and (3) Are these patterns related to policy changes?

Study area and data

Study area

The Zhejiang coastal zone is located in the southeast coast of China, adjacent to the Yangtze River Estuary in the north and the East China Sea in the east (Fig. 1). It includes eight major cities ranging in population from 1.16 to 12.0 million inhabitants—Hangzhou, Huzhou, Jiaxing, Zhoushan, Shaoxing, Ningbo, Taizhou, and Wenzhou. The study area's boundary used here is extended by adding a buffer zone of 10 km towards the sea on the basis of the administrative boundaries. The total length of the coastline is more than 6,600 km, accounting for 35% of China's national coastline length. The northeast and south coastal areas encompass vast plains, while the remaining areas are dominated by mountains and hills. The Zhejiang coastal zone includes bedrock coast, sandy coast, and muddy coast, with bedrock coast as the main coast, accounting for 80%. The bedrock coast has a deep coastal water depth and stable underwater terrain, naturally forming many natural harbors that penetrate deep into the land. From north to south, there are six bay areas including Hangzhou Bay, Xiangshan Port, Sanmen Bay, Taizhou Bay (Jiaojiang Estuary), Yueqing Bay, and Wenzhou Bay (Oujiang Estuary). There are four primary rivers in the study area: the Qiantang, Ling, Jiao and Ou Rivers. The coastal zone falls within a typical subtropical monsoon climate zone. Affected by the westerly and easterly winds, typhoons, waves, and tsunamis occur frequently, making it one of the provinces with the most serious marine disasters in China.

As a strong maritime province and a pioneer in reform and development, the development and policy innovation of Zhejiang's coastal areas have been at the forefront of the country, and its practical experience has provided important lessons for other coastal provinces. At the beginning of this century, the country and Zhejiang Province published a series of development policies to promote the development of marine economy. In 2003, the State Council issued the "Outline of National Marine Economic Development Plan", which is a programmatic document to guide the development of the national marine economy. In response to the national call, Zhejiang province also issued the "Outline of the Strong Marine Economic Province Construction Plan in Zhejiang"

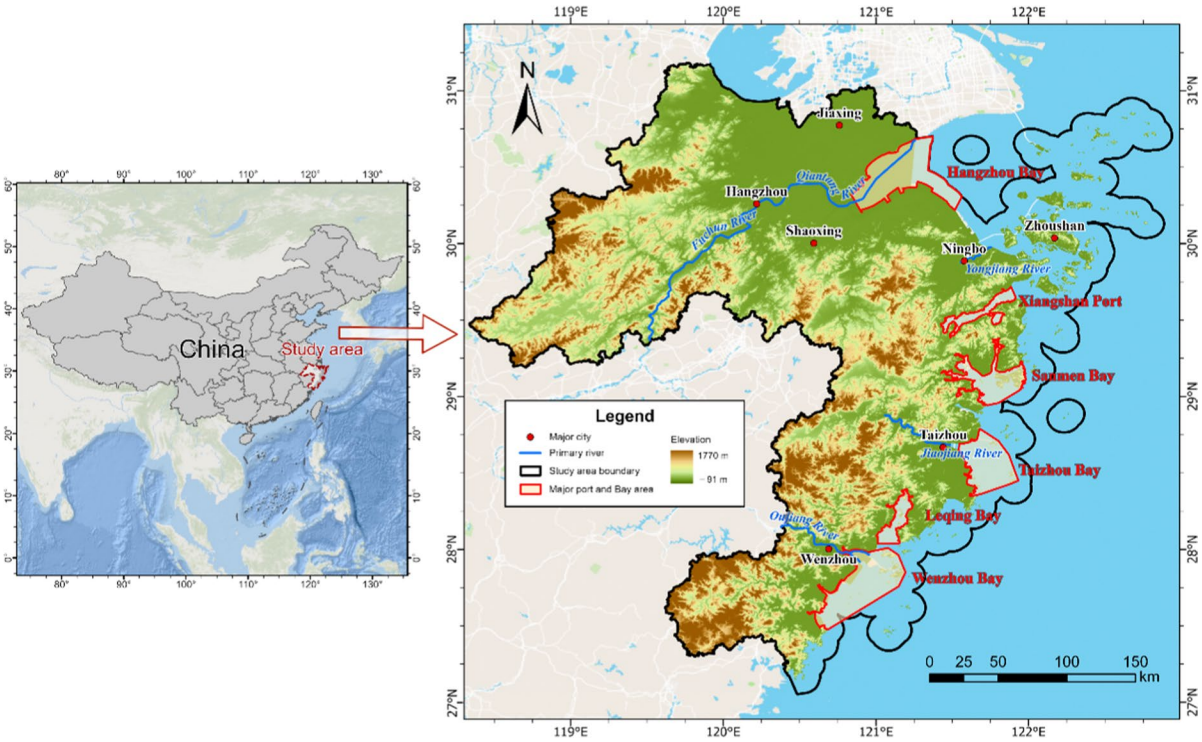

Fig. 1 A map providing an overview of the study area

in 2005. Encouraged by the policy, the population and economy of the coastal areas continue to gather. In 2020, the coastal population of Zhejiang Province reached 52.8 million, and the total GDP accounted for 88.28% of the province's total. As a result, the intensity of development of the coastline and near-shore sea areas are constantly increasing.

The contradiction between protection and development of the coastal zone has also become increasingly prominent. Studies have shown that the coastal zone of Zhejiang is one of the main reclamation areas in China, and the reclamation in Hangzhou Bay is particularly intense (Meng et al. 2017). The coastal waters are seriously degraded, with more than half of the seawater in a severe state of eutrophication (Jiang et al. 2018). In order to alleviate the degradation of the coastal ecological environment, the national and provincial governments have introduced a series of coastal zone protection policies, including among others the "Blue Barrier Action Plan of Zhejiang Province" in 2011; the "Marine Environment Protection Law" amended three times in 2013, 2016 and 2017; and the "Procedure for Protection and Use of Coastlines" issued in 2017. The promulgation and implementation of these policies has promoted the transformation of the country's coastal development from pursuing high-speed growth to harmonious and steady development, and has also formed a coastal zone management policy system that emphasizes land-sea coordination and sustainable development in the new era.

Data sources

The research data comprises three major components. The first part consists of fundamental geographic information for Zhejiang Province, which includes administrative unit data in 2004 and 2020, bay boundary data, and digital elevation model (DEM) data. Specifically, the administrative unit and bay boundary data are obtained from the Zhejiang government, and the DEM data is derived from the SRTM (Shuttle Radar Topography Mission) dataset.

The second part includes multi-source remote sensing images, auxiliary data for land use classification on GEE, and historical land use classification

data. The available Landsat TM/ETM/OLI images from 1990 to 2020 were filtered using two specific criteria. Firstly, the data acquisition was limited to two periods: June-October (vegetation period) and November-March (vegetation yellowing period). Secondly, only images with cloud cover less than 15% were considered. Following the rigorous screening process, a total of 1284 high-quality Landsat images were obtained. The historical Landsat images were used to calculate various spectral indices and were used together as input to the classifier. Auxiliary input data includes the VIIRS (Visible Infrared Imaging Radiometer Suite) nighttime light data, SRTM DEM data, and FLDAS (Famine Early Warning Systems Network Land Data Assimilation System) climate data. The auxiliary data were collected, resampled to 30 m, and snapped to Landsat image pixels on the GEE. Based on the research team's previous work on remote sensing image classification (Shen et al. 2022; Wang et al. 2022b), the LU classification was carried out using random forest classifier on the GEE, and post-processed using a bidirectional spatiotemporal consistency detection method. Supplementary Material (SM1) contains a detailed description of the LU classification approach and data quality.

The third part encompasses a series of coastal policies and socio-economic statistics issued by national and local governments over the past 30 years. These data were sourced from public information websites of relevant ministries and commissions such as the State Oceanic Administration, the Ministry of Ecology and Environmental Protection, and local governments. We have supplemented some important national-level plans through discussions with these departments. We also categorized the government data based on their respective goals. A detailed directory of the policies is given in the supplementary material (Table S1).

Methodology

This study comprises four major components: (1) policy classification and stage division, which extracted policy characteristics and classified according to the three dimensions of landscape sustainability, and divided evolution stage according to the long-term distribution of policy types; (2) provincial-level landscape function analysis, which classified landscape function into urban (artificial surface), agriculture (cropland), ecology (natural land) according to landscape sustainability, and identified the regions with drastic changes and conflicts; (3) Landscape pattern mining in the Bay areas, which used time series clustering method to reveal the spatio-temporal patterns of human expansion and ecological degradation; (4) coupling analysis of policy transformation and landscape pattern change, which divided the dominant policy types and evolution periods, and evaluated the response of landscape pattern change to policy change. The overall flowchart is shown in Fig. 2.

Policy classification and stage division

In examining the intricate web of transference and implementation relationships within coastal zone policies, our study zeroes in on the transformative effects of high-level policy shifts on local landscapes. Consequently, we've honed our focus to coastal zone policies enacted at the provincial level and beyond, serving as our primary filter. We sorted out and classified coastal zone policies implemented in Zhejiang from 2000 to 2020. This was achieved through government website retrieval and local research. Essential attributes of each policy, such as release time, release subject, action target, policy orientation, and validity period (if applicable) were carefully documented. A detailed information of policy attributes is referred to Supplementary Material (SM2). The issuing agency includes the State Council, national-level ministries and commissions, as well as provincial-level local governments. The action target was classified based on its focus on either the land side or the sea side of the coastal zone. The policy orientation was categorized as development-oriented, protection-oriented, or a balance between development and protection. We align different policy orientations with distinct dimensions of landscape sustainability by adopting Wu's conceptualization (Wu 2006, 2013, 2021). Development-oriented policies focus on social and economic sustainability, protection-oriented focus on ecological or environmental sustainability, and the integrated policy for protection and development focuses on coordinating the relationship between three dimensions (Frazier et al. 2019; Liao et al. 2020; Wu 2021). The action target and policy orientation were determined through expert

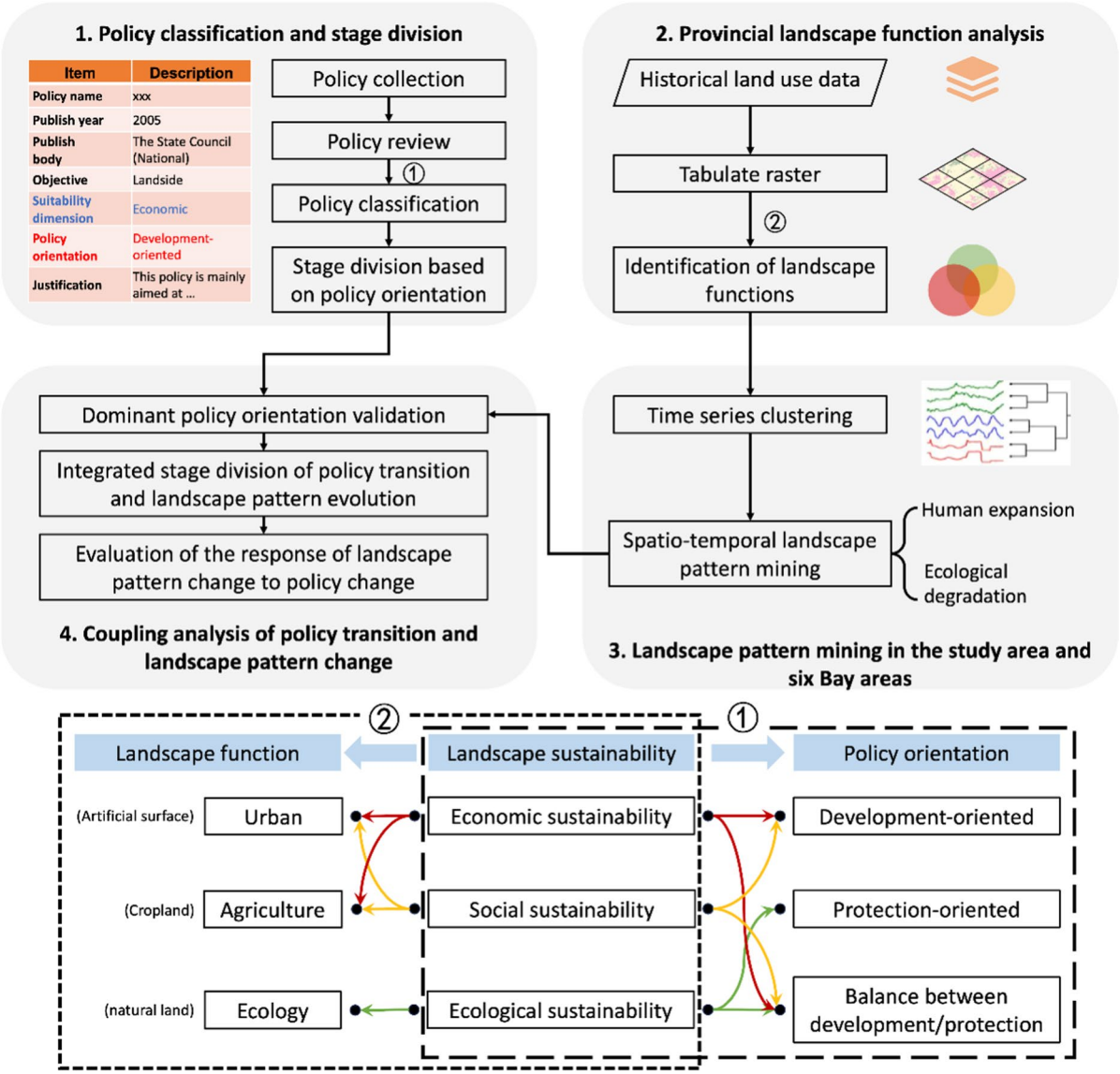

Fig. 2 Overall technical flowchart

discussion and based on specific criteria including the policy title, frequency of keywords (e.g., protection, development, coordination), and policy priorities. Note that periodic policies like the "Five-Year plan" were excluded when collecting relevant policies. Such policies are remarkably comprehensive, and their stable release frequency implies limited adjustments, leading to relatively little explanatory power for policy transformation. Finally, the policy evolution stages are divided based on the changes in policy orientation over a long period of time.

Cluster-based landscape pattern mining

Time-series clustering is a powerful tool in recognizing dynamic changes and detecting correlations between time-series. The annual classification results were cross-tabulated using a hexagon with a 1 km side length, followed by spatial and temporal aggregation (Wang et al. 2022b; Ye et al. 2022). Each grid cell records a curve of historical LU fraction for the site. Since the study area was divided into over thirty thousand grid cells, direct clustering would

be computationally intensive and time consuming. Therefore, the CLARA (Clustering LARge Applications) algorithm (Kaufman and Rousseeuw 1990) was used to mine the landscape patterns, which extends the Partitioning Around Medoids (PAM) algorithm to handle large datasets more efficiently.

We used the Euclidean distance to quantitatively express the similarity between different time series. This is one of the most widely applied lock-step (one-to-one) measurements for clustering time series. Let $F^i_{1:n} = (F^i_1, \ldots, F^i_n)$ denote a time series of areal proportion of specific LU type in grid i with length n, and the Euclidean distance $dist(i,j)$ between it and another time series $F^j_{1:n} = (F^j_1, \ldots, F^j_n)$ can be expressed as:

$$cdist(i,j) = \sum_{t=1}^{n} \sqrt{\left(F^i_t - F^j_t\right)^2} \quad (1)$$

where $dist(i,j)$ represents the similarity between grid i and j, n represents the length of the time series, t represents the t-th time point in the sequence, F^i_t and F^j_t respectively represent the areal proportion of grid i and j in the t-th time point.

The calculated time series clusters are a condensation of related or homogeneous sequences, with minimal intra-cluster differences that can reflect the average changing characteristics of all individuals within the cluster, which helps identify grid cells with similar LU changes. Additionally, we identified the overall characteristics of each time series cluster based on changes in slope and detected change points.

Coupling analysis of policy transition and landscape pattern changes

The coupling analysis in this paper differs from previous studies, employing clustering at various scales and aggregating different spatial unit types. Our focus spans two levels: the provincial and the key area (Bay area). On the provincial level, we examine three fundamental landscape types—urban, agricultural, and ecological—aligning with distinct dimensions of landscape sustainability. This analysis enables a swift identification of key areas exhibiting conflict and change in landscape functions.

Shifting to the key area level, our attention turns to more detailed landscape changes, encompassing reclamation, aquaculture ponds, and coastal ecological restoration. Additionally, at the policy level, we traversed all spatial units where policies could be implemented, subdividing them based on district and county units into functional zone types. Each functional zone type correlates with almost distinct dimensions of landscape sustainability at the policy level. Consequently, the policy aspect encapsulates vital information such as the stage of policy evolution, key nodes, and overarching objectives compared to those of the functional zones.

In terms of landscape response, we present the clustering and aggregation outcomes for basic landscape types at the provincial level and specific landscape types at the key area level. This approach enhances the clarity and coherence of the study's structure and facilitates a more seamless understanding of the coupling analysis.

Hence, we translate the coupling between policy and landscape changes into an examination of the correlation and alignment of landscape changes across various levels and spatial units with the stages of policy evolution, key nodes, and overarching goals of functional zones. Throughout this process, we employ a blend of qualitative and quantitative analysis methods. This integrated approach allows for a comprehensive understanding of the intricate relationship between policy transition and landscape pattern changes.

Results

Policy classification results

Detailed policy formulation can play a constraining role on territorial space planning. In order to adapt to the changing coastal environment, socio-economic conditions and development requirements, coastal zone policies are often updated during periods of intense land use conflicts. Since 2000, the state and Zhejiang Province have issued seven land policies and nine marine policies in the coastal zone area. Based on the review of policy orientation changes, we identified three periods of policy evolution: development-oriented period (2000–2010), conservation turning period (2010–2017) and land-sea coordination

period (2017-present) (Fig. 3). A smaller number of policies were issued during the development-oriented period to encourage the exploitation of marine resources and the development of the marine economy (SM2), while also relaxing the constraints on various development activities in coastal areas. However, rapid economic development and industrialization promptly changed the coastline landscape and wetlands, generating threats such as biodiversity loss and ecological degradation in coastal zone, which posed new challenges to land use decisions. As a result, during the conservation turning period, governments and the public became increasingly concerned about the ecological and environmental conditions of coastal zone areas, and emphasized conservation planning for coasts, oceans and islands. For example, the *National Marine Functional Zoning Plan* issued in 2012 emphasizes the protection of the marine ecological environment, while the *Regulation, Restoration, and Protection Plan for the Coastal Zone and Islands in Zhejiang Province* issued in 2014 emphasizes the protection of resources and ecological environment of sea islands. The rapid frequency of policy adjustments after 2010 (Fig. 3) reflects the transformation of the understanding of sustainable development. The policies promulgated during the latest period—land-sea coordination—were mainly aimed at balancing the protection and development of coastal zone resources, so as to scientifically plan the functional structure of the area based on its "best use" and to resolve conflicts between different stakeholders. The policies on the both sides of the timeline in Fig. 3 reflects the positive response of provincial policies to national policies. For example, in 2012, in response to the *National Marine Functional Zoning Plan*, Zhejiang Province issued the provincial marine

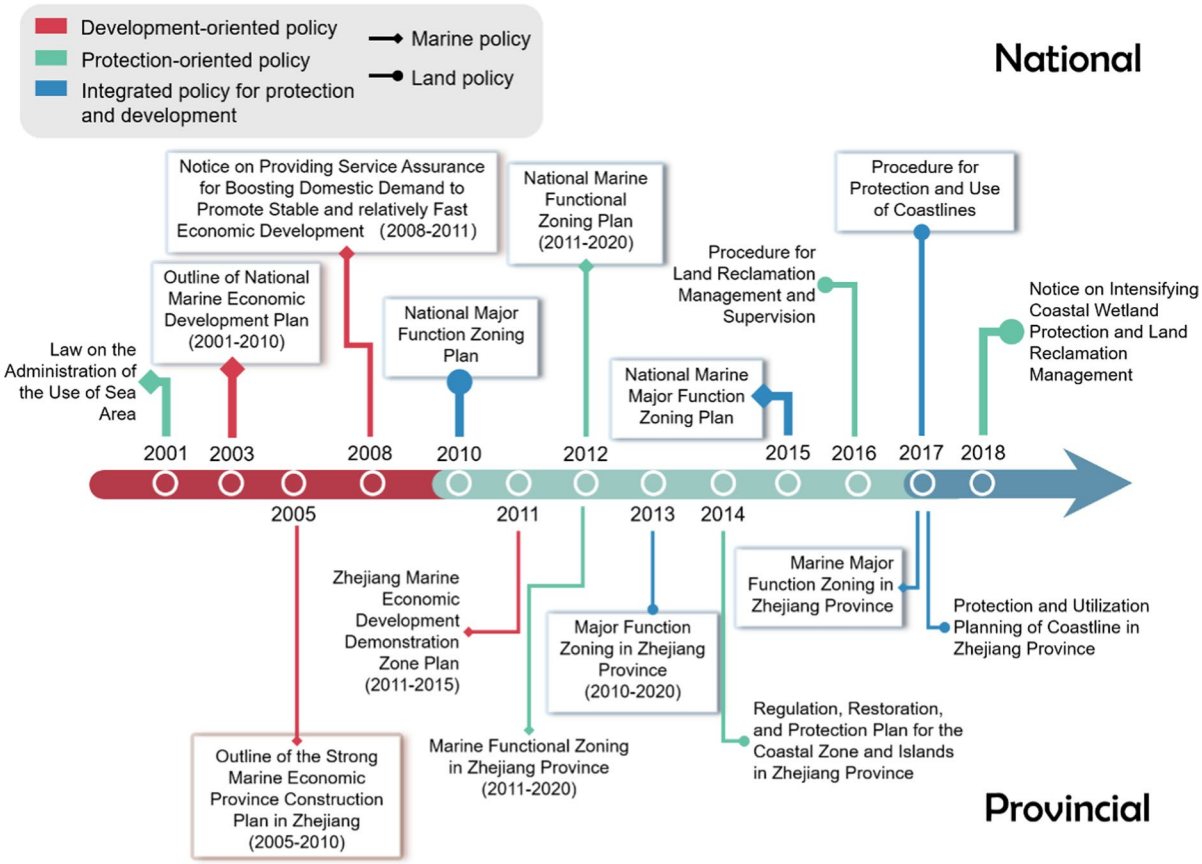

Fig. 3 Timeline of coastal zone protection and development policies in China (above the line) and Zhejiang Province (below the line)

functional zoning; in 2013; *Major Function Zoning in Zhejiang Province* was issued in response to the *National Major Function Zoning Plan* issued in 2010; and in 2017, *Marine Major Function Zoning in Zhejiang Province* was issued in response to the *National Marine Major Function Zoning Plan*. These policies help to scientifically approve sea projects, promote the protection of ecosystems in coastal areas, guide the restructuring of marine industries, and promote the orderly development of land and sea development patterns.

Provincial-level clustering results

The land use classification results on the coastal zone of Zhejiang from 1990 to 2020 is presented in Fig. 4. The area of artificial surface was relatively small in 1990, accounting for only 1.05% (975.96 km^2) of the entire region, while the proportion of cropland was as high as 24.17% (22435.98 km^2). After three decades of development, the areal proportion of artificial surface increased to 8.23% (7641.19 km^2), while the counterpart for cropland decreased to 16.96% (15738.63 km^2). The concentration of artificial surface is most pronounced in Hangzhou and Ningbo, while central cities like Jiaxing, Wenzhou, and Taizhou show a patchy distribution. The distribution of artificial surface in Hangzhou Bay, Taizhou Bay, and Wenzhou Bay is the most intensive, while the other three bays have not yet reached such levels of intensity. Cropland is mainly distributed in coastal plain areas, especially in Jiaxing and Huzhou. A certain amount of cropland is distributed in the periphery of Shaoxing, Ningbo, and Taizhou. As for aquaculture ponds, they cover only 0.35% of the entire study area, primarily occupying the vicinity of Sanmen Bay, with sporadic occurrences in other bays. Natural land is mostly distributed in mountainous and hilly areas far from the coast.

Five classes of landscape pattern change emerged from the clustering analyses for each of the three land use types (Fig. 5). These classes (I–V) represent increasing fractions of artificial surface (Fig. 5a), cropland (Fig. 5b), and natural land (Fig. 5c), respectively, within each class. From the clustering results, the landscape pattern of the coastal zone in Zhejiang Province has changed significantly in the past three decades.

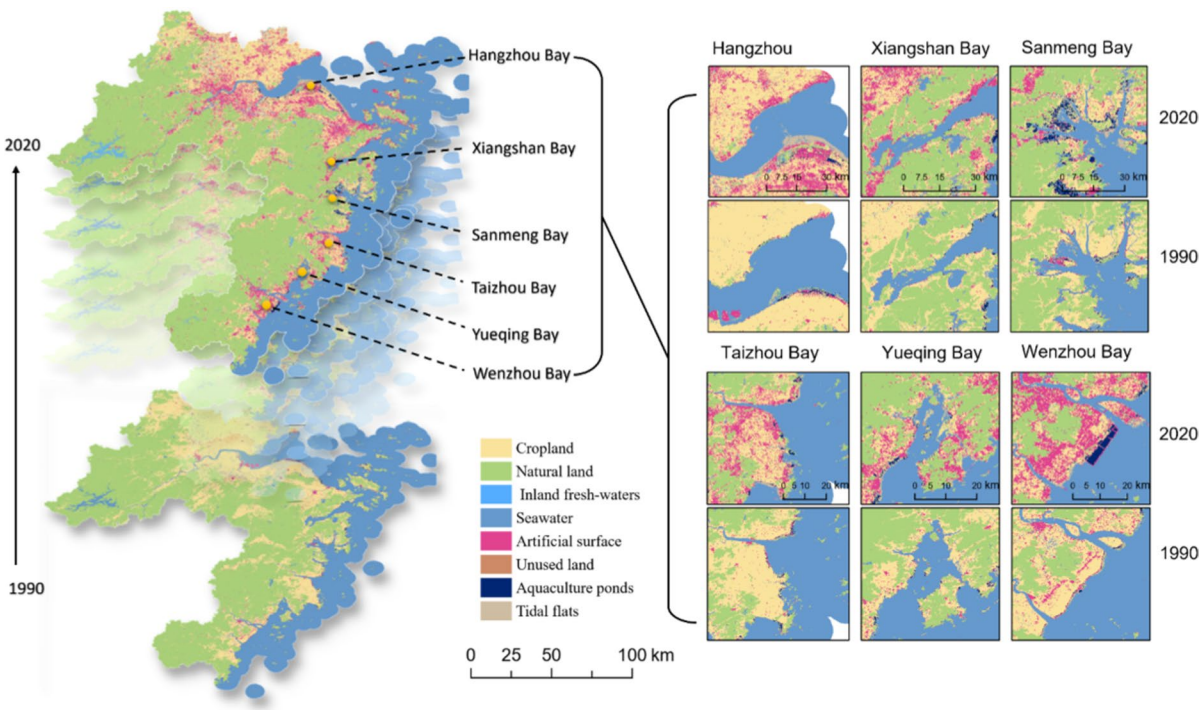

Fig. 4 Mapping of classification results in the coastal zone of Zhejiang

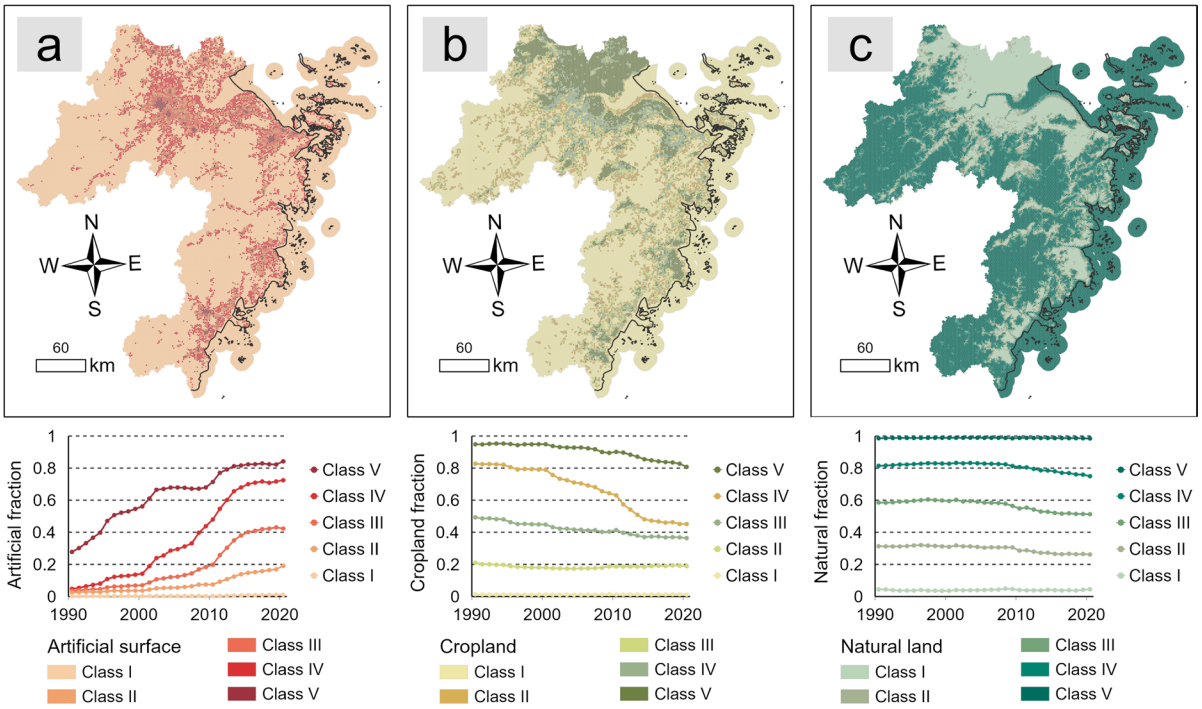

Fig. 5 Time series clustering results of artificial surface (**a**), cropland (**b**), and natural land (**c**)

An observable pattern emerges in the distribution of artificial surfaces, indicating a predominant northward trend compared to the southward direction. Additionally, the proximity to the sea exhibits a stronger prevalence of artificial surfaces compared to inland areas. Notably, the shoreline serves as a defining axis, with the expansion of artificial surfaces occurring in both the seaward and landward directions, and the expansion area concentrated on both sides of the four primary rivers in the area—the Qiantang, Ling, Jiang and Ou. (Fig. 5; see also Fig. 1). Artificial surface has grown in the past three decades, with a relatively slow growth rate before 2000 (except for Class V) and two marked accelerations in expansion around 2000 and 2010, particularly for Classes II–V (Fig. 5a). In 1990, the fraction of artificial surface was similar across Classes I–IV and very low compared to Class V; however, by 2020, Classes III and IV had clearly surpassed the highest Class V's fraction in 1990, and Class II was rapidly approaching it (Fig. 5a). In contrast to artificial land, cluster result classes for cropland and natural land showed very little growth in these land uses during any period and mostly gradual decline was observed (Fig. 5b and c). The exception to this "gradual" decline is cropland Class IV, which showed a reduction in cropland fraction by almost half, accelerating first around 2000 and again around 2010 (Fig. 5b).

Bay-level clustering results

Figure 6 shows the spatial distribution of change in seawater, aquaculture pond and artificial surface area within the hexagonal analysis cells throughout the six bays. In the clustering results of seawater (Fig. 6b), Class V shows a dramatic decrease trend in the water bodies percentage, which reflect the reclamation characteristics, while Classes III and IV reflect the trend that water bodies percentage remained stable before 2006 and slowly decreased after 2006. In terms of spatial distribution, reclamation exists in all six major bays, while Hangzhou Bay is the most dramatic (Fig. 6a). The reclamation in Sanmen Bay, Taizhou Bay, Yueqing Bay and Wenzhou Bay is mostly linear along the coastline, while the reclamation in Xiangshan Bay is relatively minor. In the clustering results of aquaculture pond, Classes II, III, and IV respectively reflect the trends of area maintaining

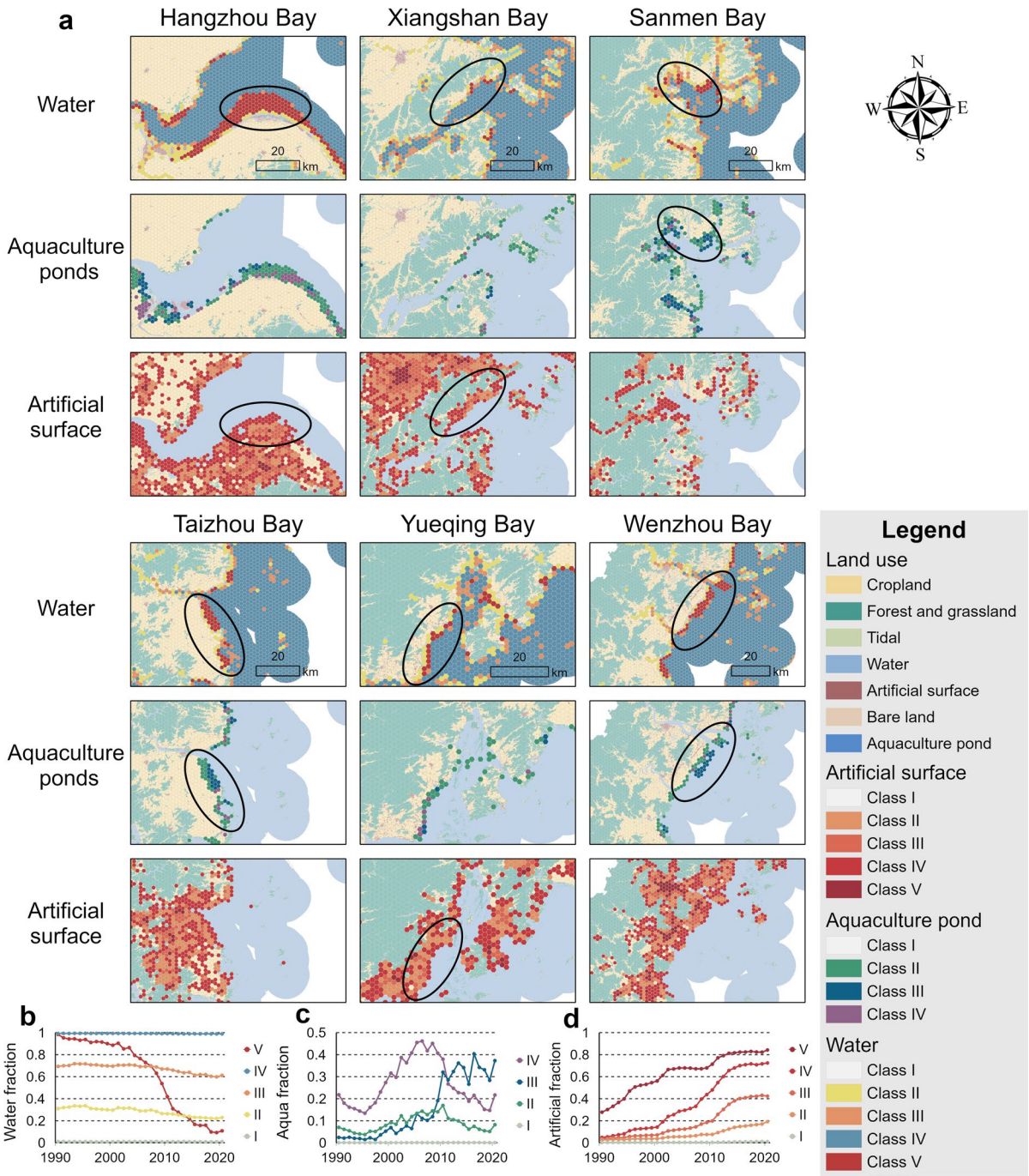

Fig. 6 Clustering results of the area fraction of water, aquaculture ponds, and artificial surface in the hexagonal analysis cells throughout the six bays, with the base map being the LU classification result of 1990 (**a**). The corresponding clustering curves for water, aquaculture ponds, and artificial surface are shown in panels **b**, **c**, and **d** respectively

at a low level, a dramatic increase from around 2010, and an increase from around 1995–2005 followed by a decrease after 2010 (Fig. 6c). The largest number of Class IV occurs within Hangzhou Bay, reflecting the fact that aquaculture pond appeared in this area as transitional features and were later covered by other

feature types. In Sanmen Bay, Taizhou Bay and Wenzhou Bay, Class III aquaculture areas are distributed in the periphery of Class II, reflecting the trend of the expansion of aquaculture ponds to the sea, and the expansion of aquaculture pond in these areas is also well coordinated with the contraction of water bodies. In contrast to the other bays, Xiangshan Bay and Yueqing Bay show much smaller areas and much lower degrees of change in aquaculture pond area, although there are certain fluctuations and rise in places. From the clustering results of impervious surfaces (Fig. 6d), the coastal areas of all major bays are strongly developed and expanded by human activities, except Sanmen Bay. Especially, in Hangzhou Bay and Yueqing Bay, most of the reclamation is caused by artificial surface expansion.

The clustering curves corresponding to each surface feature can identify the time nodes of emergent mutations, and delineate the different temporal stages of human expansion. In the clustering curve of water bodies, 2003 and 2015 are the two most typical change nodes of Class V. The curve is divided into three different stages: "stable high"—"rapidly declining"—"stable low", in the period of 2003–2015 corresponds to the most intense reclamation activities. By contrast, the years 1995 and 2010 can be considered as change nodes in the clustering curves of aquaculture pond, and their abrupt change years are both earlier than those of the reclamation. The values corresponding to the curves of Classes II, III, and IV all showed a small decrease before 1995, and turned into an increasing trend of different magnitudes between 1995 and 2010. After 2010, the Class III curve stays at high values with fluctuating changes, while the Class II and IV curves start to decline. Artificial surface can be divided by 2000 and 2010, with Class V showing a trend of staged growth and Class IV expanding most dramatically from 2007 to 2013.

Interactions between policies and landscape changes

Comparing the time series of the expansion of human activities with the evolution of policy orientation, it is easy to see that there is a fast or slow response between human expansion and coastal zone policies (Fig. 7a). During the period 2000–2010, there was a noticeable and continuous increase in both reclamation, aquaculture ponds and artificial surfaces. This trend coincided with the issuance of policies oriented to marine economic development and resource exploitation. Around 2003, in order to promote the marine economy, coastal regions in the country formulated their own marine economic development plans, with land reclamation becoming a primary approach to stimulate coastal economic growth. In 2008, the State Oceanic Administration issued the "Notice on the Promotion of Stable and Rapid Economic Development for the Expansion of Domestic Demand", which streamlined the approval procedure for sea reclamation once the regional sea construction plan was approved. Under the influence of a series of policies, the reclamation in Zhejiang have entered a period of rapid expansion. The reaction in human expansion to development policies shown in Fig. 7a is even more pronounced in the high intensity landscape change classes in Figs. 5 and 6.

Since 2010, national and local coastal policies were issued with emphasis on coastal zone protection and restoration. As a response to the protection-oriented policies in this period, the expansion of aquaculture ponds shifted from rapid expansion to gradual decay, and the expansion of artificial surface also shifted from rapid expansion to slow expansion, while the rapid expansion of reclamation continued in the previous period, and the rapid expansion of reclamation was effectively curbed only after 2015 (Fig. 7b). The policies promulgated during the period of land-sea coordination have struck a balance between conservation and development, reflecting the gradual advancement of policy makers' understanding of the concept of sustainable development. Governments at all levels advocated "sea-land integration and coordination" and carried out protection work such as returning reclamation to the sea and delineating the marine ecological conservation red line, while focusing on high-quality construction of marine ports and promoting the marine economy.

Summarizing the coupling analysis of policy evolution and human activities in the three periods since 2000, we can see that human activities responded more positively to the stimulating policies in the development-oriented period, while there was a long time lag in the response to the restrictive and constraining policies in the conservation turning and land-sea coordination periods, and it was difficult for the government to see the effect of policy implementation in the short term, so the frequency of policy adjustment gradually accelerated in the later period.

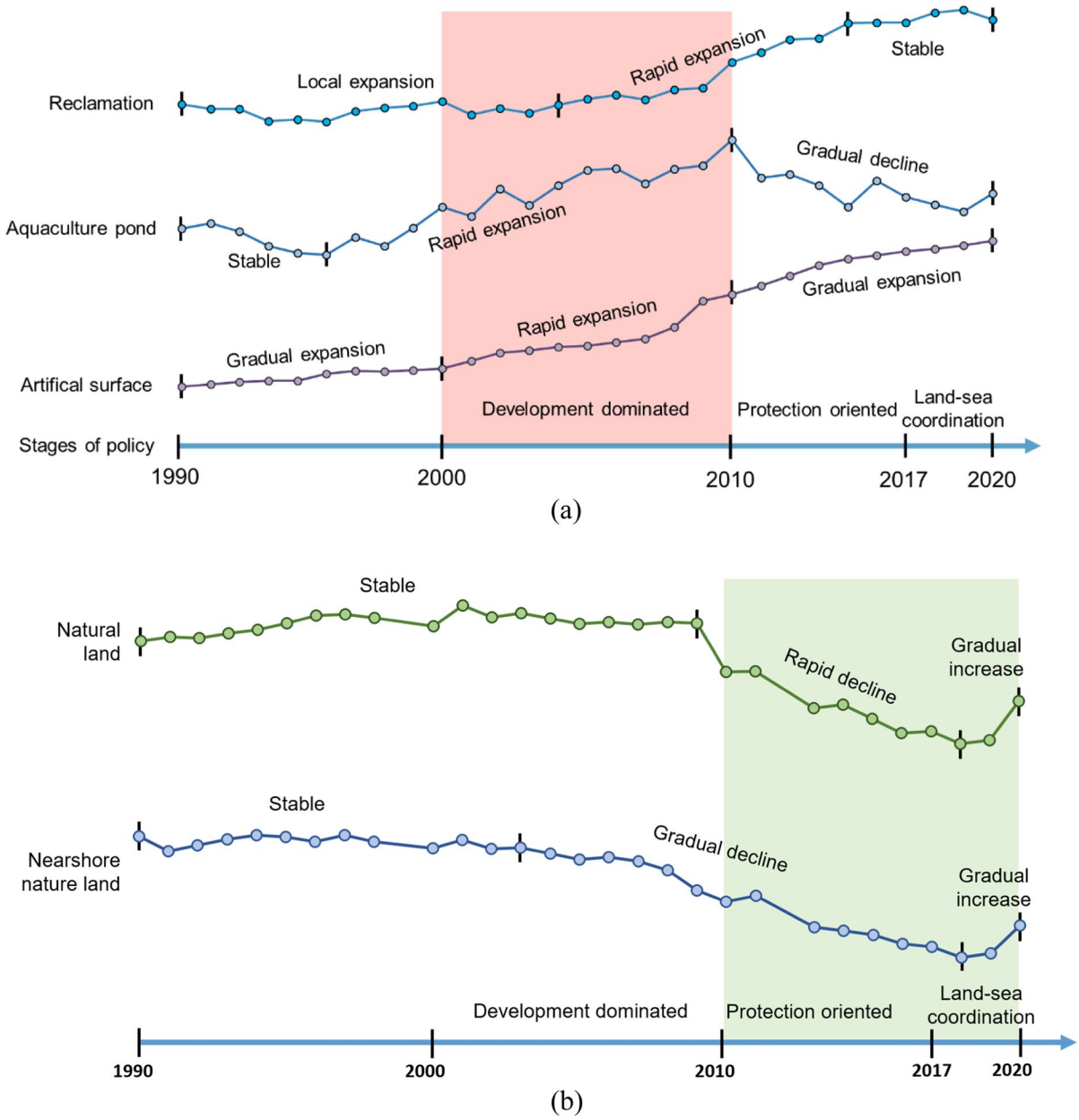

Fig. 7 The coupling of policy evolution and landscape change in Zhejiang Province

Compared with the expansion of human activities, natural land is less sensitive to the evolution of coastal zone policies and has a longer lag period in response to policy changes. Here we additionally analyze natural land within the 10 km area from both sides of the shoreline as nearshore natural land. During the development-oriented period from 2000 to 2010, the natural land in the whole area of the coastal zone remained relatively stable in the early stage, and only after 2009 did the trend of decline become obvious. By contrast, nearshore natural land has been shrinking since 2003, which shows that in the nearshore, natural land responds more obviously to development-oriented policies—or, to put it another way, artificial surface expansion in response to development-oriented policies impacts natural lands faster in the nearshore area

than in the broader coastal zone. the decline in natural land continued well into the period turning towards conservation (2010–2017), both in the coastal zone as a whole and in the nearshore area (Fig. 7b). This is due to the strong inertia of the development-led policy, causing its impact to continue for several years despite national and local governments vigorously pursuing conservation-oriented and balanced development and conservation policies since 2010. As a result of the inertia, it was not until 2018 that natural land began to recover, with a gradual increase in area.

From the policy lineage combing and the coupling analysis of human expansion, ecological restoration and policy, it is clear that China's coastal zone policy is still in the process of continuous development and improvement. The policies in both the development-oriented and conservation turning phases in the early stage only targeted a single dimension of development or conservation, ignoring the fact that another dimension has an equally important role in the development process of coastal areas. In addition, China's political performance assessment system is GDP-oriented, and ecological construction and environmental protection indicators are only symbolically added to the assessment, and their weight is very small. The imperfect policy system led to rapid expansion of human activities in the development stage (2000–2010), while conservation policies in the protection stage (2010–2017) be effectively implemented in a relatively short period of time. In addition, the differences in the response of human expansion to different types of policies, especially the rapid response to development-stimulating policies in the short term and the delayed response to conservation policies in the longer term, also indicate the need for adequate risk assessment across scales before policy implementation.

Discussion

Maintaining diverse landscape functions and adaptive capacity is essential for urban and rural sustainability (Wu 2021; Reyers et al. 2022; Walker et al. 2023), particularly in rapidly changing coastal zones. Landscape planning and coastal zone policies play an important role in determining landscape functions, directly and indirectly, and learning from the effects of past policies on landscape patterns can help us create and maintain sustainable coastal urban and rural landscapes in the future. Our coupling analysis of urban expansion, agriculture, and ecological conservation in response to coastal zone polices provides such a learning opportunity at the landscape pattern–ecosystem services–human wellbeing nexus. Our findings reveal: (1) differences in the timing and degree of local landscape change in response to policies; (2) trade-offs and a lack of land-sea coordination between policy objectives and landscape functions; and (3) the necessity of policy coordination for landscape sustainability, which we discuss here with implications for urban and rural landscape sustainability, coastal planning, and the SDGs.

Spatial and temporal differences in landscape response to policies

Our results reveal significant differences in the speed and degree of landscape change in response to various types of policies in Zhejiang Province, China, which supports previous studies (Wang et al. 2014; Miao and Xue 2021). Among these, human expansion is most sensitive to development-oriented policies. Li et al. (2020) also demonstrate that reclamation activities are more responsive to stimulus policies than restriction or tightening policies, with stimulus policies encouraging reclamation often yielding short-term responses. During the development-oriented policy period from 2000 to 2010, all coastal areas in Zhejiang Province responded positively to national or local development policies. Particularly, after the issuance of the *Outline of the Strong Marine Economic Province Construction Plan* in Zhejiang in 2005, coastal development and construction in various areas experienced significant growth (Wu et al. 2014; Duan et al. 2016; Yan et al. 2023).

Taking the six bay areas as examples, local responses to policies were evident in the expansion of human activities such as port construction, industrial park development, infrastructure construction, shoreline engineering, and aquaculture and fishery. However, variations existed in the size, order of expansion range, and response time (Wang et al. 2017). First, this can be seen in the spatial and temporal differences in the reclamation expansion of the six bay areas. We counted the year-by-year water body area change curves within each of the six bays separately (Fig. 8) and delineated the most intense temporal stages of reclamation. Each bay area

started reclamation in different years, Yueqing Bay and Hangzhou Bay being the earliest (around 2004); while Wenzhou Bay was the latest (2010), and most of the bays experienced dramatic reclamation expansion between 2005 and 2015, which is basically consistent with the results revealed by the overall clustering (Fig. 6). The response of Wenzhou Bay is relatively late, with two significant declines between 2003 and 2005, and 2010–2020, the latter being more drastic.

In addition, the information we gathered through field research also confirms this. Hangzhou Bay, where Ningbo and Zhoushan are located, exhibited the earliest response time to policies and the most pronounced expansion of human activities (Fig. 9). From 2000 to 2010, the petrochemical industry experienced significant development along the coast of Ningbo, establishing a large-scale petrochemical base centered around Hangzhou Bay and the Ningbo Petrochemical Economic and Technological Development Zone. Concurrently, Zhoushan vigorously promoted projects connecting the mainland and islands, including the construction of Cengang Bridge and Jintang Bridge (Zhang et al. 2014; Wang et al. 2017). During this decade, the two cities experienced substantial improvements in socio-economic development, with population and GDP growth rates reaching 25% (1.762 million people) and 379% (459.347 billion yuan), respectively. The urbanization ratio also increased from 40 to 53% (Lin et al. 2018). By contrast, Sanmen Bay and Taizhou Bay focused on developing mariculture-based fisheries, establishing fishing economic zones such as Jiaojiang Qianqian, Yuhuan Kanmen, and Sanmen Jiantiao. Figure 9 illustrates a significant increase in newly added aquaculture ponds in Sanmen Bay and Taizhou Bay during this period (Li et al. 2018). Notably, the fishery output value of Taizhou, the prefecture-level city where Taizhou Bay is located, increased from 8.87 billion yuan in 2000 to 13.52 billion yuan in 2010.

Complementing the results of our study, some scholars have found similar diversity when analysing the impact of policies on the landscape in other coastal areas. Bao et al. (2019) analyzed the response relationship between coastal landscape and policy in Jiangsu Province on a 100-year scale. The results indicate that traditional land use policies often lag behind coastal development, leading to a continuous intensification of human land conflicts. However, after 2000, with the increasing demand for sustainable coastal development, the adjustment speed of coastal policies has accelerated, shifting from passive to proactive response to environmental changes and stakeholder conflicts. Luo et al. (2022) analyzed the important role of policy in promoting the expansion of aquaculture ponds in four major aquaculture

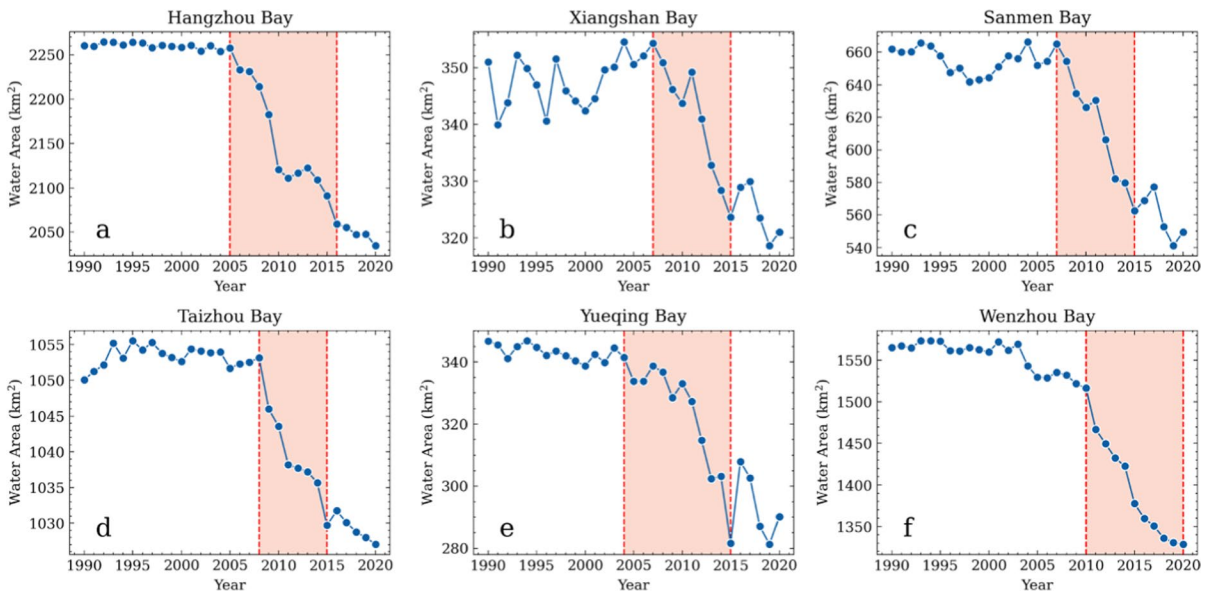

Fig. 8 The curve of seawater area changes in the six bay areas, reflecting the intensity of reclamation

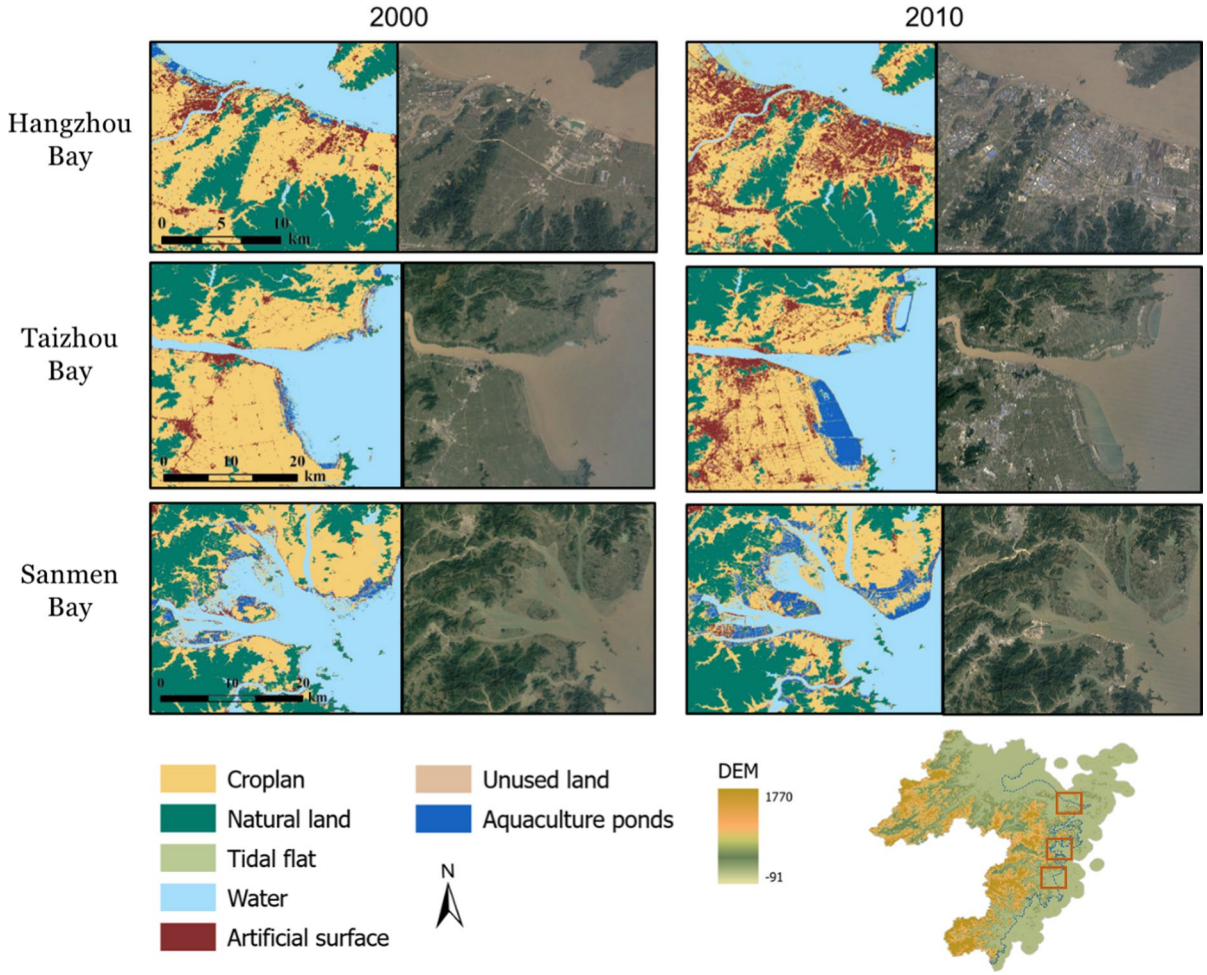

Fig. 9 Comparison of human expansion in Hangzhou Bay, Taizhou Bay and Sanmen Bay

countries in Southeast Asia. It can be seen that in different regions and different landscapes, the relationship between policy and landscape is also different.

These results suggest that different SDGs, supported by different landscape functions, will be more or less responsive to policy adjustments depending upon a number of factors. Economic development (SDG 8) seems to be the most responsive to development-stimulating policies while at the same time being the likely cause of temporal lags and dampening of ecosystem (SDGs 14 and 15) responses to protection-oriented and coordinated policies. Scholars have argued that the SDGs and the 2030 Agenda are still based on an economic growth paradigm that places the environment secondary to the economy (Eisenmenger et al. 2020; Forestier and Kim 2020). Next to this, our results show that economic development policies have a greater impact on landscape patterns than environmental policies. Taken together, the implications for any attempt to protect and restore terrestrial and marine ecosystem functions in coastal zones are that conflicts and trade-offs with the economy need to be navigated, vested economic interests need to be controlled, system inertia needs to be acknowledged and managed, and temporal lags in ecosystem responses (both to policies and also to degradation) need to be at the forefront of long-term planning for coastal urban and rural sustainability.

Trade-offs between land-sea policy objectives and landscape functions

Although the rapid expansion of coastal human activities in Zhejiang Province during the development-oriented policy period contributed to local economic development to some extent, it also resulted in adverse impacts such as environmental pollution, biodiversity reduction, and habitat degradation, which caught the attention of national and local governments at all levels (Wang et al. 2021a; Yang et al. 2022). With the introduction of the *National Major Function Zoning Plan* in 2010 and the *National Marine Functional Zoning Plan* in 2012, coastal policies shifted from development-oriented to protection-focused and land-sea coordination. However, our coupling analysis of landscape change and policies reveal that the policies implemented during the conservation shift and land-sea coordination period did not yield the expected results for ecosystems. Two primary reasons contribute to this outcome: (1) lack of coordination between terrestrial and marine policies; and (2) lack of simultaneous implementation of terrestrial and marine policies.

Most policies exclusively target either the land area or the sea area of the coastal zone, leading to differences in functional positioning and policy orientation between the two areas along the same coastline (Walsh 2021; Wang et al. 2021b; Yue et al. 2023). Figure 10 shows the major functional zones (MFZs) on both terrestrial and marine areas across the Zhejiang coastal zone, as well as the end point rate (EPR) of shoreline movement, and indicators of terrestrial and marine development intensities and ecological degradation degrees. Among them, the northern and central coastal areas of Zhejiang Province are relatively consistent in their functional positioning, such as the land and sea function positioning of Hangzhou Bay are optimized development zones. However, there is a big difference between land and sea policies in the southern region. For example, the land area of Yueqing City on the west side of Yueqing Bay is positioned as a significant development zone, while the adjacent sea area is designated as a reservation zone. The land area of Yuhuan City on the east side of Yueqing Bay is positioned as an ecological security zone, while the sea area is an optimized development zone. The incoordination of land and sea policies led to a high degree of ecological degradation in the sea area of Yueqing City, which should have been protected originally. The faster shoreline migration rate (Fig. 10b) also reflected the serious damage to the local natural shoreline (Li et al. 2018). The lack of alignment between terrestrial and marine policies not only hampers the effective allocation of economic resources but also impairs the coordination of development and protection on both sides of the shoreline (i.e., at sea and on land), hindering the sustainable development of coastal areas (Scarff et al. 2015; Schlüter et al. 2020; Van Assche et al. 2020; Singh et al. 2021).

The implementation effects of various policies differ due to discrepancies in the releasing subjects and timeframes. For instance, the *National Major Function Zoning Plan*, led by the National Development and Reform Commission (NDRC), integrates both protection and development aspects in land policies (Fan et al. 2019). Conversely, the *National Marine Functional Zoning Plan*, led by the State Oceanic Administration, primarily focuses on protecting the sea. Consequently, the latter's implementation lags significantly behind the former (Smith et al. 2011; O'Hagan et al. 2020). Although the NDRC released the *National Marine Major Function Zoning* in 2015, it was five years later than the *National Major Function Zoning*, and there was an additional 1–2 year gap between the promulgation of national policies and the implementation of local policies. As a result, sea policies remained disconnected from land policies for an extended period, exacerbating the lack of coordination between sea and land development (Yu et al., 2020; Walsh 2021).

Therefore, it is imperative to strengthen the coordination and harmonization of land and sea policies in the future. In China, the traditional perspective that land is more important than the sea should be revised at the decision-making level, and the relationship between land and sea in industry, ecology, resources, and other aspects should be comprehensively planned and addressed to achieve unified implementation subjects, integrated development planning, and coordinated spatial layout.

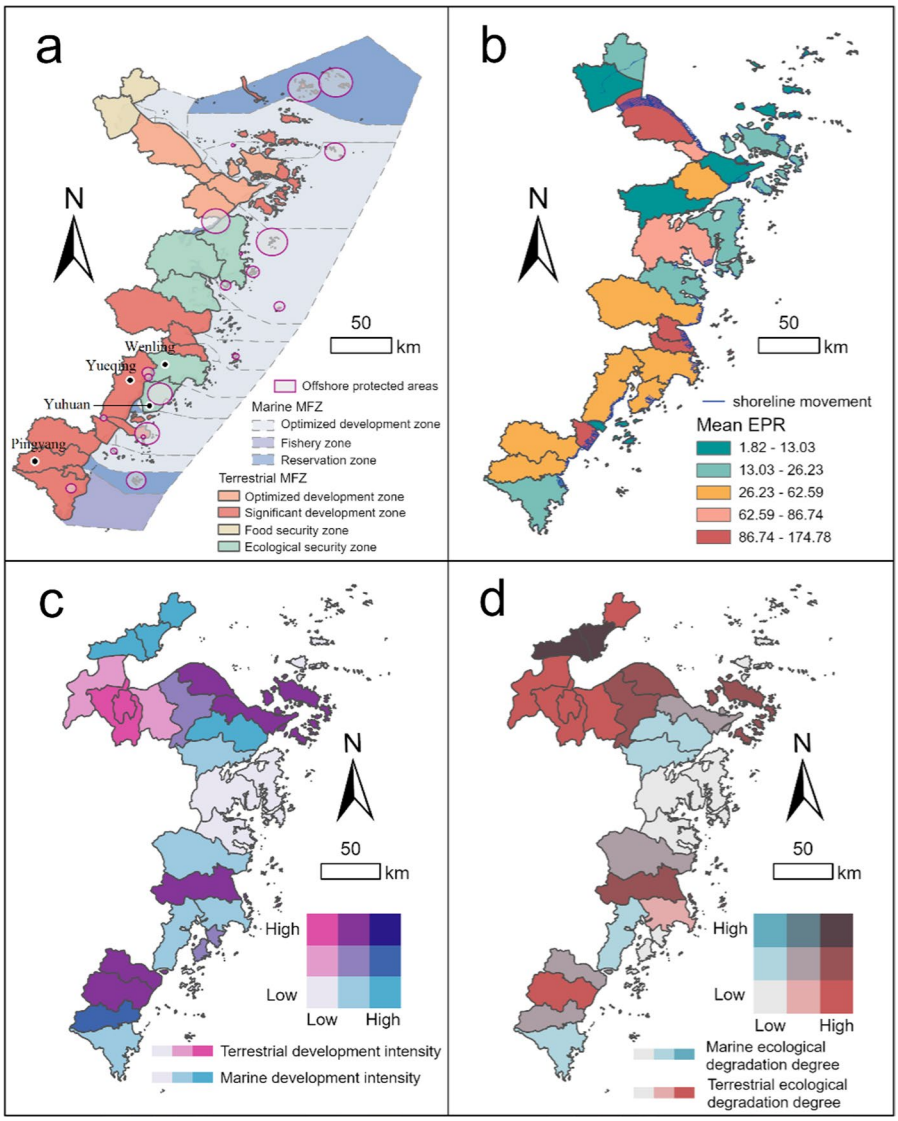

Fig. 10 Terrestrial and marine MFZs (**a**), mean EPR of shoreline movement (**b**), coupling of land-sea development intensity (**c**), and ecological degradation degree (**d**). The data sources and methodologies are referred to Supplementary Material (SM3)

Policy coordination and landscape sustainability

Policy coordination and coherence across goals, sectors, regions, scales, and between society and the environment, is widely argued to be essential for achieving the SDGs (Nilsson et al. 2016; Nilsson and Wietz, 2019; Scown et al. 2023a). Our results confirm that coordination between terrestrial and marine policies is particularly important for achieving the SDGs in coastal zones, but lack of such coordination is currently a barrier in China and possibly elsewhere around the world. Spatial coordination of diverse landscape (and seascape) functions to continually support different goals is also essential (Wu 2006, 2013). In Fig. 10a, fishery zones and food security zones mainly provide various agricultural products and aquatic products (SDG 2 – Zero hunger). In order to ensure fishery and food production, local development intensity in such zones should be limited. However, our findings reveal that when either land or sea areas are dominated by development-led functional types, such as in Cangnan and Haiyan districts and counties (identified as optimized development zones), it leads to an adverse impact on fishery and food production capacity in these zones. Additionally, this results in an excessive increase in development intensity (Fig. 9b and c).

Ecological security zones and reservation zones are important areas to ensure the stability of the ecosystem (SDGs 14 and 15), so mandatory protection measures need to be implemented. The mismatch between land and sea development intensity caused by the spatial dislocation of land and sea functions may further exacerbate the risk of ecological degradation (SDG 14 and 15) in these areas. This finding is particularly evident in Pingyang, Yuhuan and Wenling districts and counties, where ecologically safe and reserved areas coexist with urbanized or marine economic development-dominated zones, including fishery and food security areas. As a consequence, development intensity in both land and sea areas increases more rapidly than in districts and counties with coordinated land and sea policies, amplifying the degree of ecological degradation (Fig. 9d). Balancing and navigating tensions and trade-offs among SDGs in coastal urban and rural landscapes will require policy coherence and coordination, but also thinking and planning across scales and spatially to continually support functional diversity (Wu 2021; Scown et al. 2023a; Walker et al. 2023).

Conclusion

Exploring the impacts of policy changes on landscape patterns is essential for achieving coastal urban and rural sustainability. In this study, we utilized the GEE platform and multi-source data to conduct spatio-temporal coupling analysis of policy changes and landscape pattern evolution, aiming to identify inflection points and local characteristics of human expansion and ecological restoration. The findings reveal that the implementation period of coastal zone development policies coincides with the inflection point of the evolution of human expansion, particularly concerning reclamation activities. Policies often result in rapid increases in human expansion within the same year of their issuance. Moreover, the study highlights that coastal zones exhibit a faster response to national development policies compared to protection policies, with a lag period of 2–5 years typically observed for the implementation effects of protection policies. However, the exact duration of the lag depends on the specific subject and content of policy implementation.

This study uncovers a lack of coordination between the implementation periods of development and protection policies in coastal land and sea areas. This lack of coordination severely hampers policy effectiveness and further impedes the sustainable transformation of coastal zones. To address this issue, we recommend strengthening the implementation and periodic assessment of coastal zone policies, with a particular focus on harnessing the synergistic effects of different policies. This approach will enable timely adjustments to unsustainable situations. Additionally, it is crucial to enhance the spatial planning system to facilitate land-sea coordination in coastal areas. Development activities should be carried out based on the limits of natural system, ensuring that the upper limit of coastal ecosystems is not exceeded. Legislative measures should be implemented to strengthen control over coastal zone space, strictly limit the scale of reclamation, and establish clear examination and approval processes. It is also necessary to enhance coordination among various government departments and foster collaboration with social organizations, groups, and communities to collectively restore the coastal ecosystem. Such cooperative efforts will foster a harmonious and sustainable balance between human activities and the preservation of our precious coastal landscapes.

This paper emphasizes the dominant role of national and provincial governments in shaping and safeguarding coastal zones. However, it neglects the essential contributions of local governments, including their inherent needs and spontaneous initiatives, which are crucial for achieving sustainable transformation and ecological protection in coastal zone development. Achieving alignment between macro policies and local requisites is crucial, influencing spatial and temporal patterns in coastal zone landscape changes. The potential lies in the development of quantitative approaches, utilizing scenario design and modeling to discern contributions from natural factors, socio-economic factors, and policy changes across different scales. Future research should delve deeper into these aspects for a more comprehensive understanding.

Author contributions YFW led the conceptualization, framework, methodology and writing. JFL and YXY supported the original draft and partial visualization. DOB contributed to the original draft, review and revision. MWS co-led and contributed to the conceptualization, framework and the writing. All authors provided intellectual input and drafted the final version of the manuscript.

Funding Open access funding provided by Lund University. This research was funded by the National Natural Science Foundation of China (No.42001131) and Key Laboratory of Ocean Space Resource Management Technology, MNR (No. KF-2021-102).

Data availability Data are available from the authors upon request.

Declarations

Competing interests The authors declare no competing interests.

Ethical approval Not applicable.

References

Bao J, Gao S, Ge J (2019) Dynamic land use and its policy in response to environmental and social-economic changes in China: a case study of the Jiangsu coast (1750–2015). Land Use Policy 82:169–180

Bazant-Fabre O, Bonilla-Moheno M, Martínez ML et al (2022) Land planning and protected areas in the coastal zone of Mexico: do spatial policies promote fragmented governance? Land Use Policy 121:106325

Cheng P, Wang H, Nie X et al (2021) What are the impacts of a coastal zone protection policy on farmers' livelihood capital? Empirical analysis from the perspective of farmer participation. Front Mar Sci 8:689182

Duan H, Zhang H, Huang Q et al (2016) Characterization and environmental impact analysis of sea land reclamation activities in China. Ocean Coastal Manag 130:128–137

Duan Y, Li X, Zhang L et al (2020) Detecting spatiotemporal changes of large-scale aquaculture ponds regions over 1988–2018 in Jiangsu Province, China using Google Earth Engine. Ocean Coastal Manag 188:105144

Eisenmenger N, Pichler M, Krenmayr N et al (2020) The sustainable development goals prioritize economic growth over sustainable resource use: a critical reflection on the SDGs from a socio-ecological perspective. Sustain Sci 15:1101–1110.

Fan J, Wang Q, Wang Y et al (2018) Assessment of coastal development policy based on simulating a sustainable land-use scenario for Liaoning Coastal Zone in China. Land Degrad Dev 29(8):2390–2402

Fan J, Wang Y, Wang C et al (2019) Reshaping the sustainable geographical pattern: a major function zoning model and its applications in China. Earth's Future 7:25–42

Forestier O, Kim RE (2020) Cherry-picking the sustainable development goals: goal prioritization by national governments and implications for global governance. Sustainable Dev 28:1269–1278

Frazier AE, Bryan BA, Buyantuev A et al (2019) Ecological civilization: perspectives from landscape ecology and landscape sustainability science. Landsc Ecol 34:1–8

Goldberg L, Lagomasino D, Thomas N et al (2020) Global declines in huma-driven mangrove loss. Global Change Biol 26(10):5844–5855

Guo Y, Guo X, Tian J et al (2015) Study of reciprocal effects between mandatory pollutant emissions reduction policy and structural change within the manufacturing sector in a Chinese coastal area. Environm Sci Technol 49(21):12840–12850

Gussmann G, Hinkel J (2021) A framework for assessing the potential effectiveness of adaptation policies: coastal risks and sea-level rise in the Maldives. Environ Sci Policy 115:35–42

Halpern BS, Frazier M, Afflerbach J et al (2019) Recent pace of change in human impact on the world's ocean. Sci Rep 9:1–8

Jiang Q, He J, Wu J et al (2018) Assessing the severe eutrophication status and spatial trend in the coastal waters of Zhejiang province (China). Limnol Oceanogr 64(1):3–17

Kaufman L, Rousseeuw PJ (1990) Clustering large applications (Program CLARA). Finding groups in data: an introduction to cluster analysis. Wiley, Hoboken, pp 63–128

Li J, Ye M, Pu R et al (2018) Spatiotemporal change patterns of coastlines in Zhejiang Province, China, over the last twenty-five years. Sustainability 10(2):477

Li F, Ding D, Chen Z et al (2020) Change of sea reclamation and the sea-use management policy system in China. Mar Policy 115:103861

Liao C, Qiu J, Chen B et al (2020) Advancing landscape sustainability science: theoretical foundation and synergies with innovations in methodology, design, and application. Landsc Ecol 35:1–9

Lin W, Cen J, Xu D et al (2018) Wetland landscape pattern changes over a period of rapid development (1985–2015) in the ZhouShan Islands of Zhejiang Province, China. Estuarine. Coastal Shelf Sci 213:148–159

Lincke D, Hinkel J, Mengel M et al (2022) Understanding the drivers of coastal flood exposure and risk from 1860 to 2100. Earths Future 10(12):e2021EF002584

Loizou E, Chatzitheodoridis F, Polymeros K et al (2014) Sustainable development of rural coastal areas: impacts of a new fisheries policy. Land Use Policy 38:41–47

Luo J, Sun Z, Lu L et al (2022) Rapid expansion of coastal aquaculture ponds in Southeast Asia: patterns, drivers and impacts. J Environm Manag 315:115100

Meng W, Hu B, He M et al (2017) Temporal-spatial variations and driving factors analysis of coastal reclamation in China. Estuar Coastal Shelf Sci 191:39–49

Mentaschi L, Vousdoukas MI, Pekel JF et al (2018) Global long-term observations of coastal erosion and accretion. Sci Rep 8:12876

Miao D, Xue Z (2021) The current developments and impact of land reclamation control in China. Mar Policy 134:104782

Murray NJ, Worthington TA, Bunting P et al (2022) High-resolution mapping of losses and gains of Earth's tidal wetlands. Sci 376(6594):744–749

Nicholls RJ, Cazenave A (2010) Sea-level rise and its impact on coastal zones. Sci 328(5985):1517–1520

Nilsson M, Weitz N (2019) Governing trade-offs and building coherence in policy-making for the 2030 agenda. Polit Gov 7(4):254–263

Nilsson M, Griggs D, Visbeck M (2016) Policy: map the interactions between sustainable development goals. Nat 534(7607):320–322

O'Hagan AM, Paterson S, Le Tissier M (2020) Addressing the tangled web of governance mechanisms for land-sea interactions: assessing implementation challenges across scales. Mar Policy 112:103715

Reyers B, Moore ML, Haider LJ et al (2022) The contributions of resilience to reshaping sustainable development. Nat Sustain 5(8):657–664

Scarff G, Fitzsimmons C, Gray T (2015) The new mode of marine planning in the UK: aspirations and challenges. Mar Policy 51:96–102

Schlüter A, Van Assche K, Hornidge AK et al (2020) Land-sea interactions and coastal development: an evolutionary governance perspective. Mar Policy 112:103801

Scown MW, Craig RK, Allen CR et al (2023a) Towards a global sustainable development agenda built on social–ecological resilience. Global Sustain 6:e8

Scown MW, Dunn FE, Dekker SC et al (2023b) Global change scenarios in coastal river deltas and their sustainable development implications. Global Environ Change 82:102736

Shen Z, Wang Y, Su H et al (2022) A bi-directional strategy to detect land use function change using time-series Landsat imagery on Google Earth Engine: a case study of Huangshui River Basin in China. Sci Remote Sens 5:100039

Shih JS, Driscoll CT, Burtraw D et al (2022) Energy policy and coastal water quality: an integrated energy, air and water quality modeling approach. Sci Total Environ 816:151593

Singh GG, Cottrell RS, Eddy TD et al (2021) Governing the land-sea interface to achieve sustainable coastal development. Front Mar Sci 8:709947

Smith HD, Maes F, Stojanovic TA et al (2011) The integration of land and marine spatial planning. J Coastal Conserv 15:291–303

Strokal M, Kroeze C, Wang M et al (2017) Reducing future river export of nutrients to coastal waters of China in optimistic scenarios. Sci Total Environ 579:517–528

Tu C, Ma H, Li Y et al (2022) 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. Front Mar Sci 10:670397

Van Assche K, Hornidge AK, Schlüter A et al (2020) Governance and the coastal condition: towards new modes of observation, adaptation and integration. Mar Policy 112:103413

Vélez JMM, García SB, Tenorio AE (2018) Policies in coastal wetlands: key challenges. Environ Sci Policy 88:2–82

Von Glasow R, Jickells TD, Baklanov A et al (2013) Megacities and large urban agglomerations in the coastal zone: interactions between atmosphere, land, and marine ecosystems. Ambio 42:13–28

Walker B, Crépin AS, Nyström M et al (2023) Response diversity as a sustainability strategy. Nat Sustain 6:621–629

Walsh C (2021) Transcending land–sea dichotomies through strategic spatial planning. Reg Stud 55(5):818–830

Wang W, Liu H, Li Y et al (2014) Development and management of land reclamation in China. Ocean Coastal Manag 102:415–425

Wang X, Liu Y, Ling F et al (2017) Spatio-temporal change detection of Ningbo coastline using landsat time-series images during 1976–2015. ISPRS Int J Geo-Information 6(3):68

Wang X, Xiao X, Xu X et al (2021a) Rebound in China's coastal wetlands following conservation and restoration. Nat Sustain 4(12):1076–1083

Wang Y, Fan J, Li J et al (2021b) Methodological framework for identifying sustainability intervention priority areas on coastal landscapes and its application in China. Sci Total Environ 766:142603

Wang Y, Liao J, Ye Y et al (2022a) Long-term human expansion and the environmental impacts on the coastal zone of China. Front Mar Sci 9:1033466

Wang H, Yao Y, Dai X et al (2022b) How do ecological protection policies affect the restriction of coastal development rights? Analysis of choice preference based on choice experiment. Mar Policy 136:104905

Wu J (2006) Landscape ecology, cross-disciplinarity, and sustainability science. Landsc Ecol 21(1):1–4

Wu J (2013) Landscape sustainability science: ecosystem services and human well-being in changing landscapes. Landsc Ecol 28(6):999–1023

Wu J (2021) Landscape sustainability science (II): core questions and key approaches. Landsc Ecol 36:2453–2485

Wu T, Hou X, Xu X (2014) Spatio-temporal characteristics of the mainland coastline utilization degree over the last 70 years in China. Ocean Coastal Manag 98:150–157

Yan F, Wang X, Huang C et al (2023) Sea reclamation in mainland China: process, pattern, and management. Land Use Policy 127:106555

Yang S, Wang Y, Fang Q et al (2022) The transformation of 40-year coastal wetland policies in China: network analysis and text analysis. Environ Sci Technol 56(22):15251–15260

Ye Y, Wang Y, Liao J et al (2022) Spatiotemporal pattern analysis of land use functions in contiguous coastal cities based on long-term time series remote sensing data: a case study of Bohai Sea Region, China. Remote Sens 14:3518

Yu JK, Li YH (2020) Evolution of marine spatial planning policies for mariculture in China: overview, experience and prospects. Ocean Coastal Manag 196:105293

Yue W, Hou B, Ye G et al (2023) China's land-sea coordination practice in territorial spatial planning. Ocean Coastal Manag 237:106545

Zhang X, Pan D, Chen J et al (2014) Evaluation of coastline changes under human intervention using multi-temporal high-resolution images: a case study of the Zhoushan Islands, China. Remote Sens 6(10):9930–9950