1 **An assessment of the Ecological Conservation Redline: Unlocking priority areas for**
2 **conservation**

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10 **Abstract:** Protected areas (PAs) are established to conserve wildlife habitats and biodiversity. To this end,
11 the Chinese central government has initiated a pioneering environmental planning and management policy
12 known as the Ecological Conservation Redline (ECR). Whilst ecological benefits of ECR policy have
13 been extensively evaluated, spatially explicit assessment of the ECR remains understudies. Here, we
14 propose an element-function-structure framework for assessing the concurrence of ECR areas and
15 ecological conservation hotspots to further outline priority areas for conservation. Results show that 67%
16 of existing PAs are protected by ECR areas, while that of ecological corridors is only 11%. Regional
17 variation in the ECR representativeness can be leveraged by deliberately protecting tailored ecological
18 conservation hotspots in specific locations and stepping stones in ecological corridors. This study
19 highlights the substantial space for ecological management to achieve the goals of ECR policy, and
20 discourses on the co-production of knowledge from researchers and policy makers.

21

22 **Keyword:** Protected areas; biodiversity conservation; natural resource management; ecological security;
23 assessment framework

24

1. Introduction

Originally, terrestrial Protected Areas (PAs) are established worldwide to constrain destructive human activities and safeguard endangered species in perpetuity (Folharini et al., 2021; Kroner et al., 2019; Ribeiro et al., 2021). Yet, evidence suggests that PAs are confronted with increasing alterations from human activities that characterize the Anthropocene (Ellis & Ramankutty, 2008; Geldmann et al., 2014), despite the rapid expansion of PA coverage over the past decades (Buchadas et al., 2022). At a global scale, only 42% of PAs are free of any detectable human disturbance, whereas approximately 33% are extensively modified (Jones et al., 2018). For example, in the United States, national parks, wilderness areas, community conserved areas, and nature reserves are declining in their ability to conserve biodiversity due to human disturbance (Radeloff et al., 2010). Furthermore, the established species-oriented indicators have played a key role in assessing the outcome of PAs (Gray et al., 2016), but they may fall short in the context of increasingly divergent goals of conservation. For instance, Maxwell et al. (2020) state that PAs must effectively contribute to meeting global goals, ranging from preventing specie extinctions to retaining the most-intact ecosystems.

Consistent with the inclusive goals of conservation efforts, the central government of China has initiated a pioneering environmental planning and management policy known as the Ecological Conservation Redline (ECR, see Gao (2019) and Schmidt-Traub et al. (2020)). The ECR policy, which aims to protect more than one-quarter of China's territory, is currently one of the nation's highest priorities for policy implementation (Zhang et al., 2022). Basically, ECR boundaries outline regions with privileged ecological functions by assimilating the principles of ecosystem service, ecological sensitivity, and biodiversity priorities into management practices (Bai et al., 2021; Gao et al., 2020). Ideally, the establishment of ECR can benefit habitat quality and maintain habitat connectivity (Luo et al., 2020). Therefore, the ECR vision resembles the concept of ecological networks in terms of integrity and connectivity, but it is more conducive to safeguarding ecological security in terms the willingness for political action (Ma et al., 2022; Montoya et al., 2006).

The joint legislation regarding the ECR policy by multiple central government departments[1] is intended to play a critical role in ecological conservation, and assessments of management practices have been extensively conducted in such context (Gao et al., 2020). These assessments help better reconcile

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[1] http://gi.mnr.gov.cn/202208/t20220819_2756940.html

53 conservation goals with local economic development under the premise that ECR areas have been
54 optimally identified (Busch & Amarjargal, 2022). To the best of our knowledge, however, few studies
55 have assessed the rationality of the issued ECR coverage. Given that no clear planning framework has
56 been set to maximize the representativeness and effectiveness of conservation goals, government and local
57 authorities are facing the dilemma of ECR conflicts with regional socio-economic development, despite
58 the fact that they inherently prefer socio-economic development in most cases. This issue has largely led
59 to spatial mismatch, isolation, and severe human interference inside or around the ECR areas. For example,
60 Liang et al. (2022) find that, in Jiangsu province of China, a large proportion of built-up land is located in
61 ECR areas, in addition that ECR boundaries do not always match local landforms, which is prone to absurd
62 patterns of regional development due to land-use conflict (de Jong et al., 2021).

63 As such, the objective of this study is to facilitate a framework for a comprehensive science-based
64 assessment of ECR, and possibly to unlock priority areas for future optimization of ECR delineation. To
65 achieve this, ecological conservation hotspots are firstly identified based on ecosystem element, function,
66 and structure. These ecological conservation hotspots are further used to delineate the ecological
67 representativeness of ECR coverage at both provincial and county scales. Finally, priority areas for
68 conservation are identified by synthesizing ecological function zones and ecological stepping stones. We
69 implement this approach for the case of Zhejiang province, which plays a critical role in China's ecological
70 protection, as it is the place where the ECR policy originates.

2. Materials and methods

72 In this study, we propose a stepwise method to assess the effectiveness of ECR coverage (Fig. 1). First,
73 ecological conservation hotspots are identified accounting for ecological element, function, and structure.
74 Specifically, ecological element is depicted by integrating the wide range of existing PAs. Ecological
75 Functional Zones (EFZs) maximize the dominant ecological functions and serve the functional objective
76 of ECR patches, which are connected by ecological corridors that serve the holistic ECR system objective.
77 Second, the entire retention of these three ecological conservation hotspots in ECR areas is investigated
78 (i.e., ecological representativeness) for each of the three components. Third, we compare the variation in
79 ECR representativeness among Major Function-oriented Zones, the blueprint for the future development
80 and protection pattern of China's territory (Fan, 2015), in order to better reflect practical issues across
81 different counties. In addition, management characteristics of ECR are discussed from the perspective of
82 regional competition for land. Finally, we identify priority areas for conservation, to illustrate the gap

83 between management practice and policy goals, and to inform sound policy-making for regional
84 optimization of ECR coverage.
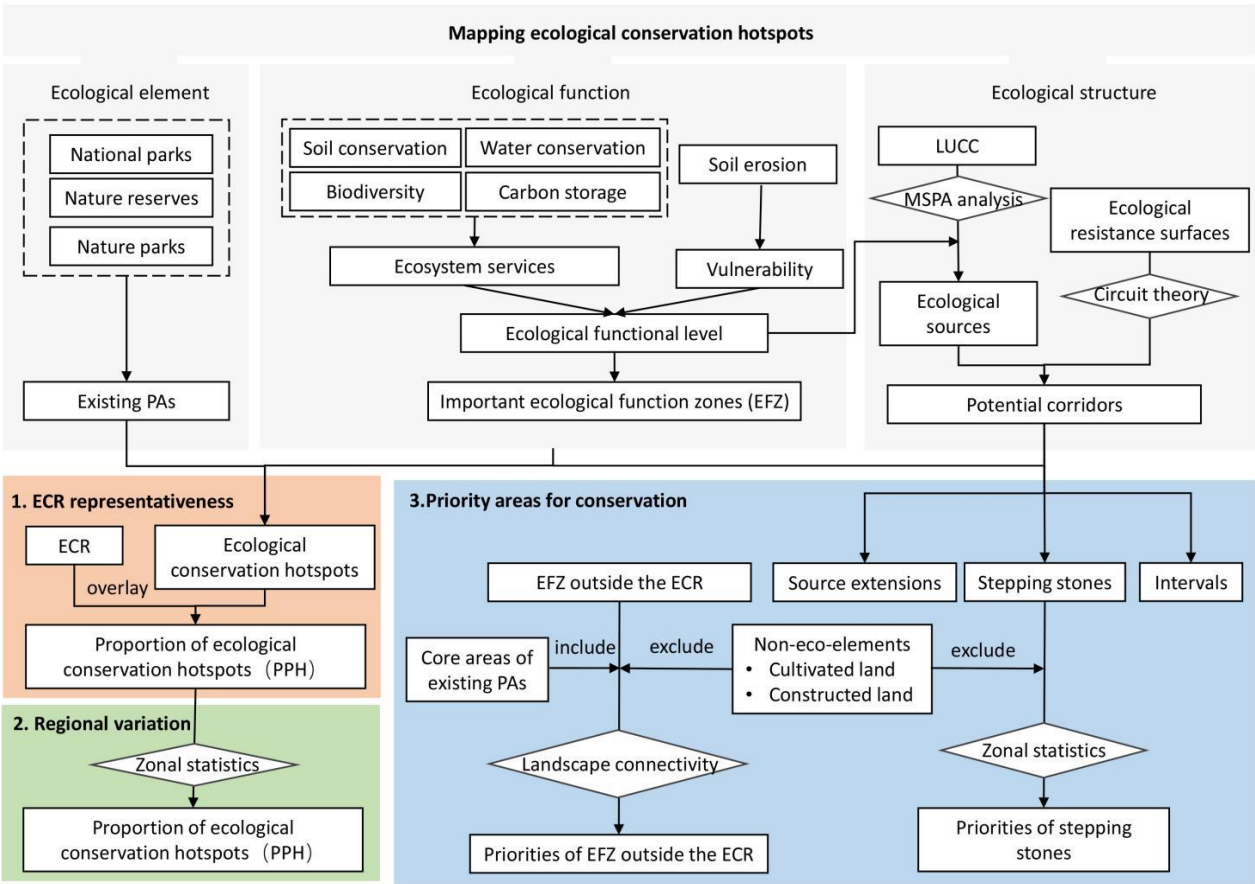
Figure 1. Workflow for the assessment of ECR coverage. *The three columns in gray represent the element-function-structure that altogether depict ecological conservation hotspots.*

2.1. Study area

89 Zhejiang province is located in the southeast coast of China (Fig. 2). This province covers an estimate of
90 105,000 km^2, of which forest land and cultivated land account for 62% and 23%, respectively (Table S1).
91 Owing to its abundant vegetation and valuable biological resources, Zhejiang province performs essential
92 ecological functions at both regional and national scales. Notably, in 2000, a local flagship program
93 analogous to the current ECR policy was first launched in the Anji County of Zhejiang province (Gao,
94 2019, also see Fig. 2).

95 In addition, Zhejiang is a densely populated province in the south wing of the Yangtze River Delta and it

96 is now experiencing rapid urbanization (Wang et al., 2017). It governs 11 cities and 89 counties, with a

97 total GDP and per capita GDP ranking among the top five in China. Currently, the terrestrial ECR areas

98 in Zhejiang province cover an area of 24,852 km^2, more than 23% of the land (Table S2).
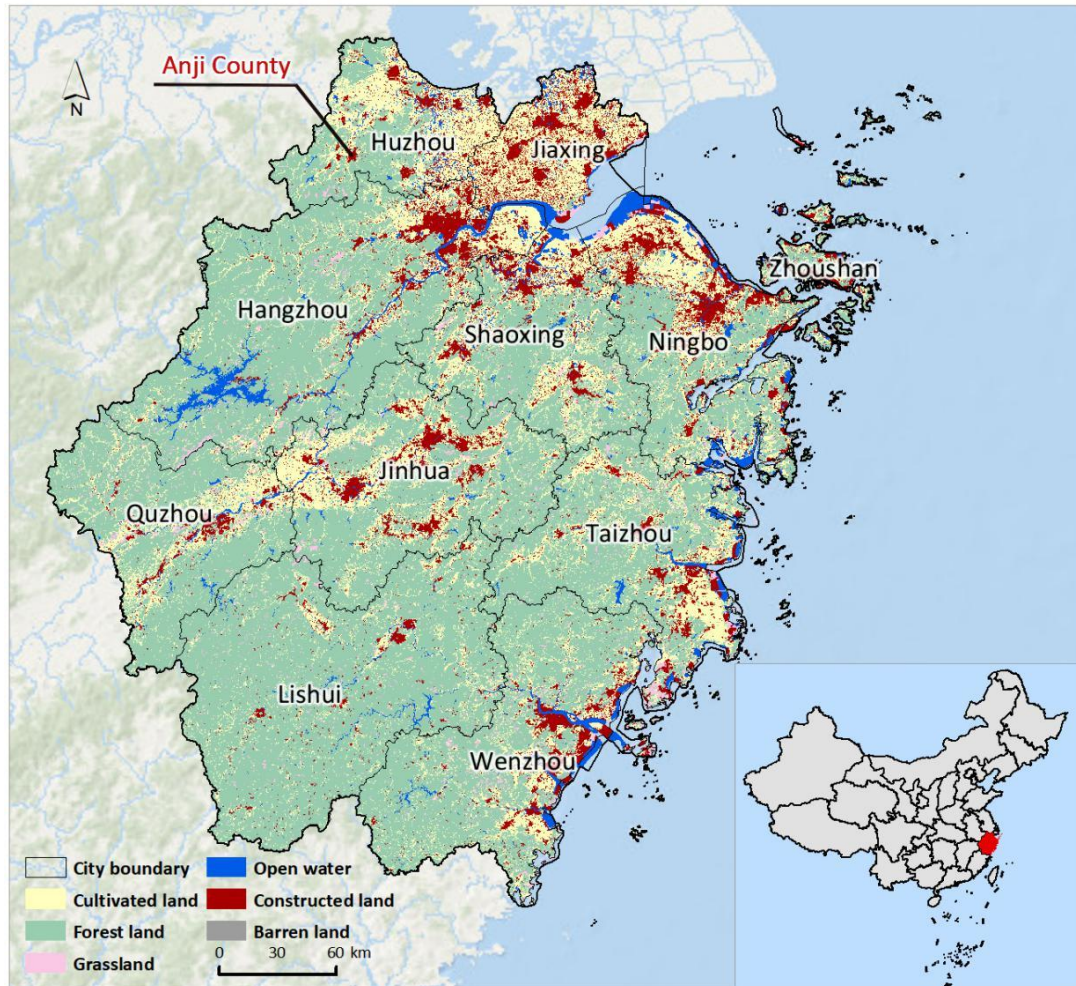
100 *Figure 2. Location and land use patterns of Zhejiang province. Land use data is derived from the*

101 *National Land Cover Datasets (NLCDs, see Liu et al. (2014)) for the year 2018. The topographic basemap*

102 *is publicly available at ESRI ArcGIS $^®$.*

2.2. Dataset

104 Various datasets are used in this study (Table S3). These datasets can be categorized into 4 classes: 1)

105 Land use. Land use data with a spatial resolution of 30 m are obtained from the Resource and

106 Environmental Science and Data Center (https://www.resdc.cn/), and was reclassified into six categories:

107 cultivated land, forest land, grassland, open water, constructed land, and barren land. 2) Terrain. Digital

108 elevation model (DEM) with a spatial resolution of 30 m is downloaded from the Geospatial Data Cloud

109 (http://www.gscloud.cn/). 3) Biophysical elements. Normalized Difference Vegetation Index (NDVI) and

110 Net Primary Productivity (NPP) are derived from Landsat-8 satellite imaginaries; Soil properties are

111 provided by the World Soil Database, which includes soil depth, organic matter content, soil composition

112 and others; Temperature and precipitation are derived from the observation data of 42 meteorological

113 stations covering Zhejiang Province, and precipitation and potential evapotranspiration in 1995–2018 are

114 interpolated using the Kriging method. 4) Socioeconomic factors. Road Network is obtained from the

115 OpenStreetMap (OSM, https://www.openstreetmap.org/); ECR boundaries, major function-oriented zones,

116 and existing PAs are acquired from the local government (https://www.zj.gov.cn/).

117 Pre-processing operations such as geo-referencing and merging are implemented on ArcGIS 10.5 platform.

118 All data layers are uniformly projected to the spatial reference of WGS_1984_UTM_Zone_50N, and the

119 grid size is resampled to 100 m × 100 m.

120 **2.3. Determination of ecological conservation hotspots**

121 In this section, we elaborate the methods used to extract existing PAs, EFZs, as well as ecological corridors,

122 which are the three most relevant components for ECR delineation (i.e., element, function, and structure,

123 respectively).

124 **2.3.1. Protected Areas (PAs)**

125 Existing spectrum of PAs in China consists of national parks, nature reserves and parks (Miller-Rushing

126 et al., 2017), with a decreasing sequence of ecological importance and management intensity accordingly.

127 We compile the scheme of PAs, and manually merge PAs regardless of their relative importance in the

128 ArcGIS platform (https://www.esri.com/).

129 **2.3.2. Important Ecological Functional Zones (EFZs)**

130 Ecological functions can be portrayed as the ecosystem services (ESs) and ecological vulnerability (Peng

131 et al., 2019). According to Zhejiang's ecological conditions and expert knowledge, we select and assess

132 four types of ESs and one indicator for ecological vulnerability with the InVEST model, NPP index, and

133 the Revised Universal Soil Loss Equation (RUSLE). For more technical details, please see the

134 Supplementary Method. These four ESs subsequently are normalized using Min-Max value method, and

135 summed with equal weights. Lastly, we extract 20% of areas with the largest values as EFZs (Bai et al.,

136   2018).

2.3.3. Potential ecological corridors

138   Regions protected by ECR areas are not isolated space for many large species that are largely dependent
139   on habitat outside the ECR, and corridors linking them together are therefore crucial elements for animal
140   movement (Dai et al., 2021; Ghoddousi et al., 2022). Literally, an ecological corridor that connects
141   multiple sources is a narrow strip of vegetation that is distinct from other nearby ecological elements. The
142   graph-based approach and circuit theory have been widely used to identify potential corridors (Huang et
143   al., 2020; Peng et al., 2018). Following the circuit theory, landscape can be regarded as a conductive
144   surface and the probability in the biological migration conforms to Ohm's law:

145    $$I = U / R \qquad (1)$$

146   where R characterizes the resistance of the conductive, U represents the voltage across a given node, and
147   I is the current through the node. In this study, the regional ecological network is regarded as a circuit, and
148   the flow is considered as the current between ecological sources.

149   As for the application of circuit theory, the key is to determine ecological sources and resistance surfaces.
150   Ecological sources are the origin of species dispersal and provide important ecosystem services as well as
151   take great structural importance (Dai et al., 2021). In light of this, ecological sources are identified as these
152   core areas with high ecological functions. Specifically, the research objects of the Morphological Spatial
153   Pattern Analysis (MSPA) are divided into two categories: foreground (forest land, grassland, open water)
154   and background (cultivated land, constructed land, barren land) to distinguish the core area (Lin et al.,
155   2021). Consequently, the value of ecological functions is categorized into one out of the five levels
156   following the natural break method, with the top 20% bin considered as ecological function zones (Peng
157   et al., 2018).

158   Meanwhile, resistance value indicates the difficulty for species to disperse, which are determined by
159   natural conditions and human activities. According to the characteristics of the study area and existing
160   researches (Wang et al., 2021), resistance value can be represented by land use/cover, elevation, slope,
161   distance from road, and distance from constructed land (Table S4).

2.4. Ecological representativeness of ECR coverage

163   We analyze the overall pattern of these different types of ecological hotspots (i.e., ecological element,

164 function, and structure), the proportion of ecological conservation hotspots (PPH) within its area and the

165 percentage of overlap with hotspots (PEH), to measure ecological representativeness (Bai et al., 2021).

166 PPH is obtained by calculating the percentage of area of all hotspots that are protected in Zhejiang

167 province, to assay the extent of the protection of ecological hotspots. PEH is obtained by calculating the

168 percentage of ECR areas that concur with ecological conservation hotspots in each of the 89 counties,

169 interpreting the representativeness of the current ECR. Thus, PPH reveals the overall protection of all

170 ecological conservation hotspots, and PEH represent the percentage of ECR areas covers hotspots relative

171 to non-hotspot areas (Bai et al., 2021). To further examine the regional variation of ECR representativeness

172 in Zhejiang province, we distinguish four clusters according to the major function-oriented zones,

173 determined by natural conditions and human activities therein (Fan et al., 2012).

174 2.5. Determination of conservation priorities

175 Implementing official adjustments of the issued ECR coverage may be unrealistic in the short term. Hence,

176 we determine the ecological optimization target through the overall analysis with regards to EFZ and

177 ecological stepping stones.

178 2.5.1. Importance zoning of EFZ

179 After dissolving the core areas of the established PAs in ECR areas, conservation priority of non-

180 overlapping EFZ is graded into one out of the four levels according to the summed level of ecological

181 functions and landscape connectivity of their ecological sources.

182 Moreover, we use graph-based connectivity indicators to characterize the overall connectivity in a

183 landscape and the importance of each patch for connectivity (Saura & Pascual-Hortal, 2007). Specifically,

184 Integral Index of Connectivity (*IIC*) and Probability of Connectivity (*PC*) are chosen to calculate the

185 relative importance (*dI*) of landscape connectivity by using Conefor 2.6 software. The main calculation

186 formula is as follows:

$$187 \qquad IIC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{a_i * a_j}{1+nl_{ij}}}{A_L^2} \tag{2}$$

$$188 \qquad PC = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}P_{ij}^{*}a_i * a_j}{A_L^2} \tag{3}$$

$$189 \qquad dI = 0.5 * dIIC + 0.5 * dPC \tag{4}$$

190   where n is the total number of patches; a_i and b_j are areas of patches i and j respectively; nl_{ij} is the number

191   of connections between patches i and j; A_L is the area of the entire landscape; and P_{ij}^* represents the

192   maximum probability that patch i and j are connected.

193   **2.5.2. Ecological stepping stones**

194   Ecological corridors play a crucial role in biological dispersal and species persistence (Rocha et al., 2021),

195   while linear construction projects such as roads and railways threaten the protection of ecological corridors

196   (Marcantonio et al., 2013). In that case, however, stepping stones in corridors can still provide essential

197   ecological linkage (Rocha et al., 2021; Saura et al., 2014). In this study, we use the Pinchpoint Mapper to

198   identify ecological stepping stones following the circuit theory. According to the maximum migration

199   distance of terrestrial animals and plants (Rouget et al., 2006), the width of potential ecological corridors

200   is determined to be 1.2 km, and the cost-weighted density (CWD) of corridors is graded into five classes

201   using the natural break method. We assign the areas that fall into the highest density bin as the essential

202   locations for ecological flow. Considering the exclusivity of ecological elements and integrity (Saura et

203   al., 2014), we eventually define ecological patches with an area > 10 km^2 as stepping stones, of which the

204   total current value can further reflect their relative importance.

205   # 3. Results

206   ## 3.1. Ecological representativeness of ECR coverage

207   Overall, ecological conservation hotspots cover approximately 31% of the total terrestrial area of Zhejiang

208   Province (Fig. 3), and this proportion is moderately higher than the national target of ECR policy (25%).

209   Specifically, PAs, which cover a terrestrial area of 10110 km^2, are mostly distributed in Hangzhou City

210   and Wenzhou City (Fig. 3a and Table S5). Moreover, 84% of these PAs are established to restrict human

211   activity in forestry areas (Table S5). In contrast, the total area of EFZ hotspots reaches nearly 25,000 km^2

212   (Fig. 3b and Table S6), which is also dominated by forestry (Table S6). Ecological corridors, however,

213   only cover a small area of 8297 km^2 (Fig. 3c), with an average length of 56 km. The vast majority of land

214   in ecological corridors is currently used for forestry and agricultural production, accounting for 47% and

215   36%, respectively (Table S7).

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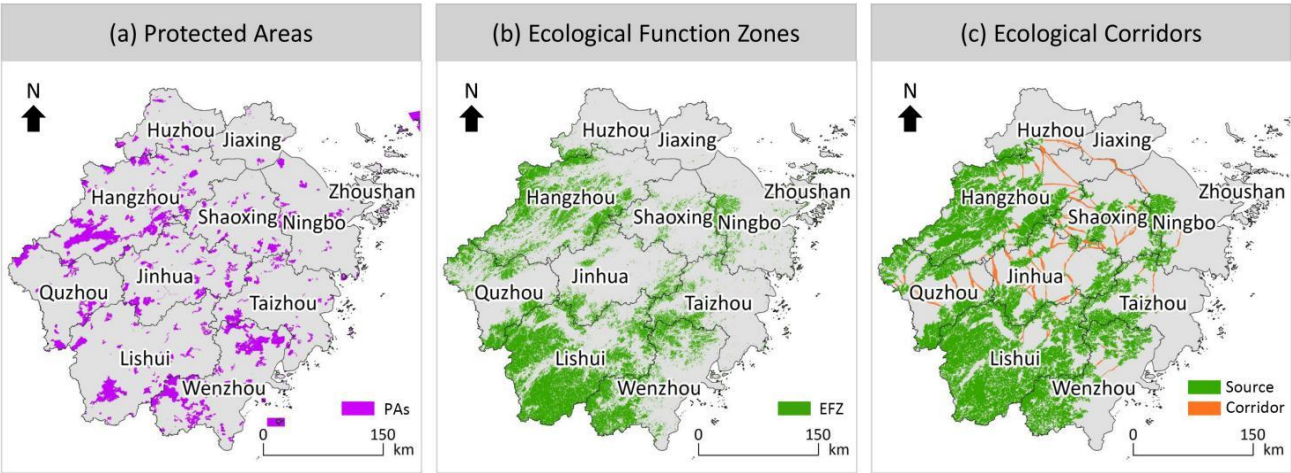
Figure 3. Ecological conservation hotspots. (a) *Protected Areas;* **(b)** *Ecological Function Zones; and* **(c)** *Ecological Corridors. To further explore the enhanced visualization of these results, please check the interactive map viewer at* *https://landbigdata.github.io/ECR/*

The PPH, or the proportion of ecological conservation hotspots protected by ECR areas, for all of Zhejiang is only 48%, suggesting an enormous space for spatial optimization. Yet, there is a large variation in terms of PPH among the three dimensions (i.e., ecological element, function, and structure). In the dimension of ecological elements (i.e., PAs), PPH is roughly 67%. Local governments reserve space for tourism and construction development, and thus ECR protection is prone to leave gaps in PAs (Fig. 4a), especially in nature parks (e.g., in the northeast of Wenzhou city,). In the dimension of ecological functions, 48% of the entire EFZ is protected by ECR areas (Fig. 4b). However, ECR areas in the south and northwest of Zhejiang province cannot sufficiently protect EFZ, and these in central Zhejiang province protect a large proportion of land outside the EFZ. In terms of ecological structure (i.e., ecological corridors), however, PPH is only 11%, highlighting the remarkable insufficiency of ecological corridors protected by ECR areas.
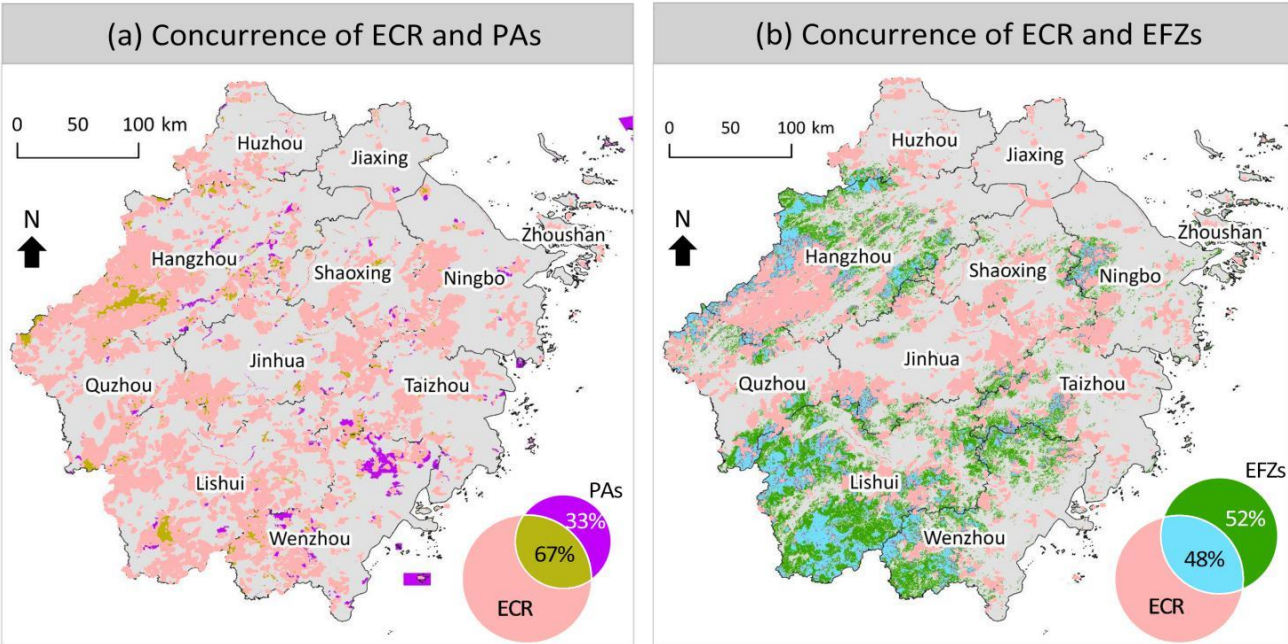
Figure 4. Concurrence of ECR and ecological conservation hotspots. (a) *ECR and PAs, and* **(b)** *ECR and EFZ. For enhanced visualization of these results, please also explore the interactive map at* https://landbigdata.github.io/ECR/

3.2. Regional variation in ECR delineation

As the spatial congruity between ECR areas and ecological conservation hotspots differs across space, we compare the representativeness (PEH) among different counties, particularly with regards to four types of major function-oriented zones (i.e., urban development areas, priority development areas, main agricultural areas, and key eco-function areas). Results show that the proportion of non-ecological land in ECR areas increases substantially with the increasing priority for socio-economic activities in the 89 counties, manifested as the low ecological representativeness of ECR coverage (Fig. 5a-b).

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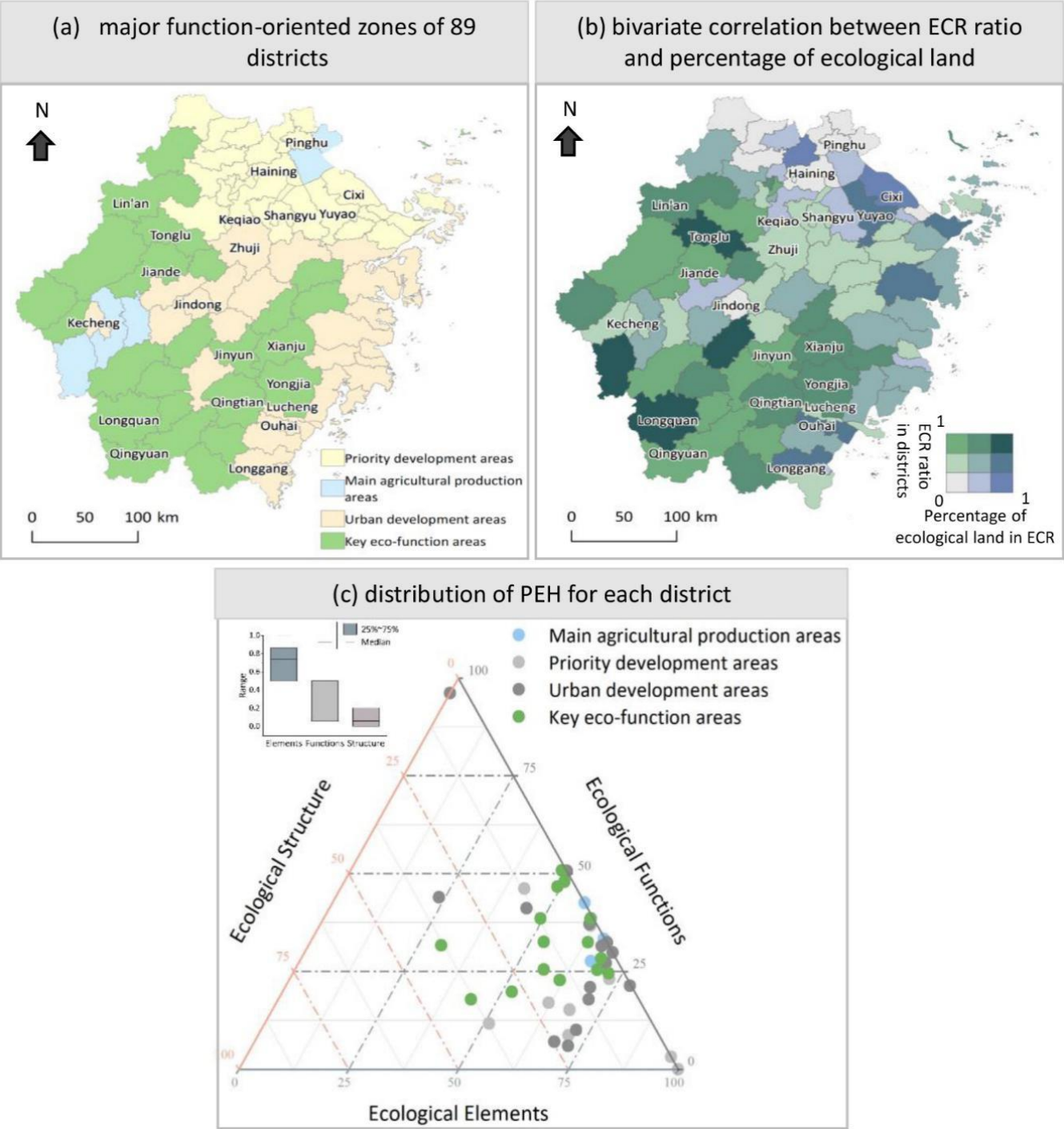
Figure 5. Regional variations in the ecological representativeness of ECR coverage. (a) division of major function-oriented zones; (b) bivariate correlation between ECR ratio and percentage of ecological land; (c) distribution of the ecological representativeness of three hotspots (PEH) for each county, with color indicating the categories.

249   Among the four types of major function-oriented zones, the urban development areas exhibit the highest

250   representativeness in terms of PAs (Fig. 5c). As the main area of economic activities, local authorities tend

251   to strictly protect the existing PAs in the progress of socioeconomic development to meet local ecological

252   needs. However, given the frequent disturbance of human activities, ecological corridors are largely pre-

253   occupied for residence and food production. In particular, many counties like Lucheng county are in such

254   a dilemma with 5% of construction land located in ECR areas (Tables S8 and S9). Priority development

255   areas are dominated by counties in the northeast of Zhejiang, where people act more multifarious and

256   concentrated, and thus ecological functions are generally under the median (Fig 5c), which can be

257   attributed to the scarcity of ecological land. Notably, the ratio of non-ecological land roughly increases

258   with increase of ECR coverage. For example, in Cixi County and Haining county, nearly 60% of the ECR

259   areas are in non-ecological regions (Tables S8 and S9).

260   Overall, ECR areas in the main agricultural production zones are less representative in terms of ecological

261   function and structure (i.e., EFZ and ecological corridors, respectively). There is quite some non-

262   ecological land that is protected by ECR areas (Table S9). For example, 63% of total land in Pinghu

263   County is used for cultivation, whereas 57% of its total cultivated land is found in ECR areas (Tables S8

264   and S9). By contrast, almost all counties in the key eco-function areas effectively represent ecological

265   functions. The proportion of ecological land in these counties is over 80% (Tables S8 and S9), and thus

266   land-use competition is less intensive in ECR areas.

267   3.3. Priority areas for conservation

268   To increase the ecological representativeness of ECR coverage at the provincial level, counties in the

269   southwest of Zhejiang province can act as the leverage point for balancing ecological functions and

270   landscape connectivity (Fig. 6a). Thus, these counties are responsible for the most protection, but are still

271   plagued by inadequate EFZ protection despite the highest ECR ratios. Counties in the western mountains

272   and coastal hills have high ecological functional importance and good landscape connectivity (dI-level =

273   3), which are potential areas for ECR protection. Notably, counties in the west of Zhejiang provinc already

274   have large proportions of ecological conservation hotspots protected by the ECR areas, such as Lin'an

275   County, Tonglu County, and Kecheng County. However, counties in coastal hills show relative low

276   representativeness of ecological hotspots, such as Xianju County, Qingtian County, and Jinyun County.

277   Moreover, the coverage of ECR areas in the urban development areas, such as Yuyao County and Yongjia

278   County, have only marginal contributions to the overall ecological security (dI-level = 1/2).

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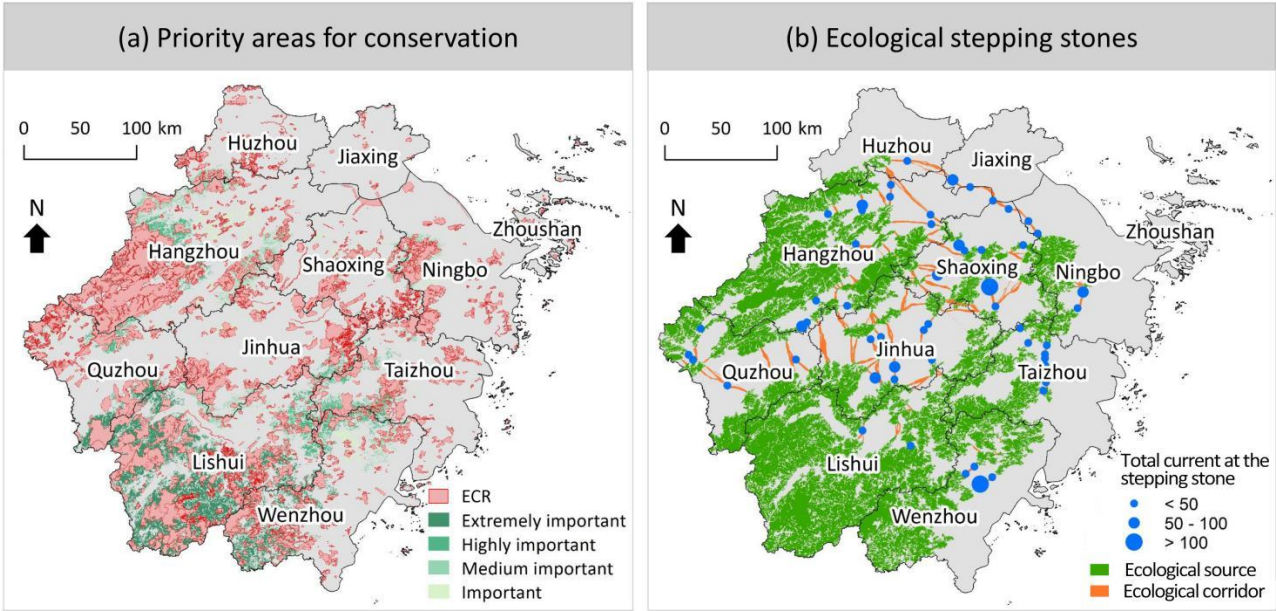
Figure 6. Priority areas for conservation (a) and ecological stepping stones at ecological corridors (b).
To facilitate sound policy-making for local government and decision-makers, both maps can be explored
interactively in the map viewer at https://landbigdata.github.io/ECR/

Several counties assume the important responsibility of maintaining landscape connectivity, although they may provide minimal ecosystem functions (Fig. 6b). Based on the circuit theory, we identify 59 stepping stones with an average size of 2.5 km^2 and a total area of 149 km^2, which accounts for 38% in size of potential ecological corridors. The hills and basins in the geographical center of Zhejiang province, such as Keqiao County, Zhuji County, and Jiande County are hotspots of ecological stepping stones (Fig. 6b and Table S10). Similarly, a large proportion of land in Ouhai County, Haining County, and Shangyu County is along river banks that act as ecological stepping stones (see the interactive map). However, many stepping stones in these counties have been occupied by non-ecological land (Table S10), especially in Jiaxing City, where the vast majority of these stepping stones are used for agricultural production (Table S11).

4. Discussion

4.1. Conservation policies in China

To resolve sustainability crisis, the central government of China has enacted a wide range of nature conservation policies in the past few decades, including Three-north Shelter Forest Program, Natural

297 Forest Conservation Program, and Grain for Green Program, among others (Bryan et al., 2018). In
298 particular, these programs have largely contributed to forest restoration and biodiversity conservation in
299 China (Chen et al., 2019; Deng et al., 2014; Viña et al., 2016). For example, China plays a leading role
300 during the greening process on Earth (25%) with forests contributing to 42% of greening in China (Chen
301 et al., 2019).

302 Moreover, the Chinese government have also launched a number of programs to address biodiversity
303 issues, particularly, Wildlife Conservation and Nature Protection Program, by which PAs are established
304 all over the country (Bryan et al., 2018). In order to foster the effectiveness of PAs, which now covers
305 ~18% of the country's land, the Chinese government recently established a new scheme of PAs that
306 consists of national parks, nature reserves and parks (Miller-Rushing et al., 2017; Wei et al., 2020). In
307 addition, a series of efforts has been carried out to warrant the maintenance of PAs, including establishment
308 of conservation monitoring networks, synthesis of species catalogues, and legislation of conservation
309 priority areas (Ma et al., 2017; Wei et al., 2020). These efforts altogether have substantially contributed to
310 the nation-wide strategy of ecological civilization (Wei et al., 2020).

311 4.2. Significance of this study and implications for ECR Policy

312 ECR policy is supposed to be distinguished from other conservation policies in China with regard to the
313 integrity of ecological protection, strict requirements for spatial accuracy, and overall-process
314 management (Gao et al., 2020). To the best of our knowledge, this study is a unique exploration in the
315 assessment of ECR coverage, and can therefore benefit the conservation community in the following
316 aspects.

317 While other studies have explored approaches to the assessment of ECR coverage (Hu et al., 2020; Zuo
318 & Gao, 2021), this study broadens the scope for ecological assessments by incorporating multiple goals
319 for conservation. Ecological benefits, among social outcome and nature-human interactions, have always
320 been a key indicator in examining the management effectiveness of PAs (Ghoddousi et al., 2022). Prior
321 studies, on the one hand, overwhelmingly investigate ecological vulnerability and habitat quality in PAs
322 to illustrate protection effectiveness (Ke et al., 2017; Ribeiro et al., 2021; Xu et al., 2017), and on the other
323 hand, analyze social and conservation outcomes of PAs (Oldekop et al., 2016; Porter-Bolland et al., 2012).
324 These assessments are frequently carried out within a given area. However, ECR is the bottom line
325 (threshold) of ecological security, which is irreplaceable space for ecosystem conservation. We prioritize

326 potential ecological areas by assessing the ecological importance of the entire area.

327 Although ECR areas have been formally delineated across China (Gao et al., 2020), local governments
328 and authorities may fail to achieve their overall targets for conservation without an effective
329 operationalization at an appropriate scale. The lack of definite standards still causes a large uncertainty on
330 how to define and implement ECR. However, we downscaled targets and analysis to counties, which are
331 the operators of ECR delineation. In addition, the characteristics of counties with different functions are
332 clustered, thus enabling local authorities to make informed decisions and optimization. Moreover, unlike
333 the common research on a macro-scale (Barber et al., 2014; Edgar et al., 2014) or micro-scale (Jones et
334 al., 2020; Liu et al., 2001), this study supplements the discussion from an intermediate perspective.

335 A preferable pathway to ECR implementation is site-specific management at the county scale as it is the
336 scale at which environmental planning and management policies are primarily targeted, in the meanwhile,
337 this can account for spatial heterogeneity therein. Specifically, we find that the proportion of ecological
338 conservation hotspots protected by ECR is nearly 70% in many counties in the southwest of Zhejiang
339 province. Yet, this proportion for many counties in the northeast of Zhejiang province is less than 5%.
340 With equity as one consideration, we suggest that ECR coverage in the southwest counties should be
341 extended to the highest priority regions identified in Fig. 6a, while ECR coverage in counties elsewhere
342 could be extended to less prioritized regions. Moreover, we suggest to play close attention to landscape
343 connectivity in northeast counties by protecting ecological corridors, and particularly stepping stones, as
344 results show that only 11% of ecological corridors are protected by ECR areas. Finally, the core and non-
345 core areas of ecological conservation need to be distinguished, and hierarchical regulation must be applied.
346 Given the complexity of ecological security, establishing buffer zones outside ECR areas and coordinate
347 all ecological land through hierarchical supervision are necessary to maintain ecosystem integrity.

4.3. Embracing the multifaceted goals of conservation

349 Globally, there is a growing recognition that government and local authorities should enact policies that
350 are capable to mitigate trade-offs between biodiversity protection and other aspects of human well-being
351 including cultural values, social relations, as well as public health (de Omena & Hanazaki, 2022;
352 McKinnon et al., 2016). Similarly, the original goals of the ECR policy in China include protecting species
353 from extinction, maintaining and restoring wildlife habitats, enhancing ecosystem services, and protecting
354 biological diversity (Gao et al., 2020; Wei et al., 2020). However, government and local authorities

355   increasingly acknowledge that Indigenous community and cultural landscape need to be accounted in the
356   practice of ECR delineation. According to the latest protocol on the implementation of ECR policy,
357   Indigenous people are authorized to build houses, raise livestock, and cultivate land in ECR areas, that is,
358   ECR areas are not exclusively for biodiversity conservation. Our assessment demonstrates that a large
359   proportion of ECR areas in non-hotspot regions (in or nearby urbanized areas), which we speculate that
360   this is because that the goal of ECR delineation to conserve natural habitat and biodiversity is
361   compromised to people's demand for aesthetic enjoyment and perception (O'Connor et al., 2021).

362   Conservation targets are challenging to be clearly set as multiple conservation goals are often closely
363   intertwined (Díaz et al., 2020). In particular, there are often trade-offs and synergies in terms of
364   conservation outcomes for nature or for people (Carranza et al., 2020; O'Connor et al., 2021). For instance,
365   studies investigating multiple outcomes of conservation policy suggest synergies between habitat quality
366   and species richness (Zhou et al., 2021), but may also demonstrate potential trade-offs between habitat
367   quality and economic prosperity (Jones et al., 2020). As such, the evaluation of conservation effectiveness
368   should be critical, and preferably outcome-oriented (Ghoddousi et al., 2022; Maxwell et al., 2020;
369   Rodrigues & Cazalis, 2020). To better implement of ECR, government and local authorities need to
370   improve the transparency and promote public participation of ECR delineation to bring multiple targets
371   of conservation to the table, ensuring that ECR policy can spontaneously contribute to the conservation
372   outcomes for nature and for people. Moreover, open-access monitoring network is required to safeguard
373   the implementation of ECR policy in a real-time mode (Mi et al., 2021; Wang et al., 2021), as this allows
374   for prompt feedbacks from governments, local communities and stakeholders, among many others.

4.4. Limitations

376   We acknowledge that our assessment has uncertainties and limitations. Conceptually, our assessment
377   focuses on the ecological importance of ECR coverage without social dimensions. As a policy tool,
378   researchers, government, residents, and other stakeholders are supposed to work together on the
379   delimitation of ECR (Bai et al., 2018). However, their negotiation may affect the marginal distribution of
380   local patches, causing ambiguous effects on the identification of regional ecological conservation hotspots.
381   Therefore, the proposed framework is more helpful in intuitively judging the ecological representativeness
382   of ECR coverage. Methodologically, although the InVEST model and circuit theory are widely adopted
383   in the construction of ecological networks (Cai et al., 2020; Luo & Wu, 2021), theoretical consensus on
384   the determination of key parameters and thresholds, such as the width of ecological corridors, are still not

385 reached. However, exploratory analysis suggests that variation in thresholds has only marginal effects on
386 the representativeness of ECR coverage. Lastly, our assessment does not include dynamic factors. The
387 ecosystem is in a dynamic state under the interaction of biology and environment, and the ecological data
388 of a single year may be accidental. Thus, carrying out more meaningful prioritization and clearer policy
389 guidance becomes challenging. In the following research, long-term data will be synthesized to increase
390 the reliability and robustness of the assessment.

5. Conclusions

392 In this study, we propose a comprehensive framework of "element-function-structure" to assess the of
393 coverage of ECR areas in Zhejiang province, China. First, the InVEST model, MSPA analysis, and circuit
394 theory are employed to identify three types of ecological conservation hotspots, and these hotspots are
395 further used to assess the ecological representativeness of ECR coverage. Moreover, regional variation of
396 ECR coverage among different counties is analyzed with regard to major function-oriented zones, the
397 official zoning scheme to coordinate future development and protection pattern. Lastly, priority areas for
398 conservation are outlined to leverage ecological benefit. This framework provides a new perspective and
399 feasible approach to ensure that key components for ecological security are prioritized, contributing to the
400 optimization of ECR coverage. The conclusions are as follows:

401 • ECR areas and ecological conservation hotspots often do not coincide. The retention rate of
402   existing PAs in ECR areas is nearly 67%, followed by ecological function areas, which is
403   approximately 48%. However, the existing ECR coverage is remarkably insufficient to protect
404   potential ecological structure, namely, ecological corridors.

405 • The ecological representativeness of ERC areas corresponds to key function zones. In key eco-
406   function areas, for example, ECR areas account for a relative large proportion of ecological lands.

407 • The priority areas for conservation suggest that regions in the southwest of Zhejiang province
408   can be the leverage point to increase ecological benefits by maintaining ecological functions.
409   While counties elsewhere with less ecological function can also contribute to ecological
410   conservation, particularly by maintaining landscape connectivity via stepping stones.

411 • We argue that assessment of ECR coverage needs to account for multiple demands from
412   conservation, ranging from biodiversity conservation to human well-being.

413   **Data Availability Statement.** Datasets that support findings of this article are available at

414   https://landbigdata.github.io/ECR/

415   **Declaration of Competing Interest.** The authors declare that they have no known competing financial

416   interests or personal relationships that could have appeared to influence the work reported in this paper.

417

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