Spatial identification of conservation priority areas for urban ecological land: An approach based on water ecosystem services

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Abstract: How to effectively prevent land degradation and ecosystem deterioration in the pro- cess of urbanization has been the focus of land degradation researches in urban areas. Urban ecological land can be defined as the natural base on which a city relies to eco- logically survive. It closely links the social economy with the natural eco-environment, providing an important integrated approach to resolve the contradiction between urban expansion and natural ecosystems conservation in the process of urbanization. The research question addressed in this study is how to accurately identify the conservation priority areas for urban ecological land. Taking Zhuhai City, located in China, as an example, an approach based on seven kinds of water ecosystem services was put forward, combining social demand and natural supply for the services to determine service targets and conservation priority areas. The results showed that the conservation priority areas in Zhuhai City covered 868 km2, accounting for 51.03% of the total land area, which were mainly covered by woodlands or paddy fields and fish ponds. In addition, by synthesizing ecological importance and ecological sensitivity, management zones for urban ecological land were delineated, including

510 km2 of primary control areas and 358 km2 of secondary control areas. In the supply and demand view of water ecosystem services, this study put forward an integrated ecosystem- based approach for conservation priority area identification of urban ecological land, aiming to prevent land degradation and achieve urban ecological sustainability.

Keywords: conservation priority areas, spatial identification, urban ecological

land, water ecosystem services, Zhuhai City, China

1 Introduction

Since the beginning of this century, rapidly increased population and intensified utilization of land resource have caused continuous degra- dation of land as well as ecosystem deterioration at the global scale, threatening food and ecological security on the mid to long term (Capps, Bentsen, & Ramírez, 2016; Ng, Leung, Cheung, & Fang, 2017). Hence, combating land degradation is vital to sustainable development. Land degradation research should not only measure or predict the drivers of land degradation but, more importantly, also focus on the prevention of land degradation, especially in developing regions. As a significant trend of human development, urbanization has become the most prominent feature of social development since the 20th century (H. Li, Peng, Liu, & Hu, 2017; Y. Li, Sun, Zhu, &Cao, 2010; Qiu, Song, & Li, 2017). Urban expansion would often trans- form the original natural ecosystem into impervious surface with fun- damental change of material and energy flows (Alberti, 1999) and thus bringing significant degradation of habitat quality (Bajocco, Angelis, Perini, Ferrara, & Salvati, 2012; W. Li, Wang, Li, & Liu, 2017; Oliveira, Tobias, & Hersperger, 2018). The quantity and quality changes of eco- system services have led to urban eco-environmental problems such as urban heat islands, air pollution, and flood disasters (Cheng, Chen, Sun, & Kong, 2018; H. Fu & Chen, 2017; J. Li et al., 2011).

As the most fundamental material basis for the survival and devel- opment of human society, land provides the basic spatial carrier for human activities (Felipe- Lucia, Comín, & Bennett, 2014; Ólafsdóttir & Júlíusson, 2015). Because land use is the most predominant carrier for human's influence on natural ecosystems, human society is closely linked with natural ecosystems through the inherent connection between land

50 use and land cover (B. B. Lin et al., 2018; Runfola & Pontius, 2013; Thomas, Sporton,

51 & Perkins, 2015). Urban ecological land, as one functional type of land use, can be

52 defined as the natural base on which a city relies to ecologically survive (Peng, Zhao,

53 Guo, Pan, & Liu, 2017). It not only maintains the ecological cycle and biodiversity but

54 also provides the ecosystem services to satisfy human demands (Bergsten, Galafassi, &

55 Bodin, 2014; McPhearson, Kremer, & Hamstead, 2013). Thus, urban ecological land is

56 fundamental to urban ecological sustainability, and effectively protecting urban

57 ecological land has been considered as one of the key issues in combating land

58 degradation in urbanizing areas.

59 With increasing global awareness about ecological security and sustainability (Q. Lin,

60 Mao, Wu, Li, & Yang, 2016; Peng, Yang, et al., 2018; Runfola et al., 2017; Zhang, Peng,

61 Liu, & Wu, 2017), research on identification and protection of important urban

62 ecological land has flourished over recent years. For example, the method of ordered

63 weighted averaging was used to identify priority areas for forest resto- ration with the

64 objective to improve water resource conservation (Vettorazzi & Valente, 2016); optimal

65 conservation planning of multiple hydrological ecosystem services was conducted

66 considering land use and climate change (M. Fan, Shibata, & Wang, 2016); the

67 conservation and management of urban green space were reviewed considering the

68 biodiversity of terrestrial fauna species (opucki & Kiersztyn, 2015); green infrastructure

69 was designed on the premise of spatial conservation prioritization (Snäll, Lehtomäki,

70 Arponen, Elith, & Moilanen, 2016); and urban green infrastructure planning was

71 explored combining the conservation of biodiversity and the delivery of ecosystem

72 services (Capotorti, Vico, Anzellotti, & Celesti- Grapow, 2016). Among the

73 abovementioned studies, whether the restoration and protection of urban ecological

74 land, the identification and management of urban green space, or the planning and

75 design of urbangreen infrastructure were all based on prioritizing the protection of

76 ecologically important areas. Given the huge human pressure on natu- ral ecosystems

77 in the process of rapid urbanization, the protection of most important ecological land

78 units with a limited investment should be considered as a basic principle of urban

79 ecological management. This is crucial for securing the welfare of future generations

80 through long- term ecosystem management.

81 Inherently linking natural ecosystem process with human well-being (Kong et al.,

82 2016; C. Li et al., 2015; Zheng et al., 2016), ecosystem services provide an effective

83 approach for assessing con- servation needs and spatially identifying the priority areas

84 for urban ecological land. Water- related ecosystem services, referred to as the "water

85 ecosystem services" (Yang, Zhang, Li, & Wu, 2015), are considered as the core services

86 to meet urban residents' demands. Water ecosystem services can strongly influence a

87 wide range of other (nonwater) ecosystem services and thus dominate the most

88 important feedback mechanisms between man and nature. As water ecosystem services

89 can also be quantitatively measured and monitored (Farooqui, Renouf, & Kenway, 2016;

90 Martin- Ortega, Ojea, & Roux, 2013; Moore & Hunt, 2012; Mulatu, Veen, & Oel,

91 2014), they meet the representa- tive, comprehensive, and threshold requirements for

92 identifying con- servation priority areas for urban ecological land. Consequently, water

93 ecosystem services can be considered as an effective tool to identify the conservation

94 priority areas for urban ecological land.

95 Zhuhai City is located in the lower reaches of the Pearl River Basin, the third largest

96 drainage basin in China. The city is built near the river, covering natural habitat for

97 water- related flora and fauna. As a result, natural ecosystems as well as the daily

98 activity of local res- idents are closely linked with water. Thus, Zhuhai City is the ideal

99 study area for identifying conservation priority areas in view of water ecosystem

services. Furthermore, as one of the earliest special eco- nomic zones established in China, Zhuhai City is ushering in a new round of urban construction against the background of new phase of intensified urbanization. Consequently, it is most urgent that the city identifies the conservation priority areas for urban ecological land based on water ecosystem services. The objectives of this study are (a) to establish a framework for measuring and mapping water ecosystem services; (b) to identify conservation priority areas for urban ecological land based on water ecosystem services; and (c) to delineate management zones for urban ecological land considering both ecological importance and sensitivity.

2 Materials and methods

2.1 Study area and data sources

Zhuhai City is located south of Pearl River Delta and along the west side of the Pearl River estuary (Figure 1), covering the estuary of the Modaomen, Jitimen, Hutiaomen, and Yamen water systems in the Pearl River Basin (113°03′–114°19′E, 21°48′–22°27′N). The city is characterized by wet climate condition, with an average annual rainfall amount of 2,042 mm. However, the rainfall is unevenly distributed during the year with remarkably less over the winter and spring and more over the summer and autumn. More precisely, the precipitation tends to be concentrated in the flood season from May to June, which accounts for more than 30% of the total annual rainfall. Xijiang River, the main stream of the Pearl River, is divided into a plurality of tributaries as it enters Zhuhai City in the northern part of Doumen District. The tributaries then merge into three main streams and discharge into the South China Sea from north to south, where disasters such as extensive flooding are occurring frequently.

5

124   As a result, soil retention, runoff reduction, and flood regulation are selected as key

125   regulating services in this study. In addition, water pollution is a serious issue in this

126   city, as drinking water sources often contain chemical pollutants, and most groundwater

127   is also contaminated by heavy metal ions. Thus, water protection and water

128   conservation are selected as key provisioning services in the view of water quality and

129   quantity, respectively. Moreover, as a coastal city, there are various kinds of water

130   landscapes, including a large amount of waterfront parks. Accordingly, close- to-

131   water recreation and distant- water appreciation are selected as key cultural services.

132   The whole city occupies an area of 7,836 km2, with 1,701 km2 of land area and 6,135

133   km2 of sea area. Land use types in Zhuhai City mainly include woodland, paddy field

134   and fish pond, and construction land, accounting for 28.24%, 26.44%, and 23.67% of

135   the total land area, respectively. Woodland and construction land are interdependently

136   distributed, with a large amount of woodland distributed within or around the built- up

137   areas. Paddy field and fish pond are mainly dis- tributed along the water system and the

138   reservoirs. Furthermore, there are also almost 200 km2 of unused land and a small

139   amount of water bodies, dry croplands, and grasslands.

140   The data of this study mainly included two categories:

141   Spatial data. Land cover data for the year 2010 from the Globeland30- 2010 dataset

142   were provided by the Chinese Basic Geographic Information Center

143   (www.globallandcover.com/ GLC30Download/ index.aspx). Digital elevation model

144   data SRTM90m (CGIAR- CSI) were provided by the Computer Network Information

145   Center of the Chinese Academy of Sciences (http://www.cnic.cas.cn/ zcfw/ sjfw/

146   gjkxsjjx/). Normalized difference vegetation index data were obtained from the

147   MODIS MOD13Q1 product with spatial resolution of 250 m, provided by the U.S.

148   Geological Survey (https:/ / lpdaac.usgs.gov/ dataset_ discovery/ modis/

6

149 modis_products_table/ mod13q1). Soil type data were the 1:1,000,000 soil dataset of

150 Western Environmental and Ecological Science Data Center of the Chinese Academy

151 of Sciences. Meteorological data, including precipitation, temperature, and sunshine,

152 were from the Chinese Meteorological Data Service Platform (http:/ / data.cma.cn/).

153 Urban and regional planning reports, which were collected from the official websites

154 of the governmental departments of Zhuhai City, include the following documents:

155 urban master planning, overall planning for land utilization, geological disaster

156 protection planning, water supply engineering scheme, water resources comprehensive

157 planning, green space system planning, and the major function- oriented zoning.

158 **2.2 Research framework**

159 aking ecological land as the spatial carrier of ecosystem services and integrating the

160 supply and demand of ecosystem services, a concep- tual framework of spatially

161 identifying conservation priority areas for urban ecological land was developed (Figure

162 2). First, seven kinds of water ecosystem services covering the three categories of

163 regulating, provisioning, and cultural services were selected in the study area, together

164 with mapping the supply of these services. Second, for each kind of water ecosystem

165 services, service targets were determined according to societal demand and natural

166 supply capacity. Third, based on the supply capacity of ecological land in terms of

167 ecosystem services, ecological land fulfilling the service target was identified. Finally,

168 all the identified ecological lands were overlapped using ArcGIS in order to spatially

169 identify conservation priority areas for urban ecological land in Zhuhai City. In addition,

170 by synthesizing ecological importance and sensitivity, management zones for urban

171 ecological land were delineated.

2.3 Spatial identification of ecosystem service land

(1) Regulating service land

Regulating services refer to the services and benefits derived from the regulatory effect on ecosystem processes. Water regulation services achieve their regulatory effect by controlling hydro-ecological processes, including the services of soil retention, runoff reduction, and flood regulation.

Soil erosion reflects the degree of soil loss, which is related to rainfall erosivity, soil erodibility, slope length, slope steepness, crop management and support practices (Guo et al., 2018; Liu et al., 2010). Ecological land with high soil retention service was identified by calculating the difference of soil erosion amounts from areas that included and excluded ecological land. According to the degree of soil erosion in Zhuhai City and its hazard level, the mild soil erosion rate ($2500 \, \text{tons} \cdot \text{km}^{-2} \cdot \text{a}^{-1}$ or more) was selected as the service target of soil retention. Ecological land with soil retention service exceeding the target amount was identified as the service land of soil retention.

The revised version of the Universal Soil Loss Equation, i.e. RUSLE (Galdino et al., 2016), was used to calculate the total amount of soil retention (B):

$$B = R \cdot K \cdot L \cdot S \cdot (1 - C) \cdot P \tag{1}$$

Where R is the rainfall erosivity factor, calculated using Wischmeier's empirical formula (Fu et al., 2005); K is the soil erodibility factor, calculated by the K-value estimation method proposed in the EPIC model (Polyakov et al., 2007); L is the slope length factor, calculated by an empirical formula that combines horizontal slope length and slope length index (Kinnell, 2010); S is the slope steepness factor, calculated according to McCool's classic slope formula based on the gradient (Nakil & Khire, 2016); C is the crop management factor, obtained by the vegetation coverage, which

196   can be calculated from the average annual NDVI; and *P* is the support practice factor.

197   Referring to previous studies, the *P* value of various types of land cover was determined

198   (Panagos et al., 2015; Taye et al., 2017).

199   To identify service land of runoff reduction, the Sponge City Construction

200   Technology Guide promulgated by the Ministry of Housing and Urban-Rural

201   Development of China was followed. According to the technology guide which was

202   based on a statistical analysis of the daily rainfall in 200 Chinese cities during 1983-

203   2009, the runoff reduction target in Zhuhai City was set as 70%, and the corresponding

204   design rainfall was 25.2 mm hr^{-1}. In details, the main steps were as follows. Firstly, the

205   runoff collection point in a catchment area was identified as the regulation control point

206   after dividing catchment areas. Secondly, the demanding size of service land of runoff

207   reduction was determined according to the runoff load in the catchment area and the

208   regulating capacity of ecological land. Finally, based on the spatial location of the

209   regulation control point and the demanding size of service land, the service land of

210   runoff reduction was spatially identified.

211   The United States Soil Conservation Service (SCS) hydrological model was used to

212   calculate the runoff load (Ajmal et al., 2015). The model can reflect a wide range of

213   underlying factors, such as land use, soil type and pre-soil wetting conditions, as well

214   as the impact of human activities on rainfall runoff. Relatively few parameters are

215   required in the model.

216
$$Q = \begin{cases} \frac{(P-0.2S)^2}{S+P-0.2S}, & P > 0.2\,S \\ 0, & P \le 0.2\,S \end{cases} \qquad (2)$$

217   Where *Q* is the runoff (mm), *P* is the total rainfall (mm), and *S* is a parameter

218   reflecting the effects of soil and water conservation. As a mean of measuring the value

219   of *S*, the SCS model was used, which has a dimensionless parameter called the curve

220   number (CN) based on physical features and soil types. It also defined the relationship

221   between S and CN as follows:

222                          $$S = 254 \times \frac{100}{CN-1} \qquad (3)$$

223   In this study, the original CN values for hydrological groups of soils were amended

224   based on previous studies in Pearl River Delta (Fan et al., 2013; Lin et al., 2014; Xu et

225   al., 2016). The runoff pattern under rainfall events was simulated using the SCS model,

226   and thus the runoff of each catchment area was calculated to obtain the runoff load.

227   In flood regulation, what downstream cities such as Zhuhai can do is mainly

228   manifested in two aspects, i.e. maintaining the smooth flow of the flood discharge

229   channel and ensuring the rivers to access the floodplains. In this study, Laolao Creek,

230   Helao Creek, Hengkeng Waterway, Chifen Waterway, Luozhou Creek, Huangyang

231   River, Jintimen Waterway, Modaomen Waterway, and Tiansheng River, all of which

232   connected Xijiang River and Pearl River estuary, were identified from more than 170

233   rivers in Zhuhai City as the main protected flood discharge channels. According to the

234   green space system planning of Zhuhai City, a 100-m buffer zone on both sides of the

235   flood discharge channels was set as the flood avoidance area. Important flood discharge

236   channels and the 100-m buffer zone were integrated as the service land of flood

237   regulation.

238   **(2) Provisioning service land**

239   Water provisioning services are the services that human obtains directly from natural

240   water resources, including the provision of drinking, industrial and agricultural water.

241   Ecological land plays a significant role in water provisioning services through

242   protecting and conserving water resources. The main water supply channels, water

243   intake points and water storage areas are the most vulnerable areas in the view of the

244   safety of urban water source. Thus, they were designated as water protection areas.

10

245   Meanwhile, according to the relationship among rainfall, runoff and evaporation, urban

246   ecological land characterized by high water conservation capacity was set as water

247   conservation areas.

248   In order to specify the water protection areas more precisely, the water supply

249   engineering scheme of Zhuhai City was considered. It identified (i) the Modaomen

250   Waterway and Huangyang River as main sources of drinking water, (ii) the Hutiaomen

251   Waterway as the main source of industrial water, and (iii) the reservoirs in the middle

252   and western part of the city as auxiliary water sources. Furthermore, in the water

253   resources comprehensive planning of Zhuhai City, two levels of water protection area

254   were designated. The first level was set as the target of water protection, according to

255   the effect and cost of ecological land for protecting water sources. Subsequently, based

256   on the set service targets, the following riparian areas were classified as water protection

257   areas (Kingsford et al., 2011): (i) the rivers with main function of water supply, (ii) the

258   water areas within 1500m upstream and downstream of the five water intake points,

259   and (iii) the land within 100 meters distance from the water intake points. In fact,

260   although ultimately aiming at the provisioning of water resource, criteria (ii) and (iii)

261   also refer to the highest service of water purification. In addition, all the 26 reservoirs

262   in the city, as well as their corresponding catchment areas with the first-level protection

263   were also classified as water protection areas.

264   For water conservation service, the conservation degree of rainfall by ecological land

265   was calculated through the relationship among water conservation and water

266   demanding. The relationship between regional annual water conservation H and water

267   demanding X is as follows:

268 $$k \cdot H = X \tag{4}$$

269 $$H = \alpha \cdot P \tag{5}$$

270   where k is the local water use efficiency, and P is the average annual rainfall.

271   According to the water resources comprehensive planning of Zhuhai City, k was set as

272   56% with 2042 mm for P, and X was 440 million m^3 including domestic, ecological

273   and agricultural demanding. As a result, the degree of conservation (α) should reach

274   22.7%, compared with the total rainfall.

275   To remain consistent with runoff reduction, assuming 25.2 mm of rainfall in 1 hour

276   as the representative rainfall event, the degree of conservation in this rainfall event

277   should also be 22.7%. Considering the area of Zhuhai City, such a representative rainfall

278   event would produce a rainfall amount of 42.56×10^6 m^3, and the amount of water

279   conservation should reach 9.67×10^6 m^3. In a single rainfall event, for ecah spatial unit,

280   assuming that the amount of water conservation   is x, the rainfall is p, the runoff is q,

281   and the evaporation is z, the following water balance equation will exist:

282    $$x = p - q - z \tag{6}$$

283   Furthermore, water conservation capacity for ecological land was calculated using

284   SCS model as mentioned above. The ecological lands with the highest conservation

285   capacity were selected as water conservation area, meeting the demanding amount of

286   water conservation.

287   **(3) Cultural service land**

288   Cultural ecosystem services refer to the non-material benefits people obtain from

289   natural ecosystem. As a kind of ecological land, water body can also fulfill important

290   cultural services. In this study, water-based recreation was regarded as the

291   representative of water-related cultural services, including both close-to-water

292   recreation and distant-water appreciation. Water-based recreation relies on areas that

293   have recreation attraction. The important recreation areas in Zhuhai City were extracted

294   as the basic evaluation units, including recreational rivers, natural and cultural heritage

295   areas, nature reserves, scenic locations, urban parks, and greenways.

296   In terms of service land of close-to-water recreation, it should include not only water

297   bodies with recreation attraction, but also ecological land with high accessibility to the

298   water bodies. According to the water resources comprehensive planning of Zhuhai City,

299   water bodies with recreation attraction were extracted. Based on the extracted water

300   bodies, the usual distance that connects scenic spots, i.e. a five-minute walking distance

301   of 360 m (Bassett et al., 2000), was used to determine the buffer zone. These water

302   bodies and recreation areas within the buffer zone were identified as water recreation

303   areas.

304   To identify distant-water appreciation areas, recreation areas from which water

305   bodies could be watched with high frequency were considered. Taking the main water

306   bodies as watching objects, spatial pattern of watching frequency of these main water

307   bodies across the entire city was obtained using the sight analysis tool of GIS software.

308   More precisely, recreation areas with water-watching frequency above the average were

309   included in the cultural service land.

310   **2.4 Partition control of urban ecological land**

311   A city is a coupled human and nature system, with great spatial heterogeneity in its

312   component and functioning. Ecological land is the spatial basis for provisioning

313   ecosystem services. However, for different kinds of ecological land, and even the same

314   kind of ecological land at different locations, their importance and sensitivity to

315   ecosystem services maybe be quite different. Partition control has become an effective

316   way in urban ecological land management. Ecological importance of urban ecological

317   land refers to the intrinsic ecological functions and services it undertakes, whereas

318   ecological sensitivity of urban ecological land can be defined as the sensitivity of the

land to maintain ecosystem services under the impact of strong external disturbance

(Peng et al., 2015). Hence, through grading the ecological land according to ecological

importance and ecological sensitivity, and overlaying the two kinds of grading, a

partition management for urban ecological land could be conducted.

To quantify the ecological importance, the three maps of regulating service land,

provisioning service land, and cultural service land were overlaid in ArcGIS. And

subsequently, the ecological importance of ecological land was graded into three levels,

i.e. high importance, medium importance, and low importance, corresponding to the

appearance in three, two, and one kind of service land maps, respectively.

When investigating the ecological sensitivity, urban areas, towns, villages, roads and

railways were considered to quantify human threats on biodiversity using habitat

quality module of InVEST, which helped to grade the sensitivity of ecological land.

InVEST model has been widely used to analyze the impact of human-induced

ecological threating on land cover, and further to evaluate habitat quality and its

degradation (Posner et al., 2016). The principle of ecological sensitivity evaluation is

as follows:

$$D_{xj} = \sum_{r=1}^{R} \sum_{y=1}^{Y_r} (\frac{w_r}{\sum_{r=1}^{R} w_r}) r_y i_{rxy} \beta_x S_{jr} \qquad (7)$$

$$i_{rxy} = 1 - (\frac{d_{xy}}{d_{r\max}}) \qquad (8)$$

where D_{xj} is the ecological sensitivity, R is the number of sensitive source, w_r is the

sensitivity weight, Y_r is the pixel number of sensitive source, r_y is the number of

sensitive source on each pixel, i_{rxy} is the threating of sensitive source, β_x is degree of

legal protection, S_{jr} is the sensitivity coefficient, d_{xy} is the sensitive distance, and d_{rmax}

is the maximum sensitive distance of sensitive source. Specifically, urban areas, towns

and roads were considered to exert higher threating on ecological land, whereas it was

14

343 relatively small for villages and railways. In addition, dry croplands, paddy fields and

344 fish ponds as well as unused land were considered to be most sensitive to these threating,

345 followed by grassland, woodland and water body. (Table 1).

346 [Table 1 is here]

347   As the result of management zoning, primary and secondary control areas were

348 spatially identified through overlaying the maps of ecological importance and

349 ecological sensitivity. Using the method of natural break, ecological sensitivity of

350 ecological land could be divided into three levels, i.e. high sensitivity, medium

351 sensitivity, and low sensitivity. Then the management zones for urban ecological land

352 in Zhuhai City were delineated according to the combination of ecological importance

353 level and ecological sensitivity level. In detail, ecological land with high ecological

354 importance or high ecological sensitivity was identified as primary control area,

355 whereas the other part of conservation priority areas were identified as secondary

356 control areas.

357 # 3 Results

358 ## 3.1 Key areas supplying ecosystem services

359   Through integrating the supply and demanding of ecosystem services, spatial

360 distribution of key areas supplying the demanded seven ecosystem services were

361 obtained (Figure 3). I This result showed that the soil retention service was mainly

362 distributed in mountainous areas characterized by abundant vegetation that could

363 effectively retain soil (Figure 3a). The runoff reduction service was concentrated in the

364 low-lying areas around the main water systems (Figure 3b), covering a total area of 128

365 km^2 with the minimum and maximum patch area of 1 ha and 249 ha, respectively. The

366 flood regulation service was chiefly distributed in riparian zone around major rivers

367 with the potential to ameliorate or prevent flood disaster (Figure 3c). The water

368 protection service covered a total area of 120 km^2, locating around such water sources

369 as rivers and reservoirs (Figure 3d). The water conservation service had an area of 444

370 km^2, accounting for 26.10% of the total land area, and was mostly provided by

371 woodlands and paddy fields (Figure 3e). The water recreation service was located in

372 areas adjacent to water body and contained all the offshore islands and the banks of the

373 rivers (Figure 3f). The water appreciation service was concentrated in the high-lying

374 areas, which had the topographical induced advantage of having a great sight potential

375 for attractive waterscape (Figure 3g).

376 [figure 3 is here]

377 3.2 Conservation priority areas for urban ecological land

378 Spatial distributions of the three categories of ecosystem service land were obtained

379 through overlaying key areas of ecosystem services in the same category (Figure 4). As

380 shown in Figure 4a, regulating service land was 547 km^2, accounting for 32.16% of the

381 total land area. Comprised of soil retention area, runoff reduction area, and flood

382 regulation area, the regulating service land included the main mountain areas with high

383 vegetation coverage, the major flood channels and floodplains, as well as the low-lying

384 green areas distributed at the outlets of various sub-catchments. The area of

385 provisioning service land was 509 km^2, accounting for 29.92% of the total land area. It

386 contained 120 km^2 of water protection area and 444 km^2 of water conservation area,

387 and was mainly distributed in water supply channels and water bodies, woodland in

388 mountain areas, and paddy fields in the plain (Figure 4b). The area of cultural service

389 land was 498 km^2, accounting for 29.28% of the total land area. It was mainly located

390   in the surrounding areas of inland rivers, reservoirs and ponds (Figure 4c). Being close

391   to the main water bodies, the cultural service land had the advantages of providing

392   water-related recreation and appreciation services.

393   [figure 4 is here]

394   Based on the relationship between ecological land and its ecological functions and

395   services, which was embodied in ecological processes, ecological land that met the

396   demanding targets of key ecosystem services was defined as conservation priority areas.

397   More specifically, through overlaying the regulating service land, provisioning service

398   land and cultural service land, the conservation priority areas of water ecosystem

399   services in the study area could be mapped (Figure 5). After removing the overlapped

400   ones among the three kinds of service land, the conservation priority areas for urban

401   ecological land in Zhuhai City were determined to be 868 km^2, accounting for 51.03%

402   of the total land area. They were mainly composed of woodlands in mountain areas,

403   water bodies and cropland in the plains.

404   [figure 5 is here]

405   **3.3 Management zoning for urban ecological land**

406   As shown in Figure 6a, there was distinct spatial agglomeration for ecological

407   importance grades of conservation priority areas in Zhuhai City. In total an area of 243

408   km² (accounting for 28% of the conservation priority areas) was contained in the maps

409   of three kinds of service land, and hence, it was classified as area of high ecological

410   importance. These areas included two parts: one was found in the mountainous areas

411   with dense vegetation coverage, referring to the ecosystem services of soil retention,

412   water conservation, and water appreciation. The other one was mainly located across

413   the main rivers, representing the ecosystem services of water recreation, water

17

414 protection, runoff reduction and flood regulation. Furthermore, the medium and low

415 ecologically important areas, i.e. contained in two and one kind of service land map,

416 counted to be 241km² and 384 km², respectively. Low ecological importance area was

417 mainly composed of woodlands in the plains providing water conservation service,

418 paddy fields, fish ponds and beaches for runoff reduction service.

419   Ecological sensitivity of conservation priority areas was also quantified (Figure 6b).

420 In total an area of 245 km² was identified as areas of high ecological sensitivity,

421 accounting for 28.23% of the conservation priority areas. These areas mainly covered

422 the runoff reduction land and water conservation land close to the urban areas in the

423 plain, as well as the locations along the periphery of Fenghuang Mountain, Huangyang

424 Mountain and Jiangjun Mountain. The areas of medium and low ecological sensitivity

425 counted to be 249 km² and 374 km² respectively, both concentrated in the central part

426 of mountain areas as well as islands far away from human activities.

427   By synthesizing ecological importance and sensitivity, 510 km^2 of primary control

428 areas were identified, accounting for 58.76% of the conservation priority areas for

429 ecological land. These primary control areas were mainly concentrated in mountains

430 and islands, or runoff reduction land, with high ecological importance or severe human

431 disturbance. The secondary control areas covered an area of 358 km^2, accounting for

432 41.24% of the conservation priority areas for ecological land. It was mainly distributed

433 in the plains with lower ecological importance or sensitivity. Generally speaking, the

434 primary control areas should implement the strictest ecosystem protection. For example,

435 any construction activities, unrelated to a specific ecological protection, scientific

436 research or educational purpose, should be prohibited. Population growth should be

437 strictly controlled through the gradual relocation of permanent residents out of the areas

438 (Gong et al., 2017). Besides strictly controlling human interference with original

439 　landform, vegetation and water system, ecological protection, restoration and

440 　construction should also be implemented by means of biological engineering measures

441 　(Bai et al., 2018). On the contrary, human activities such as infrastructure construction

442 　could be permitted in the secondary control areas, under the premise of non-increasing

443 　the risk of environmental pollution or ecological degradation.

444 　[figure 6 is here]

445 **4 Discussion**

446 **4.1 Spatial differentiation of conservation priority areas**

447 　　The spatial differentiation of conservation priority areas in Zhuhai City was analyzed

448 　in the view of land use type and elevation, which were highly correlated with area

449 　proportion of conservation priority areas. Seven land use types in the study area were

450 　considered, i.e. construction land, woodland, water body, dry cropland, paddy field and

451 　fish pond, grassland and unused land. Through comparing the area proportion of land

452 　use types in conservation priority areas, and that of land use types identified as

453 　conservation priority areas, land use differentiation of conservation priority areas could

454 　be analyzed (Figure 7). The results showed that the main land use types in the

455 　conservation priority areas were woodland (430.2 km^2), and paddy field and fish pond

456 　(175.1 km^2), accounting for 49.56% and 20.17% of the total conservation priority areas,

457 　respectively. As an efficient kind of ecological land with multiple ecosystem services,

458 　woodland had been mostly identified as conservation priority areas, with an area

459 　proportion of 88.98%. Because of the focus on water ecosystem services in this study,

460 　more than 95% water bodies were identified as conservation priority areas. Although

461 　having a high area proportion in total land area of 38.69%, paddy fields and fish ponds

462　only covered 20.17% of the conservation priority areas. In addition, including beach

463　and bare land with high water ecosystem services, 38.92% unused land was also

464　identified as conservation priority areas. That was to say, water body, wood land, unused

465　land, and paddy field and fish pond had the top priority for ecological conservation in

466　Zhuhai City, due to their importance in supplying water ecosystem services.

467　[figure 7 is here]

468　　According to the topographical features of Zhuhai City, the areas with the elevation

469　less than 25 m, 25–60 m, 60–200 m, and 200–600 m were classified as plains, hills, low

470　mountains and high mountains, respectively. Through comparing the area proportion of

471　topographical types in conservation priority areas, and that of topographical types

472　identified as conservation priority areas, elevation differentiation of conservation

473　priority areas was investigated (Figure 8). As the most common terrain in Zhuhai City,

474　the plains occupied 57.65% of the conservation priority areas. However, as low as 37.87%

475　of all the plains were covered in conservation priority areas, which might be due to the

476　high importance of woodland in supplying ecosystem services and its low distribution

477　in the plains. Considering the high suitability for construction, conservation priority

478　areas in the plains were in face with severe human disturbance, and the trade-offs

479　between economic development and ecological conservation usually occurred in land

480　use policy. On the contrary, hills, low mountains and high mountains occupied only a

481　small proportion of the conservation priority areas, accounting for 13.18%, 23.70% and

482　5.47% respectively. However, almost all were included in the conservation priority

483　areas with the ascending order of their conservation proportion. This was mainly

484　because of the increasing woodland coverage and intensified vegetation activity, along

485　with the elevation rising.

486　[figure 8 is here]

4.2 Limitations and future research directions

Although quantification is an obvious advantage compared to studies focusing on the

identification of spatial pattern of ecosystem services (Peng et al., 2018a, Peng et al.,

2018b), there are still some limitations needing further improvement in this study.

Firstly, spatial distributions of three kinds of service land were obtained based on the

simple overlaying of various key areas supplying ecosystem services, with equally

weighting of each kind of ecosystem services. In fact, the weights of the specific

ecosystem service might be different, slightly or obviously, especially considering

potential difference in human preference and thus ecosystem services trade-offs in

policy making. Accordingly, weighting issue also lied in the overlying of different

service land maps to obtain the map of conservation priority areas.

In addition, this study was conducted based on human demanding for ecosystem

services. Although it considered the dynamic process of human development, the

proposed identification approach was a kind of prediction based on static data in

temporal dimension. More dynamic data should be introduced as regards ecological

processes. Moreover, the timeliness and uncertainty of multivariate data should be

focused on in future studies.

5 Conclusions

Although demand quantification is an obvious advantage compared with studies

focusing on the identification of spatial pattern of ecosys- tem services (Peng, Yang, et

al., 2018; Peng, Pan, Liu, Zhao, & Wang, 2018), there are still some limitations needing

further improvement in this study. First, spatial distributions of three kinds of service

land were obtained based on the simple overlaying of various key areas supplying

ecosystem services, with equal weighting of each kind of ecosystem services. In fact, the weights of the specific ecosystem service might be different, slightly or obviously, especially considering potential difference in human preference and thus ecosystem services trade- offs in policy making. Accordingly, weighting issue also lied in the overlying of different service land maps to obtain the map of conservation priority areas.

In addition, this study was conducted based on human demand for ecosystem services. Although it considered the dynamic process of human development, the proposed identification approach was a kind of prediction based on static data in temporal dimension. More dynamic data should be introduced as regards ecological processes. Moreover, the timeliness and uncertainty of multivariate data should be focused on in future studies.

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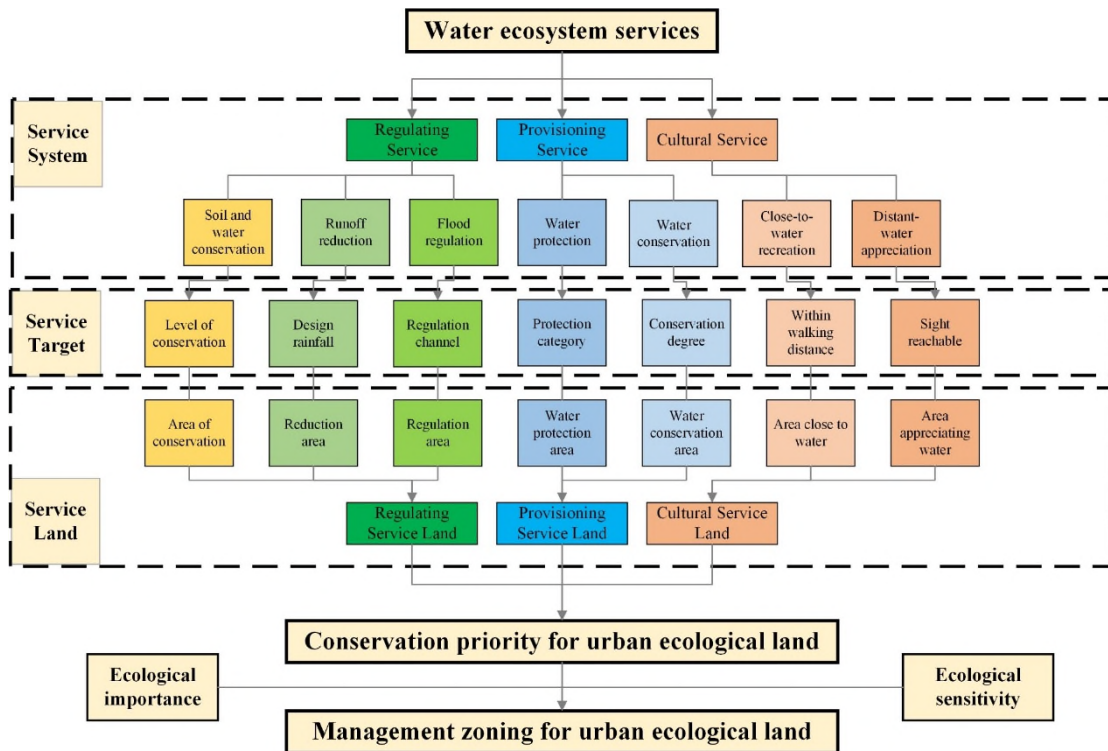
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Figures and tables

Figure 1 The geographical location of Zhuhai City
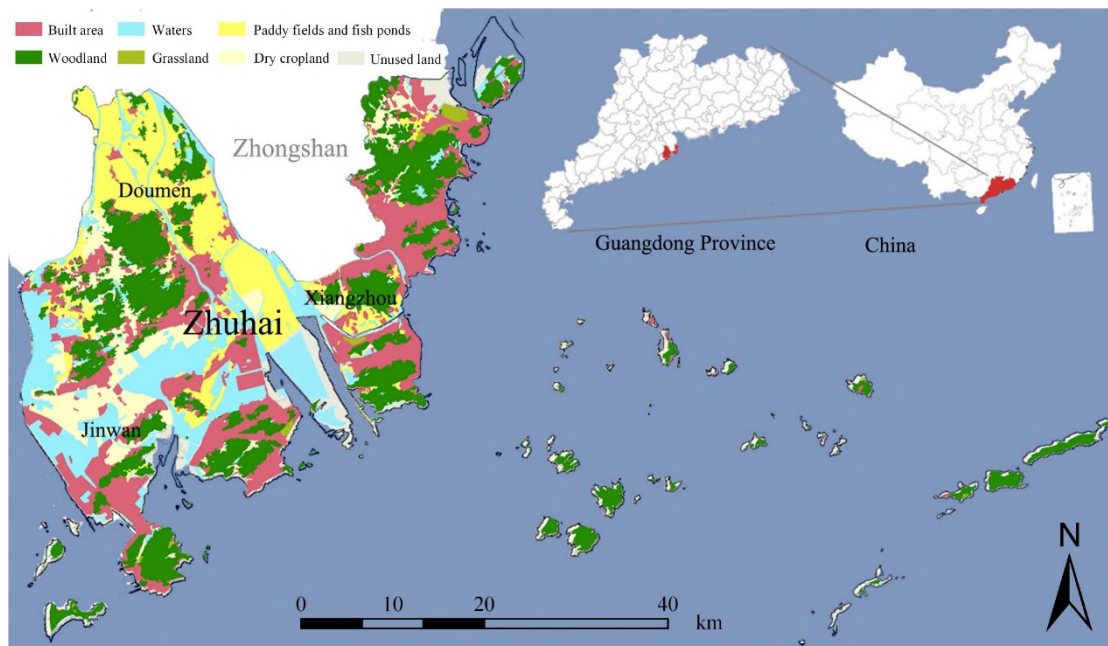
Figure 2 Research framework for identifying the conservation priority area and
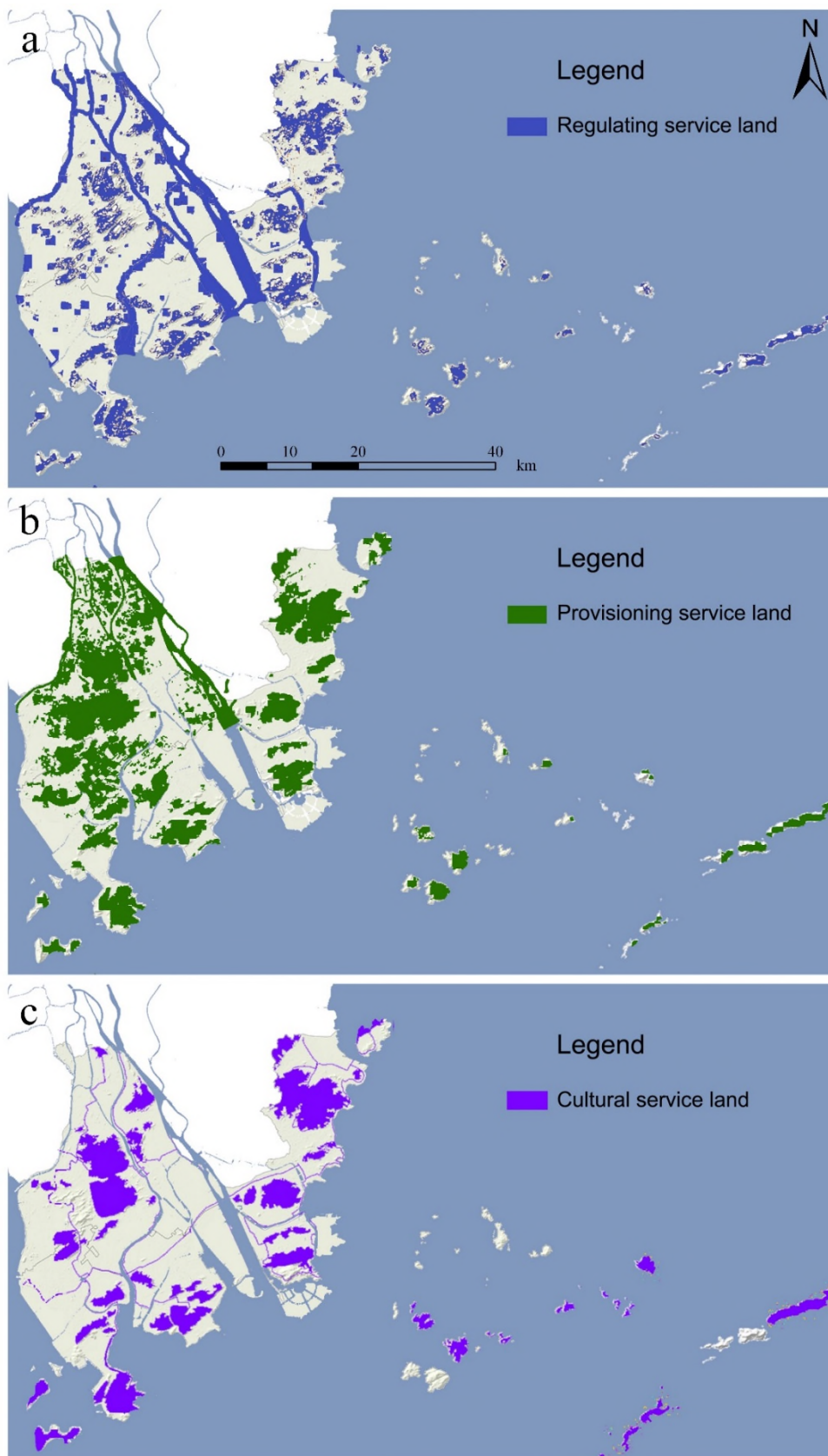
management zoning for urban ecological land

705 Figure 3 Spatial distribution of key areas for water ecosystem services in Zhuhai City.

706 a) Soil retention area; b) Runoff reduction area; c) Flood regulation area; d) Water

707 protection area; e) Water conservation area; f) Water recreation area; g) Water

708 appreciation area.
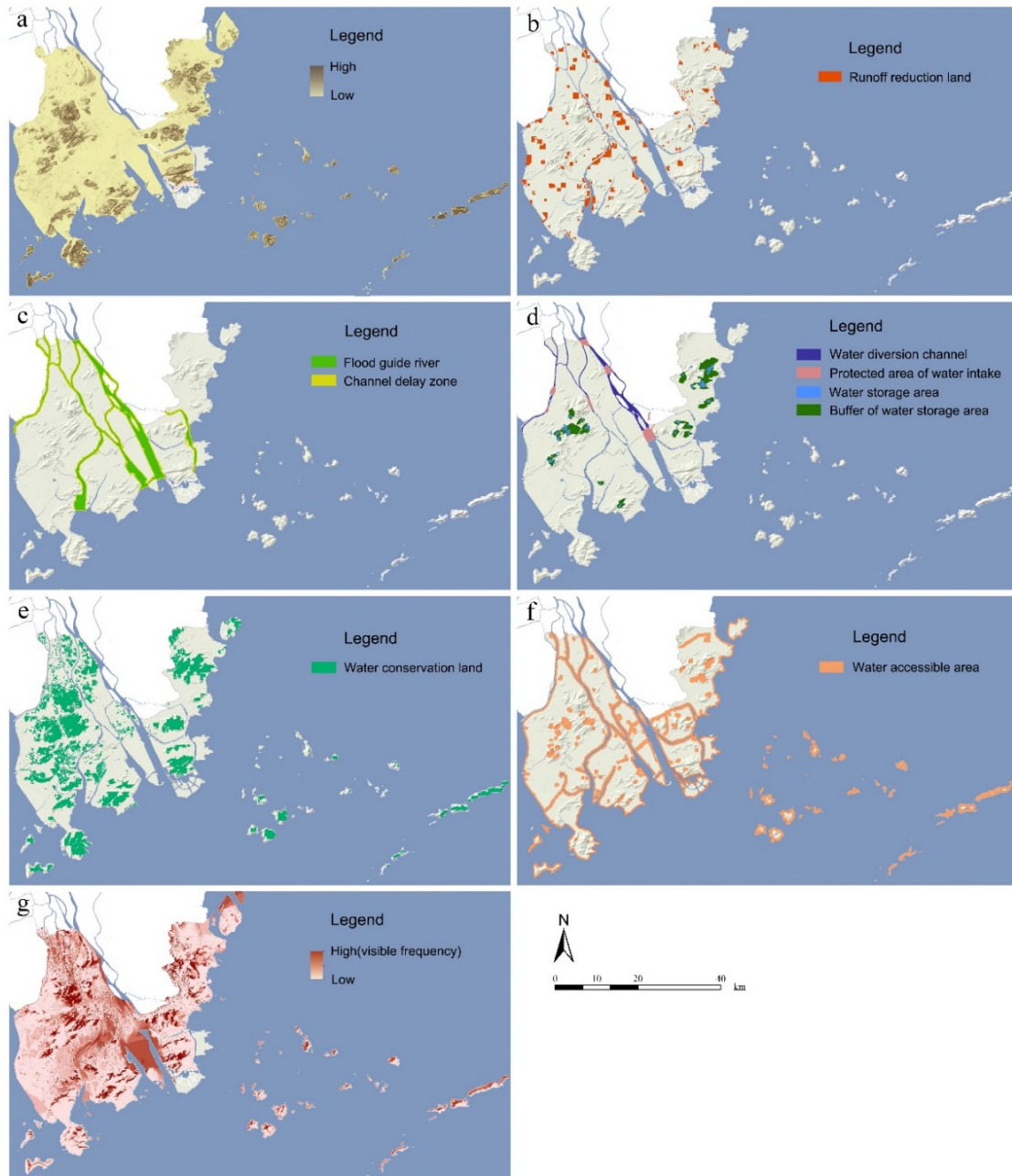
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711　　Figure 4 Spatial distribution of water ecosystem service land in Zhuhai City.

712　　a) Regulating service land; b) Provisioning service land; c) Cultural service land

713　　Figure 5 Conservation priority areas for urban ecological land in Zhuhai City
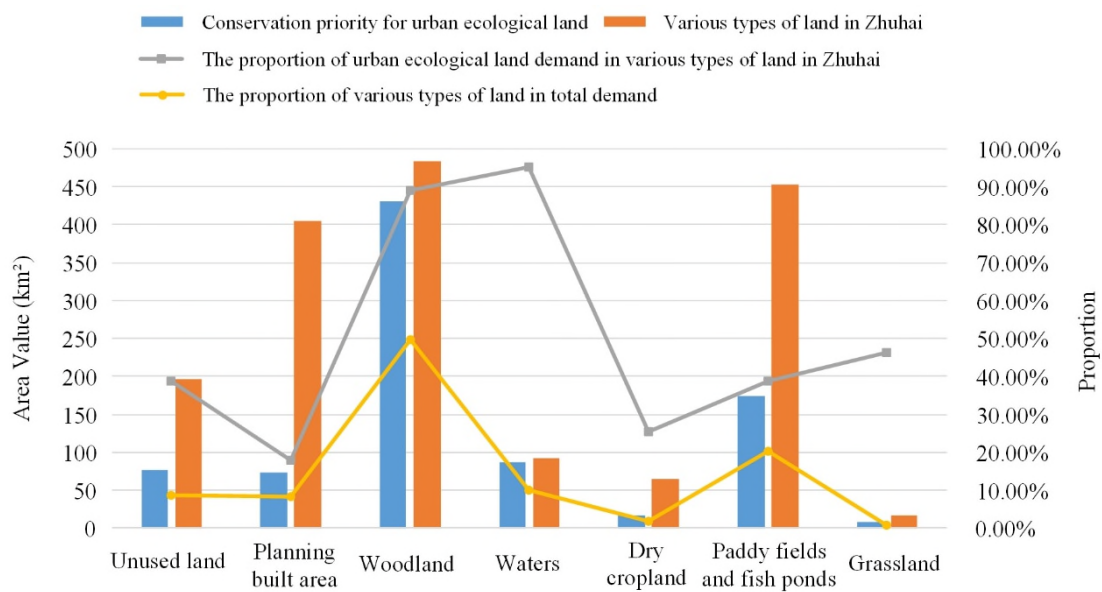

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715   Figure 6 Management zoning for urban ecological land in Zhuhai City. a) Ecological

716   importance; b) Ecological sensitivity; c) Management zoning
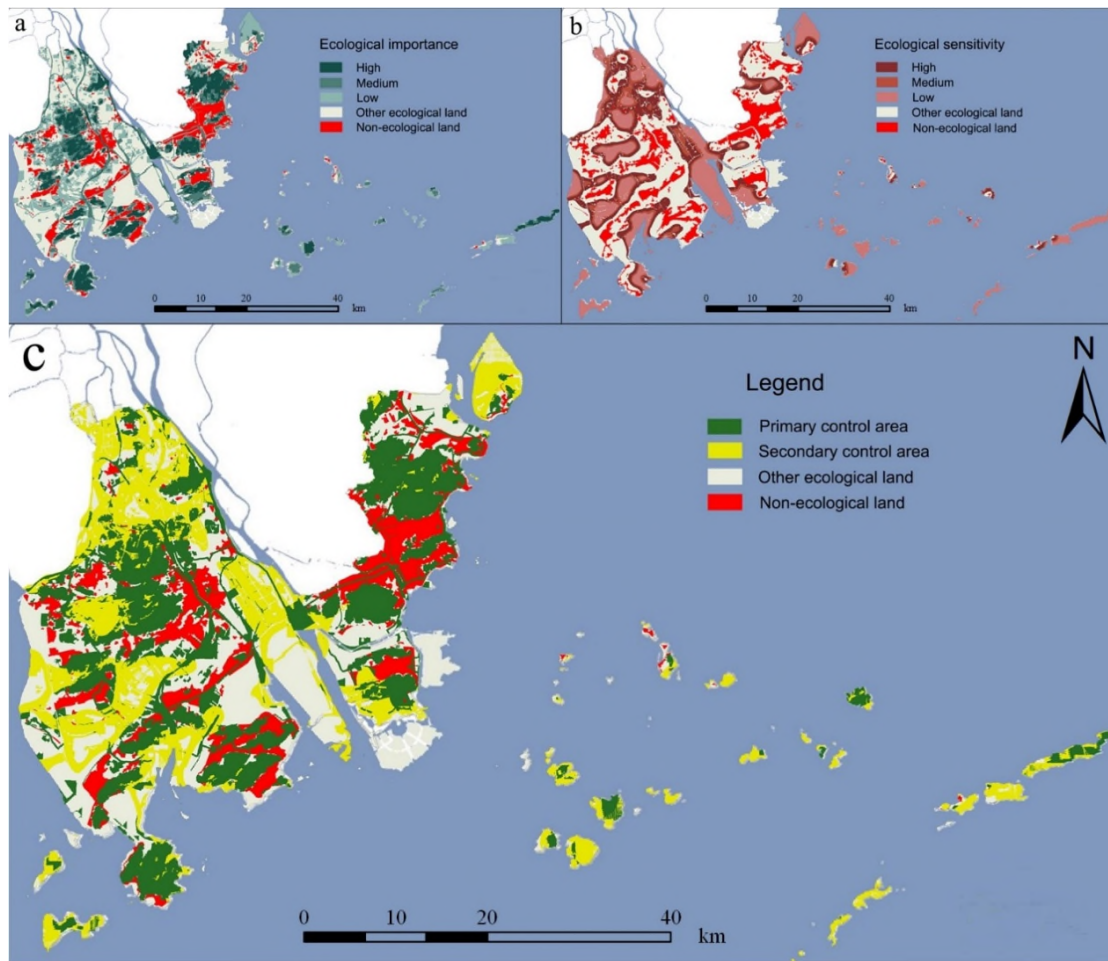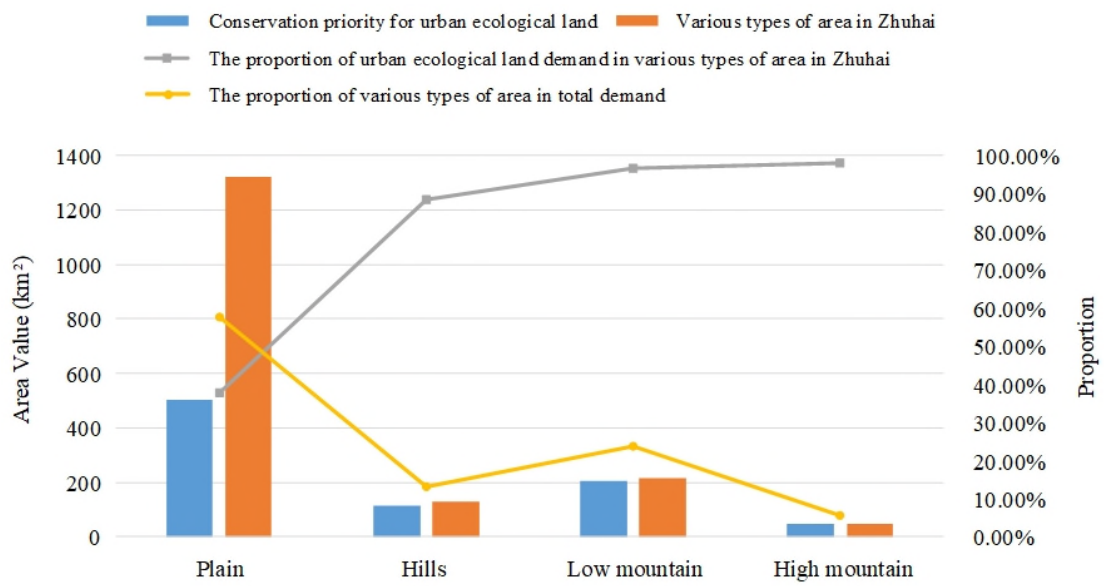

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719   Figure 7 Area proportion contrast of land use types in the conservation priority area

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722   Figure 8 Area proportion contrast of topographical types in the conservation priority

723   area

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727   Table 1 Sensitivity coefficient of ecological land

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Table

Table 1. Sensitivity coefficient of ecological land.

Sensitive source	Sensitive distance (km)	Sensitivity weight	Sensitivity coefficient					
			Woodland	Water body	Dry cropland	Paddy field and fish pond	Grassland	Unused land
Urban area	6	1	0.8	0.8	1	1	0.8	1
Town	4	0.8	0.7	0.7	0.8	0.8	0.7	1
Village	3	0.5	0.5	0.5	0.3	0.3	0.5	0.5
Road	4	0.6	0.7	0.7	0.9	0.9	0.8	0.9
Railway	2	0.3	0.3	0.3	0.5	0.5	0.5	0.5