1 **Effect of activities associated with coastal**
2 **reclamation on the macrobenthos community in**
3 **coastal wetlands of the Yellow River Delta, China:**
4 **a literature review and systematic assessment**

5 Wei Yang*, Tao Sun, Zhifeng Yang

6 Author family names: Yang, Sun, and Yang

7 (State Key Laboratory of Water Environment

8 Simulation, School of Environment, Beijing

9 Normal University, Beijing 100875, China)

10 * Corresponding author: No. 9 Xijiekouwai St.,

11 Haidian District, Beijing, China.

12 Tel./fax 86-10-5880-5053

13 E-mail address: yangwei@bnu.edu.cn

1 **Abstract:** Human activities such as seashore reclamation can have profound negative
2 impacts on the macrobenthos of coastal wetlands. Using the Yellow River Delta as a
3 case study, we conducted a thorough search of the literature to create a synthesis
4 about the effects of reclamation processes. We found 31 publications that met our
5 selection criteria, and we summarized their data to systematically quantify the impacts
6 of reclamation on the dominant species, biomass, abundance, and biodiversity indices.
7 We found that the dominant species changed remarkably, from Mollusca in the 1980s
8 to Polychaeta, Crustacea, and Insecta (indicating a transition from a marine to a
9 terrestrial environment) after 2000. The number of macrobenthos species in the
10 community decreased by more than half from the 1980s to the 2010s and the effect
11 sizes in the 2000s and 2010s both differed significantly from 0 ($p < 0.01$; t -test).
12 Both the biomass and the abundance of the macrobenthos decreased significantly in
13 the 2000s ($p < 0.05$ and $p < 0.01$, respectively; t -test), but not in the 2010s. The
14 Margalef, Shannon-Wiener, and Pielou biodiversity indices did not differ significantly
15 among four periods (from 1985 to 2015) or among the various reclamation activities.
16 The number of species and biomass have decreased significantly under the
17 comprehensive influence of seashore reclamation activities. Under individual
18 reclamation activities, the number of species and their biomass decreased slightly but
19 not significantly. The results of this research improve our understanding of the
20 relationships among reclamation activities and the resulting changes in the
21 macrobenthos community, thereby improving our ability to sustainably use these
22 wetlands. We have prepared a suggested list of criteria to help future seashore
23 reclamation researchers increase the quantity and quality of the data available to
24 support future meta-analyses.

- 25 **Keywords:** reclamation activities, macrobenthos community, systematic assessment,
- 26 Yellow River Delta, meta-analysis

1 Introduction

The macrobenthos is a particularly important part of the biocenosis in coastal wetlands because these organisms play a key role in transferring energy and materials within the food web (Covich et al. 2004; Dauvin et al., 2006). Due to its ecological importance, obvious presence, high sensitivity to disturbance, and direct contact with sediments, the macrobenthos of coastal ecosystems is widely used as a tool to detect the environmental impacts of pollution and other consequences of reclamation activity (Buschbaum et al., 2012; Li et al., 2016), and has therefore been used to support ecologically sustainable marine management (e.g., Borja et al., 2000; Naser, 2011; Crippa et al., 2013; Nishijima et al., 2015).

The Yellow River Delta is the largest and youngest coastal wetland in the warm temperate zone of China. However, in recent years, the demands of urbanization and economic development have led to serious impacts on the delta's wetlands due to intensive land reclamation activities, which include the construction of ports and tidal embankments, oilfield exploitation, and the development of aquaculture. Such seashore reclamation activities are typically associated with both short- and long-term impacts that affect the characteristics and patterns of the macrobenthos community (Airolidi and Beck, 2007).

The responses of the macrobenthos community to seashore reclamation have been studied in Yellow River Delta wetland by means of field surveys and a range of experimental approaches. Most of these studies have focused on the responses of the macrobenthos during a specific period or at specific sites (Wang et al., 2008; Mao et al., 2011). Some have assessed the qualitative or quantitative impacts of specific reclamation activities on the macrobenthos community, such as protection of the shoreline by establishing *Spartina alterniflora* communities (Shen et al., 2009) and

ecologically risky activities oilfield exploitation (Chen et al., 2012). This information is useful, but is restricted to point observations at the sampling sites, and therefore cannot provide the benefits of a comparative analysis of long-term time-series data. Walker et al. (2008) used field surveys and detected increased spatial variation of species diversity and biomass after reclamation. Song and Liu (2013) reviewed the impacts of reclamation activities on the ecosystem of estuarine delta wetlands, but did not quantitatively assess the influence on the macrobenthos. Some comparative surveys have indicated that a high-intensity of coastal reclamation contributed to a pronounced decline in species diversity and biomass (e.g., Yan et al., 2015). The distinctiveness of each delta and of each part of a large delta makes it important to perform quantitative comparisons to reveal long-term changes in the macrobenthos associated with coastal reclamation in a specific delta wetland.

In this paper, we systematically assessed the impacts of reclamation activities in the Yellow River Delta based on a literature review. We identified 31 studies that considered the long-term impacts of seashore reclamation activities on the delta's macrobenthos. Our goal was to answer three main questions: (1) Have seashore reclamation activities changed the dominant taxa since 1980 (the earliest data available)? (2) Did the seashore reclamation activities decrease the biomass, abundance, and biodiversity of the macrobenthos community? (3) Which reclamation activities had the greatest impact? Based on the results of our literature review, we have also created a list of suggested criteria that future seashore reclamation researchers should use to design their research in order to increase the quantity and quality of the data available to support future meta-analyses.

2 Study area

The Yellow River Delta (37°35'N to 38°12'N, 118°33'E to 119°20'E) is located on the western coast of the Bohai Sea (Fig. 1), and is the largest and youngest coastal wetland in China. The delta is one of the most active regions of land-ocean interaction and among the largest river deltas in the world. The region has a temperate, semi-humid, continental monsoon climate. The average annual temperature is 12.1°C, with monthly means ranging from a minimum of -1.3°C in December to a maximum of 27.7°C in August. The average annual precipitation is 552 mm, of which 70% falls during the summer (May to July). The average annual pan evaporation is 1962 mm. These climate characteristics mean that the study region is relatively dry, and relies heavily on flows of water from upstream regions to maintain its wetland ecosystems. Under these circumstances, human activities (and particularly the construction of dams in upstream regions) can endanger this already vulnerable ecosystem.

With economic development in the delta accelerating and urbanization increasing the demand for land, reclamation activities such as the construction of ports and tidal embankments, aquaculture, land reclamation, and road construction have expanded continuously. Figure 1 shows the locations of the main reclamation activities: I, aquaculture; II, port construction and oilfield exploitation; III, *Spartina alterniflora* planting for bank protection and sediment-flow regulation; and IV, aquaculture and *Spartina alterniflora* planting for bank protection. Tidal embankments have been constructed at all locations. These reclamation activities have greatly increased the vulnerability of the Yellow River Delta wetlands. The wetland habitat has therefore been suffering from severe disturbance, which has decreased its biodiversity, and the delta's ecosystem structure and functions are facing serious threats (Ottinger et al., 2013).

#Fig. 1 approximately here#

3 Methods and materials

3.1 Literature review

We performed a systematic review of the scientific literature to identify studies of the Yellow River Delta that provided quantitative evidence of the impacts of seashore reclamation activities on the macrobenthos community. We used the ISI Web of Science database (<http://wokinfo.com>), which provides access to peer-reviewed studies, with no restriction on the publication date. We used the following search term combination: (Macrobenth* OR megalobenth* OR benth*) AND (Yellow River OR Huanghe) AND (wetland* OR estuary OR delta). We refined the preliminary search results to focus on the following subject areas: Environmental Sciences, Ecology, Marine Freshwater Biology, Geology, Plant Sciences, Engineering, Fisheries, Zoology, and Biodiversity Conservation. When we found a paper that contained these words, we classified the paper as a “related record.” This left us with 35 papers.

We then examined the title and abstract of each reference to assess its potential for meeting the selection criteria for inclusion in our review. The selection criteria required that the paper report quantitative measures of one or more variables relating to the macrobenthos community, in the context of an assessment of one or more seashore reclamation activities. The result was 31 studies that met our selection criteria. Supplemental [Appendix S1 presents the results of our](#) literature review.

We began our literature review with 31 papers published in peer-reviewed journals that examined macrobenthos responses to reclamation activities in the Yellow River Delta (estuary). The papers were published between 1 May 1989 and 30 February 2015. The number of papers is relatively small because we strictly limited our selection to the study area rather than including similar areas in China and other

countries. We extracted the most important information from our literature review: the type of activities associated with coastal reclamation, survey years, dominant species (identified to the Class level), mean number of species, biomass, abundance (here, defined as the total number of individuals of all species per unit area), and values of three biodiversity indices (see section 3.2) for the macrobenthos community. All records were subsequently analyzed based on this predetermined list of variables and categories ([Supplemental Appendix S2](#)), which we believed were likely to provide a tangible, measurable influence on the responses of the macrobenthos to seashore reclamation activities.

In this analysis, we felt there was insufficient data to report meaningful data on changes in populations of individual species; instead, we have reported the proportions of the total number of surveys that reported the presence of a particular class of organism.

3.2 Indices used for assessment of macrobenthos responses to reclamation activities

We adopted the “response ratio” ($\ln R$) to indicate the effect size of the reclamation activities on the macrobenthos community. The response ratio is computed as follows:

$$\ln(R) = \ln (x_2 / x_0) = \ln x_2 - \ln x_0 \quad (1)$$

where x_2 is the mean value of a given index for the macrobenthos community after the reclamation activities, and x_0 is the natural background value of the corresponding index. Here, x indicates the number of species, the biomass, and the abundance of the macrobenthos community.

To describe the biodiversity of the macrobenthos community, we used Margalef's (1958) index (d), the Shannon-Wiener index (H ; Shannon and Weaver, 1948), and Pielou's (1966) evenness index (J):

$$d = (S - 1) / \log_2 N \quad (2)$$

$$H = -\sum_{i=1}^S \left(\frac{n_i}{N}\right) \ln\left(\frac{n_i}{N}\right) \quad (3)$$

$$J = H / \ln S \quad (4)$$

where S is the number of species; N is the total number of individuals in the sample; and n_i is the number of individuals of species i . Of the three indices, Margalef's index is used to estimate species richness independently of the sample size; the Shannon-Wiener index, one of the most well-known and widely used diversity indices, is a measure of entropy, and has mathematical properties that are useful for combining diversity measures (e.g., when calculating regional diversity); and Pielou's evenness index is calculated from the Shannon-Wiener index, but modified by accounting for the number of species to quantify the numerical equality of the species that make up the community.

We used authoritative data from a comprehensive survey report for China's national oceans (OCSO, 1961), based on surveys conducted in the 1950s, and from China's gulf notes and data (CGCC, 1998), based on surveys conducted in the early 1980s, to determine the natural background values for species in the macrobenthos community of the Yellow River Delta. The area surveyed by this baseline assessment overlaps the areas censused by the studies identified through our literature review, which ensured that the different datasets were comparable.

3.3 Intensity of the activities associated with coastal reclamation

To calculate the overall pressure created by coastal reclamation, we used indices developed during previous research to account for the intensity of the reclamation activities. We calculated this pressure by multiplying the standardized values of several reclamation pressure indices by the corresponding weights. The reclamation pressure indices included the tidal embankment intensity, port construction intensity, land reclamation intensity, road construction intensity, and dam construction intensity. [Supplemental Appendix S2](#)) summarizes these indices, and [Jin et al. \(2016\)](#) provide more details.

3.4 Statistical analysis

We divided the studies of reclamation activities and other human impacts into four periods: the 1980s (actually from 1985 to 1989), the 1990s, the 2000s, and the 2010s (actually from 2010 to 2015). By comparing the data between the four periods, we were able to identify trends in macrobenthos characteristics resulting from their responses to seashore reclamation and other human impacts.

We identified effect sizes ($\ln R$) that differed significantly from zero by means of the t -test. To compare the three biodiversity indices between periods, we confirmed homogeneity of variance using the Levene's test, then tested for significant differences between periods for the three indices by means of one-way analysis of variance (ANOVA). When the ANOVA results showed a significant difference between periods, we used *post hoc* least-significant-difference (LSD) tests to identify which pairs of values differed significantly. All statistical analysis was performed using version 20.0 of the SPSS statistical software (SPSS Inc., Chicago, IL, USA). Differences were considered significant at $p < 0.05$.

4 Results

4.1 Overall literature review

The survey and publication years covered the period from 1985 to 2013 and from 1989 to 2015, respectively, and most of the investigation of the macrobenthos community in the Yellow River Delta happened after 2000. The mean time lag between the year of the investigation and publication of the associated results was 3 years.

Eight types of human impacts, including land reclamation activities or activities associated with land reclamation, were described in the literature: aquaculture, environmental pollution, oil exploitation, port construction, sediment-flow regulation, bank protection by planting *Spartina alterniflora*, tidal embankments, and wetland restoration. Many of the publications (38.7%) did not specify the type of human impacts, so we classified them as comprehensive influences (i.e., the results reflected the net impact of all activities in the delta). Figure 2 shows the frequency of each category of reclamation activity or impact in the literature.

#Fig. 2 approximately here#

4.2 Changes in the macrobenthos community in the coastal wetlands of the Yellow River Delta in different periods

We divided the studies of reclamation activities and other human impacts into four periods: the 1980s (actually from 1985 to 1989), the 1990s, the 2000s, and the 2010s (actually from 2010 to 2015). By comparing the data between periods, we were able to track the trends in macrobenthos characteristics resulting from their responses to seashore reclamation and other human impacts.

4.2.1 Species and dominant species

Table 1 shows the changes in the dominant taxa of the macrobenthos community in the coastal wetlands of the Yellow River Delta during the four periods. There were clear changes in the dominant taxa of the macrobenthos. Nematodes and polychaetes were the taxa with the highest numbers in the 1980s and 1990s, but the proportion of polychaetes increased greatly from the 1980s to the 1990s. However, gastropods became the taxon with the highest number in the 2000s, accounting for 40% of the published records, followed by polychaetes (20%), insects (20%), and crustaceans (20%). The taxa with the highest number in the 2000s changed greatly, with polychaetes and insects accounting for 42.9% and 28.6% of the total records, respectively.

#Table 1 approximately here#

Figure 3 compares the effect size ($\ln R$) for the number of species based on the changes from the 1980s to the 2010s. The papers published in the 1980s did not report the number of species, and only one paper in the 1990s reported this number. The effect sizes for the number of species in the 2000s and 2010s were both significantly lower than 0 ($p < 0.01$, t -test), which indicates that the number of macrobenthos species has decreased significantly since 2000.

#Fig. 3 approximately here#

4.2.2 Biomass and abundance

Only a few papers in the 1980s and none in the 1990s described the biomass and abundance of the macrobenthos community (Fig. 4). For biomass (Fig. 4a) and abundance (Fig. 4b), the effect size was significantly less than 0 ($p < 0.05$, t -test) in the 2000s but not in the 2010s. This suggests a potential reduction in both biomass and abundance in the 2000s, followed by stabilization of both parameters in the 2010s.

#Fig. 4 approximately here#

4.2.3 Biodiversity and evenness indices

We adopted the raw values of the biodiversity and evenness indices from the literature to illustrate the changes in biodiversity during the four periods (Fig. 5 and 6). One-way ANOVA showed that the values of the biodiversity indices (d and H) and the evenness index (J) did not differ significantly among the four periods ($p > 0.05$). The values of the Shannon-Wiener index (H) were 1.84 ± 1.17 (mean $\pm$ SD) in the 1990s, 1.69 ± 0.75 in the 2000s, and 1.86 ± 0.87 in the 2010s. According to the classification of Chainho et al. (2007), these values suggest that biodiversity in the Yellow River Delta has been *moderate* or *poor* since the 1990s. All the effect sizes for the three diversity indices were significantly greater than 0 (Fig. 6), which means that biodiversity increased during the study period.

#Fig. 5 approximately here#

#Fig. 6 approximately here#

4.3 Effect of reclamation activities and other human impacts on the macrobenthos community

Figure 7 shows the changes in the effect size for the number of species, biomass, and abundance of the macrobenthos community in response to the different reclamation activities and other human impacts. The effect sizes for the number of species under comprehensive influences (CI), aquaculture (AQ), and sediment-flow regulation (SFR) were significantly less than 0 (Fig. 7a). For biomass, the effect sizes were significantly less than 0 for comprehensive influences (CI) and significantly greater than 0 for aquaculture (AQ). The effect size for abundance for *Spartina alterniflora* planting for bank protection (SAB) was significantly less than 0 (Fig. 7c). This suggests that comprehensive influences, aquaculture, and sediment flow

regulation significantly decreased the number of species, that comprehensive influences significantly decreased and aquaculture significantly increased biomass, and that *Spartina alterniflora* planting for bank protection significantly decreased abundance.

#Fig. 7 approximately here#

One-way ANOVA showed that the values of the diversity indices did not differ significantly among the comprehensive influences and other specific reclamation activities ($p > 0.05$, [Figure 8](#)), possibly due to the small sample sizes.

#Fig. 8 approximately here#

4.4 Relationships between reclamation intensity and the macrobenthos community

Previously, our research group assessed the reclamation intensity in the Yellow River Delta from the 1980s to the 2010s; details are found in one of our published papers ([Jin et al., 2016](#)). Figure 9 illustrates the relationships between the reclamation intensity calculated in that paper and the values of the macrobenthos diversity indices. The reclamation intensity that determined the overall pressure was calculated by multiplying the standardized values of the reclamation pressure indices by the corresponding weights. We found an initially negative influence of reclamation intensity on the number of species, biomass, and abundance, but after 2000, the number of species and their abundance increased (Fig. 9a), and the similar trend between the reclamation intensity and the biodiversity indices (d and H) for the macrobenthos (Fig. 9b).

#Fig. 9 approximately here#

5 Discussion

Coastal reclamation activities and other human impacts alter wetland habitats and soil, thereby affecting the macrobenthos community (Baek et al., 2014). We found that the dominant species changed remarkably during the study period, from nematodes and polychaetes in the 1980s to gastropods, polychaetes, crustaceans, and insects in the 2000s and later. In the study area, tidal barriers, whose length increased from 54.3 km in the 1980s to 190.4 km in the 2010s (SBSP, 2015), contributed strongly to these changes. In addition, the sedimentary environment (especially sediment salinity and water content) changed drastically due to the reduction or elimination of tidal currents by the barriers (Koo et al., 2008; Li et al., 2016). Our latest research also found that decreased sediment salinity made it possible for many oligohaline species, such as *Chironomus* sp. and *Cladotanytarsus mancus*, to live in the areas with lower salinity inside the tidal barriers (Yang et al., 2016). In addition to any effects on habitat quality, this may indicate an increasingly polluted environment; the presence of large number of insects also indicates expansion of terrestrial environments in the Yellow River Delta. Oilfield exploitation, aquaculture, and land reclamation have contributed to a dramatic transition of the dominant taxa. The sediment-flow regulation and wetland restoration activities that have been performed since 2001 and 2002, respectively, in our study area are both positive activities designed to alleviate the influence of reclamation and other human impacts, and our data suggest that these activities may have begun to mitigate the impacts of increasing intensity of seashore reclamation and other human activities.

Our results indicate that seashore reclamation and other human impacts have had a negative influence on the number of species, biomass, and abundance of the macrobenthos. This is consistent with results from previous studies, which indicated

that human activities in coastal wetlands have a negative impact on these parameters (Seitz et al., 2006; Wilson and Bayley, 2012). Naser (2011) observed a significant difference in the numbers of macrobenthos between control and experimental treatments, with a survival percentage of only 41.8% of the control value in the experimental treatment, thereby demonstrating the negative impacts of coastal dredging and reclamation on the macrobenthos assemblages. Huang et al. (2011) found that human activities (such as embankment construction and reclamation) changed the habitat characteristics, resulting in a simpler community structure and a lower community similarity index for communities on opposite sides of a barrier. Yan et al. (2015) found that all coastal reclamation activities in the Yellow Sea, East China Sea, and South China Sea had significant negative impacts on species biodiversity and the biomass of the macrobenthos. Our results indicate that we should pay more attention to the comprehensive, long-term, and cumulative effects of multiple reclamation activities and other human impacts on the wetland ecosystem, rather than focusing on the short-term ecological impact of a single activity or impact. In addition, our results demonstrate the importance of long-term monitoring to detect trends that may require management interventions. However, the three biodiversity indices did not differ significantly among the four periods, possibly because of the small sample sizes for some parameters in some periods.

Another problem relates to differences in how researchers have described reclamation activities and other human impacts, ecosystem and macrobenthos indices, and the ecological responses to the reclamation activities and other human impacts. Differences in these descriptions complicate efforts to gather data to perform a meta-analysis such as the one in the present study to examine trends in the response to reclamation and other human impacts. Thus, providing a list of criteria to guide future

seashore reclamation researchers would be beneficial for future meta-analyses. To support such analyses, researchers should clearly describe the types, scales, and characteristics of reclamation activities, the antecedent and starting conditions, the program parameters, the time scale of the monitoring, and the sampling characteristics. The collection of ecological data (e.g., on the macrobenthos, but not limited to these taxa) before and after the reclamation activities should be prioritized for new reclamation programs to improve our understanding of the impacts of these alterations. Table 2 summarizes our suggestions of parameters that future researchers should consider when designing their studies, but we also hope that they will help to refine this list.

#Table 2 approximately here#

6 Conclusions

In this paper, we systematically reviewed the long-term impacts of seashore reclamation activities and other human impacts on the macrobenthos community using the coastal wetlands of the Yellow River Delta as a case study. We found that the dominant taxa have changed remarkably from the 1980s to the 2010s in response to changes in the available habitats and their quality in the study area (e.g., more polluted environments, a greater proportion of terrestrial environments). The changes in the effect sizes ($\ln R$) showed that seashore reclamation activities and other human impacts have sharply decreased the number of species since 2000, and reduced their biomass and abundance in the 2000s. The biodiversity and evenness indices did not differ significantly among the four periods, but this might have resulted from the small sample sizes for some parameters and some periods. For the comprehensive influences, the effect sizes for the number of species, biomass, and abundance differed significantly from 0, but the impact of the comprehensive influences on the

biodiversity and evenness indices did not differ significantly from those of the individual reclamation activities and other human impacts possibly due to the small sample sizes. Our results therefore indicate that we should pay more attention to the comprehensive, long-term, and cumulative effects of multiple reclamation activities and other human impacts on wetland ecosystems, rather than focusing on the short-term ecological impacts of a single reclamation activity or other human impact. Finally, we have proposed a list of criteria that all future seashore reclamation researchers should use to design their research; this will increase the quantity and quality of the data available to support meta-analyses.

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References

- Airoidi, L., Beck, M., 2007. Loss, status and trends for coastal marine habitats of Europe. *Oceanogr. Mar. Biol.* 45, 345-405.
- Baek, M. J., Lee, Y.J., Choi, K.S., Lee, W.C., Park, H.J., Kwak, J.H., Kang, C.K., 2014. Physiological disturbance of the *Manila clam*, *Ruditapes philippinarum*, by altered environmental conditions in a tidal flat on the west coast of Korea. *Mar. Pollut. Bull.* 78, 137-145.

391 Borja, A., Franco, J., Pérez. V., 2000. A marine biotic index to establish the
392 ecological quality of soft-bottom benthos within European estuarine and coastal
393 environments. *Mar. Pollut. Bull.* 12, 1100-1114.

394 Buschbaum, C., Lackschewitz, D., Reise, K., 2012. Nonnative macrobenthos in the
395 Wadden Sea ecosystem. *Ocean Coast. Manage.* 68, 89-101.

396 CGCC (China's Gulf Compilation Committee). 1998. China's gulf notes and data.
397 Beijing: Ocean Press. (In Chinese)

398 Chainho, P., Costa, J.L., Chaves, M.L., Dauer, D.M., Costa. M.J., 2007. Influence of
399 seasonal variability in benthic invertebrate community structure on the use of
400 biotic indices to assess the ecological status of a Portuguese Estuary. *Mar. Pollut.*
401 *Bull.* 54(10), 1586-1597.

402 Chen, K., Xiao, N.W., Wang, B.X., Li. J.S., 2012. The effects of petroleum
403 exploitation on water quality bio-assessment and benthic macro-invertebrate
404 communities in the Yellow River Delta wetland, Dongying. *Acta Ecol. Sinica*
405 32(6), 1970-1978. (In Chinese with English Abstract)

406 Covich, A.P., Austen, M.C., Barlocher, F., Chauvet, E., Cardinale, B.J., Biles, C.L.,
407 Inchausti, P., Dangles, O., Solan, M., Gessner, M.O., Statzner, B., Moss, B., 2004.
408 The role of biodiversity in the functioning of freshwater and marine benthic
409 ecosystems. *Bioscience* 54(8), 767-776.

410 Crippa, L.B., Stenert, C., Maltchik, L., 2013. Does the management of sandbar
411 openings influence the macroinvertebrate communities in southern Brazil
412 wetlands? A case study at Lagoa do Peixe National Park-Ramsar site. *Ocean*
413 *Coast. Manage.* 71, 26-32.

414 Dauvin, J.C., Desroy, N., Janson, A.L., Vallet C., Duhamle, S., 2006. Recent changes
415 in estuarine benthic and suprabenthic communities resulting from the
416 development of harbour infrastructure. *Mar. Pollut. Bull.* 53, 80-90.

417 Huang, S.F., Liu, Y., Li, C., Huang, J.M., 2011. Influence of reclamation on
418 macrobenthic community in the Pearl River Estuary. *Chinese J. Appl. Environ.*
419 *Biol.* 17, 499-503. (in Chinese)

420 Jin, Y.W., Yang, W., Sun, T., Yang Z.F., Li, M. 2016. Effects of seashore reclamation
421 activities on the health of wetland ecosystems: a case study in the Yellow River
422 Delta, China. *Ocean Coast. Manage.* 123, 44-52.

423 Koo, B.J., Je, J.G., Woo, H.J., Kim, E.S., 2008. Changes in macrobenthic community
424 structure on Gunsan tidal flat after the closing of the Saemangeum 4th Dyke.
425 *Ocean Polar Res.* 30, 497-507.

426 Li, M., Yang, W., Sun, T., Jin, Y.W., 2016. Potential ecological risk of heavy metal
427 contamination in sediments and macrobenthos in coastal wetlands induced by
428 freshwater releases: A case study in the Yellow River Delta, China. *Mar. Pollut.*
429 *Bull.* 103(1-2), 227-239.

430 Mao, J.X., Yan, Q.L., Wang. L.J., 2011. Changes trend of species number, biomass
431 and density of zoobenthos in typical estuaries of China. *Mar. Environ. Sci.* 30 (1),
432 37-40. (in Chinese with English summary)

433 Margalef, R., 1958. Information theory in ecology. *Gener. Systems* 3, 36-71.

434 Naser, H.A., 2011. Effects of reclamation on macrobenthic assemblages in the
435 coastline of the Arabian Gulf: a microcosm experimental approach. *Mar. Pollut.*
436 *Bull.* 62, 520-524.

437 Nishijima, W., Umehara, A., Okuda, T., Nakai, S., 2015. Variations in macrobenthic
 438 community structures in relation to environmental variables in the Seto Inland
 439 Sea, Japan. Mar. Pollut. Bull. 92, 90-98.

440 OCSO (Ocean Comprehensive Survey Office). 1961. The comprehensive survey
 441 report for the national oceans (Book 5). Tianjin: Ocean Comprehensive Survey
 442 Office. (In Chinese)

443 Ottinger, M., Kuenzer, C., Liu, G.H., Wang, S.Q., Dech. S., 2013. Monitoring land
 444 cover dynamics in the Yellow River Delta from 1995 to 2010 based on Landsat 5
 445 TM. Appl. Geogr. 44(4), 53-68.

446 Pielou, E., 1966. The measurement of diversity in different types of biological
 447 collections. J. Theor. Biol. 13, 131-144.

448 SBSP, 2015 Shandong Provincial Social Economic Statistical Yearbook. Statistics
 449 Bureau of Shandong Province, Jinan City. (in Chinese).

450 Seitz, R.D., Lipcius, R.N., Olmstead, N.H., Seebo, M.S., Lambert. D.M., 2006.
 451 Influence of shallow-water habitats and shoreline development on abundance,
 452 biomass, and diversity of benthic prey and predators in Chesapeake Bay. Mar.
 453 Ecol. Prog. Ser. 326, 11-27.

454 Shannon, C.E., Weaver. W., 1948. A mathematical theory of communication. Bell
 455 Syst. Technol. J. 27, 379-423, 623-656.

456 Shen, B.Z., Tian, J.Y., Yu, X., Li, J.Q., Shi, D.L., 2009. Effects on zoobenthos
 457 diversity by *Spartina* spp. invasion in tidal flat of Yellow River Delta. Adv. Mar.
 458 Sci. 27(3), 384-392. (In Chinese with English Abstract)

459 Song, H.L., Liu. X.T., 2013. Effect of reclamation activities on wetlands in estuarine
 460 delta in China. Wetland Sci. 11(2), 297-304. (In Chinese with English Abstract)

461 Walker, S.J., Schlacher, T.A., Thompson. L., 2008. Habitat modification in a dynamic
 462 environment: the influence of a small artificial groyne on macrofaunal
 463 assemblages of a sandy beach. *Estuar. Coast. Shelf S.* 79, 24-34.

464 Wang, X.C., Li, X.F., Wang, H.F., Li, B.Q., Wang, J.B., Yu, Z.S., 2008.
 465 Macrobenthic ecology of the intertidal zones of Chajiandao, Dakouhedao and
 466 Wangzidao of Yellow River Estuary in autumn. *Chinese J. Zool.* 43(6), 77-82. (in
 467 Chinese with English summary)

468 Wilson, M.J., Bayley. S.E., 2012. Use of single versus multiple biotic communities as
 469 indicators of biological integrity in northern prairie wetlands. *Ecol. Indic.* 20,
 470 187-195.

471 Yan, J.G., Cui, B.S., Zheng, J.J., Xie, T., Wang, Q., Li. S.Z., 2015. Quantification of
 472 intensive hybrid coastal reclamation for revealing its impacts on
 473 macrozoobenthos. *Environ. Res. Lett.* 10(1), 014004.

474 Yang, W., Li, M., Sun, T., Jin, Y.W., 2016. The joint effect of tidal barrier
 475 construction and freshwater releases on the macrobenthos community and
 476 environmental characteristics: a case study in the Yellow River Delta (China).
 477 *Estuar. Coast.* (In minor revision)

478 **Figure captions**

479 **Fig. 1.** Map of the wetlands of the Yellow River Delta. Numbers represent the
480 locations of the main reclamation activities: I, aquaculture; II, port construction and
481 oilfield exploitation; III, *Spartina alterniflora* planting for bank protection and
482 sediment-flow regulation; IV, aquaculture and *Spartina alterniflora* planting for bank
483 protection. Tidal embankments have been constructed at all locations.

484 **Fig. 2.** Reclamation activities and their impacts reported in the literature from 1985 to
485 2015, and the frequency of their occurrence in the 31 publications. “Comprehensive
486 influences” represent the number of papers that did not specify the type of human
487 impact.

488 **Fig. 3.** Boxplots for the effect size ($\ln R$) for the number of species in the
489 macrobenthos community in the four periods. (N represents the number of
490 publications). Significance: **, significantly different from 0 (t -test, $p < 0.01$). In the
491 boxplots, the horizontal line represents the mean, the black dot represents the median,
492 the grey shaded area represents the 95% confidence interval, and the range bars
493 represent the maximum and minimum observed values.

494 **Fig. 4.** Boxplots for the effect sizes ($\ln R$) for (a) biomass and (b) abundance of the
495 macrobenthos community during the four periods. Significance: values are
496 significantly different from 0 (t -test) at *, $p < 0.05$, and **, $p < 0.01$. In the boxplots,
497 the horizontal line represents the mean, the black dot represents the median, the grey
498 shaded area represents the 95% confidence interval, and the range bars represent the
499 maximum and minimum observed values.

500 **Fig. 5.** Values ($\text{mean} \pm \text{SD}$) of the biodiversity and evenness indices for the
501 macrobenthos community in the four periods: (a) Margalef’s diversity (d), (b) the
502 Shannon-Wiener diversity (H), and (c) Pielou’s evenness index (J).

Fig. 6. Boxplots of the effect sizes ($\ln R$) for the biodiversity and evenness indices for the macrobenthos community in the four periods: (a) Margalef's diversity (d), (b) the Shannon-Wiener diversity (H), and (c) Pielou's evenness index (J). In the boxplots, the horizontal line represents the mean, the black dot represents the median, the grey shaded area represents the 95% confidence interval, and the range bars represent the maximum and minimum observed values.

Fig. 7. Boxplots for the effect sizes ($\ln R$) for changes in the (a) number of species, (b) biomass, and (c) abundance of the macrobenthos community in response to the different reclamation activities and other human impacts. Abbreviations: AQ, aquaculture; CI, comprehensive influences; PC, port construction; PM, pollution mitigation; SAB, *Spartina alterniflora* planting for bank protection; SFR, sediment-flow regulation; TE, tidal embankment construction; WR, wetland restoration. Values of the effect size for a given parameter that are labeled with different letters differed significantly (ANOVA followed by an LSD test, $p < 0.05$). Significance: values are significantly different from 0 (t -test) at *, $p < 0.05$, and **, $p < 0.01$. In the boxplots, the horizontal line represents the mean, the black dot represents the median, the grey shaded area represents the 95% confidence interval, and the range bars represent the maximum and minimum observed values.

Fig. 8. Boxplots for the biodiversity and evenness indices for the macrobenthos community in response to the different reclamation activities and other human impacts: (a) Margalef's diversity (d), (b) the Shannon-Wiener index (H), and (c) Pielou's evenness index (J). Abbreviations: AQ, aquaculture; CI, comprehensive influences; OE, oil exploitation; PM, pollution mitigation; SAB, *Spartina alterniflora* planting for bank protection; SFR, sediment-flow regulation; TE, tidal embankment construction; WR, wetland restoration. In the boxplots, the horizontal line represents

528 the mean, the black dot represents the median, the grey shaded area represents the 95%
529 confidence interval, and the range bars represent the maximum and minimum
530 observed values.

531 **Fig. 9.** Relationships between the reclamation intensity and (a) No. of species,
532 biomass, and abundance, and (b) the biodiversity and evenness indices (d , Margalef's
533 index; H , the Shannon-Wiener index; J , Pielou's evenness index).

534 **Table captions**

535 **Table 1** Dominant species in the macrobenthos community in the coastal wetlands of
536 the Yellow River Delta in different periods. Values in brackets represent the number
537 of records of a taxon divided by the total number of surveys during the survey period.

538 **Table 2** Examples of parameters that should be reported in all studies of coastal
539 wetland reclamation activities and other human impacts to increase the power of
540 future meta-analyses.

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

1 **Table 1** Dominant species in the macrobenthos community in the
2 coastal wetlands of the Yellow River Delta in different periods. Values
3 in brackets represent the number of records of a taxon divided by the
4 total number of surveys during the survey period.

Survey period	Classes of the dominant species and their proportions of the total	Representative species
1980s	Nematodes (2/3), Polychaeta (1/3)	<i>Dorylaimopsis</i> sp., <i>Parodontophora</i> sp., <i>Lumbrineris</i> sp.
1990s	Polychaeta (3/5), Nematodes (2/5)	<i>Dorylaimopsis</i> sp., <i>Parodontophora</i> sp., <i>Scapharca subcrenata</i>
2000s	Gastropoda (6/15), Polychaeta (3/15), Insecta (3/15), Crustacea (3/15)	<i>Umbonium thomasi</i> , <i>Assimineia</i> sp., <i>Lumbrineris</i> sp., <i>Tendipes attenuatus</i>
2010s	Polychaeta (3/7), Insecta (2/7), Crustacea (1/7), Gastropoda (1/7)	<i>Lumbrineris</i> sp., <i>Tendipes attenuatus</i> , <i>Alvenius ojanus</i> , <i>Cultellus attenuatus</i>

1 **Table 2** Examples of parameters that should be reported in all
2 studies of coastal wetland reclamation activities and other human
3 impacts to increase the power of future meta-analyses.

Parameter	Example
Reclamation activity or impact type	Port construction
Scales and characteristics of the reclamation program or impact	Total tonnage capacity of all wharfs, port functions (e.g., passengers, oil transport)
Starting condition (prior to the reclamation program or impact)	Dominant species (number, biomass, abundance, diversity indices)
Antecedent conditions (prior to the first reclamation program or impact)	Time since last reclamation program or impact
Monitoring program target	Change in species biomass from a reference value
Location	Exact location (GPS) and site name
Parameters monitored	Species number, biomass, abundance, diversity indices
Time scale of monitoring	Season
Habitat characteristics	Water depth, available habitats, habitat quality, water temperature
Sampling characteristics	Time, method, sites, and sample size