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Hydrology and Earth System Sciences
Discussions

Interactive comment on "A century scale human-induced hydrological and ecological changes of wetlands of two large river basins in Australia (Murray) and China (Yangtze): development of an adaptive water resource management framework" *by* G. R. Kattel et al.

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Reviewer #2 comments and answers "The author discussed the long term impacts of human activity on hydrological and ecological regimes shifting in two world's large river basins. I found the article is well written; the topic is interesting and should find a relatively wide audience."

Answer:

Thank you, we are very pleased that the article is interesting and can reach into wider audiences.

"I do have some questions: 1. What do the changes of N2 imply in terms of human activities (e.g. construction dams)? I know the author discussed it in the paper or maybe I missed it. But perhaps the authors could elaborate a bit more on how this change is induced by human activity?"

What is the final consequence to the environment (say, dominance/distinct of one species leads to what consequence)?"

Answer:

The changes in N2 diversity and the possible consequences of one species dominated ecosystems have been addressed in the revised manuscript by adding the following statements in various sections including Section 1.0, Section 5.1 and Section 6.2.

Section 1.0

"…Widespread human disturbances have caused variation in biological diversity and species diversity index in many floodplain wetlands worldwide (Zhang et al., 1999; Maddock et al., 2004). However, the response of diversity index change to degree of disturbances is variable. Wetlands associated with some large rivers experienced a reduced diversity index following severe disturbance, whereas in other wetlands indications of adverse disturbance are less clear in nature with relatively increased diversity index following the disturbance (Power et al., 1996). The varying nature of disturbance over time and space has altered habitat stability, consequently reducing species diversity and ecosystem function, therefore potentially threatening the loss of wetlands (Dumbrell et al., 2008; Biswas and Malik, 2010)…" Section 5.1

"The N2 diversity index of cladocerans reflected a small change in both river systems. The Hill's N2 diversity index assumes that the number of species in an ecosystem is uniformly distributed (Hill, 1973) therefore the distribution of cladoceran species along the temporal scale should be uniform. In Kings Billabong the N2 diversity was low during the 1900s. However, prior to human disturbance of the river (c. 1870s), as well as in c. 1960s, N2 Index was relatively high (Figure 5). In Zhangdu Lake, the N2 diversity index prior to the construction of the dam (c. 1881-1954) was low compared to the post-dam construction period, during which time the taxa preferring disturbed environment increased (Fig. 5). Similarly, the N2 diversity index of Liangzi Lake during the earlier period (c. 1900-1930) was lower than post dam construction period in the Yangtze River (Fig. 6). The intermediate disturbance hypothesis (IDH) suggests that the species diversity would increase at a moderate intensity of disturbance (Townsend and Scarsbrook, 1997). The increased N2 diversity index in Yangtze River wetlands following the construction of dams suggests the likely existence of IDH. However, unlike the Yangtze River wetlands, human disturbance in Kings Billabong would have been sudden and severe, due to the arrival in the late 1800s of Europeans, who rapidly transformed the landscape." Section 6.2

"…..The alternative stable states phenomena in shallow lakes and wetlands have been widely viewed as indicative of changes to resilience of ecosystems (Scheffer and Jeppesen, 2007). Such phenomena have shown the condition of wetlands to vary from a relatively good water quality, vegetation-rich state to a poor, turbid water state, which is usually less desirable (Folke et al., 2004). Positive feedback associated with the condition of increased water quality, species richness and population dynamics of D. crassa in Kings Billabong prior to 1900 AD is characteristic of a resilient ecosystem (e.g. Suding et al., 2004). By contrast, an open water habitat, which may be characteristic of longer flood duration following regulation leading to negative feedback, which has less resilience and increased turbidity (e.g. Suding et al., 2004). Similarly, in Zhangdu and Liangzi Lakes, an increased abundance of smaller, mud-dwelling cladoceran species such as small Alona and Leydigia leydigi, as well as presence of other meso-eutrophic species, Chydorus and Bosmina following regulation is indicative of increased eutrophication (e.g. Hofmann, 1996) caused by alteration of flow regime and dehydration of wetlands. Chapin III (2000) argued that changing species diversity

has functional consequences in ecosystem processes, which may be observed via impact on ecological traits. The components of species diversity expressing certain traits include the number of species present (species richness), their relative abundances (species evenness), the particular species present (species composition), the interactions among species (non-additive effects), and the temporal and spatial variation in these properties. The consequence to the environment as a result of cladoceran diversity change in Murray and Yangtze River wetlands is difficult to predict, but in the longer term, poor functioning of the ecosystem due to reduction in diversity in Kings Billabong is expected. In the Yangtze River wetlands, the dominant species richness trait, for instance abundance of small Alona group can also lead to poor ecosystem functioning (e.g. Chapin III, 2000). This evidence strongly reflects the reduction in resilience and the limited capacity of these wetlands supporting ecosystem services for human society in these increasingly regulated river basins. Further decline in ecohydrological conditions including the water quality, water quantity, fishery resources, and recreational amenities, due to cumulative stressors can lead to the collapse of ecosystem services, in which case society will no longer be benefitted (e.g. Falkenmark, 2003). The ecosystems of both Murray and Yangtze rivers are affected largely by a range of drivers. The cumulative stressors of these wetlands are nutrient enrichments from agricultural catchments, heavy metal release from industries (mainly in Yangtze wetlands) and climate change (flooding and drought episodes). Increased nitrogen deposition has been reported to have a greater effect on diversity and ecosystem functioning of wetlands leading to collapse of ecosystems (Hooper et al., 2012). The ecological collapse may lead to crises, with conflicting demands placed on natural resources and increasingly poor public health of the local community (Kattel et al., 2013). The participatory approach of river basin management can help increase resilience of wetland ecosystems and goods and services to society (Vörösmarty et al., 2010). Joint action by various stakeholders including ecologists, resource managers and decision makers can be useful to achieve management goals for natural resources (Biswas, 2004; Carpenter et al., 2009, Liu et al., 2014). Such an adaptive management approach for water resources is increasingly appropriate for maintaining ecosystem services of large river basins (e.g. Richter et al., 2003)." This will then link to Section 6.3. (see below) 2. The ecosystem of a basin might also be affected by other drivers other than only water quantity and quality. Have the authors consider other factors (e.g. nutrients)? Or can the authors justify the use of water quantity and quality as the only drivers?

Answer:

The ecosystems of both Murray and Yangtze rivers are affected by a range of drivers. We are sorry for this misunderstanding of the link between nutrient dynamics and water quality issues in the basin that we tried to address in the manuscript. In the revised manuscript, we have elaborated the range of factors including nutrients that influence basin ecosystems (This has been addressed in Section 6.2, please see above).

3. In my opinion, the proposed adaptive WRM framework is rather vague and there is a lack of detailed contents. It is based on three pillars, but nothing more than that (with only one example in Yangtze Basin) and it is not at all into detail. I think the three bullet points that might have been mentioned in one way or another in literatures do not form a detailed innovative framework. The added value of this paper, in my opinion, should be the development of this framework. Therefore, I would suggest that the authors expand this section as it highlights the core of this paper.

This is an important comment. Section 6.3 has been rewritten to clarify the WRM framework. Mainly the three pillars have been described in detail in the new version. In the revised manuscript the development of adaptive water resource management framework has been described comprehensively. Section 6.3 "Water problems in large river basins are increasingly interconnected with multi-sector developments such as agriculture, energy, industry, transportation and communication. Several authors (Walker et al., 1995; Kingsford et al., 2000; Fu et al., 2003) suggest that maintaining ecosystem health of wetlands of large river basins requires a new paradigm in water

management. Today, the wetlands of both the Murray and Yangtze river basins have faced greater challenges from hydrological modification, water shortage and eutrophication than at any time previously (Yang et al., 2006; Shen, 2010; Gell and Reid, 2014). There are growing concerns about the uncertainties of climate change and socio-economic impacts on these river basins (Palmer et al., 2000). For example, due to a rapid decline in water quality, biodiversity and ecological characters of the lower Yangtze River, this region has already been declared as the ecosystem of "lost resilience" (Zhang et al., 2015). A comprehensive synthesis by Varis and Vakkilainen (2001) suggests that following the 1970s China's environmental pressures have surpassed the carrying capacity of the ecosystem, resulting in greater challenges for water resource management in the Yangtze and many other river basins. Similarly, a rapidly declining trend of biological diversity and ecosystem states of the Murray River basin has also been widely reported following the 1950s (Kingsford et al., 2000). For example, more than 80% of wetlands in the Lower Murray River reaches (Australia) have undergone a significant decline in flow regimes and ecosystem health, due to rapid rates of sedimentation, turbidity and loss of macrophytes (e.g. Mosley et al., 2012; Gell and Reid, 2014). While the wetlands of both large river basins have experienced substantial loss of ecosystem services, river regulation during the 20th century, increasing demand for water, food, fibre, minerals, and energy in the 21 century has degraded conditions of these natural resources even further (e.g. Davis et al., 2015). Solutions for water issues are not possible without joint effort by the various stakeholders involved in understanding the complexity of water management in large river basins (e.g. Biswas, 2004). It has been envisaged that the current management framework needs to be revitalized to resolve growing issues of wetland management and maintenance of associated ecosystem services, including the quantity and quality of water in both river basins. Adoption of an Integrated Water Resource Management (IWRM) framework has been increasingly useful to resolve issues of quantity and quality of water worldwide. The IWRM promotes water management by maximizing relevant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (Biswas, 2004). Over the past decades, IWRM approach has been constantly modified as per the societal needs of the water management. On this basis, we have proposed the development of an adaptive water resource management framework for wetlands of the two large, hydrologically-transformed river basins in Australia and China (Fig. 7). This consideration has been taken into account on the basis of eco-hydrological evolution of wetlands inferred by subfossil cladoceran assemblages and diversity (Figs. 4 & 5). These changes have been profoundly implicated by socio-economic developments in both river basins over the past century. The proposed adaptive water resource management framework (Fig. 7) is integrated and multi-disciplinary in nature, is intended to improve management and to accommodate change by learning from the outcomes of management (restoration) policies and practices, as described by Holling, (1978) initially, and debated extensively after (Jakeman and Letcher, 2003; Macleod et al., 2007; Pahl-Wostl, 2007). Such management framework has previously been facilitated by dialogue between scientists, stakeholders and policy makers, and can be expected to result in highly positive outcomes in management (Falkenmark, 2004). In the framework (Fig. 7), we consider that both quantity and quality of water determines the conditions of the wetland ecosystems of the Murray and Yangtze Rivers. Prior to regulation these wetlands were maintained by sustainable flow regimes with improved water quality and reasonably good (at baseline condition) ecological health. The natural flood inundations maintained the amount of water, nutrients, carbon and salts in wetlands supporting biological diversity, ecosystem functioning and associated goods and services (Junk et al. 1989, Thorp and Delong 1994; Humphries et al. 1999; King et al. 2003). This evidence is also supported by various eco-hydrological models being developed and tested previously to measure flow regimes and ecosystems of the large river wetlands worldwide (Vannote et al. 1980; Naiman et al. 1987; Thoms and Sheldon, 2000). The use of palaeoecological approach in this study provides the 1950s as a benchmark of change in flow regime and ecosystem of the Murray and Yangtze River wetlands (Fig. 7). Following river regulation (post 1950s), both quantity

and quality of water in the Murray and Yangtze river wetlands had significantly altered, reaching a critically low level of flow and ecosystem health by the 2000s (Fig. 7). The condition of and changes in flow regime in the Murry River basin was reported by Maheshwari et al. (1995), where the average monthly and annual flows were considerably lower than those of natural conditions prior to regulation. We argue that the 2000s was the critical level of threshold for quality and quantity of water in wetlands of both river basins, and all available restoration measures should be adopted to avoid further decline in conditions in these wetlands. In our adaptive water resource management framework (Fig. 7), we have proposed the role of three pillars: science, engineering and community engagement when restoring the degraded wetlands of these two large river basins of Australia and China. River regulation, including widespread infrastructure developments across these river basins, has consistently modified natural hydraulic residence time, leading to changes in diversity and associated ecosystem structure and function of wetlands. For example, construction of Hume Dam in 1930s in Murray River, and several large dams, including the Three Gorges Dam (TGD), since the 1950s in Yangtze River will have long-lasting effects on downstream flow regimes, and wetland ecosystem structure and function (Pittock and Finlayson, 2011; Wu et al., 2003). Whilst these infrastructures are already in place, strong scientific evidence including the understanding of alterations of historical ecology and hydrology is potentially powerful tool to unravel the benchmark of the eco-hydrologic conditions of the Murray and Yangtze River wetlands over time. The benchmark is potentially important for the development of predictive models in future wetland restoration programs (Bennion et al., 2011). Predictive models can identify early warning signals of regime shift and resilience changes in individual wetlands and lakes (Wang et al., 2012). Resource managers can target restoration measures on the basis of benchmark conditions and employ appropriate prediction models so that investment will not be wasted on restoration of wetlands that would not result in improved values. Zweig and Kitchens (2009) suggest that the predictive hydrologic models can be the foundation for restoration programs of degraded wetlands, since these models can successfully identify the hydrologic effects on the state of transitioning ecosystems. Secondly, innovative and environmentally-friendly infrastructure developments and operation have been proposed in water restoration programs worldwide and there is an increased demand of efficient infrastructure development for the Murray and Yangtze River basins (e.g. Fu et al., 2010). One of fundamental issues of the integrated water resource management program is to meet balanced water allocations between industry and environment (Poff et al., 2003; Biswas, 2004). Due to overwhelming industrial demand of water in recent decades, economists have developed efficient environmental water allocation schemes for various river basins including the Murray and Yangtze (e.g. Lee and Ancev, 2009; Jiang, 2009). The proposed adaptive water resource management framework (Fig. 7) highlights the role of institutional capacities and development of efficient water allocation infrastructures (e.g. Yu et al., 2009). Consideration of efficient use of infrastructures for consumptive water uses and environmental water allocation for sustainable ecosystem function of large river basins is crucial for wetland restoration measures and sustainable maintenance of ecosystem services (e.g. Grafton et al., 2013). Finally, the need for strong linkages between scientific community and management stakeholders is essential in order to achieve the goal of wetland ecosystem management and restoration (e.g. Pittock and Finlayson, 2011, Liu et al., 2014). The decision making should be based on the need of the local community and mutual understanding among scientists, resource managers and the community leaders (Poff et al., 2003). The successful outcomes of water resource management in river basins would be possible if the community is engaged with all aspects of water resource management programs including both structural (e.g. hydropower dams) and non-structural infrastructure developments (e.g. awareness in adaptation to change), as well as water saving (e.g. Shen, 2010). The proposed adaptive water resource management framework (Fig. 7) is expected to enhance wetland resilience by improving both water quality and quantity, including ecosystem function, consequently assisting the basin-wide management of food and water security issues through extensive community participation.

For example, the WWF-supported partnership program, together with government agencies and local communities, was highly successful for improving water resources, both quantitatively and qualitatively, in the Yangtze River Basin. Under this type of management program and in partnership with local people, the three Yangtze lakes (Zhangdu, Hong and Tian-e-zhou), which were disconnected from the main channel during the 1950s-1970s, have now been recharged by opening of sluice gates (Yu et al., 2009). The recharging of Zhangdu Lake has not only enhanced resilience of the lake environment to climate change and but also livelihoods of the local people (Yu et al., 2009). Recently, the role of community participation in water resource management has also been reported significant in an Australian river basin. For example, the coupled socio-hydrologic models have shown strong association between the trajectory of human-water co-evolution and associated goods and services in the Murrumbidgee River basin (Kandasamy et al., 2014). NEW REFERENCES ADDED IN THE REVISED MANUSCRIPT Biswas, A.K.: Integrated water resources management: a reassessment, Water International, 29, 248-256, 2004. Biswas, S.R. and Mallik, A.U.; Disturbance effects on species diversity and functional diversity in riparian and upland plant communities, Ecology, 28-35, 2010. Cai, W. and Cowan, T.: Evidence of impacts from rising temperature on inflows to the Murray-Darling Basin, Geophysical Research Letters, 35, L07701, 2008. doi:10.1029/2008GL033390. Carpenter, S.R., Mooney, H.A., Agard, J., Capistrano, D., DeFries, R.S., Diaz, S., Dietz, T., Duraiappah, A.K., Oteng-Yeboah, A., Pereira, H.M., Perrings, C., Reid, W.V., Sarukhan, J., Scholes, R.J. and Whyte, A.: Science for managing ecosystem services: beyond the millennium ecosystem assessment, Proc. Natl. Acad. Sci. U. S. A., 106, 1305–1312, 2009. Chapin III, F.S., Zavaleta, E.S., Eviner, V.T., Naylor, R.L., Vitousek, P.M., Reynolds, H.L., Hooper, D.U., Lavorel, S., Sala, O.E., Hobbie, S.E., Mack, M.C. and Diaz, S.: Consequences of changing biodiversity, Nature, 405, 234-242, 2000. Dumbrell, A.J., Clark, E.J., Frost, G.A., Randell, T.E., Pitchford, J.W. and Hill, J.K.: Changes in species diversity following habitat disturbance are dependent on spatial scale: theoretical and empirical evidence, Journal of Applied Ecology, 45, 1531-1539.

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