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Editorial

The potential of ecosystem-based management to integrate biodiversity conservation and ecosystem service provision in aquatic ecosystems

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ABSTRACT

Global aquatic biodiversity keeps declining rapidly, despite international efforts providing a variety of policies and legislations that identify goals for, and give directions to protecting the world's aquatic fauna and flora. With the H2020 project AQUACROSS, we have made an unprecedented effort to unify policy strategies, knowledge, and management concepts of freshwater, coastal, and marine ecosystems to support the achievement of the targets set by the EU Biodiversity Strategy to 2020. AQUACROSS has embraced the concept of ecosystem-based management (EBM), which approaches environmental management from a social-ecological system perspective to protect biodiversity and to sustainably harvest ecosystem services. This special issue includes contributions resulting from AQUACROSS, which either tackle selected EBM challenges from a theoretical point of view or apply EBM in one of the selected case studies across Europe. In this article, we introduce relevant topics, address the most important lessons learnt, and suggest where research should go with aquatic EBM. We hope that this special issue will foster and facilitate the uptake of EBM in aquatic ecosystems and, therewith, provide the on-ground applications needed for evaluating EBM's utility to safeguard aquatic biodiversity.

1. Introduction

Aquatic ecosystems including freshwater, coastal and marine environments are rich in biodiversity, providing a diverse array of habitats to species while delivering numerous economic benefits to society (Bennett et al., 2015). Many of these valuable ecosystems are at risk of being irreversibly damaged by human activities and pressures, including pollution, watershed disturbance, water resource development (*sensu* Vörösmarty et al., 2010) or invasive species, overfishing, and climate change (Secretariat of the Convention on Biological Diversity, 2014). These pressures threaten the sustainability of the ecosystems, their provision of ecosystem services (ESs) and ultimately human well-being (Vörösmarty et al., 2010). So far, existing EU policies have been unable to halt or even reverse the trend of declining aquatic biodiversity (Voulvoulis et al., 2017). In Europe, the current broad policy landscape, such as the EU Water Framework Directive (Council of the European Communities, 2000), the Marine Strategy Framework Directive (Council of the European Communties, 2008), the Habitats Directive (Council of the European Communities, 1992) or the Renewable Energy Directive (Council of the European Communities, 2009) among others, implies that sustainable management solutions require coordination and cooperation between different policy areas tackling freshwater, coastal, and marine ecosystems. In addition, innovative business solutions and public-private engagement are needed to consider and manage aquatic ecosystems as truly social-ecological systems (Virapongse et al., 2016).

2. What is ecosystem-based management?

To support long-term sustainable management in aquatic ecosystems, strong policy integration in terms of objectives, knowledge base,

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methods and tools, as well as engagement and knowledge exchange, is essential. The integrative nature of ecosystem-based management (EBM) shows in theory a lot of promise for supporting all of the above. Ultimately, EBM is a collaborative management approach used with the intention to restore, enhance and protect the resilience of an ecosystem so as to sustain or improve ESs and protect biodiversity, while considering nature and society, i.e. the full social-ecological system (Gómez et al., 2016a; Gómez et al., 2016b; Langhans et al., 2019). Hence, EBM treats human society as one of the essential elements that constitute an ecosystem, making use of different concepts such as integrated ecosystem assessments, marine spatial planning, resilience thinking, and complex adaptive systems (Table 1).

3. Ecosystem-based management in the AQUACROSS project

With this special issue we advance and, therewith, foster the understanding and application of EBM in aquatic ecosystems by showcasing selected results of AQUACROSS – an EU-funded Horizon 2020 project (Lago et al., 2019). Finished in November 2018, AQUACROSS aimed to support EU efforts to enhance the resilience of aquatic ecosystems, managed as a continuum, and to stop the loss of aquatic biodiversity in line with the EU2020 Biodiversity Strategy as well as to ensure the ongoing provision of ESs. Hence, AQUACROSS provided the perfect opportunity to advance the knowledge base and demonstrate practical applications of the EBM concept across a range of European case studies. One part of AQUACROSS was the development of a common and free of charge open-access online platform – the AQUACROSS Information Platform (http://dataportal.aquacross.eu/) – to disseminate research and innovation results. On one hand, this platform acted as a publishing tool for project partners focusing on the AQUACROSS case studies. On the other hand, it is now a central access point for data on different types of aquatic ecosystems, biodiversity, and EBM practices addressed to the entire scientific community, stakeholders, and policy makers. Supported by the Information Platform, we believe that AQUACROSS made an unprecedented effort to unify policy strategies, knowledge, and management concepts of freshwater, coastal, and marine ecosystems to support the cost-effective achievement of the targets set by the EU Biodiversity Strategy to 2020 (European Commission, 2011).

4. Roadmap to the special issue

The special issue opens with Lago et al. (2019), who describe the aims and approaches of AQUACROSS, its conceptual framework and case studies across Europe (Fig. 1). Gómez et al. (2016b) introduce an integrated assessment framework (further called the AQUACROSS assessment framework) to help operationalise the aims of AQUACROSS. The assessment framework is based on the water-biodiversity-nexus as the cornerstone to coordinate sectoral policies for sustainable land use, the provision of ESs, and biodiversity conservation. Core elements of the AQUACROSS assessment framework include i) harmonising and streamlining environmental policies within the context of biodiversity conservation strategies, ii) coordinating policies in different ecosystems (freshwater, marine, coastal) where different legislation applies, iii) amalgamating the relevant analytical approaches for the assessment of aquatic ecosystems and iv) addressing social-ecological systems in a truly holistic way.

A suite of studies identifies individual challenges associated with the operationalisation of the AQUACROSS assessment framework and propose ways forward. O'Higgins et al. (2019) choose the Ria de Aveiro case study in Portugal to demonstrate a methodology to characterise supply and demand for ESs. This is done on the basis of spatial properties and interdependencies between the lagoon and locations outside of the management area, and economic properties. Culhane et al. (2019) use insights from the case studies to explore aggregated impact risks from human activities on ES supply components across a range of aquatic ecosystems, including lakes, rivers, inlets, and coastal realms. Daam et al. (2019) analyse the causal links between aquatic biodiversity and ecosystem functioning. Teixeira et al. (2019) identify linkages on the supply-side of the social-ecological system, i.e. from biodiversity to ES supply, for all of the case studies. Borgwardt et al. (2019) link human activities through pressures to different ecosystem components in fresh-, coastal and marine waters, to identify the risk by each impact

Table 1
EBM components relevant for the protection of aquatic biodiversity, explanations of the components and examples of how they were considered in individual studies of this special issue.

EBM component	Explanations of EBM component	AQUACROSS examples
1) EBM considers ecological integrity, biodiversity, resilience and ESs	- Joint evaluation of multiple ESs - Protection of ecosystem integrity as a means to preserve ESs and biodiversity - Focus on multiple benefits or environmental services	Consideration of multiple ESs to select protected area sites that deliver broader benefits than just biodiversity protection (Barbosa et al., 2019) and social equity (Domisch et al., 2019)
2) EBM is carried out at appropriate spatial scales	- Consideration of ecosystems rather than jurisdictional boundaries - Can require transboundary cooperation	Selection of sites for efficient and effective river restoration based on a multi-national catchment rather than at the national level, to reach better biodiversity outcomes at lower costs (Funk et al., 2019)
3) EBM develops and uses multi-disciplinary knowledge	- Understanding of the ecological and social systems to be managed - Drawing on local & traditional knowledge	Combination of a semi-quantitative description of the social-ecological system with stakeholder input to identify drivers and pressures to be managed (Piet et al., 2019) or to meet societal goals (Lillebø et al., 2019; Martínez-López et al., 2019a); using spatial ecological and economic data to map the most cost-effective location to meet biodiversity goals (Barbosa et al., 2019, Domisch et al., 2019, Kuemmerlen et al., 2019)
4) EBM builds on social-ecological interactions, stakeholder participation, and transparency	- Balance of ecological and social concerns - Prominence to transparent and inclusive decision making - Power to collective action by building consensus on a shared vision for the future	Development of semi-quantitative models with stakeholder input, increasing scientific knowledge and building stakeholder understanding and consensus (Lillebø et al., 2019; Robinson et al., 2019)
5) EBM supports policy coordination	- Creation of new opportunities of pursuing different policy objectives simultaneously by breaking silos	Targeting river, transitional estuary, and coastal area objectives therewith aligning biodiversity and Water Framework Directive indicator monitoring and evaluation (Lillebø et al., 2019)
6) EBM incorporates adaptive management	- Ability to respond to a range of possible futures - Weighting short-term actions against long-term benefits of alternative actions	Development of scenarios that incorporate projections of population and economic growth to include them in management planning to make better informed decisions (Kuemmerlen et al., 2019, Piet et al., 2019)

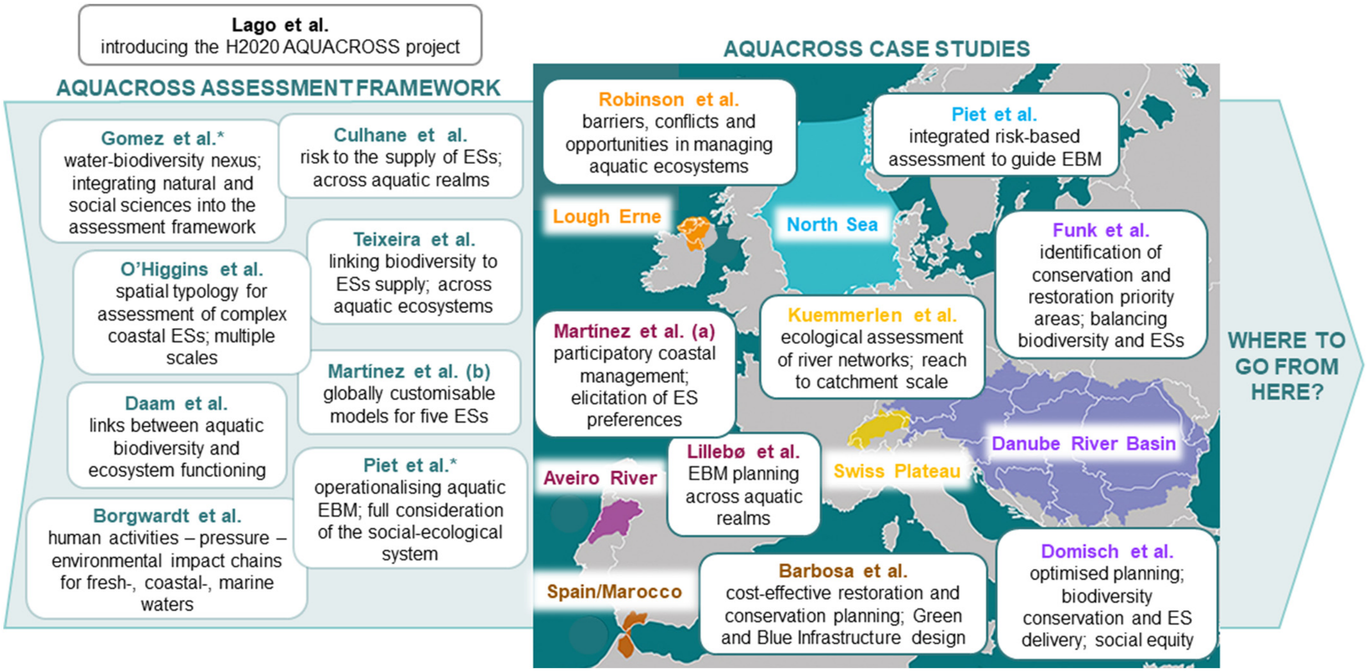

Fig. 1. Roadmap to the papers of this special issue. Manuscripts labelled with an asterisk* are deliverables of the project AQUACROSS.

chain, providing a more integrated view on different aquatic ecosystems. Martínez-López et al. (2019b) develop five ES models that can be applied to any place in the world without user input, while giving the option to customise the models with context-specific data. Domisch et al. (2019) analyse potential management plans for the Danube River basin that spatially optimise areas for conservation and ESs delivery, while accounting for social equity. Piet et al., (2017) introduce a cyclical adaptive EBM approach, each cycle consisting of four phases: i) the identification of the relevant societal goals, ii) establishing the knowledge base and identifying the main threats to the achievement of the societal goals, iii) EBM planning, and iv) EBM implementation, monitoring, and evaluation.

Seven manuscripts describe specific applications of the AQUACROSS assessment framework and EBM measures in selected case studies. Piet et al. (2019) provide guidance for (more) EBM in the North Sea based on an evaluation of the effectiveness of specific management measures in contributing to the conservation of marine biodiversity, while considering a range of societal goals such as sustainable food supply or clean energy. Barbosa et al. (2019) propose a spatial design for a Green and Blue Infrastructure network and the implementation of EBM measures in freshwater, coastal, and marine realms in a transboundary setting, namely the Intercontinental Biosphere Reserve of the Mediterranean in Andalusia and Morocco. Funk et al. (2019) prioritise river-floodplain segments for conservation and restoration along the whole Danube River, based on the multi-functionality of these segments regarding biodiversity and selected ESs, the availability of remaining semi-natural areas, and the reversibility of multiple human activities including flood protection, hydropower, and navigation. Robinson et al. (2019) explore the dependencies and interactions in the Lough Erne catchment in Northern Ireland with a social-ecological system approach, focusing on exploring how individual stakeholders perceived the goals to be affected by both biodiversity and activities found in the catchment. Lillebø et al. (2019) develop a collaborative EBM plan together with different stakeholder groups in the Ria de Aveiro coastal territory in Portugal using a spatial multi-criteria analysis approach aiming to mitigate foreseen changes connected to human activities and potential conflicts. Martínez-López et al. (2019a) focus on the same area to find optimal management actions to compensate for the predicted loss of biodiversity due to the floodbank extension in the Baixo Vouga Lagunar. Finally, Kuemmerlen et al. (2019) present a strategy based on decision support methods that aggregates reach-scale ecological assessments to describe the ecological state of entire catchments. They test the approach for selected sub-catchments in the Swiss Plateau and recommend a set of spatial criteria, which represent ecological processes or concepts such as migration, resilience and habitat diversity in a spatially explicit way.

5. Lessons learnt

EBM embraces six broader components (Table 1), reaching far beyond traditional management approaches. Equipped with these six components, EBM should be able to tackle pressing current and future environmental challenges. Indeed, the case studies described in this special issue exemplify individual components, i.e. the strengths of EBM (Table 1, column 3). In summary the case study applications show that EBM is practically doable and can be used to design more effective, efficient, and equitable management measures and policies for protecting biodiversity. The holistic management perspective, which is taken in EBM, allows trade-offs between ESs to be considered and takes several societal goals into account. EBM approaches promote the most efficient allocation of financial resources, while contributing to the sustainability of the whole social-ecological system. Hence, we conclude that this comprehensive approach has the potential to unveil win-win situations.

There are also strengths from a practitioner's perspective: EBM supports the integration of objectives and policy coordination, develops and uses quantitative, qualitative and spatial science, places stakeholders at the center of biodiversity management, recognises beneficiaries beyond biodiversity for its own sake, considers long-term and transboundary impacts, as well as prioritises evaluation and ongoing adaptive management.

6. Where to go from here?

To facilitate EBM implementation in aquatic systems and across different realms, four key challenges need particular attention: 1) Successful EBM requires well-defined, long-term monitoring and evaluation processes, considering time and costs, and relying on consistency in governance. This is, however, not unique to EBM, but a prerequisite for any adaptive management process. 2) EBM is not revolutionary, but is likely beneficial in most circumstances providing innovative solutions supported by stakeholders. The conditions under which an EBM process will yield superior results need to be identified. 3) EBM can appear difficult to practitioners and stakeholders and, therefore, they may hesitate to use the concept. Hence, EBM applications always need a fair amount of time to be dedicated to communication and discussions. 4) Tackling transboundary issues, e.g. across geographic boundaries or legislative landscapes is supported by EBM, but certainly remains challenging in practice.

Besides these challenges, integrating biodiversity protection into sectoral policy agendas and communicating the complex issue of biodiversity to different stakeholders generally needs more attention. Furthermore, research has to make an effort to better understand the links between biodiversity, ecosystems and ESs, to further develop practical models capturing the social-ecological system to support effective decision making across scales, and to support the transition from EBM as an academic concept to actually implement it on ground. We believe that EBM shows great potential for managing aquatic systems in a sustainable way, if future research and practical development is able to meet the remaining challenges.

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References

Barbosa, A., Martin, B., Hermoso, V., Arévalo-Torres, J., Barbière, J., Martínez-López, J., Domisch, S., Langhans, S.D., Balbi, S., Villa, F., Delacámara, G., Teixeira, H., Nogueira, A.J.A.H., Iglesias-Campos, A., Lillebø, A.I., Gil-Jiménez, McDonald, 2019. Cost-effective restoration and conservation planning in Green and Blue Infrastructure designs. A case study on the Intercontinental Biosphere Reserve of the Mediterranean: Andalusia (Spain) - Morocco. Sci. Total Environ. 652, 1463–1473. https://doi.org/10.1016/j.scitotenv.2018.10.416.

Bennett, E.M., Cramer, W., Begossi, A., Cundill, G., Diaz, S., Egoh, B.N., Geijzendorffer, I.R., Krug, C.B., Lavorel, S., Lazos, E., Lebel, L., Martínez-López, B., Meyfroidt, P., Mooney, H.A., Nel, J.L., Pascual, U., Payet, K., Pérez Harguindeguy, N., Peterson, G.D., Prieur-Richard, A.-H., Reyers, B., Roebeling, P., Seppelt, R., Solan, M., Tschakert, P., Tscharntke, T., Turner, B.L., Verburg, P.H., Viglizzo, E.F., White, P.C.L., Woodward, G., 2015. Linking biodiversity, ecosystem services, and human well-being: three challenges for designing research for sustainability. Curr. Opin. Environ. Sustain. 14, 76–85. https://doi.org/10.1016/j.cosust.2015.03.007.

Borgwardt, F., Robinson, L., Trauner, D., Teixeira, H., Nogueira, A.J.A., Lillebø, A.I., Piet, G., Kuemmerlen, M., O'Higgins, T., McDonald, H., Arevalo-Torres, J., Barbosa, A.L., Iglesias-Campos, A., Hein, T., Culhane, F., 2019. Exploring variability in environmental impact risk from human activities across aquatic ecosystems. Sci. Total Environ. 652, 1396–1408. https://doi.org/10.1016/j.scitotenv.2018.10.339.

Council of the European Communities, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. OJEC L206, 7–50.

Council of the European Communities, 2000. Directive 2000/60/EC of the European Parliament and the Council of 23rd October 2000 establishing a framework for community action in the field of water policy. OJEC L327, 1–72.

Council of the European Communities, 2009. Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. OJEC L140, 16–62.

Council of the European Communties, 2008. Directive 2008/56/EC of the European Parliament and the Council of 17 June 2008. Establishing a framework for community action in the field of marine environmental policy (marine strategy framework directive). OJEC L164, 19–40.

Culhane, F., Teixeira, H., Nogueira, A.J.A., Borgwardt, F.T., F., Lillebø, A., Piet, G., Kuemmerlen, M., McDonald, H., O'Higgins, T., Barbosa, A.L., van der Wal, J.T., Iglesias-Campos, A., Arevalo-Torres, J., Barbière, J., Robinson, L.A., 2019. Risk to the supply of ecosystem services across aquatic ecosystems. Sci. Total Environ. 660, 611–621.

Daam, M.A., Teixeira, H., Lillebø, A., Nogueira, A.J.A., 2019. Establishing causal links between aquatic biodiversity and ecosystem functioning: status and research needs. Sci. Total Environ. 656, 1145–1156.

Domisch, S., Kakouei, K., Martínez-López, J., Bagstad, K., Magrach, A., Balbi, S., Villa, F., Funk, A., Hein, T., Borgwardt, F., Hermoso, V., Jähnig, S.C., Langhans, S.D., 2019. Social equity shapes zone-selection: balancing aquatic biodiversity conservation and ecosystem services delivery in the transboundary Danube River Basin. Sci. Total Environ. 656, 797–807.

European Commission, 2011. Communication From the Commission to the European Parliament, the Council, the Economic and Social Committee of the Region. Our Life Insurance, Our Natural Capital: An EU Biodiversity Strategy to 2020. Brussels.

Funk, A., Martínez-López, J., Borgwardt, F., Trauner, D., Bagstad, K.J., Balbi, S., Magrach, A., Villa, F., Hein, T., 2019. Identification of conservation and restoration priority areas in the Danube River based on the multi-functionality of river-floodplain systems. Sci. Total Environ. 654, 763–777. doi.org/https://doi.org/10.1016/j.scitotenv.2018.10.322

Gómez, C.M., Delacámara, G., Arévalo-Torres, J., Barbière, J., Barbosa, A.L., Boteler, B., Culhane, F., Daam, M., Gosselin, M.-P., Hein, T., Iglesias-Campos, A., Jähnig, S.C., Lago, M., Langhans, S.D., Martínez- López, J., Nogueira, A.J.A., Lillebø, A.I., O'Higgins, T., Piet, G., Pletterbauer, F., Pusch, M., Reichert, P., Robinson, L., Rouillard, J., Schlüter, M., 2016a. The AQUACROSS Innovative Concept. Deliverable 3.1, European Union's Horizon 2020 Framework Programme for Research and Innovation Grant Agreement No. 642317.

Gómez, C.M., Delacámara, G., Jähnig, S.C., Langhans, S.D., Domisch, S., Hermoso, V., Piet, G., Martínez- López, J., Lago, M., Boteler, B., Rouillard, J., Abhold, K., Reichert, P., Schuwirth, N., Hein, T., Pletterbauer, R., Funk, A., Nogueira, A.J.A., Lillebø, A.I., Daam, M., Teixeira, H., Robinson, L., Culhane, F., Schlüter, M., Martin, R., Iglesias-Campos, A., Barbosa, A.L., Arévalo-Torres, J., O'Higgins, T., 2016b. Developing the AQUACROSS Assessment Framework. Deliverable 3.2, AQUACROSS, European Union's Horizon 2020 Framework Programme for Research and Innovation Grant Agreement No. 642317.

Kuemmerlen, M., Reichert, P., Siber, R., Schuwirth, N., 2019. Ecological assessment of river networks: from reach to catchment scale. Sci. Total Environ. 650, 1613–1627. https://doi.org/10.1016/j.scitotenv.2018.09.019.

Lago, M., Boteler, B., Rouillard, J., Abhold, K., Jähnig, S.C., Iglesias-Campos, A., Delacámara, G., Piet, G., Hein, T., Nogueira, A.J.A., Lillebø, A.I., Strosser, P., Robinson, L.A., DeWever, A., O'Higgins, T., Schlüter, M., Török, L., Reichert, P., van Ham, C., Villa, F., McDonald, H., 2019. Introducing the H2020 AQUACROSS project: knowledge, assessment, and management for AQUAtic biodiversity and ecosystem services aCROSS EU policies. Sci. Total Environ. 652, 320–329. https://doi.org/10.1016/j.scitotenv.2018.10.076.

Langhans, S.D., Domisch, S., Balbi, S., Delacámara, G., Hermoso, V., Kuemmerlen, M., Martin, R., Martínez-López, J., Vermeiren, P., Villa, F., Jähnig, S.C., 2019. Combining eight research areas to foster the uptake of ecosystem-based management in fresh waters. Aquat. Conserv., 1–19 https://doi.org/10.1002/aqc.3012.

Lillebø, A.I., Teixeira, H., Morgado, M., Martínez-López, J., Marhubi, A., Delácamara, G., Strosser, P., Nogueira, A.J.A., 2019. Ecosystem-based management planning across aquatic realms at the Ria de Aveiro Natura 2000 territory. Sci. Total Environ. 650, 1898–1912. https://doi.org/10.1016/j.scitotenv.2018.09.317.

Martínez-López, J., Teixeira, H., Morgado, M., Almagro, M., Sousa, A.I., Villa, F., Balbi, S., Genua-Olmedo, A., Nogueira, A.J.A., Lillebø, A.I., 2019a. Participatory coastal management through elicitation of ecosystem service preferences and modelling driven by "coastal squeeze". Sci. Total Environ. 652, 1113–1128. https://doi.org/10.1016/j.scitotenv.2018.10.309.

Martínez-López, J., Bagstad, K.J., Balbi, S., Magrach, A., Voigt, B., Athanasiadis, L., Pascual, M., Willcock, S., Villa, F., 2019b. Towards globally customizable ecosystem service models. Sci. Total Environ. 650, 2325–2336. https://doi.org/10.1016/j.scitotenv.2018.09.371.

O'Higgins, T., Nogueira, A.J.A., Lillebø, A.I., 2019. A simple spatial typology for assessment of complex coastal ecosystem services across multiple scales. Sci. Total Environ. 649, 1452–1466. https://doi.org/10.1016/j.scitotenv.2018.08.420.

Piet, G., Delacámara, G., Gómez, C.M., Lago, M., Rouillard, J., Martin, R., van Duinen, R., 2017. Making ecosystem-based management operational. Deliverable 8.1, European Union's Horizon 2020 Framework Programme for Research and Innovation grant agreement No. 642317.

Piet, G., Culhane, F., Jongbloed, R., Robinson, L., Rumes, B., Tamis, J., 2019. An integrated risk-based assessment of the North Sea to guide ecosystem-based management. Sci. Total Environ. 654, 694–704.

Robinson, L.A., Blincow, H.L., Culhane, F.E., O'Higgins, T., 2019. Identifying barriers, conflict and opportunity in managing aquatic ecosystems. Sci. Total Environ. 651, 1992–2002. https://doi.org/10.1016/j.scitotenv.2018.10.020.

Secretariat of the Convention on Biological Diversity, 2014. Global Biodiversity Outlook 4. Montréal. p. 155.

Teixeira, H., Lillebø, A., Culhane, F., Robinson, L., Trauner, D., Borgwardt, F., Kuemmerlen, M., Barbosa, A., McDonald, H., Funk, A., O'Higgins, T., Van der Wal, T.J., Piet, G., Hein, T., Arévalo-Torres, J., Iglesias-Campose, A., Barbière, J., Nogueira, A.J.A., 2019. Linking biodiversity to ecosystem services supply: patterns across aquatic ecosystems. Sci. Total Environ. 657, 517–534.

Virapongse, A., Brooks, S., Metcalf, E.C., Zedalis, M., Gosz, J., Kliskey, A., Alessa, L., 2016. A social-ecological systems approach for environmental management. J. Environ. Manag. 178, 83–91. https://doi.org/10.1016/j.jenvman.2016.02.028.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Reidy Liermann, C., Davies, P.M., 2010. Global threats to human water security and river biodiversity. Nature 467, 555–561. https://doi.org/10.1038/nature09440.

Voulvoulis, N., Arpon, K.D., Giakoumis, T., 2017. The EU Water Framework Directive: from great expectations to problems with implementation. Sci. Total Environ. 575, 358–366. https://doi.org/10.1016/j.scitotenv.2016.09.228.