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WATER BODIES IN EUROPE **Review Paper**

Assessment and recovery of European water bodies: key messages from the WISER project

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Abstract The EU-funded research project WISER ("Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery") developed new assessment methods required by the EU Water Framework Directive (WFD) for lakes, coastal and transitional waters. WISER also addressed the recovery of biotic assemblages from degradation. The results are summarised in five key messages, supported by papers in this special issue and by WISER results published elsewhere: (1) Response to stress differs between organism groups, water types and stressors; a conceptual model is proposed summarising how the individual organism groups respond to different types of degradation in rivers, lakes, transitional and coastal waters. (2) The sources of uncertainty differ between BQEs and water types, leading to methodological suggestions on how to design WFD sampling programmes. (3) Results from about 300 current assessment methods indicate geographical variations in metrics but assessments are comparable at an aggregated level ("ecological status"). (4) Scale and time matter; restoration requires action at (sub)-basin levels and recovery may require decades. (5) Long-term trends require consideration; the effects of both degradation and restoration at the water body or river basin scales is increasingly superimposed by multiple stressors acting at large scales, in particular by climate change.

Keywords Lakes · Rivers · Transitional waters · Coastal waters · Uncertainty · Water Framework Directive

Introduction

Driven by European policy, in particular the Water Framework Directive (WFD; Directive, 2000), assessment and restoration of European surface waters have become a research focus in recent years (Hering et al., 2010; Birk et al., 2012). Simply put, the WFD targets a "good ecological status" for all surface waters by 2015. Water bodies need to be assessed by comparison with a reference quality target; if the quality is below the "good status" target they need to be restored. Four different surface water categories are addressed by the

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WFD: rivers, lakes, transitional waters (e.g. estuaries, lagoons) and coastal waters. Their status is being assessed with “Biological Quality Elements” (BQEs), i.e. organism groups which integrate the effects of various stressors such as nutrient enrichment, acidification, hypoxia or habitat degradation. The BQEs to be investigated are phytoplankton, aquatic flora (phytobenthos and macrophytes in rivers and lakes, macroalgae and angiosperms in coastal and transitional waters), benthic invertebrates and fish.

In addition to national initiatives, several EU-funded research projects have contributed to developing and testing assessment methodologies for rivers, lakes, transitional and coastal waters (Hering et al., 2004; Schmutz et al., 2007; Carvalho et al., 2008), while others have generated tools for catchment management (Wade et al., 2002; Mysiak et al., 2005; Tippett et al., 2005). Many of these methods have been applied by Member States for the development of the first River Basin Management Plans (RBMPs) submitted to the Commission in 2009. The results clearly indicate the demand for substantial efforts in restoration: According to data reported in the first River Basin Management Plans almost 60% of European rivers, 50% of lakes and 70% of transitional waters fail to achieve WFD good status targets.

When the first RBMPs were submitted in 2009, almost 10 years after the ratification of the WFD, many countries still had not completed the development of new WFD-compliant systems for assessing ecological status. Classification systems for several relevant combinations of BQEs, ecosystem type and stressor were missing. The impact of some stressors, especially hydromorphological degradation (i.e. hydrological and structural modifications of river courses, lakes or coastal shorelines) on the biota was widely unknown, in particular for lakes and transitional/coastal waters. There was also little information on the uncertainty associated with assessment systems (see Clarke & Hering, 2006) and the comparability of status assessments between Member States (Nõges et al., 2009). Furthermore, there was insufficient knowledge on how biological assemblages recover from degradation and respond to climate change, thus limiting the predictability of the success of future restoration.

These obvious gaps in assessment methodology and restoration guidance were targeted from 2009 to 2012 by the EU-funded project WISER (Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery). For the first time, this broad-scale integrative project addressed all BQEs and all ecosystem types subjected to the WFD. WISER, in particular, addressed the following research questions:

- Which biological indicators are best suited for the assessment of aquatic ecosystems? Which are most reliable? Which are redundant? The WISER research was limited to lakes (with a special focus on hydromorphological degradation) and coastal and transitional waters.
- How can assessment results obtained with different BQEs or from different sites best be compared, intercalibrated and combined into an integrated appraisal of ecological status?
- How do BQEs recover from degradation in different ecosystem types, in particular from hydromorphological degradation and eutrophication?
- How are ecosystem assessment and restoration affected by climate change?
- How (un)certain are ecological status assessments and predictions about the effect of restoration and management measures? How can uncertainty in assessment be quantified and consequently minimised?

WISER produced a wide range of products and results, which have been laid down in 88 reports (available from www.wiser.eu/results) and more than 100 publications. In this contribution, we aim at providing an overview of the project, to introduce this special issue and to summarise the WISER outcome in “key messages”, with a focus on results relevant for the future steps of implementing the WFD.

Overview of the WISER project

WISER was composed of five scientific modules. The module “data and guidelines” compiled all the data accessible to the project, closing gaps in the data sources, storing the data generated in the project’s field campaigns, providing tools for data queries and data entry, evaluating and comparing existing assessment methods, and developing common guidelines for indicator development (Moe et al., 2012; Schmidt-Kloiber et al., 2012; Birk et al., 2012).

Two modules addressed “ecological indicators for assessment and intercalibration” in lakes and transitional/coastal waters, respectively. The lake module dealt with all BQEs used for lake assessment: phytoplankton, macrophytes, benthic invertebrates and fish. It developed and improved state-of-the-art assessment methodologies, taking into account the remaining needs to complete intercalibration of assessment systems (Lyche-Solheim et al., 2013). Each BQE was investigated in-depth, examining relationships to environmental stressors and uncertainty due to spatio-temporal variation and sampling methodology. The latter was in particular achieved by joint field sampling campaigns in 2009 and 2010 that targeted sampling at different locations within a water body, at different times and by different investigators. Most of the indicator analyses, however, were based on existing data from previous monitoring initiatives and EU-funded research projects (overview in Lyche-Solheim et al., 2013).

A similar approach was followed for transitional and coastal waters. Four BQEs (phytoplankton, macroalgae/angiosperms, benthic invertebrates and fish) were addressed and analysed mainly on the basis of pre-existing data. In addition, a field campaign was carried out to generate the data required to develop new assessment metrics and to estimate uncertainty (overview in Borja et al., 2012).

The impacts of pressure reduction (i.e. management and restoration) and climate change on the ecological status in all water categories were addressed by a separate module, which explored recovery processes of the biota in rivers, lakes and coastal/transitional waters and analysed the potential effects of different climatic conditions on ecological status and recovery. For lakes and marine ecosystems the focus was on oligotrophication (e.g. Jeppesen et al., 2010, 2012; Vaquer-Sunyer & Duarte, 2010), whereas the effects of hydromorphological restoration were analysed for rivers (Feld et al., 2011), and additionally considered for lakes. Conceptual models describing the effects of management/restoration on biota were developed. In concert, this module provided guidance for river basin management, on the ecological effectiveness of management and rehabilitation measures and on how climate change affects ecological status and recovery (see Verdonschot et al., 2012, for a summary).

Finally, a module synthesised the results on water body assessment, restoration and climate change. This module addressed uncertainty analysis for different BQEs and water types in a comparative way, and developed a new software tool to assist uncertainty analysis in bioassessment (Clarke, 2012). Further, the combination of different BQEs in water body assessment (Caroni et al., 2012), stressor-response relationships, and management/restoration-recovery relationships (Verdonschot et al., 2012) were compared across ecosystems.

Response to stress differs between organism groups, water types and stressors, demanding problem-specific monitoring programmes

As commented above, the WFD requires the use of different BQEs to assess the ecological status of surface waters. Despite some questions on the combination rules of results obtained with different BQEs (Hering et al., 2010; Caroni et al., 2012) the overall idea is positively perceived by the majority of authors, as organism groups may respond differently to stress in general or to different stressors. An overview on how different organism groups respond to stressor types in European rivers is given by Hering et al. (2006a, b) and refined with large-scale monitoring data by Dahm et al. (2013) and Marzin et al. (2012), for lakes by Lyche-Solheim et al. (2013) and for transitional and coastal waters by Borja et al. (2012).

In a simplistic way, Fig. 1 summarises the response of different BQEs to major stress types in rivers, lakes, transitional and coastal waters. Irrespective of the water type, all BQEs addressed by the WFD respond to water quality degradation, of which elevated nutrient concentrations are most widespread in European surface waters (van Buuren et al., 2002; Ferreira et al., 2011). Response to hydromorphological pressure is mainly relevant once water quality has been enhanced to a level not severely affecting the organisms. In contrast to eutrophication, the degradation of hydrological and morphological features affects the biota through various and often complex pathways, such as alterations in habitat composition, flow dynamics, shading or food sources. The cause-effect-chains linking river hydromorphology and biota have recently been reviewed by Feld et al. (2011); simple dose–response relationships between degradation and ecological response are rare, thus metrics addressing the effects of hydromorphological degradation are less certain.

For all water types, it is increasingly obvious that stressors acting at larger scales overrule the effects of local degradation. In rivers, catchment land use acts as

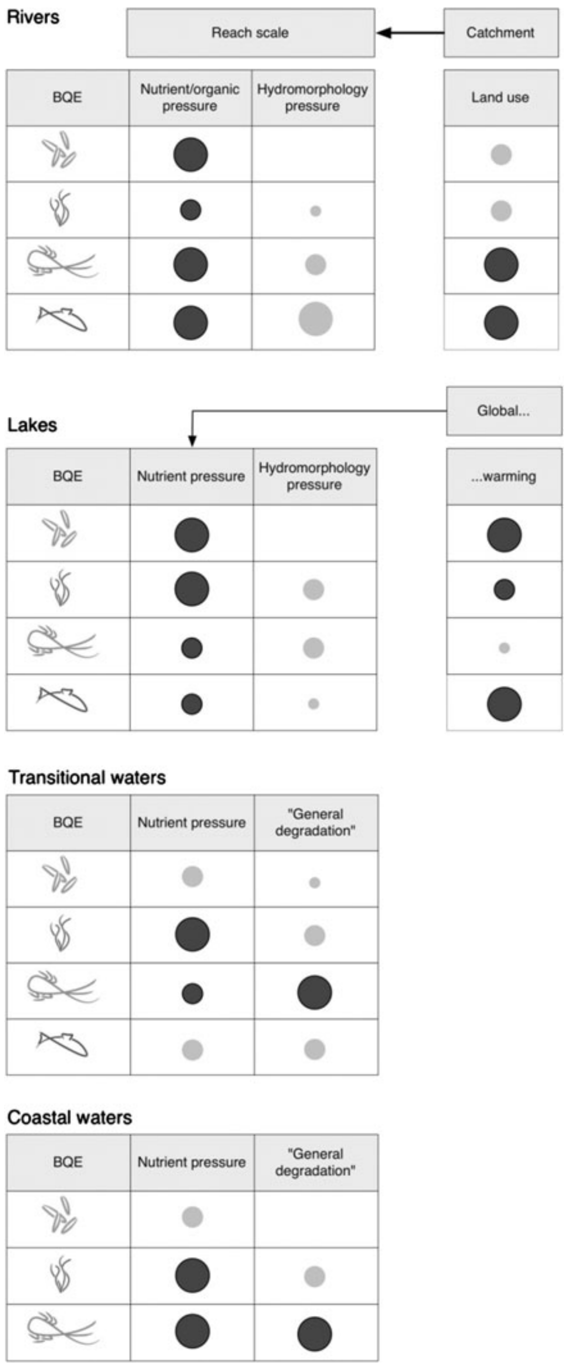

Fig. 1 Response of phytoplankton, macroflora (macrophytes in rivers and lakes; angiosperms and macroalgae in transitional and coastal waters), benthic invertebrates and fish to different stressors in rivers, lakes, transitional waters and coastal waters. The size of the *circles* indicates effect size. *Grey circles* indicate relationships strongly affected by uncertainty

an over-arching driver (Lorenz & Feld, 2012), affecting the biota at the site scale through nutrients, water temperature, sediment input, alterations of the river's discharge and toxic substances. Many state-of-the-art river assessment systems, therefore, describe "general degradation" as a stressor, which is mainly equivalent to the effects of intensive catchment land use (Norris et al., 2007; Gabriels et al., 2010; Birk et al., 2012). While agricultural and urban land uses determine nutrient levels also in lakes and transitional waters (Jeppesen et al., 2005; Vaquer-Sunyer & Duarte, 2008), lake biota are increasingly affected by global warming, which can enhance eutrophication effects (Winder & Schindler, 2005; Meerhoff et al., 2007).

In this special issue, several papers analyse the response of BQEs to stress in lakes (Argillier et al., 2012; Carvalho et al., 2012; Järvinen et al., 2012; Lyche-Solheim et al., 2013; Maileht et al., 2012; Mjelde et al., 2012; Phillips et al., 2012; Søndergaard et al., 2012), coastal/transitional waters (Alvarez et al., 2012; Basset et al., 2012; Borja et al., 2012; Dromph et al., 2012; Garmendia et al., 2012; Marbà et al., 2012; Mascaro et al., 2012) and in rivers (Carlson et al., 2012; Dahm et al., 2013; Marzin et al., 2012). These studies also indicate that different metrics within a BQE can have different sensitivities to pressures in different lake types (e.g. Phillips et al., 2012).

Be aware of inherent uncertainty when measuring ecological status

The result of a complex biotic metric used for assessing status reflects only in part ecological quality. Metrics, and therefore status, are also affected by natural variability, season, sampling method and potentially by all types of errors in field and lab procedures and in identification (Clarke & Hering, 2006; Carvalho et al., 2012; Mascaro et al., 2012). In an ideal world the effects of natural variability would be taken into account by a sophisticated water body typology incorporating all the topographic and environmental conditions significantly affecting the metric. Researcher-dependent errors might be minimised by smart sampling designs and appropriate training programmes. However, it is impossible to completely eliminate uncertainly in bio-indication; scientists and practitioners should be aware of this and take it into account in the design of monitoring schemes and the training of skilled staff.

Within WISER the main sources of uncertainty in the assessment of BQEs in lakes and transitional/coastal waters were quantified. For lakes, this led to the following recommendations to minimise uncertainty (Winfield et al., 2011; Dudley et al., 2012; Mischke et al., 2012; Thackeray et al., 2012; Carvalho et al., 2012):

- Phytoplankton assessment generally requires at least 3 monthly samples over the summer months for at least 3 years to minimise the effects of seasonal and inter-annual metric variability. Standard methods and training for sampling and analyses are needed to minimise analytical error.
- Macrophyte metrics based on helophytes were not useful for assessing the effects of nutrient pressure but are particularly important for assessing hydromorphological pressures. Metrics were also found to vary with the depth of sampling. In summary, field methods should be based on transects covering all depth zones and different habitats (emergent helophytes and submerged).
- Macroinvertebrate assessment of shoreline modifications should be based on composite or habitat specific sampling (depending on region) at various stations representing the whole range of morphological shore modification.
- Fish assessment should be based on sampling all depth strata with many gillnets, while hydroacoustic methods provide cost-effective assessment of fish abundance.

For transitional and coastal waters, the relevant sources of uncertainty differ between BQEs. For marine phytoplankton, the number of stations sampled per water body is most relevant for minimising uncertainty, while the variability between stations is crucial for macroinvertebrate assessment. For angiosperms, the spatial scale of sampling is the main source of uncertainty (Mascaro et al., 2012), while for fish there are several relevant sources, covering salinity, depth, season and temporal variation between years (overview in Borja et al., 2012).

In this special issue, the following papers provide much more detail on uncertainty in bioassessment: Balsby et al. (2012), Carvalho et al. (2012), Clarke (2012), Dromph et al. (2012), Dudley et al. (2012), Karus & Feldmann (2012) and Mascaro et al. (2012).

Intercalibration is required to compare the results of bioindicator systems in Europe

There is a multitude of biotic assessment metrics responding to the degradation of rivers, lakes and transitional/coastal waters. The WISER project reviewed 297 assessment methods (Birk et al., 2012), based on a questionnaire survey sent to water authorities in all Member States and additional countries that are implementing the WFD. Twenty-eight countries reported on methods applied to rivers (30% of all assessment methods), coastal waters (26%), lakes (25%) and transitional waters (19%). More than half of the methods are based on either macroscopic plants (28%) or benthic invertebrates (26%); in addition, phytoplankton (21%), fish (15%) and phytobenthos (10%) were assessed.

The annexes of the Commission Decision on the intercalibration results (phase 2), which is awaited for late 2012, revealed that the assessment methods for the following biological elements are almost fully intercalibrated: Phytoplankton and macrophytes in lakes, and benthic invertebrates, phytobenthos and fish fauna in rivers. Intercalibration has not been fully completed for the remaining combinations of BQEs and surface water types.

The multitude of assessment methodologies throughout Europe has its pros and cons. The high number of mainly regional methods suggests that the methods used are adapted to regional conditions, which include dominant stressors, species occurrences, taxonomic knowledge and history in biomonitoring. The negative side of this is that the results are not explicitly comparable. A minimum level of comparability has been achieved through intercalibration—which has shown that aggregated assessment results ("ecological status") of intercalibrated methods are now generally comparable for many BQEs across Europe. This comparability has not been tested for individual metrics due to the high number of assessment metrics in use, with one exception being lake phytoplankton abundance, where most assessments are based on comparable chlorophyll-*a* measurements and it is often impossible to use the original data collected for bioindication purposes for answering scientific questions due to differences in methodology and taxonomy (compare Moe et al., 2012).

Scale and time matter: restoration requires action at (sub)-basin levels and recovery may span decades

Within the WFD philosophy, water quality assessment aims at identifying water bodies not meeting the quality target “good ecological status”. Those water bodies require ecological improvement. Given the results of the first RBMPs, this applies to the majority of water bodies in Europe, particularly in densely populated regions, such as Belgium, the Netherlands or Germany, where almost all water bodies are failing “good status”. Restoration of degraded water bodies will, therefore, be a challenging task for Europe’s water management over the next decades.

There are two main questions related to restoration and recovery of aquatic ecosystems: what is the appropriate spatial extent (scale) of restoration measures needed and how long will it take until the quality target will be achieved? It is well known from many studies that broad-scale landscape factors (e.g. topography, land use) can largely control local habitat conditions (e.g. sediment particle size, peak discharges) (Frissell et al., 1986; Paul & Meyer, 2001). This hierarchical relationship also applies to drivers of stress, such as catchment agriculture or urbanisation, both of which can largely determine segment-, reach- and habitat-scale water quantity and quality (Allan, 2004; Feld et al., 2011). Besides these spatial hierarchies, there is also a qualitative hierarchy of stressors, for instance, water quality problems can superimpose hydrological and morphological conditions implying a prioritisation of restoration measures.

Our knowledge concerning time spans required for recovery is incomplete, as there is a general lack of long-term restoration monitoring. Recovery of rivers after the establishment of riparian buffers may take at least 30–40 years. These recovery estimates are derived from growth rates of riparian vegetation, though empirical data are sparse. In contrast, time series data are available for many lake ecosystems and in some cases date back for several decades (e.g. Jeppesen et al., 2005). These data suggest that biological recovery from eutrophication varies from 10 to 20 years in the case of macroinvertebrates, 2 to >40 years for aquatic macrophytes, and 2 to >10 years for fish. Estuarine and coastal waters also require long periods to recover (>10 years), although macroinvertebrates may potentially recover within months (Borja et al., 2010). In general, after long and intense periods of deterioration following decades of human pressure, a period of 15–25 years may be needed in all surface water ecosystems to attain a biotic composition, diversity and ecosystem functioning comparable to the pre-disturbed state (Verdonschot et al., 2012).

In this special issue, several papers refer to restoration and recovery in rivers (Haase et al., 2012; Lorenz & Feld, 2012) and coastal waters (Carstensen et al., 2012).

Changing climate, biomonitoring and ecosystem recovery: long-term trends require consideration

Long-term development of aquatic biota is affected by several drivers, amongst other stress intensity, restoration and recolonisation. On top of all this, there are external drivers of ecosystem change acting at the global scale, namely climate change, impacting environmental conditions (e.g. temperature, precipitation), biotic composition and functioning of aquatic ecosystems through various pathways (Kernan et al., 2010).

In particular, the effects of changing climate have been documented for biota in lakes (e.g. Winder & Schindler, 2005; Meerhoff et al., 2007). Mainly through food-web interactions in mesocosm studies, a warmer climate has generally been shown to enhance eutrophication and partly reverse the successes of oligotrophication. Within WISER this was supported by long-term trends in the fish assemblages of European lakes, which are affected by both, water quality enhancement and climate change, which cause opposite trends (Jeppesen et al., 2012).

Over longer time spans, there might be the need to reconsider both reference conditions (which may change with a warmer climate; Logez & Pont, 2012) and restoration targets, which might require extra management effort as eutrophication effects are worsened by climate change. In this special issue, Logez & Pont (2012) deal with the complex interactions of assessment/restoration and climate change.

Conclusions

WISER was most likely the last large-scale research project dealing with biological assessment systems for the WFD. Despite a few weaknesses remaining (some missing national methods; unknown sources of uncertainty of some assessment schemes) the methods available now provide a unique resource to confidently assess most of Europe's surface waters and identify sites requiring restoration. Where national assessment systems are still missing for certain combinations of BQEs and water categories, methods applicable in a broad geographic range (such as those provided by WISER) could be used (e.g. lake phytoplankton methods in Eastern Continental Europe).

The main remaining scientific challenges for supporting the implementation of the WFD's ecological targets are associated with mitigation and restoration. While much has been learned about the effects of restoration on ecological status, tools to predict future ecological status are still needed, as well as long time series documenting the trajectory of restored water bodies.

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References

Allan, J. D., 2004. Landscapes and riverscapes: the Influence of land use on stream ecosystems. Annual Review of Ecology, Evolution, and Systematics 35: 257–284.

Alvarez, M. C., A. Franco, R. Pérez-Domínguez & M. Elliott, 2012. Sensitivity analysis to explore responsiveness and dynamic range of multi-metric fish-based indices for assessing the ecological status of estuaries and lagoons. Hydrobiologia. doi:10.1007/s10750-012-1314-7.

Argillier, C., S. Caussé, M. Gevrey, S. Pédron, J. D. Bortoli, S. Brucet, M. Emmrich, E. Jeppesen, T. Lauridsen, T. Mehner, M. Olin, M. Rask, P. Volta, I. Winfield, F. Kelly, T. Krause, A. Palm & K. Holmgren, 2012. Development of a fish-based index to assess the eutrophication status of European lakes. Hydrobiologia. doi:10.1007/s10750-012-1282-y.

Balsby, T., D. Krause Jensen & J. Carstensen, 2012. Sources of uncertainty in estimation of eelgrass depth limits. Hydrobiologia. doi:10.1007/s10750-012-1374-8.

Basset, A., E. Barbone, A. Borja, M. Elliott, G. Jona-Lasinio, J. C. Marques, K. Mazik, I. Muxika, J. Magalhães Neto, S. Reizopoulou, I. Rosati & H. Teixeira, 2012. Natural variability and reference conditions: setting type-specific classification boundaries for lagoon macroinvertebrates in the Mediterranean and Black Seas. Hydrobiologia. doi: 10.1007/s10750-012-1273-z.

Birk, S., W. Bonne, A. Borja, S. Brucet, A. Courrat, S. Poikane, A. G. Solimini, W. van de Bund, N. Zampoukas & D. Hering, 2012. Three hundred ways to assess Europe's surface waters: an almost complete overview of biological methods to implement the Water Framework Directive. Ecological Indicators 18: 31–41.

Borja, A., D. Dauer, M. Elliott & C. Simenstad, 2010. Medium- and long-term recovery of estuarine and coastal ecosystems: patterns, rates and restoration effectiveness. Estuaries and Coasts 33: 1249–1260.

Borja, A., M. Elliott, P. Hendriksen & N. Marba, 2012. Transitional and coastal waters ecological status assessment: advances and challenges resulting from implementing the European Water Framework Directive. Hydrobiologia. doi:10.1007/s10750-012-1276-9.

Carlson, P. E., R. K. Johnson & B. G. McKie, 2012. Optimizing stream bioassessment: habitat, season, and the impacts of land use on benthic macroinvertebrates. Hydrobiologia. doi:10.1007/s10750-012-1251-5.

Caroni, R., W. van de Bund, R. T. Clarke & R. K. Johnson, 2012. Combination of multiple biological quality elements into waterbody assessment of surface waters. Hydrobiologia. doi:10.1007/s10750-012-1274-y.

Carstensen, J., D. Krause-Jensen, S. Markager, K. Timmermann & J. Windolf, 2012. Water clarity and eelgrass responses to nitrogen reductions in the eutrophic Skive Fjord, Denmark. Hydrobiologia. doi:10.1007/s10750-012-1266-y.

Carvalho, L., A. Solimini, G. Phillips, M. van den Berg, O.-P. Pietilainen, A. Lyche Solheim, S. Poikane & U. Mischke, 2008. Chlorophyll reference conditions for European lake types used for intercalibration of ecological status. Aquatic Ecology 42: 203–211.

Carvalho, L., G. Borics, J. Catalan, C. De Hoyos, S. Drakare, B. Dudley, M. Järvinen, C. Laplace-Treyture, A. Lyche Solheim, K. Maileht, U. Mischke, J. Moe, G. Morabito, P. Nõges, T. Nõges, I. Ott, A. Pasztaleniec, G. Phillips, S. Poikane, B. Skjelbred & S. Thackeray, 2012. Lake Phytoplankton: integrating compositional and functional metric responses to eutrophication. Hydrobiologia. doi: 10.1007/s10750-012-1344-1.

Clarke, R. T., 2012. Estimating confidence of European WFD ecological status class and WISER Bioassessment Uncertainty Guidance Software (WISERBUGS). Hydrobiologia. doi:10.1007/s10750-012-1245-3.

Clarke, R. T. & D. Hering, 2006. Errors and uncertainty in bioassessment methods—major results and conclusions from the STAR project and their application using STARBUGS. Hydrobiologia 566: 433–439.

Dahm, V., D. Hering, D. Nemitz, W. Graf, A. Schmidt-Kloiber, P. Leitner, A. Melcher & C.K. Feld, 2013. Effects of physico-chemistry, land use and hydromorphology on three riverine organism groups: A comparative analysis with monitoring data from Germany and Austria. Hydrobiologia. doi:10.1007/s10750-012-1431-3.

Directive, 2000. Directive 2000/60/EC of the European Parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Communities L 327: 1–72.

Dromph, K., S. Agusti, A. Basset, J. Franco, P. Henriksen, J. Icely, S. Lehtinen, S. Moncheva, M. Revilla, L. Roselli & K. Sørensen, 2012. Sources of uncertainty in assessment of marine phytoplankton communities. Hydrobiologia. doi: 10.1007/s10750-012-1353-0.

Dudley, B., M. Dunbar, E. Penning, A. Kolada, S. Hellsten, A. Oggioni, V. Bertin, F. Ecke & M. Sondergaard, 2012. Measurements of uncertainty in macrophyte metrics used to assess European lake water quality. Hydrobiologia. doi: 10.1007/s10750-012-1338-z.

Feld, C. K., S. Birk, D. C. Bradley, D. Hering, J. Kail, A. Marzin, A. Melcher, D. Nemitz, M. L. Petersen, F. Pletterbauer, D. Pont, P. F. M. Verdonschot & N. Friberg, 2011. From natural to degraded rivers and back again: a test of restoration ecology theory and practice. Advances in Ecological Research 44: 119–209.

Ferreira, J. G., J. H. Andersen, A. Borja, S. B. Bricker, J. Camp, M. Cardoso da Silva, E. Garcés, A.-S. Heiskanen, C. Humborg, L. Ignatiades, C. Lancelot, A. Menesguen, P. Tett, N. Hoepffner & U. Claussen, 2011. Overview of eutrophication indicators to assess environmental status within the European Marine Strategy Framework Directive. Estuarine, Coastal and Shelf Science 93: 117–131.

Frissell, C. A., W. J. Liss, C. E. Warren & M. D. Hurley, 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 12: 199–214.

Gabriels, W., K. Lock, N. De Pauw & P. L. M. Goethals, 2010. Multimetric Macroinvertebrate Index Flanders (MMIF) for biological assessment of rivers and lakes in Flanders (Belgium). Limnologica 40: 199–207.

Garmendia, M., M. Revilla & L. Zarauz, 2012. Testing the usefulness of a simple automatic method for particles abundance and size determination to derive cost-effective phytoplankton indicators, in large monitoring networks. Hydrobiologia. doi:10.1007/s10750-012-1400-x.

Haase, P., D. Hering, S. C. Jähnig, A. W. Lorenz & A. Sundermann, 2012. The impact of hydromorphological restoration on river ecological status: a comparison of fish, benthic invertebrates, and macrophytes. Hydrobiologia. doi:10.1007/s10750-012-1255-1.

Hering, D., O. Moog, L. Sandin & P. Verdonschot, 2004. Overview and application of the AQEM assessment system. Hydrobiologia 516: 1–20.

Hering, D., R. K. Johnson, S. Kramm, S. Schmutz, K. Szoszkiewicz & P. F. M. Verdonschot, 2006a. Assessment of European rivers with diatoms, macrophytes, invertebrates and fish: a comparative metric-based analysis of organism response to stress. Freshwater Biology 51: 1757–1785.

Hering, D., R. K. Johnson & A. Buffagni, 2006b. Linking organism groups—major results and conclusions from the STAR project. Hydrobiologia 566: 109–113.

Hering, D., A. Borja, J. Carstensen, L. Carvalho, M. Elliott, C. K. Feld, A.-S. Heiskanen, R. K. Johnson, J. Moe, D. Pont, A. Lyche Solheim & W. van de Bund, 2010. The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. Science of the Total Environment 408: 4007–4019.

Järvinen, M., S. Drakare, G. Free, A. Lyche-Solheim, G. Phillips, B. Skjelbred, U. Mischke, I. Ott, S. Poikane, M. Søndergaard, A. Pasztaleniec, J. Van Wichelen & R. Portielje, 2012. Phytoplankton indicator taxa for reference conditions in Northern and Central European lowland lakes. Hydrobiologia. doi:10.1007/s10750-012-1315-6.

Jeppesen, E. M., J. P. Søndergaard, K. E. Jensen, O. Havens, L. Anneville, M. F. Carvalho, R. Coveney, M. T. Deneke, B. Dokulil, D. Foy, S. E. Gerdeaux, S. Hampton, K. Hilt, J. Kangur, E. H. H. R. Köhler, T. L. Lammens, M. Lauridsen, M. R. Manca, B. Miracle, P. Moss, G. Nõges, G. Persson, R. Phillips, C. L. Portielje, D. Schelske, I. Straile, E. Willen Tatrai & M. Winder, 2005. Lake responses to reduced nutrient loading—an analysis of contemporary long-term data from 35 case studies. Freshwater Biology 50: 1747–1771.

Jeppesen, E., M. Meerhoff, K. Holmgren, I. Gonzalez-Bergonzoni, F. Teixeira-de Mello, S. A. J. Declerck, L. De Meester, M. Søndergaard, T. L. Lauridsen, R. Bjerring, J. M. Conde-Porcuna, N. Mazzeo, C. Iglesias, M. Reizenstein, H. J. Malmquist, Z. Liu, D. Balayla & X. Lazzaro, 2010. Impacts of climate warming on lake fish community structure and potential effects on ecosystem function. Hydrobiologia 646: 73–90.

Jeppesen, E., T. Mehner, I. J. Winfield, K. Kangur, J. Sarvala, D. Gerdeaux, M. Rask, H. J. Malmquist, K. Holmgren, P. Volta, S. Romo, R. Eckmann, A. Sandström, S. Blanco, A. Kangur, H. R. Stabo, M. Tarvainen, A.-M. Ventelä, M. Søndergaard, T. L. Lauridsen & M. Meerhoff, 2012. Impacts of climate warming on the long-term dynamics of key fish species in 24 European lakes. Hydrobiologia 694: 1–39. doi:10.1007/s10750-012-1182-1.

Karus, K. & T. Feldmann, 2012. Factors influencing macrophyte metrics in Estonian coastal lakes in the light of ecological status assessment. Hydrobiologia. doi:10.1007/s10750-012-1300-0.

Kernan, M., R. W. Battarbee & B. R. Moss, 2010. Climate change impacts on freshwater ecosystems. Wiley-Blackwell, Oxford.

Logez, M. & D. Pont, 2012. Global warming and potential shift in reference conditions: the case of functional fish-based metrics. Hydrobiologia. doi:10.1007/s10750-012-1250-6.

Lorenz, A. W. & C. K. Feld, 2012. Upstream river morphology and riparian land use overrule local restoration effects on ecological status assessment. Hydrobiologia. doi:10.1007/s10750-012-1326-3.

Lyche-Solheim A., C.K. Feld, S. Birk, G. Phillips, L. Carvalho, G. Morabito, U. Mischke, N Willby, M. Søndergaard, S. Hellsten, A. Kolada, M. Mjelde, J. Böhmer, O. Miler, M.T. Pusch, C. Argillier, E. Jeppesen, T.L. Lauridsen & S. Poikane, 2013. Ecological status assessment of European lakes: a comparison of metrics for phytoplankton, macrophytes, benthic invertebrates and fish. Hydrobiologia. doi: 10.1007/s10750-012-1436-y.

Maileht, K., T. Nõges, P. Nõges, I. Ott, U. Mischke, L. Carvalho & B. Dudley, 2012. Water colour, phosphorus and alkalinity are the major determinants of the dominant phytoplankton species in European lakes. Hydrobiologia. doi: 10.1007/s10750-012-1348-x.

Marbà, N., D. Krause-Jensen, T. Alcoverro, S. Birk, A. Pedersen, J.M. Neto, S. Orfanidis, J.M. Garmendia, I. Muxika, A.

Borja, K. Dencheva & C.M. Duarte, 2012. Diversity of European seagrass indicators: Patterns within and across regions. Hydrobiologia. doi:10.1007/s10750-012-1403-7.

Marzin, A., P. F. M. Verdonschot & D. Pont, 2012. The relative influence of catchment, riparian corridor and reach-scale anthropogenic pressures on fish and macroinvertebrate assemblages in French rivers. Hydrobiologia. doi:10.1007/s10750-012-1254-2.

Mascaró, O., T. Alcoverro, K. Dencheva, I. Díez, J.M. Gorostiaga, D. Krause-Jensen, T.J.S. Balsby, N. Marbà, I. Muxika, J.M. Neto, V. Nikolić, S. Orfanidis, A. Pedersen, M. Pérez & J. Romero, 2012. Exploring the robustness of macrophyte-based classification methods to assess the ecological status of coastal and transitional ecosystems under the WFD. Hydrobiologia. doi:10.1007/s10750-012-1426-0.

Meerhoff, M., C. Iglesias, F. T. De Mello, J. M. Clemente, E. Jensen, T. L. Lauridsen & E. Jeppesen, 2007. Effects of habitat complexity on community structure and predator avoidance behaviour of littoral zooplankton in temperate versus subtropical shallow lakes. Freshwater Biology 52: 1009–1021.

Mischke, U., S. Thackeray, M. Dunbar, C. McDonald, L. Carvalho, C. de Hoyos, M. Jarvinen, C. Laplace-Treyture, G. Morabito, B. Skjelbred, A. Lyche Solheim, B. Brierley & B. Dudley, 2012. Deliverable D3.1-4: guidance document on sampling, analysis and counting standards for phytoplankton in lakes. (http://www.wiser.eu/download/D3.1-4.pdf, checked on 19 Oct. 2012)

Mjelde, M., S. Hellsten & F. Ecke, 2012. A water level drawdown index for aquatic macrophytes in Nordic lakes. Hydrobiologia. doi:10.1007/s10750-012-1323-6.

Moe, S. J., A. Schmidt-Kloiber, B. J. Dudley & D. Hering, 2012. The WISER way of organising ecological data from European rivers, lakes, transitional and coastal waters. Hydrobiologia. doi:10.1007/s10750-012-1337-0.

Mysiak, J., C. Giupponi & P. Rosato, 2005. Towards the development of a decision support system for water resource management. Environmental Modelling & Software 20: 203–214.

Nõges, P., W. van de Bund, A. Cardoso, A. Solimini & A.-S. Heiskanen, 2009. Assessment of the ecological status of European surface waters: a work in progress. Hydrobiologia 633: 197–211.

Norris, R. H., S. Linke, I. Prosser, W. J. Young, P. Liston, N. Bauer, N. Sloane, F. Dyer & M. Thoms, 2007. Very-broad-scale assessment of human impacts on river condition. Freshwater Biology 52: 959–976.

Paul, M. J. & J. L. Meyer, 2001. Streams in the urban landscape. Annual Review of Ecology, Evolution, and Systematics 32: 333–365.

Phillips, G., A. Lyche-Solheim, B. Skjelbred, U. Mischke, S. Drakare, G. Free, M. Järvinen, C. de Hoyos, G. Morabito, S. Poikane & L. Carvalho, 2012. A phytoplankton trophic index to assess the status of lakes for the Water Framework Directive. Hydrobiologia. doi:10.1007/s10750-012-1390-8.

Schmidt-Kloiber, A., S. J. Moe, B. Dudley, J. Strackbein & R. Vogl, 2012. The WISER metadatabase: the key to more than 100 ecological datasets from European rivers, lakes and coastal waters. Hydrobiologia. doi:10.1007/s10750-012-1295-6.

Schmutz, S., I. G. Cowx, G. Haidvogl & D. Pont, 2007. Fish-based methods for assessing European running waters: a synthesis. Fisheries Management and Ecology 14: 369–380.

Søndergaard, M., G. Phillips, S. Hellsten, A. Kolada, F. Ecke, H. Mäemets, M. Mjelde, M. M. Azzella & A. Oggioni, 2012. Maximum growing depth of submerged macrophytes in European lakes. Hydrobiologia. doi:10.1007/s10750-012-1389-1.

Thackeray, S., P. Nõges, M. Dunbar, B. Dudley, B. Skjelbred, G. Morabito, L. Carvalho, G. Phillips, U. Mischke, J. Catalan, C. de Hoyos, C. Laplace, M. Austoni, B. Padedda, K. Maileht, A. Pasztaleniec, M. Järvinen, A. Lyche Solheim & R. Clarke, 2012. Quantifying uncertainties in biologically-based water quality assessment: a pan-European analysis of lake phytoplankton community metrics. Ecological Indicators (in press).

Tippett, J. B., C. Pahl-Wostl Searle & Y. Rees, 2005. Social learning in public participation in river basin management—early findings from HarmoniCOP European case studies. Environmental Science & Policy 8: 287–299.

van Buuren, J., T. Smit, G. Poot & A. van Elteren, 2002. Testing of indicators for the marine and coastal environment in Europe. Part 1: Eutrophication and integrated coastal zone management. European Environment Agency. EEA Technical Report 84: 48.

Vaquer-Sunyer, R. & C. M. Duarte, 2008. Thresholds of hypoxia for marine biodiversity. Proceedings of the National Academy of Sciences of the United States of America 105: 15452–15457.

Vaquer-Sunyer, R. & C. M. Duarte, 2010. Sulfide exposure accelerates hypoxia-driven mortality. Limnology and Oceanography 55: 1075–1082.

Verdonschot, P. F. M., B. M. Spears, C. K. Feld, S. Brucet, H. Keizer-Vlek, A. Borja, M. Elliott, M. Kernan & R. K. Johnson, 2012. A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. Hydrobiologia. doi:10.1007/s10750-012-1294-7.

Wade, A. J., P. G. Whitehead & L. C. M. O'Shea, 2002. The prediction and management of aquatic nitrogen pollution across Europe: an introduction to the Integrated Nitrogen in European Catchments project (INCA). Hydrology and Earth System Sciences 6: 299–313.

Winder, M. & D. E. Schindler, 2005. Climate change uncouples trophic interactions in an aquatic ecosystem. Ecology 85: 2100–2106.

Winfield, I. J., M. Emmrich, J. Guillard, T. Mehner & A. Rustadbakken, 2011. Guidelines for standardisation of hydroacoustic methods. WISER deliverable 3.4-3.