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Deliverable 2.1 - Four manuscripts on the multiple stressor framework: Framework to select indicators of multi-stressor effects for European river basin management (3/4)

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Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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Content

Note that this version does not contain benchmark indicators obtained from the questionnaire returns of Task 2.2 *Methodology for ecosystem service assessment and valuation*.

1. Introduction

To allow for a streamlined analysis of multi-stressor effects across the different spatial scales and environmental conditions targeted in MARS, we need to select "benchmark indicators". According to the DoW these indicators shall mainly address ecological status and ecosystem services. In terms of the DPSIR adaptive management cycle, we thus require '***state indicators***' for the ecosystem properties and functions, and '***impact indicators***' to assess the impact on ecosystem service capacity.

Based on questionnaire returns circulated to the MARS partners we have now concluded on a list of 15 indicators that meet determined selection criteria (see Annex 1) and were considered meaningful and practicable by the responders (see Annex 2). Most of the indicators represent 'classical' state indicators applied in EU Water Framework Directive (WFD)-related water management, some of which also cover abiotic state variables acting as direct pressures impacting on the biological state (e.g. total phosphorus concentration). Only two impact indicators are described here (toxic/nuisance phytoplankton, commercially-relevant fish), as we still intend to select suitable indicators from the questionnaire outcomes on ecosystem services (MARS Task 2.2) in the next weeks.

The benchmark indicators mainly comprise simple metrics and indices of abiotic and biotic ecosystem properties, covering physico-chemical, hydrological and riparian features of the water body and selected attributes of its biological community. The proposed indicators are known to respond to anthropogenic pressure. They are applicable in various geographical contexts and to different water categories and types of water bodies. They generally do not require acquisition of specific data, but refer to data already available.

We refrained from using multimetric indices to avoid the required standardisation of single metrics combined to multi-metrics. However, the benchmark indicators vary naturally across the gradients of environmental conditions studied in MARS (e.g. from Welsh upland brooks to Basque estuaries). We need to control for this natural variability in order to detect the effects of multiple stress on the indicators.

Most the benchmark indicators represent conventional (and approved) measures of single ecosystem properties. Innovations on multi-stress diagnosis and resilience will be addressed by the specific research done in other MARS work packages (e.g. WP6.2 on diagnostic indicators). Our selection of benchmark indicators is meant to support this research by covering a broad range of relevant ecosystem properties, allowing for the linkage of abiotic and biotic indicators, or indicators of different trophic levels; or relating state and impact indicators. WP6 on synthesizing stressors, scenarios and water management particularly needs the coherent application of the benchmark indicators across work packages and study areas (cf. WP6 Guidance document: Analysing stressor-response relationships and interactions in multi-stressor situations).

2. Details on the indicator profiles

This document presents the benchmark indicators by means of indicator profiles, i.e. concise characterisations of indicator background, context and rationale. The individual profile categories are outlined in the following.

Quality element: Refers to WFD specifications, distinguishing between physico-chemical (e.g. nutrient status), hydromorphological (e.g. morphology) and biological quality elements (e.g. fish).

Water category and water body types: Refers to WFD specifications, i.e. rivers, lakes and transitional waters. Lakes explicitly include reservoirs. Coastal waters are not addressed in MARS. Groundwaters are not covered by the selected indicators due to limited applicability and data availability.

The water body type represents an ecologically homogeneous unit characterised, for instance, by ecoregion, altitude, catchment size, background geology. In MARS we will refer to broad types established by the European Environment Agency (see Annex 3).

Selection rationale: Concise explanation highlighting the reason for indicator selection.

Indicator type (DPSIR): Refers to the adaptive DPSIR (Driver, Pressure, State, Impact, Response) management cycle, positioning the indicator in this conceptual framework.

Description: Brief summary on indicator background and features.

Spatio-temporal resolution: Specification of the spatio-temporal scope of information provided by the indicator.

Unit: Unit in which indicator is measured.

Standardisation: The benchmark indicators vary naturally across the gradients of environmental conditions studied in MARS (e.g. from Welsh upland brooks to Basque estuaries). We need to control for this natural variability in order to detect the effects of multiple stress on the indicators. This is especially relevant for studies using space-for-time substitution including different water body types. A viable option is to standardise the indicator using commonly defined, type-specific reference values, as established in the intercalibration exercise (cf. Annex 3 for the definition of broad European water body types).

Birk et al. (2013)[1] highlight that the peculiarities of differing sampling and analytical techniques also affect data comparability. These even outweigh any biogeographical differences when data are acquired based on differing protocols. A more preferred standardisation option thus includes modelling approaches disentangling the effects of biogeography and sampling protocols from the responses of multiple stress.

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[1] Birk, S., Willby, N., Kelly, M., Bonne, W., Borja, A., Poikane, S., & van de Bund, W. (2013). Intercalibrating classifications of ecological status: Europe's quest for common management objectives for aquatic ecosystems. Science of The Total Environment, 454-455, 490–499.

Data requirements: Specification of data required to apply the indicator.

Other: Any other relevant information.

MARS spatial scale: Indicator applicability at MARS experimental, basin or European scale.

References: Relevant literature references.

3. Consolidated list of benchmark indicators

The 15 MARS benchmark indicators are listed in the table below. It contains the indicator short-code, indicator name and selection rationale. The table also specifies the water categories for which the indicator is applicable (Lak=lakes, Riv=rivers, Tra=transitional waters), as well as the relevant MARS scales (Exp=WP3 experimental scale, Bsn=WP4 basin-scale, Eur=WP5 European scale). Square symbols in brackets refer to partial applicability of the indicator (e.g. chlorophyll-a only at large rivers; invertebrate feeding groups only for river experiments sampling for invertebrates). ○=alternative indicator for transitional waters.

Code	Indicator name	Selection rationale	Water category			MARS scale		
			Lak	Riv	Tra	Exp	Bsn	Eur
BInd01	Ecological status of surface water body	General indicator of key relevance for WFD river basin management	■	■	■		■	■
BInd02	Total phosphorus concentration in the water column	Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures	■	■	■	■	■	■
BInd03	Total nitrogen concentration in the water column	Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures	■	■	■	■	■	■
BInd04	Mean duration of high pulses within each year	Indicator of extreme hydrological events related to flood risk		■			■	■
BInd05	Mean duration of low pulses within each year	Indicator of extreme hydrological events related to environmental flows and water supply		■			■	■
BInd06	Annual water-level fluctuations	Indicator of extreme hydrological events related to water supply and recreation	■				■	■
BInd07	Amount of naturally-forested land in the riparian corridor of water body	Indicator of riparian state of high relevance for water body status and ecosystem services	■	■	○		■	■
BInd08	Growing season mean of water column chlorophyll-a concentration	Commonly used water quality indicator with high data availability	■	(■)	■	■	■	■
BInd09	Chlorophyll-a to total phosphorus ratio (Chl:TP)	Simple measure of production efficiency	■	(■)	■	■	■	■
BInd10	Biovolume of toxic/nuisance phytoplankton species	Direct indicator of the functional quality of recreation and water supply services	■	(■)	■		■	■
BInd11	Abundance of submerged, emergent and floating-leafed macrophytic vegetation	Integrative indicator of hydromorphological and nutrient pressure, with relevance for habitat structuring	■	■	■	(■)	■	■
BInd12	Average Score per Taxon (ASPT)	All-round indicator of general pressure	■	■	○	(■)	■	■
BInd13	Abundance ratios of invertebrate functional feeding groups	Trait-based indicator of functional relevance linked to food web structure	■	■	■	(■)	■	■
BInd14	Relative abundance of invasive alien invertebrate species	Indicator of 'biopollution'	■	■	■		■	■
BInd15	Total fish abundance (incl. abundance of commercially relevant fish)	Simple and robust indicator responding to different pressures, relevant for assessing service provision (fish yield)	■	■	■	(■)	■	■

BInd01: Ecological status of surface water body

Quality element: Various

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: General indicator of key relevance for WFD river basin management

Indicator type (DPSIR): State

Description: The ecological water body status is derived from worst case classification using bioassessment results of various biological elements. It represents the status classification based on national assessment methods, as stipulated by the Water Framework Directive. Classifying high and good status integrates non-biological assessment such as hydromorphological and physico-chemical parameters.

Spatio-temporal resolution: Water-body, single value

Unit: One out of five classes

Standardisation: Not necessary (type-specific assessment is implemented)

Data requirements: Official national WFD monitoring

Other:

Status classification to be provided according to governmental monitoring

! No classification of ecological potential !

MARS spatial scale: River-basin and European scale

Reference

ETC-ICM (2012). Thematic assessment on ecological and chemical status and pressures. ETC-ICM Technical Report 1/2012. Prague: European Topic Centre on Inland, Coastal and Marine waters.

BInd02: Total phosphorus concentration in the water column

Quality element: Physico-chemistry

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures

Indicator type (DPSIR): Pressure, State

Description: Phosphorus is an essential nutrient for plants and animals. The element is naturally limited in most fresh water systems. The concentration of total phosphorus in the water represents an indicator of the chemical ecosystem state, increased by discharge and runoff from urban and agricultural land (e.g. wastewater treatment plants, fertilized lawns and cropland, animal manure storage areas). Total phosphorus also represents a pressure causing eutrophication effects such as algal blooms, accelerated plant growth, and low dissolved oxygen as a secondary effect from the aerobic decomposition of vegetation biomass.

The indicator is a standard parameter of water quality: widely monitored, conceptually well-founded and empirically validated.

Spatio-temporal scale: Field data: sampling site, aggregated value of multiple measurements in time (e.g. annual average)

Unit: $\mu g\ L^{-1}$

Standardisation: To be standardised against type-specific background levels

Data requirements: Field data, modelled data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference: none

BInd03: Total nitrogen concentration in the water column

Quality element: Physico-chemistry

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Common water pollution factor driving primary production in aquatic systems, conditioning secondary pressures (e.g. oxygen depletion) and interacting with other pressures

Indicator type (DPSIR): Pressure, State

Description: Nitrogen is an essential nutrient for plants and animals. The concentration of total nitrogen in the water represents an indicator of the chemical ecosystem state, increased by discharge and runoff from urban, agricultural and industrial land (e.g. wastewater treatment plants, fertilized lawns and cropland, animal manure storage areas, industrial discharge). Total nitrogen also represents a pressure causing eutrophication effects such as algal blooms, accelerated plant growth, and low dissolved oxygen as a secondary effect from the aerobic decomposition of vegetation biomass. It is particularly relevant if the Chl:TP ratio is low (see also Bind09).

The indicator is a standard parameter of water quality, widely monitored, conceptually well-founded and empirically validated.

Spatio-temporal scale: Field data: sampling site, aggregated value of multiple measurements in time (e.g. annual average)

Unit: mg L^{-1}

Standardisation: To be standardised against type-specific background levels

Data requirements: Field data, modelled data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference: none

BInd04: Mean duration of high pulses within each year

Quality element: Hydromorphology

Water category and water body types: Rivers, all types

Selection rationale: Indicator of extreme hydrological events related to flood risk

Indicator type (DPSIR): Pressure, State, Impact

Description: Streamflow is the 'master factor' in stream ecosystems, establishing the physical mosaic of habitats and influencing the water quality conditions (e.g. temperature, dissolved oxygen, and nutrient concentration). The hydrological river regime is characterised by five general features: flow magnitude, frequency, duration, timing and rate of change, usually addressed within the 'range of variability approach' (Richter et al. 1997). Thus, a broad range of relevant streamflow indicators have been proposed (e.g. 32 Indicators of Hydrologic Alteration; Richter et al. 1996).

The 'mean duration of high pulses within each year' characterises the annual extreme streamflow conditions. High pulses are defined here as periods during which the daily mean flow exceeds the 75^{th} percentile of the mean annual discharge.

The natural flow regime including high pulse magnitude, frequency, duration and timing represents an intrinsic hydrological feature of a river. Drivers influencing this feature include river regulation (e.g. damming, water abstraction and diversion), groundwater pumping, climate change (e.g. precipitation, evapotranspiration), catchment land use (e.g. impervious surface, deforestation) and river structure (e.g. straightening, embankment).

High pulses affect various hydraulic parameters (hydrodynamic forces, turbulence and shear stress) and impact on stream habitats and biota. High pulse magnitude and duration are related to flood risk.

Spatio-temporal scale: Field data: gauging station, representing upstream sub-catchment

Unit: Number of days per year

Standardisation: To be standardised against natural hydrograph (e.g. % deviation from natural hydrograph)

Data requirements: Field data, modelled data (e.g. JRC LISFLOOD model)

Other: none

MARS spatial scale: River-basin and European scale

References

Richter, B., Baumgartner, J., Powell, J., & Braun, D. (1996). A method for assessing hydrologic alteration within ecosystems. Conservation Biology, 10(4), 1163–1174.

Richter, B., Baumgartner, J., Wigington, R., & Braun, D. P. (1997). How much water does a river need? Freshwater Biology, 37, 231–249.

BInd05: Mean duration of low pulses within each year

Quality element: Hydromorphology

Water category and water body types: Rivers; all types

Selection rationale: Indicator of extreme hydrological events related to environmental flows and water supply

Indicator type (DPSIR): Pressure, State, Impact

Description: Streamflow is the ‘master factor’ in stream ecosystems, establishing the physical mosaic of habitats and influencing the water quality conditions (e.g., temperature, dissolved oxygen, and nutrient concentration). The hydrological river regime is characterised by five general features: flow magnitude, frequency, duration, timing and rate of change usually addressed within the ‘range of variability approach’ (Richter et al. 1997). Thus, a broad range of relevant streamflow indicators have been established (e.g. 32 Indicators of Hydrologic Alteration; Richter et al. 1996).

The ‘mean duration of low pulses within each year’ characterises the annual extreme streamflow conditions. Low pulses are defined as periods during which the daily mean flow falls below the 10th percentile of the mean annual discharge.

The natural flow regime including low pulse magnitude, frequency, duration and timing represents an intrinsic hydrological feature of a river. Drivers influencing this feature include river regulation (e.g. damming, water abstraction and diversion), groundwater pumping, climate change (e.g. precipitation, evapotranspiration), catchment land use (e.g. impervious surface, deforestation) and river structure (e.g. straightening, embankment).

Low pulses lead to the loss of aquatic habitat availability and connectivity that generates a loss of biodiversity and biomass, poor water quality and riparian canopy die-back. Low pulse magnitude and duration are related to the concept of environmental flows and water supply.

Spatio-temporal scale: Gauging station, representing upstream sub-catchment

Unit: Number of days per year

Standardisation: To be standardised against natural hydrograph (e.g. % deviation from natural hydrograph)

Data requirements: Field data, modelled data (e.g. JRC LISFLOOD model)

Other: none

MARS spatial scale: River-basin and European scale

References

Poff, N.L., Richter, B.D., Arthington, A.H., Bunn, S.E., Naiman, R.J., Kendy, E., Acreman, M., Apse, C., Bledsoe, B.P., Freeman, M.C., Henriksen, J., Jacobson, R.B., Kennen, J.G., Merritt, D.M., O'Keeffe, J.H., Olden, J.D., Rogers, K., Tharme, R.E., Warner, A. (2010). The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology, 55(1), 147–170.

Roo, A. De, Burek, P., Gentile, A., Udias, A., Bouraoui, F., Aloe, A., Bianchi, A., La Notte, A., Kuik, O., Elorza Tenreiro, J., Vandecasteele, I., Mubareka, S., Baranzelli, C., Van der Perk, M., Lavalle, C., Bidoglio, G. (2012). A multi-criteria optimisation of scenarios for the protection of water resources in Europe. Support to the EU Blueprint to Safeguard Europe's Waters. Joint Research Centre, Ispra (IT): 134pp.

BInd06: Annual water-level fluctuations

Quality element: Hydromorphology

Water category and water body types: Lakes; all types

Selection rationale: Indicator of extreme hydrological events related to water supply and recreation

Indicator type (DPSIR): Pressure, State

Description: Lake water levels fluctuate naturally, caused by different amounts of water entering and leaving the lake. Water supply, hydropower generation or flood prevention can alter the natural hydrological regime towards more excessive fluctuation. In lakes used for recreation or navigation, water-levels are often more stable than natural ones. Climate change is an additional driver of a changed hydrological regime.

Especially the littoral zone, i.e. the belt of shallow water around the shoreline of a lake to the maximum depth at which light still reaches the bottom sediments, is affected by excessive water-level fluctuations. This zone is often more productive than the open water (pelagic zone) and provides important ecological functions (food resources, hiding places from predation, fish spawning sites). Anthropogenic fluctuations destabilize the littoral zone integrity, including the weakening of keystone species, proliferation of nuisance and invasive species, loss of biodiversity, and increased internal nutrient loading. The lake can become more eutrophic with large and more frequent cyanobacterial blooms occurring. In Mediterranean climates lake salinity may increase.

Modified water-level regimes are threats to the sustainable water supply and recreation services.

Spatio-temporal scale: Water level station, monthly measurements

Unit: Annual range of water-level fluctuation in centimetres

Standardisation: To be standardised against natural hydrograph (e.g. % deviation from natural hydrograph)

Data requirements: Field data, modelled data (e.g. JRC LISFLOOD model)

Other: none

MARS spatial scale: River-basin and European scale

References

Sutela, T., Aroviita, J., & Keto, A. (2013). Assessing ecological status of regulated lakes with littoral macrophyte, macroinvertebrate and fish assemblages. Ecological Indicators, 24, 185–192.

Wantzen, K. M., Rothhaupt, K.-O., Mörtl, M., Cantonati, M., G.-Tóth, L., & Fischer, P. (2008). Ecological effects of water-level fluctuations in lakes: an urgent issue. Hydrobiologia, 613(1), 1–4.

Zohary, T., & Ostrovsky, I. (2011). Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. Inland Waters, 1, 47–59.

BInd07: Amount of naturally-forested land in the riparian corridor of water body

Quality element: Hydromorphology

Water category and water body types: Rivers, lakes, transitional waters[2]; all types

Selection rationale: Indicator of riparian state of high relevance for water body status and ecosystem services

Indicator type (DPSIR): Pressure, State, Impact

Description: Riparian corridors represent key habitats linking aquatic and terrestrial ecosystems. They can provide important natural and social services. Natural riparian zones encompass valuable natural habitats and are often characterized by high productivity and biodiversity. Riparian areas can reduce non-point-nutrient and pollution sources via plant uptake, physical filtering and chemical transformation (e.g. denitrification), together with trapping sediment-bound pollutants and waters coming from upstream. Riparian corridors play a major role in maintaining landscape connectivity, functioning as 'dispersal corridors' within fragmented landscapes. From a hydrological risk perspective, riparian environments supply river bank stabilization and provide resistance to runoff during flood events.

The amount of naturally-forested land in the riparian corridor of the water body quantifies the relative coverage of native woody riparian vegetation (e.g. deciduous forest in Central Europe) in the buffer zone bordering the river stretch, lake or transitional water. Areas of non-native vegetation (e.g. coniferous or eucalyptus plantations) are to be excluded. If access is granted by JRC to use the modelled map on the Maximum Potential Riparian Extent (Clerici et al. 2013), the land use data can be processed on the basis of functionally delineated riparian corridors. Alternatively, a fixed buffer width depending on the water body size is to be applied. Sweeney & Newbold (2014), for instance, postulate forest buffers ≥30 m wide are needed to protect the physical, chemical, and biological integrity of streams.

Spatio-temporal scale: Continuously mapped along riparian corridor (covering entire water body or area upstream of sampling site), single point in time

Unit: Percent naturally-forested land in the riparian corridor

Standardisation: none

Data requirements:

1. CORINE Land Cover (or comparable, higher resolution national databases)

2. Map on Maximum Potential Riparian Extent according to Clerici et al. (2013)
→ subject to data access granted by JRC

2. (*alternative*) Delineation of fixed buffer widths (50 metres)

[2] **Alternative indicator for transitional waters:** Changes in intertidal areas measured by the ratio of intertidal to subtidal areas.

Other: none

MARS spatial scale: River-basin and European scale

References

Clerici, N., Weissteiner, C. J., Paracchini, M. L., Boschetti, L., Baraldi, A., & Strobl, P. (2013). Pan-European distribution modelling of stream riparian zones based on multi-source Earth Observation data. Ecological Indicators, 24, 211–223.

Feld, C. K. (2013). Response of three lotic assemblages to riparian and catchment-scale land use: implications for designing catchment monitoring programmes. Freshwater Biology, 58, 715–729.

Sweeney, B. W., & Newbold, J. D. (2014). Streamside Forest Buffer Width Needed to Protect Stream Water Quality, Habitat, and Organisms: A Literature Review. Journal of the American Water Resources Association, 50(3), 560–584.

BInd08: Growing season mean of water column chlorophyll-a concentration

Quality element: Phytoplankton

Water category and water body types: Lakes, large rivers, transitional waters; all types

Selection rationale: Commonly used water quality indicator with high data availability

Indicator type (DPSIR): State

Description: Chlorophyll-a has a long tradition as an indicator of the productivity and trophic condition of lakes and estuaries. It is a measure of phytoplankton biomass and reflects the net result (standing stock) of both growth and loss processes in pelagic waters. Chlorophyll-a is related to external nutrient loading, internal nutrient cycling, light availability, water residence time and grazing by zooplankton and benthic filter feeders.

The indicator is used to measure eutrophication pressure, featuring well-documented relationships with the water phosphorus concentration. As strong eutrophication leads to algal blooms, often followed by fish kills implying aesthetic and sanitary issues. The chlorophyll-a concentration is thus also relevant for provisioning and cultural services (water supply, recreation).

Spatio-temporal scale: Growing season mean, representative for water body

Unit: $\mu g\ L^{-1}$

Standardisation: To be standardised against type-specific reference conditions (e.g. Carvalho et al. 2008)

Data requirements: Field data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference

Carvalho, L., van Den Berg, M., Solimini, A., Phillips, G., Pietilainen, O. P., Solheim, A. L., Poikane, S., Mischke, U. (2008). Chlorophyll reference conditions for European lake types used for intercalibration of ecological status. Aquatic Ecology, 42(2), 203–211.

BInd09: Chlorophyll-a to total phosphorus ratio (Chl:TP)

Quality element: Physico-chemistry & phytoplankton

Water category and water body types: Lakes, large rivers, transitional waters; all types

Selection rationale: Simple measure of production efficiency

Indicator type (DPSIR): State

Description: The correlation of total phosphorus and chlorophyll-a is one of the best-communicated relationships in aquatic ecology. However, several factors can confound the response of surface waters to reductions in total phosphorus: zooplankton grazing, internal P-loading, climate and nitrogen limitation. Variation in the Chl:TP ratio can be used to infer the likely response of phytoplankton following phosphorus reduction. If the Chl:TP ratio is low (i.e. low amount of chlorophyll-a per unit of TP), it is likely that factors other than phosphorus availability are limiting phytoplankton productivity. Water bodies with a low Chl:TP ratio are less likely to respond to reductions in TP concentrations compared to water bodies with a high Chl:TP ratio (i.e. high TP to Chlorophyll-a transfer efficiency).

Spatio-temporal scale:

Chlorophyll-a: Growing season mean, representative for water body

Phosphorus: Annual mean, representative for water body

Unit: none

Standardisation: none

Data requirements: Field data

Other: none

MARS spatial scale: Experimental, river-basin and European scale

Reference

Spears, B. M., Carvalho, L., Dudley, B., & May, L. (2013). Variation in chlorophyll a to total phosphorus ratio across 94 UK and Irish lakes: Implications for lake management. Journal of Environmental Management, 115, 287–294.

BInd10: Biovolume of toxic/nuisance phytoplankton species

Quality element: Phytoplankton

Water category and water body types: Lakes, large rivers, transitional waters; except low alkalinity lake types (Northern Europe)

Selection rationale: Direct indicator of the functional quality of recreation and water supply services

Indicator type (DPSIR): State, Impact

Description: Many cyanobacterial species produce hazardous toxins, and high abundances of cyanobacteria threaten the use of recreational and drinking waters. In this regard the World Health Organisation established health risk thresholds for the densities of cyanobacteria in surface waters. Water retention time, water alkalinity and colour influence the presence of cyanobacteria, with low-alkalinity lakes particularly in Northern Europe naturally showing very low abundances of cyanobacteria. Nutrient enrichment, especially phosphorus, is responsible for cyanobacterial blooms, triggered by warmer and drier summer conditions. The biovolume of toxic/nuisance phytoplankton species is a direct indicator of the 'functional quality' of freshwater services regarding water supply and recreation.

Spatio-temporal scale: Growing season mean, representative for water body

Unit: $mm^3\ L^{-1}$

Standardisation: WHO thresholds for cyanobacteria

Data requirements: Field data

Other: none

MARS spatial scale: River-basin and European scale

Reference

Carvalho, L., McDonald, C., de Hoyos, C., Mischke, U., Phillips, G., Borics, G., Poikane, S., Skjelbred, B., Lyche-Solheim, A., van Wichelen, J., Cardoso, A.C. (2013). Sustaining recreational quality of European lakes: minimising the health risks from algal blooms through phosphorus control. Journal of Applied Ecology, 50, 315-323.

BInd11: Abundance of submerged, emergent and floating-leafed macrophytic vegetation

Quality element: Benthic flora

Water category and water body types: Rivers, lakes, transitional waters; all types except mountainous headwater streams

Selection rationale: Integrative indicator of hydromorphological and nutrient pressure, with relevance for habitat structuring

Indicator type (DPSIR): State

Description: The categories of submerged, emergent and floating-leafed vegetation represent different growth form types of aquatic vegetation, distinguished on the basis of coarse-level vegetative, whole-plant traits. These growth forms constitute different components of the macrophytic 'set-up' of a water body, featuring distinct reaction to various pressures. The submerged component is part of the benthic community extending into the pelagic zone. Submerged plants are influenced by the physico-chemical conditions of both water and sediment (e.g. availability of light and nutrients), and are prone to hydrodynamic forces in lotic systems. Emergent vegetation demarks the land-water ecotone and thus responds to riparian quality status, including light conditions. The floating-leafed plant component is most competitive at high productivity due to optimal light yield (photosynthetic tissue above water surface), and favours lentic conditions.

The abundance of submerged, emergent and floating-leafed macrophytic vegetation represents an integrative indicator of hydromorphological and nutrient pressure, with relevance for structuring the habitat for other aquatic organisms. Light conditions, current velocity and habitat availability form the main factors influencing the abundance and ratio of these growth forms. Furthermore, the total abundance of macrophytic vegetation (derived as the sum of individual growth form abundances) relates to nutrient enrichment, structural degradation and riparian quality. Excessive macrophyte growth represents a nuisance for boating, swimming and by obstruction of water flow. The latter is relevant for flood control.

Spatio-temporal scale: Sampling site, single survey

Unit: Percent coverage; plant volume invested; abundance sum

Standardisation: To be standardised against type-specific reference conditions

Data requirements: Field data

Other: Generic growth form lists of most freshwater macrophytes relevant in Europe are available upon request

MARS spatial scale:
Experimental*, river-basin and European scale
* NERC lakes

References

Alahuhta, J., Kanninen, A., Hellsten, S., Vuori, K.-M., Kuoppala, M., & Hämäläinen, H. (2013). Environmental and spatial correlates of community composition, richness and status of boreal lake macrophytes. Ecological Indicators, 32, 172–181.

Steffen, K., Leuschner, C., Müller, U., Wiegleb, G., & Becker, T. (2014). Relationships between macrophyte vegetation and physical and chemical conditions in northwest German running waters. Aquatic Botany, 113, 46–55.

BInd12: Average Score per Taxon (ASPT)

Quality element: Benthic fauna

Water category and water body types: Rivers, lakes, transitional waters[3]; all types

Selection rationale: All-round indicator of general pressure

Indicator type (DPSIR): State

Description: The Average Score per Taxon (ASPT) is a water quality index rating benthic invertebrate families according to their sensitivity to dissolved oxygen depletion. The ASPT was primarily developed to detect water pollution caused by organic substances. Thus, the ASPT is also sensitive to the effects of eutrophication (decay of excess plant material causing oxygen depletion). Other pressures leading to changes in oxygen availability such as impoundment (decrease of flow velocity) or siltation generate changes in ASPT. Habitat degradation and toxic stress often impact on invertebrate families that are also most sensitive to oxygen depletion (e.g. mayflies, stoneflies, caddisflies).

The ASPT is a robust indicator of widespread applicability across Europe (and worldwide), mainly for rivers and also for lakes. It was extensively used in the intercalibration exercise as a common metric.

Spatio-temporal scale: Sampling site, single survey

Unit: Average score per taxon

Standardisation: To be standardised against type-specific reference conditions

Data requirements: Field data

Other: Calculated by the ASTERICS software
(http://www.fliessgewaesserbewertung.de/download/berechnung/)

MARS spatial scale

Experimental*, river-basin and European scale

* all river experiments

References

Armitage, P.D., D. Moss, J.F. Wright & M.T. Furse, 1983. The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-waters. Water Research 17: 333-347.

Šidagytė, E., Višinskienė, G., & Arbačiauskas, K. (2013). Macroinvertebrate metrics and their integration for assessing the ecological status and biocontamination of Lithuanian lakes. Limnologica - Ecology and Management of Inland Waters, 43(4), 308–318.

[3] Alternative indicator for transitional waters: Ratio of sensitive to opportunistic species.

BInd13: Abundance ratios of invertebrate functional feeding groups

Quality element: Benthic fauna

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Trait-based indicator of functional relevance linked to food web structure

Indicator type (DPSIR): State

Description: The benthic invertebrate community is often the taxonomically and functionally most diverse organism group in aquatic ecosystems. Abundance ratios of invertebrate functional feeding groups represent trait-based and process-related indicators, based on taxon-specific morphological-behavioural adaptations for food acquisition.

The indicator distinguishes between five feeding groups: (1) Shredders feeding on large particulate organic matter such as dead leaves, (2) Gatherers and Collectors feeding on sedimented fine particulate organic matter, (3) Grazers and Scrapers feeding on biofilms, (4) active and passive Filter Feeders acquiring suspended fine particulate organic matter, and (5) Predators feeding on prey organisms. Feeding group assignments are available from http://www.freshwaterecology.info.

The indicator is sensitive to detect functional changes in the biological community related to the nutritional resource base. Various ratios can be calculated, e.g.

- Grazers and Scrapers /to/ Shredders, Gatherers and Collectors
  → Dominant food source (autochthonous *versus* allochthonous)
- Shredders /to/ Gatherers, Collectors and Filter Feeders
  → Dominant food source (coarse particulate organic matter *versus* fine particulate organic matter)
- Predators /to/ Total of all other functional feeding groups
  → Top-down control of predators on prey

Shifts in these ratios allow for indicating the effects of multiple stressors (e.g. nutrient pollution, impoundment, siltation, riparian integrity) impacting on food availability.

Spatio-temporal scale: Sampling site, single survey

Unit: Dimensionless (abundances given as number of individuals; abundance classes; biomass)

Standardisation: To be standardised against rule-of-thumb values (e.g. Merritt et al. 2002)

Data requirements: Field data

Other: Calculated by the ASTERICS software
(http://www.fliessgewaesserbewertung.de/download/berechnung/)

MARS spatial scale
Experimental*, river-basin and European scale
* all river experiments

References

Merritt, R., Cummins, K., Berg, M., Novak, J., Higgins, M., Wessell, K., & Lessard, J. (2002). Development and application of a macroinvertebrate functional-group approach in the bioassessment of remnant river oxbows in southwest Florida. Journal of the North American Benthological Society, 21(2), 290–310.

Wooster, D. E., Miller, S. W., & Debano, S. J. (2012). An examination of the impact of multiple disturbances on a river system: taxonomic metrics versus biological traits. River Research and Applications, 28, 1630–1643.

BInd14: Relative abundance of invasive alien invertebrate species

Quality element: Benthic fauna

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Indicator of 'biopollution'

Indicator type (DPSIR): Pressure, State, Impact

Description: An alien species is defined as a taxon introduced outside its natural past or present distribution. According to the Millennium Ecosystem Assessment, invasive alien species are considered to be the third most important threat to biodiversity of inland waters (after hydromorphological degradation, and point source and diffuse pollution). Main cause for their spread in surface waters is the increasing international ship traffic and the connection of formerly separated river basins by canals (e.g. Rhine-Main-Danube Canal in Germany). Alien species also benefit from climate change effects. They are expected to be established as a prominent part of the communities of European surface water bodies in the near future.

Main impact of alien invasive species is the decrease or extinction of indigenous species populations, with effects on the entire food web, through (1) a change of the habitat quality (mostly resulting from other pressures) for native species, leaving an empty space for tolerant alien species, (2) an invasion of a new species which takes over the niche of a native or preys on them successfully and (3) an exploitation of a 'new', previously unexploited food resource (Orendt et al. 2009). Co-invasion describes the introduction of exotic diseases and parasites brought along with the invasion of aliens.

The relative abundance of invasive alien invertebrate species indicates the level of 'biological contamination' of the water body. It informs about the dominance structure of the community, assuming that impacts from invasive aliens on the native biota are proportional to their abundance in the system. The metric represents an indicator of pressure, state and impact, since alien species may also cause damage to economies, ecosystem services or human health.

The indicator is equal to the Abundance Contamination Index proposed by Arbačiauskas et al. (2008).

Spatio-temporal scale: Sampling site, single survey

Unit: Relative abundance (number of individuals *or* abundance classes *or* biomass)

Standardisation: none

Data requirements: Field data

Other: See Annex 4 for a list of alien invertebrate taxa relevant in German watercourses – the list needs to be adopted for the regional conditions

MARS spatial scale
Experimental*, river-basin and European scale
* all river experiments

References

Arbačiauskas, K., Semenchenko, V., Grabowski, M., Leuven, R., Paunović, M., Son, M., Csányi, B., Gumuliauskaitė, S., Konopacka, A., Nehring, S., van der Velde, G., Vezhnovetz, V., Panov, V. (2008). Assessment of biocontamination of benthic macroinvertebrate communities in European inland waterways. Aquatic Invasions, 3(2), 211–230.

MacNeil, C., Briffa, M., Leuven, R.S.E.W., Gell, F.R., & Selman, R. (2010). An appraisal of a biocontamination assessment method for freshwater macroinvertebrate assemblages; a practical way to measure a significant biological pressure? Hydrobiologia, 638(1), 151–159.

Orendt, C., Schmitt, C., Liefferinge, C., Wolfram, G., & Deckere, E. (2009). Include or exclude? A review on the role and suitability of aquatic invertebrate neozoa as indicators in biological assessment with special respect to fresh and brackish European waters. Biological Invasions, 12(1), 265–283.

von der Ohe, P.C., Apitz, S.E., Arbačiauskas, K., Beketov, M.A., Borchardt, D., de Zwart, D., Goedkoop, W., Hein, M., Hellsten, S., Hering, D., Kefford, B.J., Panov, V.E., Schäfer, R.B., Segner, H., van Gils, J., Vegter, J.J., Wetzel, M.A., Brack, W. (2014). Status and Causal Pathway Assessments Supporting River Basin Management. In J. Brils et al. (eds.), Risk-Informed Management of European River Basins. The Handbook of Environmental Chemistry 29. Springer, Berlin/Heidelberg: 53-149.

BInd15: Total fish abundance (incl. abundance of commercially-relevant fish)

Quality element: Fish fauna

Water category and water body types: Rivers, lakes, transitional waters; all types

Selection rationale: Simple and robust indicator responding to different pressures, relevant for assessing service provision (fish yield)

Indicator type (DPSIR): State, Impact

Description: Total fish abundance represents an integrative indicator sensitive to multiple pressures. The total abundance measured as catch per unit effort (CPUE), reacts to low dissolved oxygen concentrations and eutrophication effects (e.g. nutrient enrichment, algal blooms). Water clarity and macrophyte habitat can impact on CPUE, as well as wider catchment factors that affect fish abundance, such as the amount of non-natural catchment land use as well as habitat quality, barriers and water abstraction impacts in spawning streams. The metric is also considered a simple and robust indicator for describing the impacts of fishing intensity in aquatic ecosystems. Coupled with the information on fish species relevant for leisure or commercial fishing, the indicator allows for quantifying the service supply.

Spatio-temporal scale: Sampling site, single survey

Unit: Catch per unit effort expressed as fish number/weight caught per unit effort fishing (hours)

Standardisation: To be standardised against type-specific reference conditions

Data requirements: Field data

Other: none

MARS spatial scale

Experimental*, river-basin and European scale

* selected river experiments

Reference

Argillier, C., Caussé, S., Gevrey, M., Pédron, S., De Bortoli, J., Brucet, S., Emmrich, M., Jeppesen, E., Lauridsen, T., Mehner, T., Olin, M., Rask, M., Volta, P., Winfield, I.J., Kelly, F., Krause, T., Palm, A., Holmgren, K. (2013). Development of a fish-based index to assess the eutrophication status of European lakes. Hydrobiologia, 704(1), 193–211.

Annex 1: Criteria for selecting benchmark indicators

1. Reflecting the phenomenon of interest (concreteness & theoretical basis)

- The indicator relates to features representing ecosystem properties, functioning or services.
- The indicator is rooted in a sound conceptual framework linking anthropogenic pressures and their effects.

2. Responding to (multiple) pressure effects (responsiveness)

- The indicator responds to the effects of (multiple) pressures (including the effects of future climate change, changes in land use and water management).
- The indicator is validated based on conceptual and/or empirical models demonstrating a (significant) pressure-effect relationship.

3. General applicability

- The indicator is applicable in various geographical contexts and to different water categories and water body types.

4. Data availability

- The indicator does not require acquisition of specific data but refers to data already available (e.g. WFD monitoring, remote sensing).

5. Appropriate scaling

- The indicator addresses the relevant spatio-temporal scales to infer viable conclusions on the effects to be indicated.

6. Benchmarking

- The indicator can be standardised by referring to benchmarks (e.g. using biogeographically distinct, near-natural reference conditions) to allow for comparisons between spatially or temporally different conditions.

7. Management relevance

- The indicator provides insights applicable in water resource management.
- Indicators of specific management relevance are:
  - *Diagnostic indicators* diagnosing the cause of the effects indicated (capable of disentangling the effects of individual pressures);
  - *Recovery indicators* responding to abatement/mitigation measures (featuring an early and reliable response due to high indicator sensitivity and precision);
  - *Resilience indicators* informing about features preventing/buffering pressure effects on ecosystem properties, functioning or services (e.g. woody riparian buffer strips).

8. Policy and public awareness

- The indicator is comprehensible and accepted by decision makers, managers and the general audience.

Annex 2: Establishing the list of MARS benchmark indicators

Selecting the benchmark indicators presented above initially followed the specifications given in the DoW. Discussions during the MARS kick-off meeting in February 2014 allowed for outlining a more concrete concept for the indicator selection. On this basis, MARS Task 2.3 collated ideas for suitable benchmark indicators in March 2014. A preliminary indicator selection was circulated in form of a questionnaire to MARS partners in May 2014. This questionnaire aimed at evaluating if the different work package contributors consider the initial selection of benchmark indicators to be meaningful and practicable. The partners were asked if individual indicators are applicable in the context of their work task, and interrogated about the type and number of data available to process the indicator, and about their expert opinion on whether the proposed indicators are a reasonable choice. On the basis of 27 questionnaire returns completed by 49 responders (see below), we finalised the selection process and concluded on a consolidated and reduced list of benchmark indicators, as presented in this document.

We reduced the initially proposed 26 indicators to a final number of 15, excluding those indicators that most of the responders rejected (see Figure 1). In some cases we additionally omitted selected indicators, as their definition provoked ambiguous interpretation (e.g. *chemical water body status*). In other cases, we needed to adjust the indicator details to account for individual data availability (e.g. *total fish abundance* instead of *total fish biomass*).

List of responders

Adrian Constantinescu (DDNI), Alexander Gieswein (UDE), Ana Cristina Cardoso (JRC), Angel Borja (AZTI), Anne Lyche Solheim (NIVA), Arnaud Reynaud (JRC), Bruna Grizzetti (JRC), Bryan Spears (NERC), Camino Liquete (JRC), Christel Prudhomme (NERC), Denis Lanzanova (JRC), Dennis Trolle (AU), Elisabeth Bondar (BOKU), Ellis Penning (DELTARES), Erik Jeppesen (AU), Fabien Cremona (EMU), Florian Pletterbauer (BOKU), Francois Edward (NERC), Hans Estrup Andersen (AU), Hans Thodsen (AU), Heidrun Feuchtmayr (NERC), Henn Timm (EMU), Jannicke Moe (NIVA), Jenica Hanganu (DDNI), John Bloomfield (NERC), Katri Rankinen (SYKE), Kostas Stefanidis (NTUA), Laurence Carvalho (NERC), Lisa Schülting (BOKU), Marijn Kuijper (DELTARES), Meryem Beklioğlu (METU), Mike Bowes (NERC), Mike Hutchins (NERC), Nuria Cid (JRC), Paulo Branco (ULisboa), Peeter Nõges (EMU), Rafaela Schinegger (BOKU), Raoul Marie Couture (NIVA), Rein Järvrkülg (EMU), Shenglan Lu (AU), Stefan Auer (BOKU), Stefan Schmutz (BOKU), Steve Ormerod (CU), Susanne Schneider (NIVA), Teresa Ferreira (ULisboa), Tuba Bucak (METU), Ute Mischke (IGB), Wolfram Graf (BOKU), Yiannis Panagopoulos (NTUA)

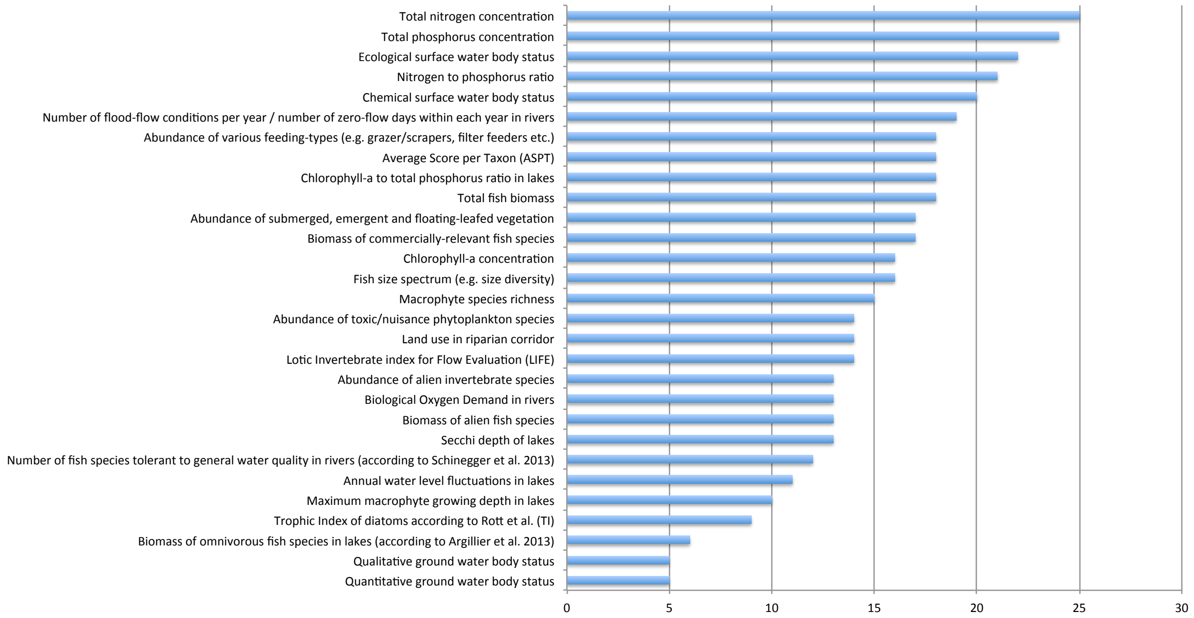

Figure 1: Number of positive votes indicating indicator applicability on the basis of 27 questionnaire returns

Annex 3: Broad river and lake types[4]

List of broad river types

Broad type name	Broad type number	Altitude (masl)	Catchment area (km²)	Geology
Very large rivers (all Europe)	1		>10 000	
Lowland, Siliceous/Organic, Medium-Large	2	≤200	100 - 10 000	Siliceous/Organic
Lowland, Siliceous/Organic, Very small-Small	3	≤200	≤100	Siliceous/Organic
Lowland, Calcareous/Mixed, Medium-Large	4	≤200	100 - 10 000	Calcareous/Mixed
Lowland, Calcareous/Mixed, Very small-Small	5	≤200	≤100	Calcareous/Mixed
Mid altitude, Siliceous, Medium-Large	6	200 - 800	100 - 10 000	Siliceous
Mid altitude, Siliceous, Small	7	200 - 800	≤100	Siliceous
Mid altitude, Calcareous/Mixed, Medium-Large	8	200 - 800	100 - 10 000	Calcareous/Mixed
Mid altitude, Calcareous/Mixed, Very small-Small	9	200 - 800	≤100	Calcareous/Mixed
Highland, Siliceous	10	>800		Siliceous
Highland, Calcareous/Mixed	11	>800		Calcareous/Mixed
Mediterranean, Lowland, Medium-Large	12	≤200	100 - 10 000	
Mediterranean, Mid altitude, Medium-Large	13	200 - 800	100 - 10 000	
Mediterranean, Very small-Small	14		≤100	

List of broad lake types

Broad type name	Broad type number	Altitude (masl)	Lake area (km²)	Geology	Mean depth (m)
Very large and deep*	1		>100		> 15
Lowland, Siliceous	2	≤200		Siliceous	
Lowland, Shallow, Calcareous/Mixed	3	≤200		Calcareous/Mixed	3 - 15
Lowland, Very shallow, Calcareous/Mixed	4	≤200		Calcareous/Mixed	≤ 3
Organic	5			Organic	
Mid altitude, Siliceous	6	200 - 800		Siliceous	
Mid altitude, Calcareous/Mixed	7	200 - 800		Calcareous/Mixed	
Highland, Siliceous	8	>800		Siliceous	
Highland, Calcareous/Mixed	9	>800		Calcareous/Mixed	
Mediterranean, Small-Very large	10		>0.5		
Mediterranean, Very small	11		≤0.5		

[4] According to: Lyche-Solheim, A., Persson, J., Stein, U., Kampa, E., Feher, J., Kristensen, P. (in prep.). Freshwater Ecosystem Assessment: Cross-walk between the WFD and Habitats Directive types, status and pressure information using broad types. EEA/ETC-ICM report.

Annex 4: List of alien invertebrate taxa relevant in German watercourses

Taxon	ID_ART
Astacus leptodactylus	4358
Atyaephyra desmaresti	9272
Barbronia weberi	8518
Branchiura sowerbyi	4494
Caspiobdella fadejewi	4563
Congeria leucophaeata	11585
Corbicula "fluminalis"	11177
Corbicula fluminea	11176
Corbicula sp.	11178
Cordylophora caspia	4743
Corophium curvispinum	4749
Corophium robustum	20515
Corophium sp.	4750
Crangonyx pseudogracilis	11227
Craspedacusta sowerbyi	19116
Dendrocoelum romanodanubiale	9363
Dikerogammarus haemobaphes	7854
Dikerogammarus sp.	8961
Dikerogammarus villosus	7517
Dreissena polymorpha	4999
Dreissena rostriformis	22042
Dreissena sp.	8965
Dugesia tigrina	5022
Echinogammarus berilloni	12328
Echinogammarus ischnus	4613
Echinogammarus sp.	8918
Echinogammarus trichiatus	10400
Eriocheir sinensis	5149
Eunapius carteri	19113
Ferrissia clessiniana	5271
Gammarus tigrinus	5294

Taxon	ID_ART
Gyraulus parvus	5358
Hemimysis anomala	10597
Hypania invalida	5634
Jaera istri	8700
Limnomysis benedeni	8730
Lithoglyphus naticoides	5896
Menetus dilatatus	13673
Musculium transversum	16776
Obesogammarus obesus	9799
Obesogammarus sp.	12360
Orchestia cavimana	14241
Orconectes immunis	21742
Orconectes limosus	6199
Orconectes sp.	9121
Pacifastacus leniusculus	6272
Pectinatella magnifica	6353
Physella acuta	6396
Physella heterostropha	6397
Physella sp.	8661
Piscicola haranti	7855
Planorbella duryi	6432
Pontogammarus robustoides	10491
Potamopyrgus antipodarum	8251
Proasellus coxalis	8703
Proasellus meridianus	8696
Proasellus sp.	9166
Procambarus clarkii	10709
Rhithropanopeus harrisii	14412
Unio mancus	7136
Urnatella gracilis	19128
Viviparus viviparus	7158