University of Pannonia, Department of Limnology
Doctoral School of Chemistry and Environmental Sciences

Phytoplankton functional group composition along the River Loire (France)

A limnological approach towards an understanding of phytoplankton longitudinal processes and ecological status indication

Ph.D. Dissertation

András Abonyi

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PHYTOPLANKTON FUNCTIONAL GROUP COMPOSITION ALONG THE RIVER LOIRE (FRANCE) - *A LIMNOLOGICAL APPROACH TOWARDS AN UNDERSTANDING OF PHYTOPLANKTON LONGITUDINAL PROCESSES AND ECOLOGICAL STATUS INDICATION*

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Témavezető: **Prof. Dr. Padisák Judit**

Elfogadásra javaslom (igen / nem) .....

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The Dissertation contains 37 Figures, and 11 Tables excluding *Appendix*

Supervision

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"Le phytoplancton des grands fleuves, ceux de l'Europe en particulier, a suscité de nombreuses recherses, qui n'ont pas été jusqu'ici poursuivies en France"

"The phytoplankton of large rivers especially in Europe, motivated numerous researches, which have not been yet pursued in France"

des Cilleuls (1926)

Abbreviations

Codon/coda	Assemblages of phytoplankton, reflecting a more or less well defined set of environmental conditions. Coda are signed by alphabetical letters.
CSR concept	Plant ecological life strategy concept of Grime (1977). C: competitive, S: stress-tolerant, R: ruderal strategies.
DO	Dissolved Oxygen.
DOC	Dissolved Organic Carbon.
EQR	Ecological Quality Ratio of each biological group in water quality indices required by the Water Framework Directive (WFD, 2000).
FG(s)	Functional groups of phytoplankton, clustering functionally similar phytoplankton taxa might be occurring under similar set of environmental conditions (Reynolds et al., 2002).
HRPI	Hungarian River Phytoplankton Index (Borics et al., 2009).
MBFG(s)	Morphology-based functional groups of phytoplankton; containing taxa with similar morphology, might be reflecting a more or less well defined set of environmental conditions (Kruk et al., 2010).
MFG(s)	Morpho-functional groups of phytoplankton; containing taxa with characteristic functional traits, might be reflecting a more or less well defined set of environmental conditions (Salmaso and Padisák, 2007).
P/R	Photosynthesis to respiration ratio.
PhytoFluss	German potamoplankton index according to Mischke et al. (2011).
$Q_{(r)}$	Potamoplankton composition metric according to Borics et al. (2007).
RCC	River Continuum Concept, described by Vannote et al. (1980).
r-K selection	Two extremes of life history strategies in phytoplankton succession; first recognised by Margalef (1958): from small, first arrivals taxa with high growth rate (r-selection) towards larger species with special abilities like N_2 fixation (K-selection).
RUE	Resource Use Efficiency ratio based on phytoplankton biomass to total phosphorus ratio (Ptacnik et al., 2008).
SEQ-Eau	Système d'évaluation de la qualité de l'eau des cours d'eau [Water quality classification system of rivers], French national method (Oudin and Maupas, 2003)
SOM	Self Organizing Map. A neural network statistical method.
SRP	Soluble Reactive Phosphorus.
SRSi	Soluble Reactive Silica.
SRSi:TP	Soluble reactive silica to total phosphorus ratio.
TN:TP	Total nitrogen to total phosphorus ratio.
WRT	Theoretical Water Residence Time.

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Summary

The term potamoplanton collects algae occurring in river plankton, independently of possible origins like autochthonous growth in the river flow, drifted from the phytobenthos, or originated from connected laterals. While compositional changes of other river biota in relation to environmental gradients are well known, longitudinal patterns of potamoplankton have been less frequently studied. For this reason, the potamoplankton of the relatively unregulated River Loire is presented in this Dissertation at whole river scale from years 2009 to 2011. Research as well as monitoring programs of river potamoplankton use species or genus level data, which are often difficult to interpret. Contrary, modeling studies often simplify potamoplankton to major algal classes, which might be insufficient to cover functional complexity required for an ecology-based implementation of river processes.

As an alternative method, grouping of algae into functional groups—'FGs' may hold the potential for new approaches in potamoplankton ecology and in river water quality management. Compositional change of FGs is expected to follow longitudinal processes in rivers, and also better indicate ecological status than other systems based on taxa composition or species richness. In order to prove the reliability of FGs in rivers, their compositional changes are related to natural gradients like geography, as well as to physical and chemical anthropogenic pressures, occurring along the Loire. Major findings of the Thesis are the followings:

(i) Different lentic phytoplankton functional approaches are able to identify reliable river zones along the Loire based on FG composition of potamoplankton. The level of understanding provided, however, depends on the taxonomical and ecological resolution of approaches. In rivers, no satisfactory water quality management can be built without fine resolution of benthic and planktonic diatoms, as well as of cyanobacterial taxa.

(ii) The FG classification is able to delimit natural and human-mediated changes in the potamoplankton composition along the River Loire. These changes can be described by the $Q_{(r)}$ composition index, which successfully indicates local morphological alternations like damming, or regional scale differences in nutrient availability according to land use practices.

(iii) Both the German PhytoFluss index based on taxa-level resolution and the Hungarian HRP index based on FGs provide comparable and reliable water quality indications along the River Loire. In case of adequate implementation of indices according to site-specific river typology, these national potamoplankton assessments can be successfully compared or implemented at international level, as also required by the European Water Framework Directive.

(iv) FG classification of potamoplankton displays similar river zonation in each year along the River Loire. Besides quantitative differences, major FGs and the subdominant accessory FGs all follow similar longitudinal trends, while further FGs were identified to reflect specific annual hydrological regimes.

(v) In the River Loire, ecosystem functioning (as the biomass:TP ratio) displayed different relationships with taxa and FG richness. The highest potamoplankton richness was identified as a consequence of physically mixed habitats from either natural or human-mediated sources, while the best functioning occurred at low taxa number and at medium FG richness. Accordingly, high richness/diversity in large rivers might not provide automatic evidence for better ecosystem functioning, and cannot be a general objective without understanding its functional properties and controlling factors at different scales.

Résumé

Le terme potamoplancton regroupe les algues présentes dans le plancton des rivières, indépendamment de leurs origines : production autochtone de la masse d'eau, enrichie par le phytobenthos et les zones latérales. Alors que les changements de composition des différents biota de la rivière liés aux gradients environnementaux sont bien connus, les répartitions longitudinales du potamoplancton ont été moins souvent étudiées. Pour cette raison, le potamoplancton de la Loire, faiblement régulée, est présenté dans cette thèse à l'échelle du bassin versant, entre 2009 et 2011. Les programmes de recherche et de surveillance concernant le potamoplancton des rivières utilisent des données principalement basées sur les espèces ou les genres, souvent difficiles à interpréter. A l'inverse, des études de modélisation réduisent le potamoplancton aux classes algales, qui ne permettent pas de mettre en œuvre une base écologique suffisante pour appréhender les processus fluviaux.

Comme méthode alternative, le regroupement des algues en groupes fonctionnels-GF' peut permettre de nouvelles approches dans l'écologie du potamoplancton et dans la gestion de la qualité de l'eau des rivières. Le changement de composition fonctionnelle devrait suivre les processus longitudinaux et mieux indiquer l'état écologique relativement aux autres systèmes basés sur la composition des taxa ou sur la richesse. Afin de prouver la fiabilité des GF dans les rivières, les changements de composition sont mis en face des gradients naturels, comme la géographie, mais aussi des pressions anthropiques, tant physiques que chimiques, subies sur tout le tracé de la Loire. Les principales conclusions de la thèse sont :

(i) Basées sur la composition des GF du phytoplancton, les approches fonctionnelles conçues pour les lacs permettent d'identifier certaines zones de la Loire. La robustesse des résultats dépend toutefois de la résolution taxonomique et écologique. En rivière, pour une connaissance satisfaisante de la qualité de l'eau, une détermination fine des diatomées benthiques et planctoniques, ainsi que des cyanobactéries, est nécessaire.

(ii) La classification fonctionnelle peut déterminer des changements longitudinaux de la composition du phytoplancton de la Loire, qu'ils soient naturels ou anthropiques. Ces changements peuvent être décrits par l'indice $Q_{(r)}$, qui détecte des perturbations physiques locales telles que des barrages, ou des variations régionales de la disponibilité nutritive selon la géographie et l'occupation des sols.

(iii) L'indice PhytoFluss allemand basé sur une résolution taxonomique fine et l'indice HRPI hongrois fondé sur les GF, donnent des indications proches et fiables sur la qualité de l'eau de la Loire. En utilisant de manière pertinente ces indices selon la typologie spécifique des sites, ces méthodes peuvent être comparées ou appliquées au niveau international, comme requis par la Directive Cadre européenne sur l'Eau.

(iv) La zonation par les GF donne, chaque année, un découpage semblable de la Loire. Malgré des différences quantitatives, la distribution des principaux GF et du GF accessoire dominant suivent les mêmes modèles longitudinaux, tandis que les GF additionnels reflètent les régimes hydrologiques annuels spécifiques.

(v) Dans la Loire, le fonctionnement des écosystèmes (basé sur le ratio biomasse:TP) évolue différemment selon la richesse des taxa et des GF. La richesse phytoplanctonique la plus élevée est le résultat d'habitats physiquement mixtes, naturels ou modifiés par l'homme, alors que le meilleur fonctionnement se produit avec un nombre faible de taxa et une richesse GF moyenne. Donc une grande diversité dans les rivières ne prouve pas forcément un meilleur fonctionnement de l'écosystème, et ne peut pas être un objectif général sans comprendre sa composition fonctionnelle et les facteurs la contrôlant, à différentes échelles.

Zusammenfassung

Der Begriff Potamoplankton umfasst alle Algen, die im Flussplankton vorkommen, unabhängig davon ob diese dem autochtonen Wachstum aus der fließenden Welle, aus der Drift vom Phytobenthos oder aus angebundenen Seitenarmen entstammen. Während Änderungen in der Zusammensetzung anderer Biota in Flüssen in Abhängigkeit von Umweltgradienten gut bekannt sind, wurde das Längsmuster des Potamoplanktons selten studiert. Aus diesem Grunde wird in dieser Doktorarbeit das Potamoplankton für den gesamten Fluss der verhältnismäßig unregulierten Loire für die Jahre 2009 bis 2011 dargestellt. Sowohl die Forschung als auch die Überwachungsprogramme des Phytoplanktons in Flüssen benützen hauptsächlich Daten auf Art- oder Gattungsebene, die oft schwer zu interpretieren sind. Auf der anderen Seite fassen Modell-basierten Studien das Potamoplankton auf der Ebene „Algenklassen“ zusammen, womit nicht alle erforderlichen ökologischen Aspekte der Flussprozesse abgebildet werden.

Als eine alternative Methode können „FGs“, die funktionellen Gruppen der Algen, zu neuen Ansätze in der Beschreibung der Potamoplankton- Ökologie und der Bewirtschaftung der Flusswasserqualität beitragen. Es wird erwartet, dass sich die Zusammensetzung der FGs mit den im Flussverlauf auftretenden Prozessen verändert, und dass die FGs besser geeignet sind, den ökologischen Zustand zu indizieren, als andere auf Artenreichtum oder auf Taxa basierende Systeme. Um die Funktionsfähigkeit von FGs in Flüssen zu prüfen, wurde ihre Zusammensetzung korreliert zu dem natürlichen Gradienten wie Geographie, als auch zu den entlang der Loire auftretenden menschlichen Belastungen bezüglich der physikalischen und chemischen Eigenschaften. Die wesentlichen Ergebnisse der Doktorarbeit können wie folgt zusammengefasst werden:

(i) Die funktionellen Ansätze, welche für lentisches Phytoplankton entwickelt wurden, sind auf Basis der Zusammensetzung der FGs des Potamoplanktons in der Lage, zuverlässig die Flusszonen zu unterscheiden. Allerdings hängt das erreichbare ökologische Verständnis von der taxonomischen Auflösung ab. Für Flussökosysteme kann die Wasserqualität ohne eine Feinauflösung von benthischen und planktonischen Kieselalgen, sowie der Arten der Cyanobakterien nicht gesichert geleitet werden.

(ii) Das FG- Klassifikation kann die Änderungen in der Potamoplankton Zusammensetzung erkennen, die durch natürliche und menschliche Änderungen entlang des Flusses Loire auftreten. Diese Veränderungen werden mit dem $Q_{(r)}$ Potamoplankton Kompositions-Index beschrieben, der in richtiger Weise lokale physikalische Störungen, wie Stau, und regionale Unterschiede in der Nährstoffverfügbarkeit nach Geographie und Landnutzungspraktiken identifiziert.

(iii) Sowohl der deutsche PhytoFluss- Index, basierend auf Artenebene und als auch der ungarische HrPi Index, basierend auf FGs, bieten eine vergleichbare und zuverlässige Indikation der Wasserqualität entlang der Loire. Bei richtiger Anwendung der Indizes gemäß den ortsspezifischen Fließgewässertypen und Ökoregionen, sind beide nationalen Bewertungsmethoden vergleichbar oder auf internationaler Ebene anwendbar, wie es auch von der Europäischen Wasserrahmenrichtlinie gefordert wird.

(iv) Die FG Klassifizierung des Potamoplanktons ist in den gleichen Abschnitten der Loire in jedem Jahr ähnlich. Abgesehen von quantitativen Unterschieden folgen die Haupt-FGs und die Verteilung der Zusatz--FGs einem ähnlichen Muster im Längsverlauf des Flusses, während für weiterer FGs nachgewiesen wurde, dass sie auf das spezifische jährliche, hydrologische Regime reagieren.

(v) Ökosystemfunktionen (hier Biomasse:TP- Verhältnis) zeigen im Fluss Loire ein unterschiedliche Beziehung zur Artenzahl und zur Vielfalt an funktionellen Gruppen. Während die höchste Vielfalt an FGs im Potamoplankton als Resultat von physikalisch diversen Lebensräume ermittelt wurde, die sowohl natürlicher als auch anthropogener Herkunft sind, trat die höchste Ökosystemfunktion bei einer geringer Artenzahl und einer mittleren FG- Vielfalt auf. Demzufolge liefert eine hohe Diversität in großen Flüssen nicht automatisch einen Beweis für eine höhere Ökosystemfunktion, noch kann sie eine allgemeine Zielvorgabe sein, ohne ihre funktionalen Eigenschaften und Kontrollfaktoren in verschiedenen Maßstäben zu verstehen.

Összefoglaló

A potamoplankton kifejezés folyókban előforduló algák összességét jelöli, függetlenül az eredettől, mint pl. a folyó autokton produkciója, vagy levált egyedek a bentoszról, különböző laterális habitatokból. A legtöbb vízi élőlénycsoport környezeti gradiensek mentén jelentkező kompozícióbeli különbsége jól tanulmányozott, ugyanakkor a teljes folyószakasz mentén lezajló potamoplankton-összetétel változásai kevésbé ismertek. Jelen doktori munka a relatíve szabályozatlan Loire folyó potamoplanktonját elemzi teljes folyószakasz mentén a 2009-2011 évekből. Folyóvízi potamoplankton kutatások, valamint monitoring programok a fajkompozícióra épülnek, mely eredmények értelmezése sokszor nehézkes. Ezzel ellentétben, a potamoplanktont a főbb algacsoportokra egyszerűsítve modellezik, ami lehetetlenné teszi funkcionalitásbeli komplexitást megkövetelő folyamatok megértését.

Egy alternatív módszer a fitoplankton funkcionális csoportokba—'FCS' való sorolása, mely új alapokat teremthet mind a potamoplankton-ökológia, mint pedig folyóvizek ökológiai minősítése számára. A FCS összetétel feltehetően követi a teljes folyószakaszon végbementő változásokat, és jobban indikálja az ökológiai állapotot, mint más, a fajkompozícióra vagy fajszámra épülő rendszerek. Ennek bizonyítására, a Loire folyó teljes szakasza mentén jelentkező potamoplankton funkcionális kompozícióbeli különbségek kerültek összevetésre természetes gradiensekkel, valamint humán eredetű fizikai és kémiai stresszorokkal. A dolgozat főbb eredményei:

(i) Tavi fitoplanktonra kifejlesztett FCS-ok lehetővé teszik azok folyóvízi adaptációját, és eltérő működésű folyószakaszok kijelölését a Loire-on. Ezen folyószakaszbeli különbségek eltérő szintű értelmezhetőséget biztosítanak. Folyóvízben, kielégítő monitoring nem hozható létre a bentikus és planktonikus kovaalgák, valamint cianobaktérium szervezetek nagyarányú funkcionális elkülönítése nélkül.

(ii) A Loire potamoplanktonjának FCS-okban való értelmezése lehetővé teszi „természetes" és „zavart" folyóvízi kompozíciók elkülönítését. Ezen különbségek a $Q_{(r)}$ potamoplankton index segítségével követhetők, amely képes lokális fizikai hatások, mint pl. tározás, vagy regionális különbségek, mint pl. a földhasználatból eredő tápanyagkülönbségek kompozícióra gyakorolt hatásának indikációjára.

(iii) A faj alapú német 'PhytoFluss', és a FCS alapú magyar 'HRPI' indexek kielégítően indikáltják a Loire folyó vízminőségének tér és időbeli változásait. Az indexek megfelelő folyótipológiai adaptációját követően összevethetők, valamint nemzetközi szinten alkalmazhatók a Víz Keretirányelv elvárásainak is megfelelően.

(iv) A Loire fitoplanktonjának funkcionális különbségei geográfiailag azonos folyószakaszok elkülönítését teszik lehetővé hidrológiailag különböző években is. A mennyiségi különbségek mellet, a domináns és szubdomináns csoportok az évek folyamán azonos folyó-menti eloszlást mutatnak, míg további FCS-ok eloszlása az egyes évekre jellemző specifikus hidrológiai körülmények eredménye.

(v) A Loire fitoplanktonjának ökoszisztéma funkciója (biom.:összes P alapján) eltérő összefüggést mutat a faj- és a FCS-számmal. A magas fajszám fizikailag kevert természetes, és/vagy mesterséges habitatok eredménye, ahol az ökoszisztéma működése alacsony faj-, és közepes FCS-számon a legmagasabb. Ennek megfelelően, a magas potamoplankton fajszám folyóvíz esetében nem tekinthető automatikusan sem a folyó kielégítő működésének, sem pedig általánosan elérendő vízminőségi célnak a kompozíció funkcionális összetételének és az azokat meghatározó tényezők eltérő skálák mentén való értelmezése nélkül.

1. Literature review

1.1. Phytoplankton in rivers

Rivers are defined as unidirectional water flow within a watershed, bordered with different kind of standing waters such as marshes, wetlands, lakes, or other river-lake systems like reservoirs (Stevenson, 2009). Algae of rivers might be divided into two basic life forms: living either attached to substrate (benthic algae), or in suspension and transported by the river flow (planktonic algae). This latter differs widely from lentic phytoplankton as in rivers, benthic and planktonic taxa may occur together when benthic algae detached by physical stress and mixed together with the possibly occurring planktonic species. If so, the term 'potamoplankton' might be considered to use.

Rivers are complex systems, where the presence/absence of taxa is hard to be presumed. According to the lack of predictability, potamoplankton studies might show contrasting results when evaluated at different temporal and spatial scales. Further divergences arise on differing watershed landmarks along river stretches, as well as on different levels of human impacts. Therefore, potamoplankton composition of rivers varies widely both among habitats and seasons. Generalities on taxa dispersal have been mostly established at larger spatial scale, related to river types: (i) in fast-flowing source river sections, benthic diatoms dominance prevails (Piirsoo, 2001; Soylu and Gönülol, 2003; Farahani et al., 2006); (ii) middle river sections often favour the dominance of centric diatoms (Gosselain et al., 1994; Garnier et al., 1995); (iii) while in the lowlands a diverse composition of green algae might develop (Pérez et al., 2009) often with cyanobacteria (Ha et al., 2002), euglenoids enriched by further algal groups. When only the presence of taxa is considered, one might conclude a diversified composition of potamoplankton in rivers (Hindák and Makovinská, 1999). Similarly, Reynolds and Descy (1996) stated that, in case of favourable environmental conditions, rivers may sustain higher phytoplankton diversity than lakes.

1.1.1. Nutrients as controlling factors of potamoplankton

Climate, the geological setting together with river dimensions are the major factors in determining algae distribution in streams and rivers worldwide (Sabater et al., 2006). Biogeochemical characteristics (Meybeck and Helmer, 1989), and hydrological conditions (Gasith and Resh, 1999) also result in consistent differences among rivers, and regions. While main geographical and hydrological changes might determine regional differences in river flow via considerable changes in controlling factors, at a smaller scale, it might be further separated to physical-, and nutrient-determined factors, biotic interactions, and the more and more emphasized human impacts.

Early studies concluded that phytoplankton nutrients such as N or P are the most relevant elements in determining phytoplankton quantity and composition (Blum, 1956), and possibly limit algal growth in streams (Chételat et al., 2006; Stevenson, 2009). The opposite, however, has been also proved (Francoeur, 2001; Salmaso and Braioni, 2008; Centis et al., 2010). Furthermore, nutrients are main factors not only to govern the composition or limit algae growth, but are critical factors to enable harmful algal blooms. The seasonal dynamics of phytoplankton itself, might regulate nutrient concentration, or modify nutrient ratio by selectivity (Xie et al., 2003). Besides N and P, silica (Si) also determines algal composition; and especially, limits the dominance of diatoms (Sommer, 1988). Ha et al. (2002) showed that diatom blooms were the most important factors controlling silica level in a reservoir system.

Thus, silica concentration might initiate community shifts (Sommer, 1988), since without Si limitation, diatoms might have one of the best position in competition. Algae can modify the form of elements transported; dissolved Si, for example, is transformed to biogenic Si by its biological uptake (Conley, 1997). Some micro-nutrients, such as Fe, are also responsible in controlling algal growth via enzymatic processes. Even if the high number of coexisting taxa has been a Gordian knot since Hutchinson (1961) models predict that species richness follows the gradient of resources and diversity might possibly increase when nutrients are available for several species, or decrease in case of extremes such as large availability or under depleted nutrient conditions (Stevenson, 2009).

1.1.2. Physical constraints in rivers

Large and especially long rivers represent a continuum of interdependent ecosystems from headwaters towards estuaries. Along this continuum, to understand the composition of phytoplankton at each point, it is required to consider the whole upstream river section being responsible for the phytoplankton development (Garnier et al., 1995). The continuous change of conditions has been summarized in the 'River Continuum Concept'—RCC (Vannote et al., 1980). The RCC hypothesizes general and predictable changes in biological variables along rivers, and highlights the dependence of biological dynamics in connection with physical gradients of the drainage network (Fig. 1a). Furthermore, the RCC points out that physical structure are coupled to hydrological cycles, and form templates for biological responses resulted in consistent patterns of community structure and function (Vannote et al., 1980).

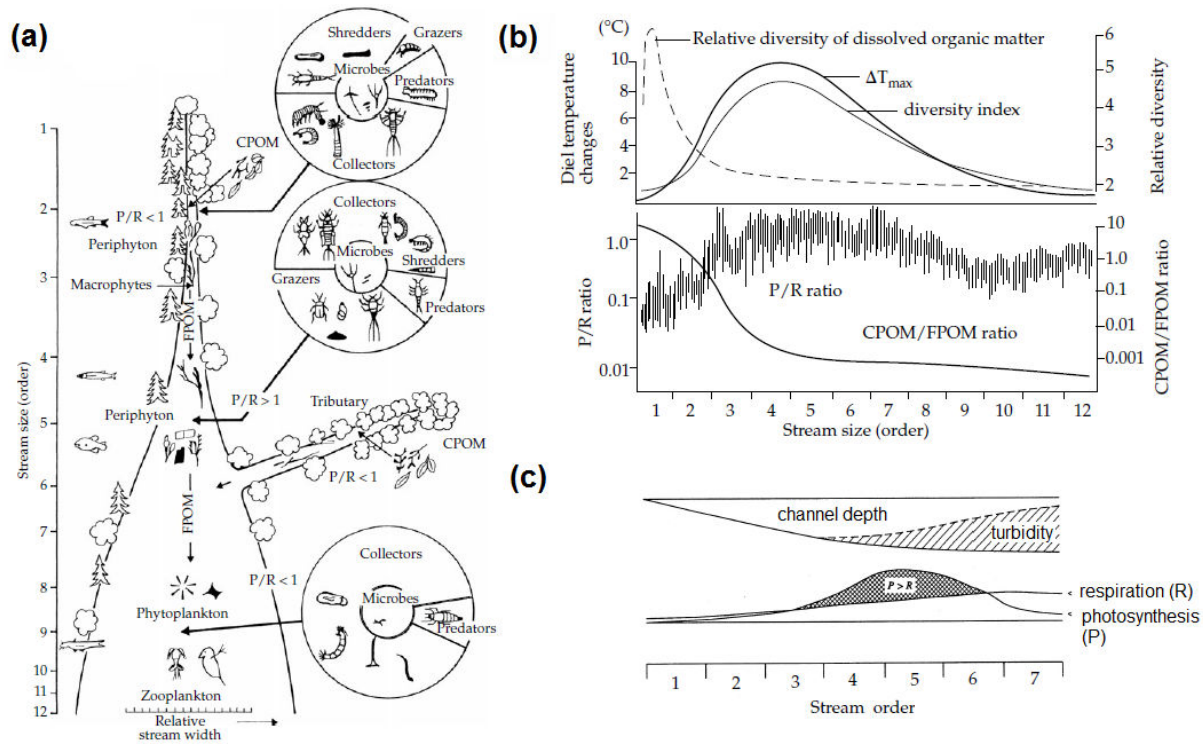

Fig. 1 (a) *Longitudinal pattern of abiotic parameters and biota in rivers* **(b)** *river order dependence of abiotic factors, diversity, P/R ratio, and organic matter composition* **(c)** *channel depth vs. turbidity and P/R ratio along river orders. Redrawn and modified from Vannote et al. (1980) and Reynolds and Descy (1996)*

The concept has been developed based on stream geometric characteristics published by Leopold and Maddock (1953) who demonstrated that river bed width, depth, flow velocity, and sediment load have a basically determined pattern along rivers. River systems have been also considered as a continuum of 'steady state' compartments without real, exact equilibrium, which concept then has been further developed into the energy input concept for landscape evolution (Leopold and Langbein, 1962).

Following the energy equilibrium concept, Vannote et al. (1980) also hypothesized and predicted that the maximum level of biotic diversity occur in middle river sections (Fig. 1b); being related to the maximum variability in environmental conditions. The more the physical environment is diverse, the more taxa have possibility to grow and co-exist. Wide diurnal fluctuation of water temperature might expose suboptimum ranges during the day; however each organism might encounters a favourable or optimum value to exist. Under such an optimum temperature, a larger number of species might co-occur (Vannote et al., 1980). Besides the example of water temperature, similar effect and pattern can be predicted for other parameters, such as water depth (Allan and Castillo, 2007), or light availability (Lamberti and Steinman, 1997). These latter two parameters, however, have simultaneous effect in rivers (Doi, 2009), as light availability is determined by both canopy cover and water depth at the same time.

In rivers, turbidity has a great influence on both benthic and planktonic algae. It regulates the distribution of sediment, and helps phytoplankton to be kept in suspension (Stevenson, 2009). The alteration of velocity determines the frequency of disturbances, and assigns the total phytoplankton biomass via light (Schmidt, 1994); as both the photosynthetic and nutrient uptakes are determined by light availability (Uherkovich, 1971; Vannote et al., 1980; Vörös et al., 2000; Leland, 2003; Sellers and Bukaveckas, 2003). Besides the longitudinal change from coarse to fine particulate organic matter along rivers, in general, downstream river sections are expected to sustain higher amount of suspended solids (Reynolds and Descy, 1996) that might shape the P/R ratio (Fig. 1c).

1.1.3. Biotic interactions of potamoplankton

Besides nutrient limitation and physical processes, biotic interactions have also the potential to influence planktonic biota (Ietswaart et al., 1999). In rivers, the phytoplankton–zooplankton interaction strongly depends on flow rate, and requires long enough slow flow period (several weeks) to allow zooplankton developments (Gosselain et al., 1998).

Phytoplankton biomass may be responsible for the abundance of predators under 'bottom up' conditions (Salmaso and Braioni, 2008), which then might be returned and balanced as 'top down' control (Descy and Gosselain, 1994; Garnier et al., 1995; Lair and Reyes-Marchant, 1997; Gosselain et al., 1998; Lair, 2005). Correspondingly, the size distribution of potamoplankton may also reflect selectivity of grazing. At downstream river sections, grazing can occasionally contribute to low phytoplankton abundance, but generally only for short periods (Chételat et al., 2006). Ha et al. (2003) demonstrated the biological control of zooplankton on a winter *Stephanodiscus* bloom, when physical constraints were alleviated. Furthermore, downstream river sections where zooplankton grazing possibly influences phytoplankton are also characterized by higher abundance of benthic cladocerans as was shown in case of the River Meuse (Viroux, 2002) and additionally abundance of rotifers may also increase downstream as in the River Elbe (Zimmermann-Timm et al., 2007).

Besides zooplankton, mussels are also potential contributors for algal decline in several cases by high filtration rate on both phyto-, and other potamoplankton. Most common examples are zebra mussel—*Dreissena polymorpha*—(Hudson et al., 1996; Caraco et al., 1997; Akopian et al., 2001; Schöl et al., 1999, 2002) and Asian clams—*Corbicula* spp. (French III and Schloesser, 1991; Brancotte and Vincent, 2002; Lercari and Bergamino, 2011; Floury et al., 2013). Their presence however, often restricted to special habitats, adequate hydrographical conditions, and convenient flow characteristics; which might be found at middle to lowland river sections, and are influenced by different human-related impacts as well.

1.1.4. Human impacts affecting potamoplankton

Human being is coupled to rivers since the very beginning of the history, and thus unaffected river landscape might not occur around populated areas. Streams of urban areas have an important position, and are vulnerable to impacts associated with land use. One of the most reliable consequences is the modified riparian vegetation. Recently, Tánago and Jalón (2006) demonstrated how ecological state of rivers can be related to longitudinal changes in vegetation and river channel dimensions affecting both the composition and structure of riparian communities.

The concept of 'Urban Stream Syndrome' described by Walsh et al. (2005) summarizes human impacts such as elevated level of nutrients and contaminants, altered channel morphology, reduced biotic richness, and the increased dominance of tolerant taxa. Rimet (2009) showed on the example of benthic diatoms that geology basically determinates the type of land use, and thus connects geological setting to water quality, which then reflected by the occurring composition of biota.

Historically, human impacts on rivers were generally restricted to local scales. Then following the industrial revolution, the human fingerprint became both intensified and expanded. This expansion was more associated to larger agriculture areas, and to larger emission of chemical components; and due to the position of fluvial systems in the landscape, they are paradigmatically integrated at a river catchment scale (Martí et al., 2006). Human impacts on fluvial biogeochemistry occur by modified hydrology, increased availability of elements (Turner et al., 2003), and the unnatural composition of chemicals (Meybeck, 2003a). These urban related water uses have clearly contributed to the eutrophication of running waters (Blum, 1956; Walsh et al., 2005).

Hydrological modifications are often imposed by artificial buildings such as reservoirs (Palau, 2006), dams (Dauta et al., 1999; Hart et al., 2002; Friedl et al., 2004; Istvánovics et al., 2010), riffles, or bridges (Ramos and Gracia, 2012). As a biological consequence, these modified water bodies might have higher efficiency in inoculation than in natural ones (Borics et al., 2007); and cause a major scientific question in restoration policy (Moss, 2008). Further influences may occur by sewage inflow (Kiss et al., 2006), or by nuclear power plants (Descy and Mouvet, 1984). Dams are able to increase food resources (Doi, 2009), fragment flow continuity, and alter hydrology towards downstream (Ward and Stanford, 1982; Nilsson et al., 2005). These modifications enhance the occurrence of new species downstream of the dam (Richardson and Mackay, 1991).

As a general consequence, human-mediated disturbances might also affect phytoplankton, its assemblages and diversity (Hambright and Zohary, 2000). The stratification patters of reservoirs can be similar to those developing in lakes (Kalff, 2002),

and thus outflow may play a key role in determining water quality following dam areas. The artificial regulations possibly cause dramatic change in phytoplankton composition, related to improved underwater light climate, and prolonged water residence time (Hart et al., 2002).

The flow regulation of rivers has degraded the structural properties of large rivers, especially of inshore ecotones (Schiemer et al., 2001), and the connectivity between rivers and floodplains, influencing habitat heterogeneity and functional processes (Tockner et al., 2000). For future restoration, Schiemer et al. (2001) concluded that hydraulic retentivity should be the main framework to study, and should become a main research focus in regulated, large rivers.

In order to manage the ecological status of large rivers according to the European Water Framework Directive (WFD, 2000), all human impacts on rivers must be defined. Despite the quantity of already available data, however, general relationships often appear to contradict (Bragg et al., 2005).

1.2. The River Loire

1.2.1. The largest Continental Atlantic river

The Loire catchment occupies almost 20% of France (117,045 km^2; Fig. 2), and it is the largest among the Continental Atlantic rivers (~1012 km of length, and ~200-300 m of width at the main channel at the middle river section—Orléans). The Loire basin includes many protected areas by Natura 2000 or by the World Heritage of UNESCO, where exceptional landscapes and habitats have been still well preserved (Oudin et al., 2009). Furthermore, its flow regime has been remained relatively unaffected when compared to other large European rivers (Descy et al., 2011). The Loire has four climatic influences at whole river scale: (i) rains arriving from the Atlantic Ocean in its western sector; (ii) marine influences originated from north (North Atlantic and North Sea); (iii) continental origin from East; and (iv) south-easterly to south-westerly, originating from the Mediterranean Sea, containing Saharan aerosols as well (Grosbois et al., 2000).

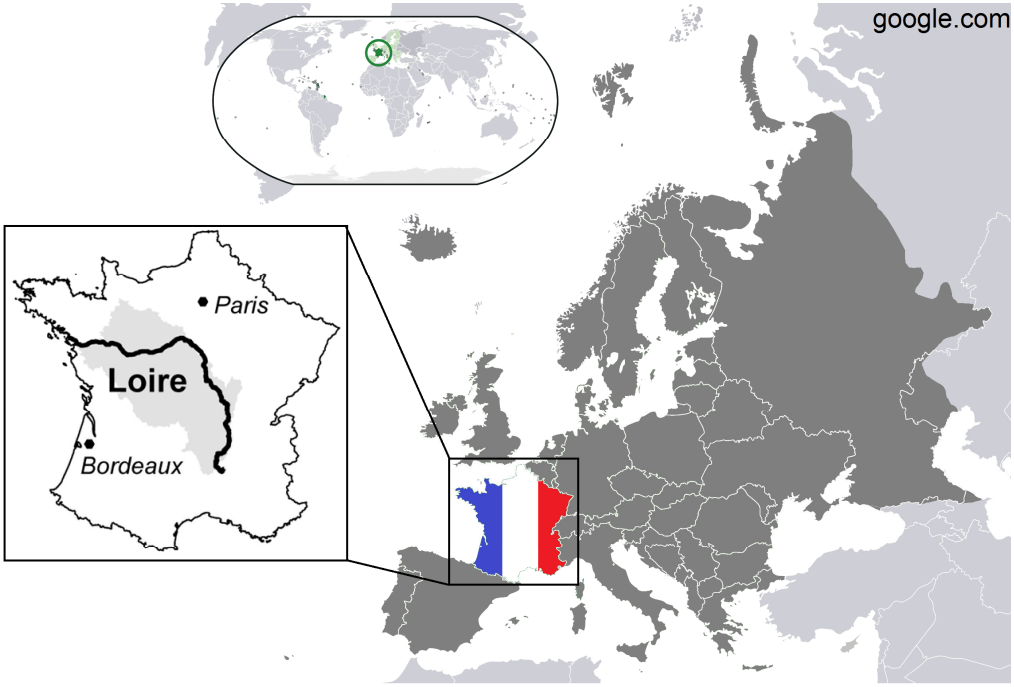

Fig. 2 *Location of the River Loire at national (France) and international scales. Redrawn and modified from google.com*

Due to elevation differences, geographical constraints change continuously along the river. The longitudinal evolution of the Loire river bed is (i) volcanic and granitic areas upstream (ii) calcareous and sedimentary alluvial valleys with gravel islands and sand banks in the middle course (iii) and argillaceous-sabulous, granitic armoricain and calcareous downstream.

Besides the natural gradient, the most relevant human pressures in the Loire catchment is land use with ~30% of arable area (Minaudo et al., 2014), up to ~70% including all agriculture activities (Oudin et al., 2009), with the dominance of grass- and croplands (Fig. 3c). Furthermore, the Loire flow regime is altered by two large dams in the upper river section: Grangent (Salençon, 2004) and Villerest (Bonnet et al., 2000). The pressure on water resources is further intensified by higher habitat density (up to 150 hab×km^{-2}; Fig. 3b) in the

upper Loire (Minaudo et al., 2014), by water supply to five large cities (>100,000 people), and by four nuclear power plants (Oudin et al., 2009) along the river.

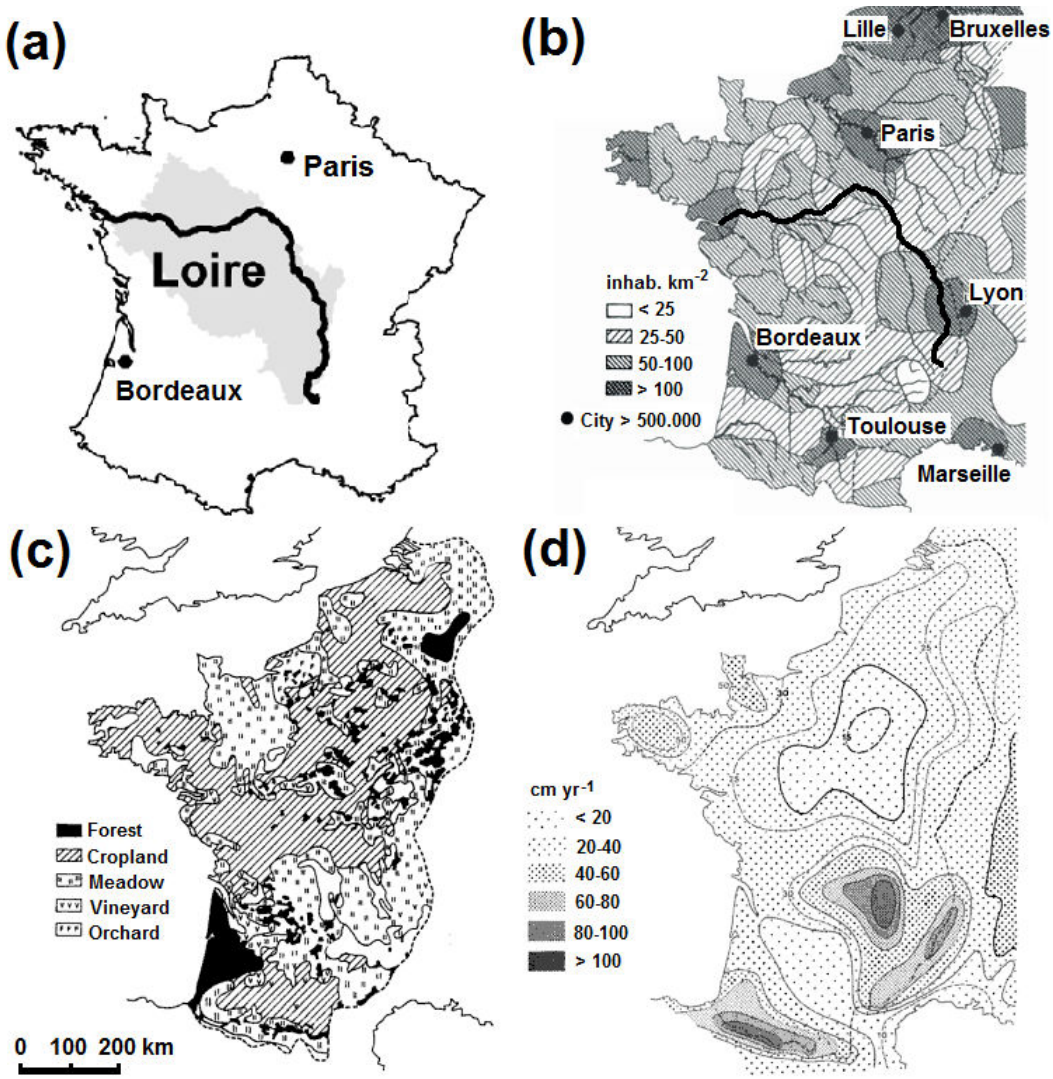

Fig. 3 **(a)** *The Loire basin in France; and its distribution of* **(b)** *habitant density* **(c)** *land use types and* **(d)** *specific runoff. Redrawn and modified from Billen et al. (2006)*

While the middle section of the river has been modified by dikes, its lower part is mostly constrained by canalization constructed for small ship navigation. Besides cities, four nuclear power plants use Loire water: at Belleville-sur-Loire (500 km from source—'km f.s.'), at Dampierre-en-Burly (550 km f.s.), at Saint-Laurent-des-Eaux (640 km f.s.) and next to the town Avoine: Chinon (793 km f.s.). Historically, the lower Loire course has also been affected by several anthropogenic impacts such as industries, agriculture and wastewater discharges since centuries (Descy, 2009). At the downstream river section, human pressure is imposed by towns such as Montluçon, Vierzon, and Bourges on the Cher, Chateauroux on the Indre, Limoges and Chinon on the Vienne. At the town of Angers, the River Maine assembles discharge and human impacts of the Mayenne, Sarthe and Loir rivers (Oudin et al., 2009).

1.2.2. Recent hydrological characteristics of the River Loire

The discharge of the River Loire shows nival characteristics with maxima occurring in February to Mars; and it is the major inflow of the Atlantic Ocean with a mean annual discharge of 850 m^3s^{-1} (Grosbois et al., 2000). van der Wateren-de Hoog (1995) demonstrated the high discharge variability in the upper Loire catchment, with similar effects of dry periods under cold and warm conditions. Along the whole river course, the Loire crosses three eco-regions (Oudin et al., 2009), where its discharge is largely influenced by two main tributaries: the River Allier and the River Cher (Fig. 4). Between them, the Loire flows along a 300 km stretch without major inflow, then at downstream four tributaries increase the mean annual discharge more than twofold within 100 km. In the middle river course, however, the relevance of ground water sources was demonstrated according to energy balances of the region (Moatar and Gailhard, 2006).

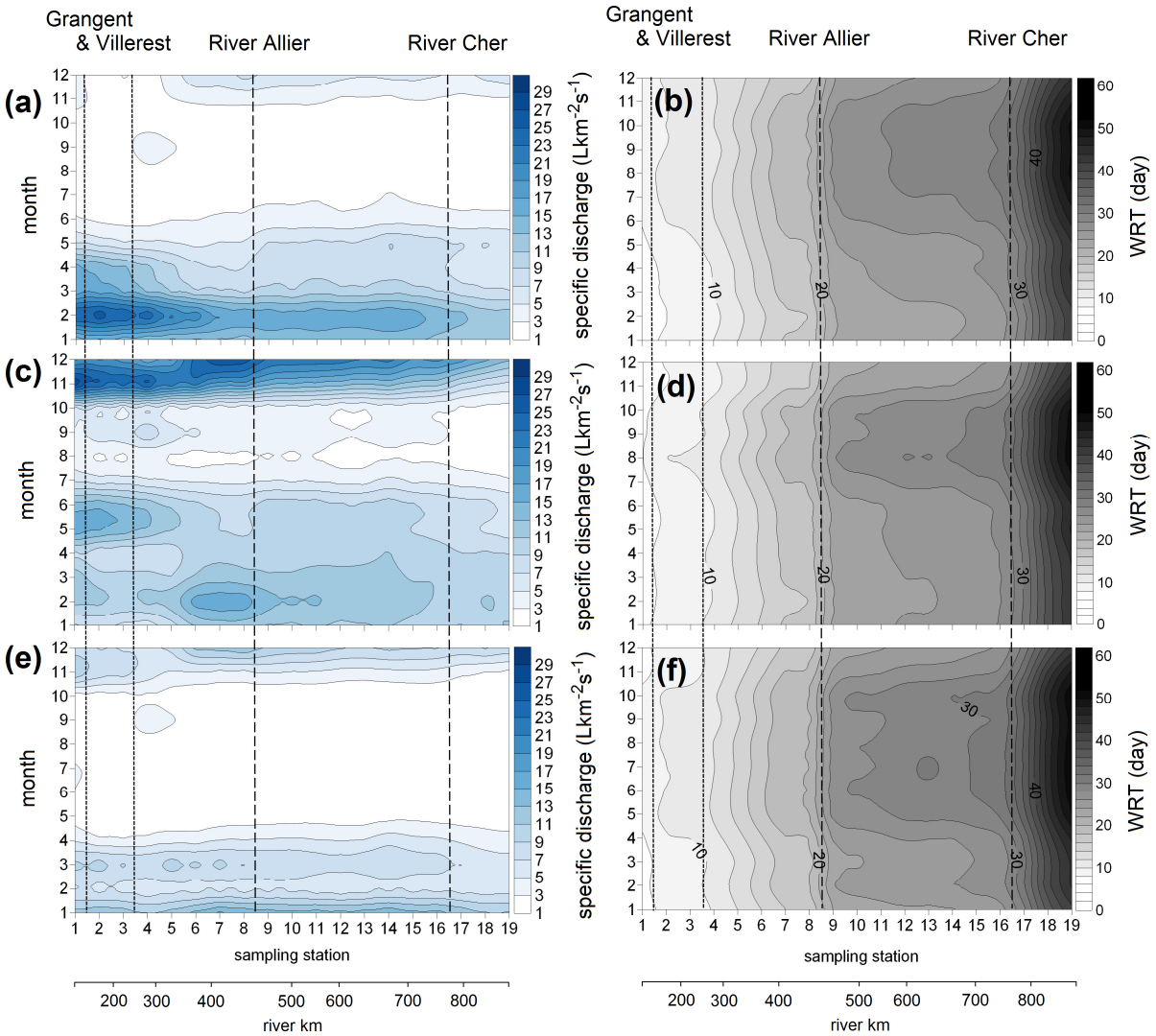

Fig. 4 *Spatio-temporal distribution of specific discharge and water residence time along the River Loire. Data of years* **(a-b)** *2009;* **(c-d)** *2010; and* **(e-f)** *2011. Specific discharge is based on monthly averages of discharge data, compared to catchment size at each station. The theoretical WRT is based on the assumptions of Søballe and Kimmel (1987) and Leopold et al. (1995). Station numbers indicate the same locations throughout the Thesis*

Due to elevation differences, geographical constraints change continuously along the river. However, the discharge of the two main inflows results in considerable changes in hydrology, representing the two major sub-basins of the Loire catchment. Theoretical WRT is ~10 days at upstream, ~20 to 30 days in the middle sections and up to 60 days in the lowermost Loire section (Fig. 4b,d,f). However the two upstream dams delay WRT by ~1 month at Grangent (Salençon, 2004), and ~3 month (springtime data) at Villerest dam stations (Bonnet et al., 2000); the exact WRTs are being calculated (F. Moatar and C. Minaudo, pers. communication). The main longitudinal hydrological changes coincide with shifts of climate regions (southern oceanic/humid mountain to temperate oceanic), and support divisions into six main hydro-eco-regions of the catchment (Wasson et al., 2004; Oudin et al., 2009).

Besides natural characteristics of river flow, some human impacts, global changes also affect the Loire as demonstrated by Moatar et al. (2010). Dams produce electricity, mitigate flood peaks and sustain continuous low flows for downstream power plants (Oudin et al., 2009). Their functioning extends WRT, disrupt continuity, sustain stratifying conditions according to maximum depth [z_{max}=50 m of Grangent (Latour et al., 2004); and z_{max}=45 m of Villerest (Bonnet et al., 2000)] and increase the shoreline development index (Kalff, 2002). Dams' outflow, especially at Villerest dam, modifies the seasonal pattern of flow characteristics (increased specific discharge in September; Fig. 4a,c,e). The lentic characteristics of dams and the high nutrient availability (mainly phosphorus) by large cities in the region (Latour et al., 2004; Minaudo et al. 2013, 2014) resulted in fast eutrophication of both reservoirs, and they still sustain regular cyanobacterial blooms (Sabart et al., 2009). The period of low specific discharge differs among years, but generally occurs between June-October, all along the whole river length (Fig. 4a,c,e). As a consequence of recent hydrology, groyne disposals were created at the middle and lower Loire in order to maintain sufficient flow conditions for navigation during these periods (Belleudy, 2000).

1.2.3. Recent patterns of in-situ parameters in the River Loire

Following the real source area (~first 100 km), the water temperature shows similar seasonal patterns all along the whole river (Fig. 5a). It increases up to 20°C even in the upper section, with one mismatch at Villerest dam station possibly because of hypolimnetic outflow. Here, lower late summer water temperatures are paralleled with lowered pH and dissolved oxygen (DO), and elevated conductivity (Fig. 5b,c,d). In contrary, high pH might occur between May and September in the middle to lower Loire, which might indicate high primary production. Conductivity increases continuously along seasons and along the whole river course (Fig. 5d); thus follows lowering specific discharge and prolonging WRT. At the middle Loire, the long term trend of conductivity has been found to increase continuously (Oudin et al., 2009). Similarly, annual and summer water temperatures have been risen by approximately 0.8 °C during the last decades, which increase was showed to accelerate since the late 1980s due to rising air temperature and lowing discharges (Moatar and Gailhard, 2006).

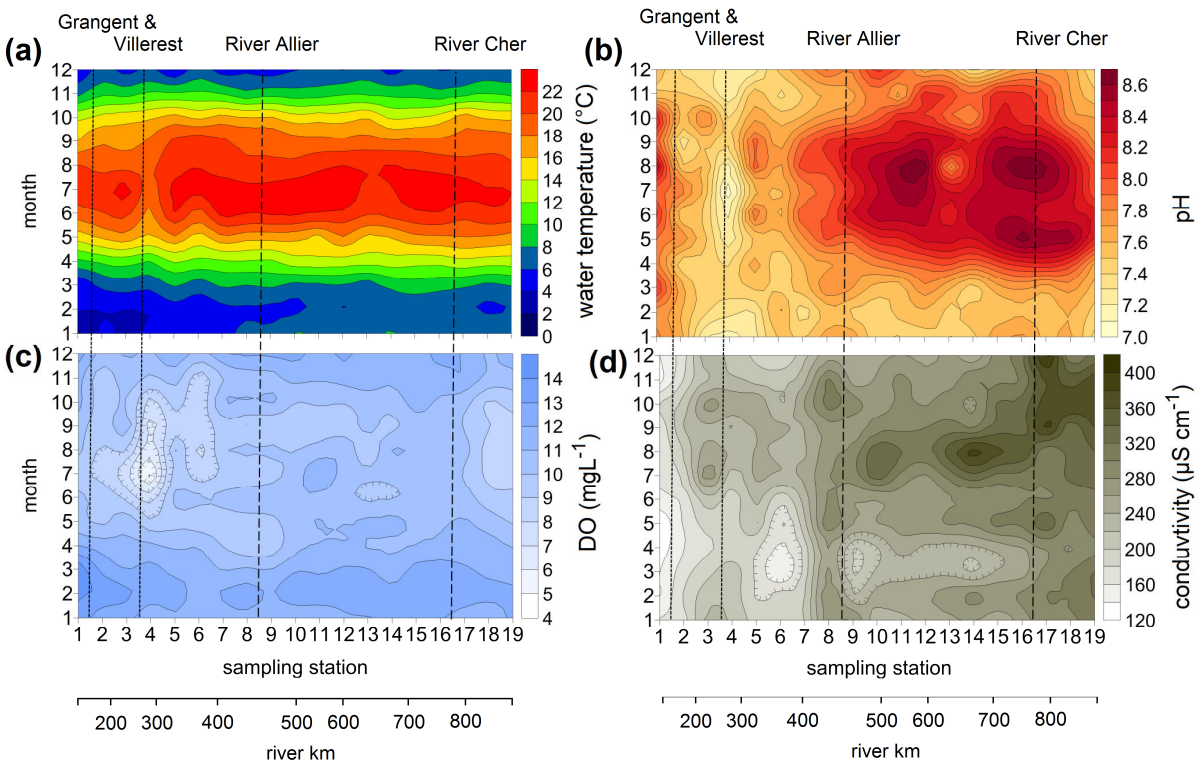

Fig. 5 *In situ parameters along the River Loire* **(a)** *water temperature;* **(b)** *pH;* **(c)** *dissolved oxygen;* **(d)** *conductivity (average data of years 2004-2008, once a month data frequency). Station numbers indicate the same locations throughout the Thesis*

1.2.4. Recent chemical compositions of the River Loire

Major ion composition

The major ion composition of the River Loire shows the dominance of Ca^{2+} >Na^{+}, and HCO_3^- >Cl^-. Compared to global averages (Table 1), sodium and chloride concentrations are relatively high, while magnesium and bicarbonate tend to be relatively low (whole river length, median values; for all data see *Appendix II*). The elevated Na^+ and Cl^- contents are also obvious when compared along different climate regions (Table 2).

Table 1 *Major ion composition of the Loire (2004-2008) compared to former literature examples on rivers. "n.d." indicates no differences*

% mEq	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
Clarke (1924)*	15.7	3.4	63.5	17.4	10.1	16.0	73.9
Livingstone (1963)**	19.3	4.2	52.8	23.8	15.6	16.5	67.9
Conway (1942)***	16.0	3.0	64.0	17.0	10.0	16.5	73.5
Rodhe (1949)***	15.6	3.4	63.5	17.5	10.1	15.6	74.3
Meybeck (2003b)****	18.6	2.7	55.7	23.0	13.6	14.5	71.9
River Loire, this study	**21.0**	**3.3**	**59.2**	**16.4**	**21.3**	**14.6**	**60.0**
global difference	*(+)*	*n. d.*	*n. d.*	*(-)*	*(+)*	*n.d.*	*(-)*

* in Hutchinson (1957); ** calculated from Livingstone (1963); in Meybeck (2003b)
*** in Cole (1979); **** calculated from Meybeck (2003b)

Table 2 *Major ion composition of rivers of different rock types and climate regions*

% mEq	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
Granite*	51.9	4.6	23.8	19.6	0	19.6	80.4
Volcanic rock*	23.9	2.9	35.4	37.7	0	2.4	97.6
Carbonate rock*	1.1	0.4	78.4	20.1	0	2.6	97.4
Tundra, Taiga**	19.1	1.3	55.4	24.2	16.1	18.2	65.7
Tropics, Amazon**	23.3	4.6	47.6	24.5	26.1	19.2	54.7
Temperate zone**	12.1	2.1	66.4	19.4	9.7	20.4	69.8
River Loire, this study	**21.0**	**3.3**	**59.2**	**16.4**	**21.3**	**14.6**	**64.0**

* calculated from Meybeck and Helmer (1989); in Kalff (2002)

** Meybeck (1979); in Kalff (2002)

At a longitudinal scale, calcium increases; sodium and magnesium show regional differences; while potassium remains almost constant along the whole river (Fig. 6). Among anions, chloride and sulphate display similar regional maxima as potassium (Fig. 7). Grosbois et al. (2000) evidenced that Na^+, K^+, Mg^{2+}, SO_4^{2-}, and Cl^- contents decrease, while HCO_3^- and Ca^{2+} increase with elevating discharge (up to 300 m^3s^{-1}). The form of CO_3^{2-} also occurs in the Loire—even upstream—, here it is not presented since the lack of satisfactory amount of data. Its presence was, however, already explained by Meybeck (2003b) in connection with high primary production and pH exceeding 9. The downstream increase of ion concentrations are related to prolonged WRT, increasing evapo-transpiration, and the larger influence of the Atlantic coast (Meybeck 2003b). The major ion composition presented here (for detailed data, see *Appendix II*) is in well accordance with of Grosbois et al. (2000) proposed for the middle Loire section.

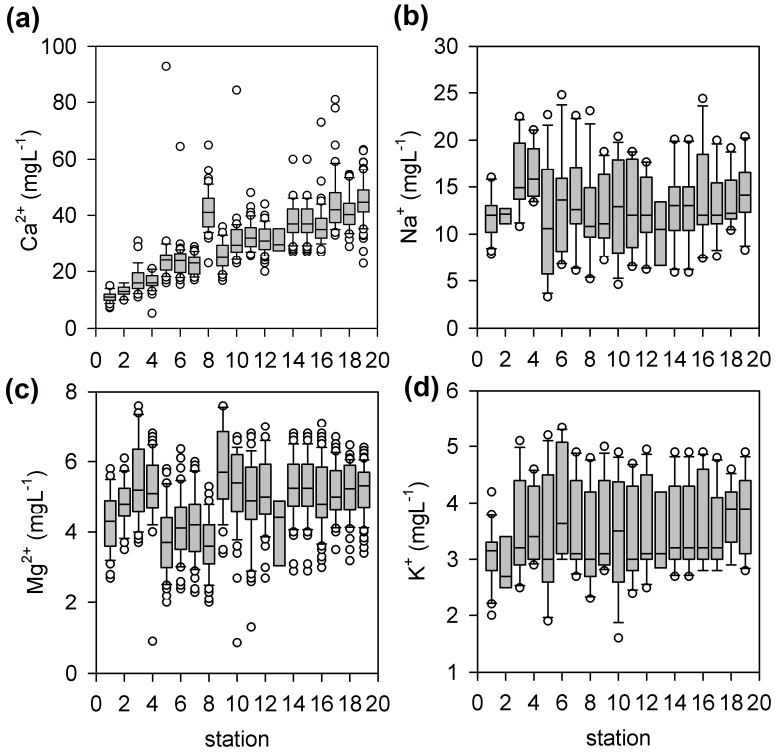

Fig. 6 *Major cation distribution along the River Loire (years 2004-2008, twice a year data)* **(a)** *calcium;* **(b)** *sodium;* **(c)** *magnesium; and* **(d)** *potassium. Box plots represent median values by solid black line, and display each outlier. Station numbers indicate the same locations throughout the Thesis*

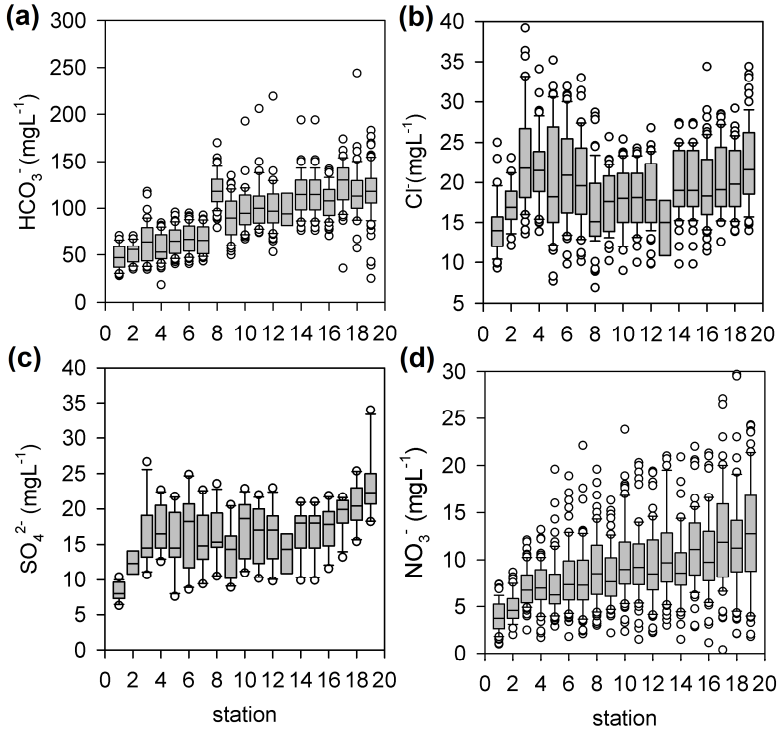

Fig. 7 *Major anion distribution* **(a)** *hydrogen carbonate;* **(b)** *chloride;* **(c)** *sulphate along the River Loire; as well as* **(d)** *nitrate (years 2004-2008, twice a year data for major ions; once a month data frequency for nitrate). Box plots represent median values by solid black line, and display each outlier. Station numbers indicate the same locations throughout the Thesis*

Nirate and total phosphorus in the River Loire

Nitrate shows persistent increase along the whole River Loire (Fig. 8a). The eutrophication at the middle Loire was already recognised in the 1980s (Chalon, 1979) by elevated Chl-*a* up to 150 µg L^{-1}. This primary production—besides discharge—affects both the longitudinal and the seasonal oscillation of nitrate (Meybeck et al., 2003). Both its annual average and its seasonal differences seem to decline in the recent decades (Moatar and Meybeck, 2005; Oudin et al., 2009; Minaudo et al., 2013). However, appropriate farming practice might not yet installed in all regions, and still affects the nitrogen balance via underground sources (Bouraoui and Grizzetti, 2008).

Besides the high nitrate availability, recent TP values show rather low values during the vegetation period at the middle to downstream river section (Fig. 8b). In these cases, concentrations might approximate background values (< 0.05 mgTP L^{-1}) suggested for large German rivers (Mischke et al., 2011). The lowered TP concentration, in some cases, might potentially limit algal growth (Descy et al., 2011). These latter phenomena open towards international trends such as the possibility of better nutrient management (Istvánovics and Honti, 2012), decreasing river discharge (Nohara et al., 2006), and the invasion of new arrivals like the Asian clams—*Corbicula* spp. occurring in the Loire as well (Sousa et al., 2008; Pigneur et al., 2011; Floury et al., 2013). Conversely, at the upper river section, higher TP—and SRP—still occurs (Fig. 8b), might be related to high population density and severe water stresses in the region (Minaudo et al., 2013). Latter authors prospected a long term decrease of TP for the whole length of the River Loire; without similar assumption for nitrate.

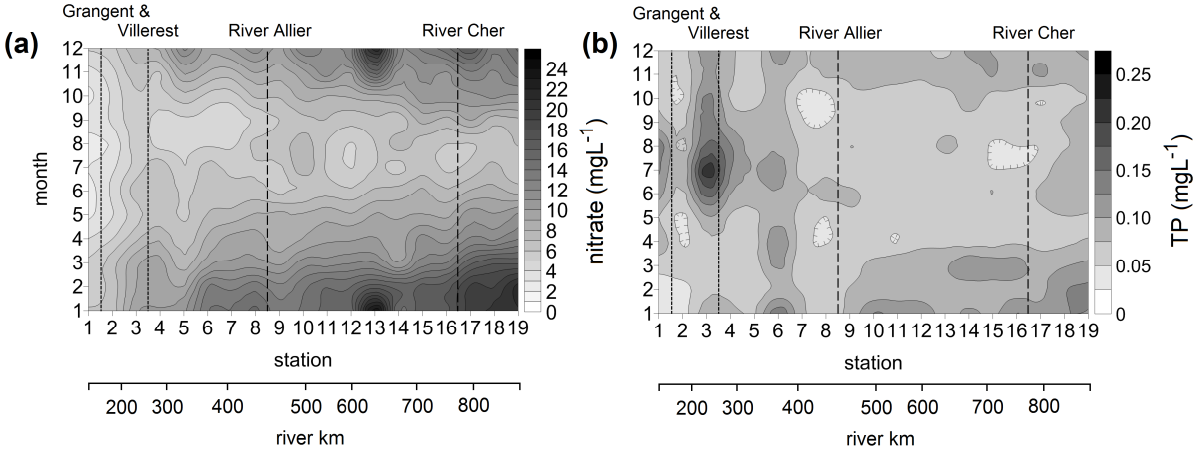

Fig. 8 *Spatio-temporal distribution of* **(a)** *nitrate; and* **(b)** *TP along the River Loire (average data of years 2004-2008, once a month data frequency). Station numbers indicate the same locations throughout the Thesis*

1.2.5. Former biological studies along the River Loire

Similarly to other large rivers, longitudinal researches have been mostly evaluated on sessile biota, or ones being characteristic for river zones along the Loire. At a whole river scale, zonation has been studied for the riparian vegetation (Wisskirchen et al., 1998), fish (Lasne, 2007; Lasne et al., 2007; Bergerot et al., 2008) and macro-invertebrates (Usseglio-Polatera et al., 2000).

In the plankton, heterotrophic protists and micro-metazoans were exclusively studied in the middle Loire, occasionally paralleled by potamoplankton (Lair and Sargos, 1981, Lair et al., 1999; Picard and Lair, 2005). Recently, the invasion of new taxa like Asian clams was demonstrated in the River Loire (Sousa et al., 2008; Pigneur et al., 2011) and was related to global changes controlling climate variables (Floury et al., 2013).

1.2.6. Former phycological studies along the River Loire

First phycological studies of the Loire were limited to the lower river section, especially the Anjou region (des Cilleuls, 1928; Bioret, 1931; Germain, 1935). In the 1920s, des Cilleuls (1926) observed an overwhelming dominance of diatoms, followed by Chlorophyceae, desmids, cyanobacteria and Dinophyceae. Dominant species of these years were *Melosira varians*, *Fragilaria capucina*, *F. construens*, *F. crotonensis* enriched by taxa such as *Ankistrodesmus falcatus*, *Actinastrum hantzshii*, and *Merismopedia* [*glaucum*] *glauca*. He also emphasized the absence of euplanktonic—"autopotamique"—taxa dominance in the lower Loire. On the contrary, during the following years of 1928 to 1929, the Loire almost dried out in its lower section, and the potamoplankton composition changed to the dominance of *Scenedesmus acuminatus*, *S. quadricauda*, *Fragilaria crotonensis*; paralleled by new occurrences such as *Pediatrum duplex*, *Acanthosphaera zachariasii*, *Golenkinia radiata*, or *Coelastrum reticulatum* (des Cilleuls, 1930, 1932).

Later phytoplankton studies were mainly focused on water quality issues, and were limited to few sites along the Loire: (i) the upstream eu-, hypertrophic dams in context with *Microcystis* dominance (Michard et al., 1996; Bonnet and Poulin, 2002; Latour et al., 2004);

and (ii) the monitoring areas of nuclear power plants at the middle Loire (Lair and Sargos, 1993; Lair and Reyes-Marchant, 1997; Lair et al., 1999). Longitudinal processes of potamoplankton have been considered only in a few studies (Leitão and Lepretre, 1998; Descy et al., 2011). The major controlling factors in connection with typological differences were first assumed by Leitão and Lepretre (1998). Recently, Descy and his co-authors (2011) pointed out that mechanisms controlling potamoplankton of the Loire are similar to those observed in other, large regulated rivers. This latter work also emphasized that habitat diversity and water level fluctuation are the key factors in this relatively unregulated river. The total potamoplankton taxa richness accumulated during the last two decades was estimated to be > 600 in the River Loire (Descy et al., 2011).

Both longitudinal studies (Leitão and Lepretre 1998; Descy et al., 2011) however, were limited to a few numbers of stations, and could not allow the authors to study the level of continuity at whole river scale, as well as excluded upstream dams' areas. Recently, in a long term study, Larroudé et al. (2013) found dramatic changes in the phytoplankton community at the middle Loire, and explained it by global changes in the influential factors like increased impact of agriculture, and consequently of pesticides.

Further data on the Loire potamoplankton are available since the end of 1980s, presented by the Society Bi-Eau (Angers) in annual reports to the Loire-Bretagne Water Authority (AELB, France). At the beginning of the 1990s, the eutrophic composition of the potamoplankton was already recognized (Bi-Eau, 1996) pointing out some compositional shifts at long term scale (Table 3).

Besides long term compositional changes in the Loire, former literature provide some taxa occurrence according to longitudinal positioning (Table 4). At the upper Loire, mainly benthic diatoms dominate such as *Amphora*, *Melosira varians*, *Navicula* spp., *Nitzschia* spp. (Leitão and Lepretre, 1998; Descy et al., 2011), however, some euplanktonic elements occur like *Microcystis* (Bonnet and Poulin, 2002; Latour et al., 2004; Descy et al., 2011) or *Dolichospermum* (Descy et al., 2011).

Table 3 *Long term changes in potamoplankton taxa composition of the River Loire; extraction of the most frequent taxa (Bi-Eau, 1996). * indicates correction to the current taxonomic name according to AlgaeBASE (Guiry and Guiry, 2013)*

des Cilleuls, 1928	Lair et al., 1978	Lair and Sargos, 1981	Bi-Eau, 1996
**Asterionella formosa* var. *gracillima*	**Pseudopediastrum boryanum*	*Scenedesmus* spp.	*Dictyosphaerium* spp.
Melosira varians	*Pediastrum duplex*	*Cyclotella glomerata*	*Monoraphidium* spp.
Nitzschia acicularis	**Monactinus simplex*	*Cyclotella meneghiniaia*	*Pediastrum* spp.
**Nitzscia holsatica*	*Pediastrum* spp.	*Stephanodiscus hantzschii*	*Scenedesmus* spp.
Fragilaria crotonensis	*Scenedesmus* spp.	*Actinastrum hantzschii*	*Aulacoseira granulata*
**Ulnaria ulna*	*Cyclotella glomerata*	*Coelastrum* spp.	*Cyclotella meneghiniaia*
Actinastrum hantzschii	*Cyclotella meneghiniana*	*Dictyosphaerium* spp.	*Melosira varians*
Ankistrodesmus falcatus	**Diadesmis confervacea*	*Pediastrum* spp.	*Nitzschia acicularis*
**Acutodesmus acuminatus*		*Navicula viridula*	*Stephanodiscus hantzschii*
**Desmodesmus quadricaudatus*		*Nitzschia acicularis*	**Planktothrix agardhii*
			**Limnothrix redekei*

The middle Loire disposes a diverse potamoplankton composition mainly by the dominance of planktonic centrics (*Cyclotella* spp., *Stephanodiscus hantzschii*, *Cyclostephanos* spp., *Skeletonema potamos*) and green algae (such as *Scenedesmus* spp., *Micractinium pusillum*, *Mucidosphaerium pulchellum*, *Micractinium pusillum*). The lowermost river section is resamblant to the middle Loire in potamoplankton composition, with some more frequent

occurrence of some taxa such as *Chlamydomonas, Actinastrum hantzschii*, *Scenedesmus* spp., *Merismopedia tenuissima*, or *Nitzschia fruticosa*.

Table 4 *Some dominant taxa along the River Loire in former literatures. * indicates correction to the current taxonomic name according to AlgaeBASE (Guiry and Guiry, 2013)*

Upper Loire	Middle Loire	Lower Loire
Amphora (Leitão and Lepretre, 1998); *Achnanthes* (Leitão and Lepretre, 1998); *Cocconeis* (Leitão and Lepretre, 1998); *Surirella* (Leitão and Lepretre, 1998); *Gomphonema* (Leitão and Lepretre, 1998); *Lyngbya* (Leitão and Lepretre, 1998); *Microcystis* (Bonnet and Poulin, 2002; Descy et al., 2011; Latour et al., 2004); *Navicula gregaria* (Leitão and Lepretre, 1998); *Fragilaria construens* (Leitão and Lepretre, 1998); *F. brevistriata* (Leitão and Lepretre, 1998); *Chlamydomonas* (Leitão and Lepretre, 1998); *Melosira varians* (Descy et al., 2011); **Dolichospermum* (Descy et al., 2011); *Planktothrix* (Descy et al., 2011)	*Skeletonema potamos* (Descy et al., 2011; Leitão and Lepretre, 1998); *Stephanodiscus hantzschii* (Descy et al., 2011; Leitão and Lepretre, 1998); *Cyclotella meneghiniana* (Descy et al., 2011; Leitão and Lepretre, 1998); *Cyclostephanos dubius* (Descy et al., 2011); *Nitzscia fruticosa* (Leitão and Lepretre, 1998); **Cylindrotheca closterium* (Leitão and Lepretre, 1998); *Nitzschia acicularis* (Leitão and Lepretre, 1998); *Monoraphidium* spp. (Leitão and Lepretre 1998); *Actinastrum hantzschii* (Descy et al., 2011; Leitão and Lepretre 1998); **Mucidosphaerium pulchellum* (Descy et al., 2011; Leitão and Lepretre 1998); *Dichotomococcus curvatus* (Descy et al., 2011; Leitão and Lepretre, 1998); **Desmodesmus quadricaudatus* (Leitão and Lepretre 1998); *Crucigenia lauterbornii* (Leitão and Lepretre, 1998); *Golenkinia* (Leitão and Lepretre, 1998); *Scenedesmus* spp. (Descy et al., 2011; Leitão and Lepretre, 1998); *Micractinium pusillum* (Descy et al., 2011); *Discostella pseudostelligera* (Descy et al., 2011); *Cyclostephanos invisitatus* (Descy et al., 2011); **Ulnaria delicatissima* var. *angustissima* (Descy et al., 2011)	*Nitzschia fruticosa* (Leitão and Lepretre, 1998); *Asterionella formosa* (Descy et al., 2011; Leitão and Lepretre, 1998) ; *Scenedesmus* spp. (Descy et al., 2011; Leitão and Lepretre, 1998); *Fragilaria crotonensis* (Descy et al., 2011; Leitão and Lepretre, 1998) ; *Aulacoseira granulata* (Leitão and Lepretre, 1998); **Discostella stelligera* (Leitão and Lepretre, 1998); **Dolichospermum* (Leitão and Lepretre, 1998); *Oscillatoria* (Leitão and Lepretre, 1998) ; *Microcystis aeruginosa* (Leitão and Lepretre, 1998) ; *Aphanocapsa elachista* (Leitão and Lepretre, 1998); *Merismopedia tenuissima* (Leitão and Lepretre, 1998) ; *Thalassiosira pseudonana* (Descy et al., 2011; Leitão and Lepretre, 1998); *Chlamydomonas* (Descy et al., 2011; Leitão and Lepretre, 1998); *Coelastrum* (Descy et al., 2011; Leitão and Lepretre, 1998); *Actinastrum hantzschii* (Descy et al., 2011; Leitão and Lepretre, 1998)

1. 3. Phytoplankton functional group concepts

1.3.1. Traditional taxonomy *vs.* functional groups

According to the possibly co-occurring high number of taxa (Hutchinson, 1961), phytoplankton as model system has been used widely to understand vegetation processes such as species succession (Sommer et al., 1986, 2012), or species competition (Tilman et al., 1982; Sommer 1983, 1986). Besides the traditional phenotypic taxonomical classification of phytoplankton, new approaches like molecular methods are now applied to determine reliable phylogenetic positions of taxa (Krienitz and Bock, 2012; Zapomělová et al., 2012). However, non taxonomic, polyphyletic classifications based on functional traits of phytoplankton receive an increasing scientific interest. At first, Margalef (1958) recognised that phytoplankton composition is directed towards two possible end of selectivity: r- or K-selected species; where seasonal succession tends to be oriented from small, first colonizer taxa with high growth rate (r-strategy) towards larger species with special abilities (for example motility, N_2 fixation) to overcome others (K-strategy)—(Fig. 9a).

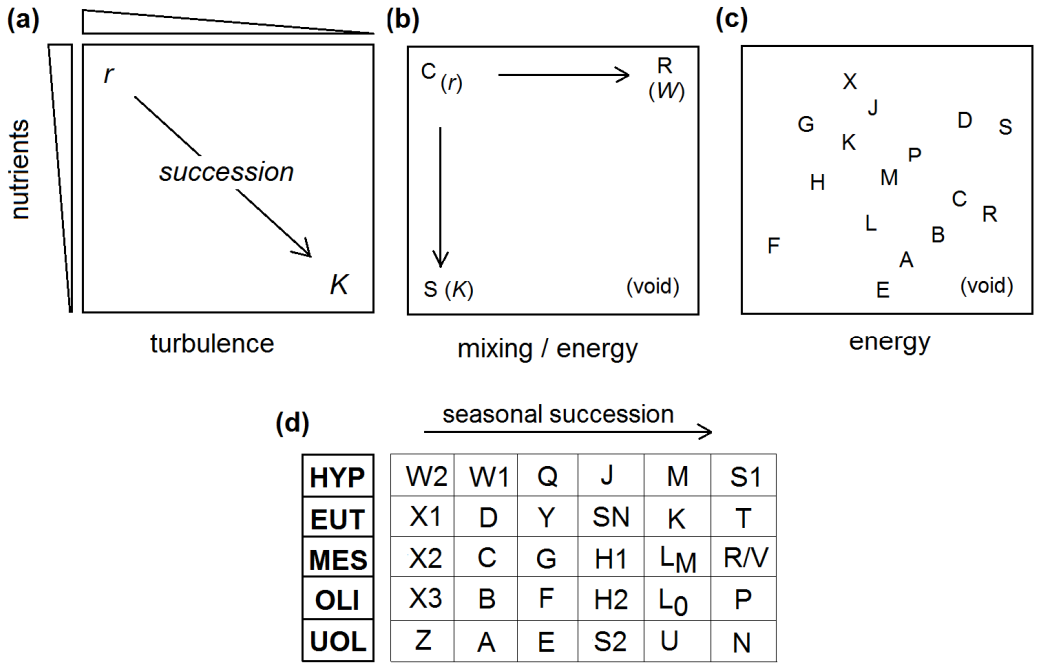

Fig. 9 (a) *Sequences of phytoplankton succession from* r- *towards* K-*selected species in the light of nutrient content and physical mixing (Margalef, 1958);* **(b)** *Reynolds's representation of the* r-K *succession, complemented by the* R *strategy (Reynolds, 1997);* **(c)** *habitat templates of species associations (coda) based on Reynolds (1987, 1997);* **(d)** *seasonal succession- and trophic state-mediated coda classification of Reynolds (2005). Redrawn and modified for similar organization form Margalef (1958), Reynolds (1997, 2005*)

Further milestone was the reconsideration of the CSR plant strategies of Grime (1977) for phytoplankton (Reynolds, 1987); and then, the continuous recognition of phytoplankton species groups sharing similar morphological or physiological characteristics being able to develop in similar habitats under a more or less well defined environmental conditions (Reynolds, 1984, 1997; Reynolds et al., 2002). Functional groups of phytoplankton thus collect species with similar morphological, physiological, or phenological traits, which impact their growth, reproduction, or survival (Violle et al., 2007); and help them to benefit under

specific environmental conditions. Accordingly, these traits are responsible for the success of each taxon, and determine the structure and composition of communities (Weithoff, 2003; Litchman et al., 2007; Litchman and Klausmeier, 2008).

1.3.2. The phytoplankton functional group concept

Since the recognition of 14 typical lake phytoplankton assemblages (Reynolds, 1984) signed by alphabetic letters (coda), the described coda number has been increased up to 40 including river systems (Padisák et al., 2003a, 2006, 2009; Borics et al., 2007). Besides the fact that the FG concept was built based on lentic phytoplankton assemblages, the relevance of the functional groups approach in river systems was also explained by the same author (Reynolds, 2003). The success of the FG concept relies further on the fact, that phytoplankton composition is highly related to physical constraints (Reynolds, 1994; Naselli-Flores and Barone, 2011), and disturbances (Reynolds et al., 1993; Lindenschmidt and Chorus, 1998; Hambright and Zohary, 2000); as well as to the trophic state of the milieu. Altogether, the FG concept makes possible to determine physic *vs.* nutrient templates of coda (Fig. 9c); and to open towards the predictability of phytoplankton composition according to characteristics of the environment. In connection with the Water Framework Directive's requirements, the FG concept was used to develop water qualification systems for lakes (Reynolds, 2005; Padisák et al., 2006), as well as for rivers (Borics et al., 2007). In lakes, the seasonal succession of phytoplankton might be predictable according to the trophic state (Fig. 9d, modified from Reynolds, 2005), and the late summer composition might be successfully used in monitoring systems (Padisák et al., 2006). In rivers, potamoplankton composition might be assessed according to nutrient state, turbulence, the sufficient time for the development of the each assemblage, and risk of functional traits with potential toxicity (Borics et al., 2007). The efficiency of the FG classification has been already supported by papers addressed to reservoirs (Crossetti and Bicudo, 2005, 2008; Becker et al., 2009a, 2009b; Hu et al., 2013; Zhu et al., 2013), floodplains (Huszar and Reynolds, 1997; Stević et al., 2013), rivers (Borics et al., 2007; Devercelli, 2010; Stanković et al., 2012; Devercelli and O'Farrell, 2013; Zhu et al., 2013), as well as to estuarine (Costa et al., 2009) environments.

1.3.3. Further functional classifications

Besides the FG classification, two others, the morpho-functional classification—MFGs (Salmaso and Padisák, 2007) and the morphology-based functional classification—MBFGs (Kruk et al., 2010) share high scientific interest. The MFG was develeped to understand phytoplankton dynamics in Alpine lakes, and was successfully used almost in similar environments (Tolotti et al., 2010, 2012). The MBFG concept was proposed as a simple classification tool for water quality management; and has been applied mainly in shallow turbid environments (Pacheco et al., 2010; Gallego et al., 2012; Segura et al., 2013). While most of the recent publications test only one of these classifications, some comparative analyses already provide results for reservoir (Hu et al., 2013), floodplain (Izaguirre et al., 2012) and for river ecosystems (Stanković et al., 2012). According to former comparisons, authors often found more sensitive the FG and the MFG classifications; and they paid the attention that the MBFG classification underestimates the importance of light climate in shallow lakes (Izaguirre et al., 2012), cannot proceed to interpret species richness in detail (Gallego et al., 2012) as it keeps all diatom taxa in a single group thus might produce bias when it is correlated to environmental parameters (Stanković et al., 2012; Hu et al., 2013).

Theoretical overlaps between the three classifications is provided in Table 5, based on all phytoplankton taxa involved in the review of Padisák et al. (2009).

Table 5 *Theoretical overlaps and morphological differences between the three most frequently used phytoplankton functional classifications: MBFGs (Kruk et al., 2010); MFGs (Salmaso and Padisák, 2007); and FGs (Reynolds et al., 2002; Borics et al., 2007; Padisák et al., 2009)*

MBFGs	Morphology in MBFGs	MFGs	Morphology in MFGs	Further morphological subclasses in MFGs	FGs
I	Small organisms with high *S/V*	**4**	Unicellular Cyanobacteria	Unicellular Cynobacteria	**Z**
		5	Colonies Cyanobacteria	**5d** Small Chroococcales colonies	**Z, Z_{MX}, K, L_0**
		9	Small other unicellular	**9a** Small unicells (Conjugatophytes)	**N, N_A, X3**
				9b Small unicells (Chlorococcales)	**X3, X1, J**
				9d Small unicells (Other groups)	
II	Small flagellated organisms with siliceous exoskeletal structures	**2**	Small (unicellular)	**2a** Small Chrysophytes/Haptophytes	**X3, X2, E**
				2b Small Dinophytes	**L_0**
				2c Small Euglenophytes	**W1, W2**
				2d Cryptophytes	**X2, Y,**
		3	Phytomonadina	**3a** Unicellular Phytomonadina	**X2, XPh, W_0**
				3b Colonial Phytomonadina	**G, W1, W_0**
		9	Other mall unicellular	**9c** Small Chrysophytes	**X3, X1**
III	Large filaments with aerotopes	**5**	Colonial (Filamentous) Cyanobacteria	**5a** Thin filaments (Oscillatoriales)	**MP, S1, S2, R**
				5e Nostocales	**MP, SN, H1, H2**
IV	Organisms of medium size lacking specialized traits	**5**	Colonial (Filamentous) Cyanobacteria	**5a** Thin filaments (Oscillatoriales)	**MP, TC**
				5c Large colonies, mostly non-vacuolated Chroococcales	**TC, K, Lo**
		8	Other large unicellular	**8a** Large unicells (Conjugatophytes/Chlorophytes)	**P, T_D, X3, X1**
				8b Large unicells (Other groups)	
		10	Other Filaments	**10a** Filaments (Chlorophytes)	**T_D**
				10b Filaments (Conjugatophytes)	**N, P, MP, T, T_D**
				10c Filaments (Xanthophytes)	
		11	Non filamentous colonies	**11a** Chlorococcales (Naked colonies)	**X1, J, K**
				11c Other colonies	
V	Unicellular flagellates of medium to large size	**1**	Large (colonial or unicellular)	**1a** Large Chrysophytes/Haptophytes	**E, U, WS, Q**
				1b Large Dinophytes	**Z_{MX}, Y, L_o, LM**
				1c Large Euglenophytes	**W1, W2**
VI	Non-flagellated organisms with siliceous exoskeletons	**6**	Large Diatoms	**6a** Large Centrics	**A, B, C, D, P**
				6b Large Pennates	**A, C, D, N, P, MP, T_D, T_B**
		7	Small Diatoms	**7a** Small Centrics	**A, B, C, D**
				7b Small Pennates	**D, MP, T_D, T_B**
VII	Large mucilaginous colonies	**5**	Cyanobacteria colonies	**5b** Large vacuolated Chroococcales	**L_0, L_M, M**
		11	Other non filamentous colonies	**11b** Chlorococcales (Gelatinous colonies)	**F**

Besides the aforementioned classifications, Fraisse et al. (2013) recently proposed a new morphological classification for potamoplankton. The most important characteristics included in the system are: (i) presence/absence of motility; (ii) level of complexity (single cell/colony, filament); (iii) shape and linear dimension; and (iv) presence/absence of silica. The author found this approach successful to assess potamoplankton composition in rivers with contrasting flow characteristics.

A detailed description of classifications and their possible use in research and water quality assessments can be found in recent doctoral theses of Devercelli (2008), Cellamare (2009), Kruk (2010), Centis (2011), Stanković (2013), and Fraisse (2013). Furthermore, a comprehensive review among phytoplankton functional approaches is being published by Salmaso et al. (in press).

2. Introduction and Thesis outline

Potamoplankton is one of the biological elements required to be included in river water quality monitoring by the European Water Framework Directive (WFD, 2000). Traditional monitoring systems are based on phytoplankton biomass and Chl-*a* (Mischke et al., 2011), in some cases on further accessory photosynthetic pigments, or on these combinations (Friedrich and Pohlmann, 2009). Many river phytoplankton monitoring and researches use mainly species or genus level data, resulting in long taxonomical lists, which are often difficult to interpret (Ibelings et al., 1998; Wu et al., 2011b). The opposite end, however, frequently occurs in modeling researches where data are often restricted to major algal classes (Garnier et al., 1995) or explicitly to the afore-mentioned Chl-*a* (Sellers and Bukaveckas, 2003; Caraco et al., 1997). This latter simplification, however, might prohibit covering all functional aspects required for an ecology-based implementation of river processes, or water quality status. In addition, these latter variables are not able to reflect species or functional trait level properties of phytoplankton, and their quantities are highly conditioned according to age and growth conditions of populations (Padisák, 2003). Furthermore, while the relationships between phytoplankton biomass and human impacts are often difficult and unclear, the composition of phytoplankton seems to be more reliable to understand these relationships (Walsh et al., 2005).

As an alternative method, grouping river algae into polyphyletic functional groups—'FGs' (*Chapter 1.3.*) may hold the potential for new approaches in potamoplankton ecology and in river water quality management as well. The compositional changes of FGs is expected to follow longitudinal processes of rivers at a spatio-temporal scale, and might better indicate ecological status than other systems based on explicitly taxa composition, biomass, Chl-*a*, or species richness. Accordingly, the Thesis opens towards the use of phytoplankton functional classifications in river water quality monitoring and ecological research, and it is purposed to provide an example of how new scientific approaches might be successfully implemented into existing surveillance systems like the Loire phytoplankton monitoring. To verify the sensitivity and reliability of phytoplankton FGs in rivers, their compositional changes are studied along the Continental Atlantic River Loire, and are related to different anthropogenic pressures might occurring along the natural gradients disposed by geographical, hydrological, and chemical data patterns at a whole river scale.

Besides water quality issues, longitudinal changes of potamoplankton composition have been still less frequently studied worldwide (Lampert and Sommer, 2007). This assumption is explicitly valid for the River Loire, where former phytoplankton studies were mainly restricted to either the upper (Michard et al., 1996; Bonnet and Poulin, 2002; Latour et al., 2004), or to the middle Loire part (Lair and Sargos, 1993; Lair and Reyes-Marchant, 1997; Lair et al., 1999). Though Leitão and Lepretre (1998), and recently Descy et al. (2011) already pointed out main controlling factors on phytoplankton along the Loire, according to the few number of stations used, these studies could not detail the level of connectivity along this relatively unregulated river (Descy, 2009; Descy et al., 2011), which factor, however, mainly determines all riverine processes (Tockner and Stanford, 2002; Ward et al., 2002; Frenette et al., 2012). Therefore, a second major objective of the Thesis is to provide a comprehensive longitudinal description on potamoplankton composition along the Loire, and to discuss potamoplankton FGs' distribution in relation to different seasonally *vs.* longitudinally dependent controlling factors (Fig. 10). Accordingly, the Thesis further opens towards a coupling of well known riverine theories like the 'River Continuum Concept' (Vannote et al., 1980), or the "Riverine Ecosystem Synthesis model' (Thorp et al., 2006) and

applied ecological questions, which maintain the aim of understanding river water quality issues at a whole River Loire scale.

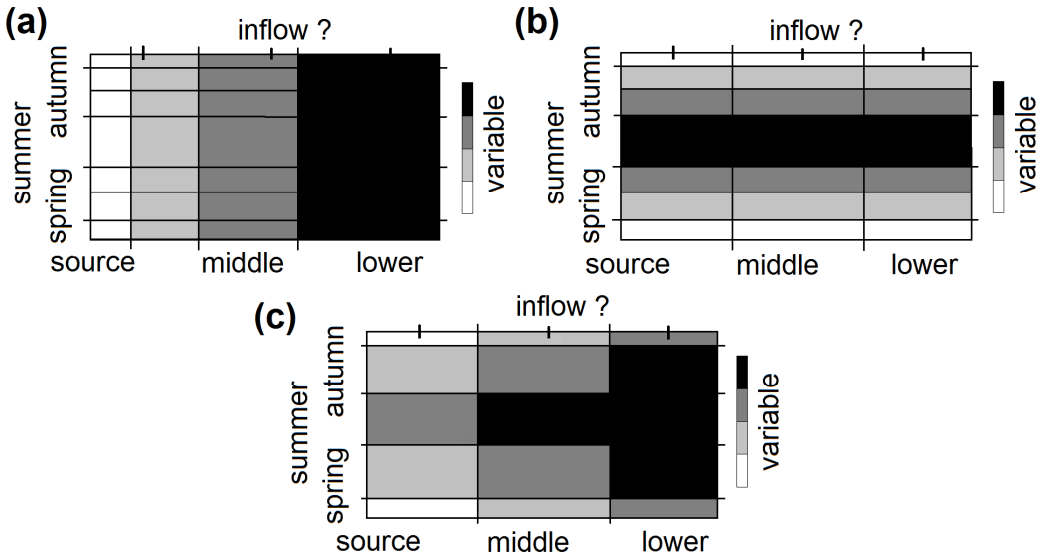

Fig. 10 *Theoretical distribution of variables at a spatio-temporal, one year scale* **(a)** *only longitudinal/regional differences;* **(b)** *only seasonal dependence of the variable; and* **(c)** *both seasonal and spatial patterns in distribution*

2.1. Specific objectives of the Thesis

Objective 1: Specify potamoplankton river zones based on different functional group classifications along the River Loire. (One year data, 2009)

Recently, three phytoplankton functional classifications receive a distinguished scientific interest: the morphology-based functional classification (Kruk et al., 2010), the morpho-functional system (Salmaso and Padisák, 2007), and the functional group classification (Reynolds et al., 2002). These systems were mostly studied in lentic, but in few cases in lotic environment. The 1st thesis objective is to study (i) whether these classifications are adequate in rivers in their present form, or not; (ii) which classification(s) is/are the most reliable to follow river longitudinal processes, including hydrology- and geography-determined regional differences?; and (iii) which classification(s) is/are able to display reliable potamoplankton river zones, if relevant along the River Loire?

Objective 2: Study phytoplankton functional groups as ecological indicators of human impacts along the River Loire. (One year data, 2009)

As biological processes and nutrient availability are highly related to hydrological regimes, while hydrology is basically determined by geographic location and climate, a general continuous change is expected to occur in the potamoplankton composition along rivers, in accordance with theories like the 'River Continuum Concept' (Vannote et al., 1980). Any discontinuity thus might be a sign of either natural or human-mediated constrain. The 2nd thesis point is to study the relationships between the FG composition based on the $Q_{(r)}$ potamoplankton index (Borics et al., 2007) and human impacts along the River Loire, with

the following specific questions: (i) how natural is the seasonal succession of potamoplankton along the River Loire?; (ii) which kinds of succession stages are recognized by the $Q_{(r)}$ potamoplankton composition index?; and (iii) how the $Q_{(r)}$ is related to algal dominance ranks indicated by the Shannon–Weaver diversity index?

Objective 3: Ecological status estimation of the River Loire based on potamoplankton. A comparison of species and functional groups in water quality assessments. (One year data, 2009)

According to the European Water Framework Directive's requirements (WFD, 2000), human impacts must be identified, and then attenuated to reach good water quality by 2015. In Europe, only two potamoplankton indices exist: the German PhytoFluss (Mischke et al., 2011), and the Hungarian HRPI (Borics et al., 2009). The 3rd thesis point is to study these indices along the River Loire, and to answer to the following questions: (i) which is the actual estimated ecological state of the River Loire based on potamoplankton?; (ii) which is the level of suit to implement these indices into the Loire?; (iii) when and why these indices perform better, if so, along the Loire?

Objective 4: Specify similarities and dissimilarities of FGs' occurrence along the River Loire between three consecutive years with contrasting hydrological characteristics. (Three year data, from 2009 to 2011)

While the presence of potamoplankton taxa at a river section might be hard to be prognosticated among years (Reynolds and Descy, 1996), FGs might be more reliable for this indication according to functional clustering of taxa into larger groups. A reason for their possible success is a kind of similar functioning of river zones/regions among years, which might provide similar functioning for major controlling factors even hydrologically distinct years, resulting in a predictable FGs' patchiness. The 4th objective is aimed to compare the three consecutive years along the River Loire (i) in the longitudinal distribution of FGs; (ii) in succession stages based on the $Q_{(r)}$ potamoplankton index (Borics et al., 2007); and (iii) to identify the main physical and chemical factors controlling potamoplankton composition along the river.

Objective 5: Analyse longitudinal patterns of potamoplankton species vs. *functional group richness, and their relationships to ecosystem functioning in the River Loire. (Three year data, from 2009 to 2011)*

For lentic phytoplankton communities, the stability and productivity have been shown to depend on diversity and taxonomic richness in natural communities (Ptacnik et al., 2008; Weyhenmeyer et al., 2013), as well as under culture conditions (Corcoran and Boeing, 2012). Potamoplankton, however, largely differ in organization from lake phytoplankton, where physical processes basically determine the composition between two ends: autochthonous directed succession and chaotic mixing. This latter dependence of potamoplankton composition, however, has not been yet discussed elsewhere in connection with ecosystem functioning. The 5th thesis point aims to study (i) how species and FG richness of potamoplankton are related to ecosystem functioning based on biomass:TP ratio (Ptacnik et al., 2008), and in the light of Loire longitudinal processes?; and (ii) how taxa and FG richness depend on year specific seasonal and longitudinal differences in hydrology along the River Loire?

3. Material and Methods

3.1. Sampling stations

The sampling stations were designated between Malvalette and Montjean towns, thereby excluding the real river source and the downstream sector submitted to tidal influence of the Atlantic Ocean (Fig. 11). Station names are converted into station numbers through the Thesis (from upstream towards downstream), as the followings: 1) Malvalette: at 145 km distance from source—'km d.f.s.', 2) Saint-Just-Saint-Rambert: 176 km d.f.s., 3) Balbigny: 223 km d.f.s., 4) Villerest: 258 km d.f.s., 5) La Motte Saint-Jean: 336 km d.f.s., 6) Bourbon-Lancy: 372 km d.f.s., 7) Decize: 412 km d.f.s., 8) Nevers: 448 km d.f.s., 9) Fourchambault: 461 km d.f.s., 10) Saint-Satur: 506 km d.f.s., 11) Gien: 555 km d.f.s., 12) Jargeau: 609 km d.f.s., 13) Meung-sur-Loire: 648 km d.f.s., 14) Muides-sur-Loire: 672 km d.f.s., 15) Chaumont-sur-Loire: 707 km d.f.s., 16) Villandry: 766 km d.f.s., 17) Chouzé-sur-Loire: 794 km d.f.s., 18) Saint-Mathurin-sur-Loire: 840 km d.f.s., 19) Montjean-sur-Loire: 885 km d.f.s.

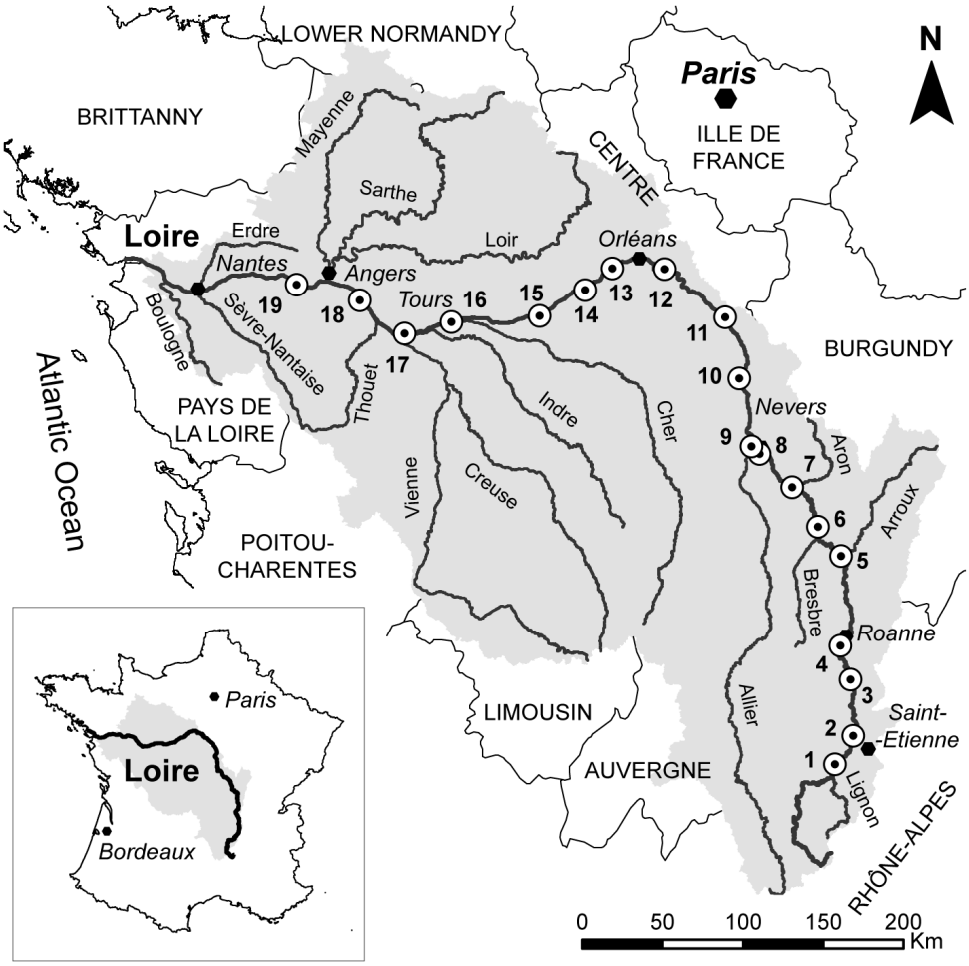

Fig. 11 *The River Loire phytoplankton sampling stations in years 2009-2011 (Numbers indicate the corresponding station locations detailed in the text)*

3.2. Phytoplankton analyses

Phytoplankton was sampled once a month between March and November from years 2009, 2010, and 2011; as part of the regular water quality monitoring program conducted by the Loire-Bretagne Water Authority (France). Samples were taken at the thalweg using a bucket, then fixed *in situ* by acidified Lugol's solution, and transported to the Bi-Eau consultancy for analyses (division of labour is detailed in *Appendix I*, Table 1). The Utermöhl (1958) method was used to quantify phytoplankton, performed with an inverted microscope (Olympus CK2) using 10× and 40× objectives. The counting unit was individuum (unicell, coenobium, filament or colony). In each sample, at least 400 sedimentation units were counted (Lund et al., 1958). During the count, transects were used in most of the cases, except spring diatoms' peak, when fields were preferred without sample dilution. The biomass was determined by specific biovolume, where the dimensions of each taxon were based on multiple measurements from Loire populations. Geometric forms were approximated according to Lund and Talling (1957) and Rott (1981). Biomass was expressed in fresh weight by the equation: $1mm^3L^{-1}=1\ mgL^{-1}$ (Holmes et al., 1969). In this standard monitoring system, biomass calculation included only taxa representing more than 1% in counts.

Phytoplankton taxa were identified according to Geitler (1930-1932), Huber-Pestalozzi (1955), Fott (1968), Ettl et al. (1978, 1985), Komárek and Fott (1983), Starmach (1985), Popovský and Pfiester (1990), Komárek and Anagnostidis (1999, 2005). In cases of diatoms' dominance, permanent slides were prepared using the European standard method (CEN, 2003). Diatoms were determined using manuals by Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b, Lange-Bertalot (2001) and Krammer (2002).

3.3. Functional classifications of phytoplankton

Phytoplankton taxa were classified into phytoplankton functional groups—'FGs' according to Reynolds et al. (2002), Borics et al. (2007) and Padisák et al. (2009), into morpho-functional groups—'MFGs' using proposals of Salmaso and Padisák (2007), and into morphology-based functional groups—'MBFGs' applying Kruk et al. (2010).

3.4. Hydrological, geographical and chemical data

Geographical and chemical parameters were provided by the official water quality website of 'OSUR'—(web[1]), while daily discharge values were used as monthly averages, available at the page 'Banque Hydro'—(web[2])'. Theoretical water residence time (WRT) was calculated by the equation of $WRT=0.08*Ad^{0.6}*Q^{-0.1}$, where Ad: drainage area (km^2) and Q: water discharge (m^3s^{-1}) (Søballe and Kimmel, 1987; Leopold et al., 1995). For molar ratio calculations of TN:TP and SRSi:TP (N:P and Si:P further in the text), the addition of nitrate-N, nitrite-N and Kjeldahl-N was used, while TP and SRSi contents were directly obtained from the online available data set. In case of amounts below detection limits, the half detection values were used for data analyse, as well as for figures.

3.5. Statistical analyses

In order to preserve both spatial and temporal variation of data, the Self Organizing Map (SOM) method was used in *Chapter 3.1.* to analyse FG composition of potamoplankton. While conventional methods might distort along non-linear relationships (Giraudel and Lek,

2001), SOM is stated to be useful for exploratory data analysis in a multidimensional scale (Shanmuganathan et al., 2006). The SOM method has been already used successfully in potamoplankton ecology (Várbíró et al., 2007; Stanković et al., 2012); in fish zonation (Lasne et al., 2007); as well as in diatom research at large spatial scales (Rimet et al., 2004; Park et al., 2006; Stenger-Kovács et al., 2014).

In *Chapter 3.2.,* hierarchical cluster analysis was performed in order to determine similar sampling stations based on potamoplankton and chemical compositions. The Syntax 2000 software (Podani, 1988) was used with Bray-Curtis dissimilarity indices using UPGMA fusion algorithm.

In *Chapter 3.3.,* Pearson correlation was used to compare water quality values provided by the PhytoFluss and HRPI potamoplankton assessments and, to relate them with general water quality parameters such as Chl-*a* content, TP, total potamoplankton biomass, and relative biomass of different algae classes.

The longitudinal distribution of potamoplankton coda was analysed in *Chapter 3.4.* by a general linear regression between the seasonal average of relative biomass contribution of each FG to the total biomass and the distance from the source in the SigmaPlot for Windows v. 11.0 program. Furthermore, a canonical correspondence analysis—'CCA' was performed in order to determine relationships between the distribution of FGs' biomass, physical, and chemical data. For this purpose, FGs' biomass was log transformed, while environmental parameters were normalized. Prior to CCA analysis, draftsman plot analysis was conducted to estimate the potential for colinearity, and also Kolmogorov-Smirnov test for the estimation of normality of data. The CCA was run by the CANOCO 4.5 software (ter Braak and Šmilauer, 2002) using 499 Monte Carlo permutation tests.

Variables of potamoplankton and chemical data were plotted using the Surfer Surface Mapping System v. 9.0 with the Kriging gridding method and the SigmaPlot for Windows v. 11.0 (Systat Software, Inc.) program.

4. Results

4.1. A large river (River Loire, France) survey to compare phytoplankton functional approaches: Do they display river zones in similar ways?[1]

Thesis Objective 1

[1] This chapter was presented at the 8th SEFS (Symposium for European Freshwater Sciences) meeting, held 1-5 July 2013, Münster, Germany; and accepted for publication in a slightly modified version in ECOLOGICAL INDICATORS.

Abonyi, A., M. Leitão, I. Stanković, G. Borics, G. Várbíró & J. Padisák, 2014. A large river (River Loire, France) survey to compare phytoplankton functional approaches: Do they display river zones in similar ways? Ecological Indicators 46(0):11-22 doi:http://dx.doi.org/10.1016/j.ecolind.2014.05.038.

4.1.1. Specific introduction

Upper parts of streams are basically heterotrophic ecosystems where decomposition of allochthonous sources dominates over autotrophic production (Lampert and Sommer, 2007; Üveges and Padisák, 2012). Significant autotrophic primary production is expected to occur only in large rivers (Thorp and Delong, 1994) and it is limited to middle river sections, or to lowland areas of high river orders, presuming favourable conditions for phytoplankton growth (Reynolds and Descy, 1996).

Theoretical concepts have been developed to understand longitudinal patterns of various biotic (Huet, 1959; Vannote et al., 1980) and abiotic (Newbold et al., 1981) parameters along rivers, but longitudinal changes of river phytoplankton composition have been scarcely studied (Lampert and Sommer, 2007). While biological processes might change continuously along rivers (Vannote et al., 1980), the 'Riverine Ecosystem Synthesis model' (Thorp et al., 2006) presumes the existence of functionally different river zones based on hydro-morphological and geo-morphological differences. Thus, based on these longitudinal distinctions, the model predicts the existence of different river zones reflected by the corresponding composition of biota.

Here, the use of phytoplankton functional groups is proposed to test their success in determining river zones by compositional changes in potamoplankton along the River Loire. Three functional approaches gained considerable scientific interest in recent years (Salmaso et al., 2012): phytoplankton functional groups—FGs (Reynolds et al., 2002), the morpho-functional classification—MFG (Salmaso and Padisák, 2007), and the morphology-based functional classification—MBFG (Kruk et al., 2010). While the MBFG classification has been proposed as a simple tool for water quality management, FGs have been already used to develop water quality indices for lakes (Padisák et al., 2006) and for rivers (Borics et al., 2007). Most of the recent publications test only one of these classifications, some comparative analyses already provide results for reservoirs (Hu et al., 2013), floodplain lakes (Izaguirre et al., 2012) and river ecosystems (Stanković et al., 2012).

Furthermore, the European official demand for ecological monitoring (WFD, 2000) has led to the development of new assessment methods for lake phytoplankton (Reynolds, 2005; Padisák et al., 2006), for potamoplankton (Borics et al., 2007; Mischke et al., 2011), as well as for benthic diatoms (Kelly et al., 2009; Jüttner et al., 2012). However, ecoregional differences still pose a major challenge in their application at large spatial scale (Tison et al., 2005; Beltrami et al., 2012; Várbíró et al., 2012).

Former Loire phytoplankton studies were mainly focused on water quality issues, and they were restricted to analyses of influence of upstream dams (Michard et al., 1996; Bonnet and Poulin, 2002; Latour et al., 2004), and of nuclear power plants in the middle Loire (Lair and Reyes-Marchant, 1997; Lair et al., 1999). Longitudinal changes of the phytoplankton, however, were considered only in a few publications. Leitão and Lepretre (1998) described some topographical relationships of potamoplankton composition along six stations in the Loire. Recently, Descy and his co-authors (2011) concluded similar functioning and controlling factors to those found in other large, but more regulated European rivers. Furthermore, Abonyi et al. (2012) highlighted that human impacts might be successfully indicated by the $Q_{(r)}$ compositional index (Borics et al., 2007) along the Loire; and that besides natural processes, shifts in FGs are also related to human mediated physical and chemical impacts.

The objective of this article is to compare three phytoplankton functional classifications (MBFG, MFG, FG) as potential ecological, and water quality management tools along the River Loire. The authors use the same dataset presented by Abonyi et al. (2012); applying the three functional systems independently, with the following specific questions:

(i) How these classifications display river zones, reflected by the correspondent morphological, morpho-functional, and functional composition of potamoplankton?

(ii) Which relationships can be found between these river zones and basic regional differences in geography, climate and hydro-ecoregions along the River Loire?

(iii) How the identified river zones (if relevant) are able to follow the main chemical characteristics in the River Loire?

4.1.2. Specific methods

Hydrological and chemical characteristics of the River Loire

Month average of specific discharge ($Lkm^{-2}s^{-1}$) was used to characterize hydrological differences according to catchment size at each sampling station. The distribution of essential phytoplankton nutrients was characterized using molar ratios of total nitrogen to total phosphorus; and soluble reactive silica—'SRSi' to total phosphorus (N:P and Si:P further in the text). Total nitrogen was determined by the sum of nitrate-N, nitrite-N and Kjeldahl-N; while TP and SRSi contents were directly obtained from the data set.

Statistical analyses

The SOM data matrix contained 170 samples and 56 variables (7 MBFGs, 25 MFGs, and 24 FGs). In the first selection phase of SOM, the weights of the output layer were assigned randomly. Then, after random choose of a sample, the best matching unit (BMU) was selected by Euclidean distance (ranged between 0.5-1.0) between the input and output layer weights, using the Ward algorithm. The selection of the BMUs was based on normalized values of relative biomass of each functional group in each classification. After the learning phase, a hexagon map was obtained with hexagon subsets of the weight/coda compositions for each classification (See *Appendix III*). These final hexagon maps visualized the component planes (CPs), where each CP represented the supplied variables by the SOM algorithm.

4.1.3. Results

SOM clusters based on the three functional classifications

Using the best matching units of SOM, six sample clusters were created for each classification (First letters of clusters refer the first author of original papers describing approaches). Based on the MBFGs, most samples (76) were placed in cluster 6 (K6 further in the text) containing samples with diatom dominance (GVI of MBFGs). Another large SOM cluster, (K4) contained 45 samples, without any clear relation to one or more MBFGs. The smallest sample cluster (K2) was separated by the dominance of large filaments with aerotops—GIII and large mucilaginous colonies—GVII.

Applying the SOM for MFG data, three main functional clusters can be distinguished (i) cluster S4, dominated by small centrics, diverse group of flagellates, and unicellular cyanobacteria —7a, 1a, 3a, 4 (ii) S5, by the dominance of large pennate diatoms—6b (iii) S2, a diverse algal group of euglenoids, filamentous and chroococcalean cyanobacteria, benthic pennate diatoms and filamentous conjugatophytes—1c, 5a, 5b, 5c, 7b, 10b, 11c. The smallest

separated cluster, S1, contained only 8 samples, with the dominance of cryptophytes and large centric diatoms—2d, 6a.

Table 6 *Characteristic taxa of the SOM clusters based on functional approaches of MBFGs (Kruk et al., 2010), MFGs (Salmaso and Padisák, 2007), and FGs (Reynolds et al., 2002), (Borics et al., 2007), (Padisák et al., 2009). Numbers - 'n°' indicate the number of samples involved in each SOM cluster, while functional groups in brackets indicate slight relation to the given cluster. (Full taxonomic names are given in* Appendix IX*)*

	SOM cluster	Representative taxa	Representative functional group	n°
MBFGs	K1	*Dinobryon*, *Chrysococcus*, *Scenedesmus*, *Coelastrum*	(GII, GIV)	20
	K2	*Anabaena*, *Planktothrix*, *Microcystis*, *Aphanocapsa*	GIII, GVII, (GI)	2
	K3	*Plagioselmis*, *Chlamydomonas*, *Trachelomonas*, *Euglena*	GV	5
	K4	chlorococcalean greens, diatoms	(GIV, GVI)	45
	K5	*Monoraphidium*, *Scenedesmus*, *Chrysococcus*	GIV, GII, (GI)	22
	K6	diatoms	GVI	76
MFGs	S1	*Plagioselmis*, *Aulacoseira*, *Cyclotella*, *Stephanodiscus*	2d, 6a	8
	S2	*Planktothrix*, *Microcystis*, *Anabaena*, *Euglena*, *Trachelomonas*	1c, 2c, 5a, 5b, 5c, 5e, 7b, 9a, 9d, 11c	23
	S3	*Eudorina, Volvulina*, *Synechococcus*	(6a, 3b, 4)	28
	S4	centrics, *Chlamydomonas*, *Dinobryon*	7a, 3a, 1a, 4	52
	S5	*Navicula*, *Nitzschia*	6b, (7b)	38
	S6	*Scenedesmus*, *Monoraphidium*, *Dictyosphaerium*, *Merismopedia*	5d, 8a, 9b, 11a, 11b	21
FGs	R1	*Navicula*, *Nitzschia*, *Eudorina*, *Volvulina*	**T_B**, **G**	12
	R2	*Chlamydomonas*, *Aulacoseira ambigua, Plagioselmis*, *Cyclostephanos*	**B, C, X2, (X1)**	39
	R3	*Nitzschia acicularis*, *Skeletonema potamos*, *Stephanodiscus*, centrics	**D**	31
	R4	*Aulacoseira granulata*, *Fragilaria crotonensis*, *Planktothrix*, *Anabaena*	**P**, **M**, **H1**, **K**, **S1**, **T_C**, (**T_D**, **X3**, **Y**)	8
	R5	*Scenedesmus*, *Monoraphidium*, *Dictyosphaerium*	**J**, **X1**, **F**, **L_0**	23
	R6	*Nitzschia*, *Navicula*, *Trachelomonas*, *Euglena*	**T_B**, **T_D**, **W1**, **W2**	57

Based on the FGs classification, large SOM groups were (i) R6, containing benthic diatoms—codon **T_B** with euglenoids (coda **W1**, **W2**); (ii) R2, with small flagellates (**X2**) and mesotrophic centric diatoms of coda **B**, **C**; (iii) R3 with eutrophic diatoms—codon **D**; (iv) R5 by the co-occurrence of single celled and mucilaginous chlorococcalean greens (coda **X1**, **F**) with dinophytes of codon **L_0**. Smaller clusters were separated by the mixture of (i) limnophilic meso-eutrophic pennate diatoms (codon **P**), planktonic cyanobacteria (coda **M**, **S1**), and samples containing benthic filamentous cyanobacteria (codon **TC**) in cluster R4; and (ii) benthic diatoms (**T_B**) together with volvocalean green algae (codon **G**) in cluster R1 (for further details, see Table 6).

Spatio-temporal distribution of SOM clusters

The three functional approaches provided different phytoplankton functional zonation based on SOM clusters in the River Loire. Based on MBFGs (Fig. 12a), spring samples along the whole river, and autumn samples at the upper and middle Loire were grouped together (cluster K6). During spring and summer, other SOM clusters showed scattered, discontinuous distribution along the river, where only the cluster K5 showed considerable spatio-temporal coherence. It displayed a river zone by all summer samples at downstream (st.12 to st. 19), with some point-like upper stream appearance.

The SOM clusters of MFGs created river zones at both seasonal and longitudinal scales (Fig. 12b). Spring phytoplankton samples are gathered together in S4 from station 6 towards downstream. Additionally, further functional zones are displayed in summer by (i) cluster S3 in the middle Loire (st. 7 to st. 17); and by S6 at downstream stations between st. 12 and st.

19. Cluster S5 displayed a distinct river zones at the middle Loire in autumn, but also contained spring samples from the upper Loire section.

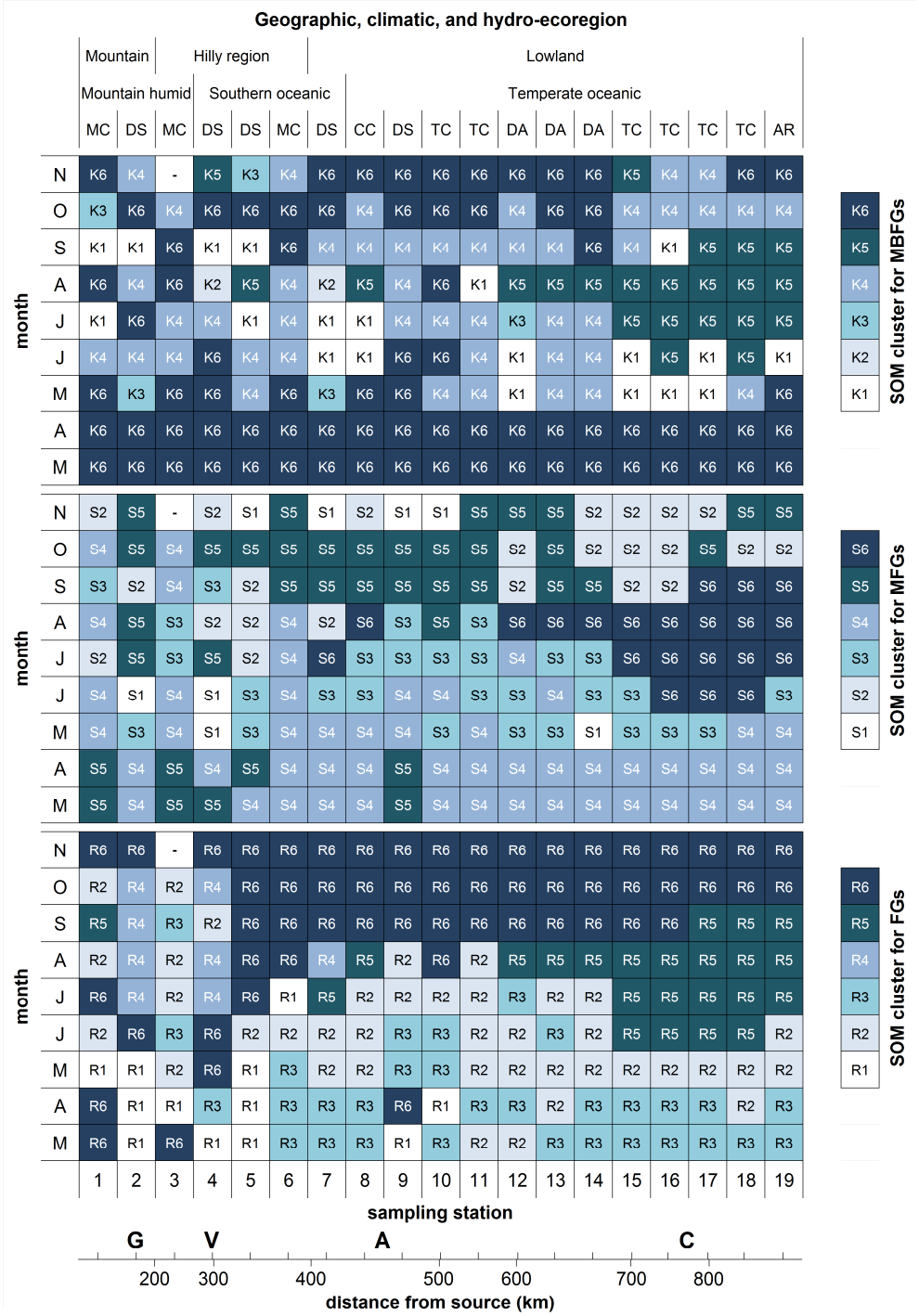

Fig. 12 *SOM clusters along the River Loire (2009) based on* **(a)** *morphology-based functional groups;* **(b)** *morpho-functional groups;* **(c)** *phytoplankton functional groups. Above abbreviations of hydro-ecoregions are:* ***MC****: Massif Central;* ***DS****: Depressions Sedimentaires;* ***CC****: Cotes Calcaires;* ***TC****: Tables Calcaires;* ***DA****: Depots Argilosableux; and* ***AR****: Armoricain. Beneath abbreviations are:* ***G****: Grangent dam;* ***V****: Villerest dam;* ***A****: River Allier; and* ***C****: River Cher*

SOM clusters of FGs also showed the presence of functionally different river zones (Fig. 12c). The upper river section represented all of the SOM clusters, but with the prolonged occurrence of cluster R1, R2 and R6. The cluster R4 was restricted to late summer occurrence at st. 2 and st. 4. In the middle Loire, all spring samples were gathered together in R3 between st. 6 and st. 19, which cluster then changed to R2 in summer along the whole section. At the middle to downstream stations in summer (st. 12 to st. 19), a well defined river zone was displayed by cluster R5. Furthermore, R6 disposed a whole river scale functional zone in autumn, including some spring samples from the upper Loire.

SOM clusters and the physical environment

Most of the SOM clusters appeared at altitude between 100 and 200 m (a.s.l.) in average (Fig. 13a). Higher altitude occurrence was relevant in case of cluster K2, K3 based on MBFGs; and of R1, R4 of the FG classification. Lowland (~50 m) distribution occurred in one case of each approaches: K5, S6, and R5.

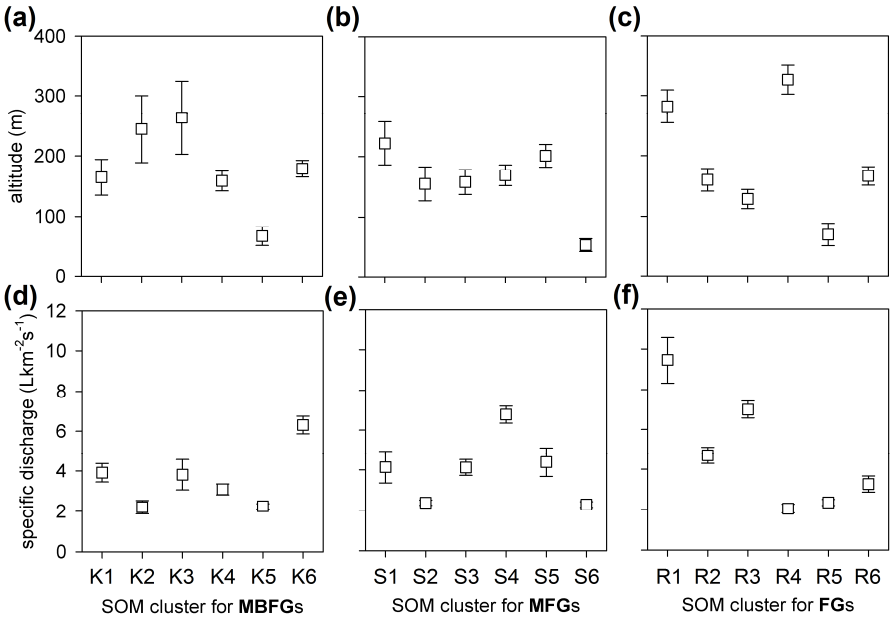

Fig. 13 *Mean values ± SE of altitude (m, a.s.l.) and catchment area specific discharge (Lkm^{-2}s^{-1}) in SOM clusters based on* **(a, d)** *MBFGs;* **(b, e)** *MFGs; and* **(c, f)** *FGs*

Specific discharge differed slightly among SOM clusters (Fig. 13b), and occurred ~3-4 Lkm^{-2}s^{-1} in most of the cases. More elevated values, however, characterized clusters K6, S4, R3 (~6 Lkm^{-2}s^{-1}), and R1 (~9 Lkm^{-2}s^{-1}). The lowest values in average occurred ~2 Lkm^{-2}s^{-1}, and were an attribute of two clusters in each functional approach: K2, K5; S2, S6; and R4, R5.

Water temperature showed remarkable differences among SOM clusters (Fig. 14a,b,c). The highest values in average (>20°C) occurred for cluster K1, K2, and K5 of MBFGs; for S3 and S6 of MFGs; as well as for R5 of FGs. The lowest temperatures typified the cluster K6 and cluster R1. In general, SOM clusters did not differ considerably by average values of conductivity (~200-300 µScm^{-1}). However, lower values were relevant for two small clusters: K3 and R1. Clusters with the highest averages were similar to those found at the highest water temperature K5, S6, and R5 (Fig. 14d,e,f).

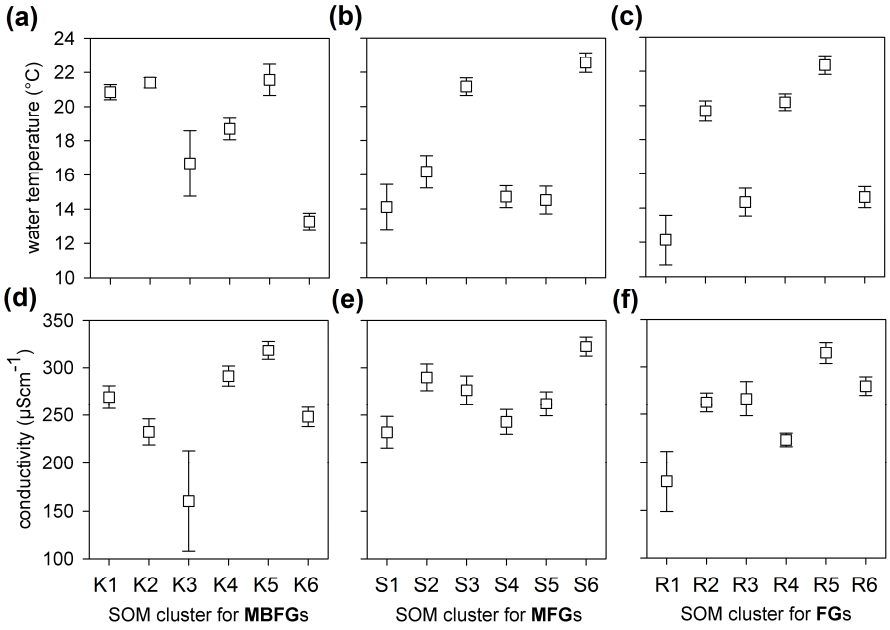

Fig. 14 *Mean values ± SE of water temperature (°C) and conductivity (µScm^{-1}) in SOM clusters based on* **(a, d)** *MBFGs;* **(b, e)** *MFGs; and* **(c, f)** *FGs*

SOM clusters and nutrient ratios

Compared to physical gradients, chemical composition by nutrient ratios differed weakly among SOM clusters (Fig. 15). Most of them occurred at N:P ratio between 50-100. Higher means were relevant only for cluster K6; for S2 and S4; as well as for R3. The lower means (< 25) were characteristic only in case of cluster K2, and R4. The Si:P ratio remained similar (~50 to 100) among all SOM clusters (Fig. 15d,e,f). The highest (>150) and lowest (< 50) Si:P ratio, however, occurred both in clusters based on the FG approach: in R1 and R4, respectively.

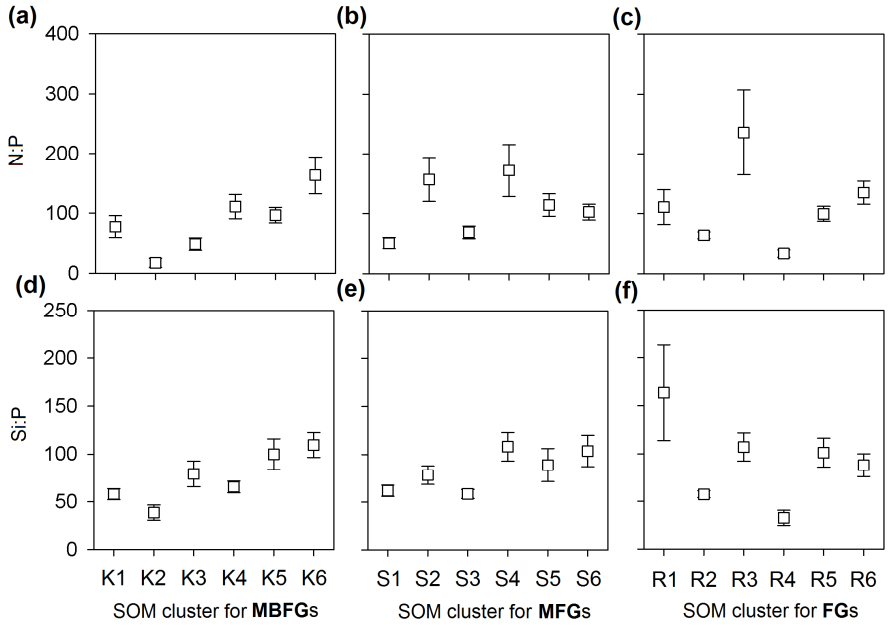

Fig. 15 *Mean values ± SE of N:P and Si:P (based on µmolL^{-1}) in SOM clusters based on* **(a,d)** *MBFGs;* **(b,e)** *MFGs; and* **(c,f)** *FGs*

4.1.4. Discussion

Functional river zones and regional differences

Along the three ecoregions and six main hydro-ecoregions, the MBFG classification could display only one main shift in phytoplankton composition: up- and downward from st. 12 (Jargeau, Middle Loire). Since in this approach all diatom taxa are grouped together, this separation can be explained by the dominance transition of diatoms to coccal green algae. Here, as emphasized by the discrete K5 cluster (similarly to S6 of MFGs and R5 of FGs), the Loire arrives to its lowermost part, represented by the lowest specific discharge, higher water temperature, and higher conductivity, reflecting calm physical conditions with prolonged water residence time. The absolute summer dominance of green algae is a regular characteristics of downstream Loire parts (Leitão and Lepretre, 1998; Descy et al., 2011) as well as of other, lowland sections of rivers like the Danube (Stoyneva, 1994), the River Seine (Garnier et al., 1995; Leitão and Rouquet, 2002), or at the Kieltsau catchemnt in Germany (Wu et al., 2011b).

By contrast, both the MFG and FG classifications indicated further zonation differences in the upper Loire. Similarity based on these approaches, river zones with the distinct dominance from benthic pennates (S5, R1, R6), to planktonic centrics (S4, R3) followed the geographical and climatic regions from the mountain to the hilly sites (~st.6-st.7). While benthic diatoms frequently dominate in headwaters (clearly displayed only by cluster R1 of FGs) sustaining short water residence time (Reynolds and Descy, 1996); centric diatoms are able to predominate only further downstream in still highly flushed, light limited conditions (Reynolds, 2006), according to hydrology-determined flow velocity (Bahnwart et al., 1999), turbidity and suspended solids (Krogstad and Løvstad, 1989; Salmaso and Braioni, 2008). These two approaches disposed continuous compositional shift in the upper lowland Loire by S4→S3 and R3→R2 towards the same downstream conditions (S6, R5), described for cluster K5 of MBFGs. Centric diatoms, in this middle river searches are the most common potamoplankton taxa in rivers (Holmes and Whitton, 1981; Salmaso and Zignin, 2010); where their size might matter regarding both nutrient and physical conditions. The most abundant, bloom forming taxa of recent years in the Loire could not be identified, owing to the very small size (~3-4 µm) and scarce ornamentation under both light and SE microscope. However, during the spring to summer bloom, a very diverse assemblage may coexist: *Stephanodiscus hantzschii*, *Discostella pseudostelligera*, *Cyclotella meneghiniana*, *Cyclostephanos dubius*, *C. invisitatus* with small-celled ones like *Cyclotella atomus* or its var. *gracilis* (Full taxonomic names are given in *Appendix IX*). Small-sized algae might occur owing to the accelerated rate of valve multiplication (Jewson, 1992), thus reflecting favourable conditions for growth; or, small-sized species dominate according to competitiveness by more efficient nutrient uptake due to their high surface area to volume ratio (Reynolds, 2006). Additionally, small cell size might provide competitive advantage against sedimentation (Sommer, 1988), being one of the most relevant physical constrain in shallows of the Loire lowland (Descy et al., 2011). Consequently, S4 contained the dominance of smaller celled centrics (7a), while the FG classification could display this river zone only by the mixture of cluster R2 and R3, containing taxa independently of cell size. Besides the intermediate specific discharge, further physical parameters such as higher water temperature (Winder et al., 2009; Yvon-Durocher et al., 2011) might also affect the centric diatom composition in these middle Loire conditions.

Physical properties might also explain the discrete position of clusters K2 and R4 upstream. In these cases, low specific discharge and higher water temperature co-occur at

higher altitude; and composition is governed by limnophilic pennates (codon **P**) and cyanobacteria (coda **M**, **H1**, **K**, **S1**). As presented in Abonyi et al. (2012), these potamoplankton compositions are relevant ecological indicators of dams' functioning; which prolong WRT, maintain summer stratification (Bonnet et al., 2000), and thus provoke additional species occurrences towards downstream (Sabart et al., 2009).

Functional river zones along nutrient ratio gradients

Several studies were published on the understanding of nutrient limitation of algae (Tilman et al., 1982; Hecky and Kilham, 1988), species competition for nutrients (Sommer, 1983, 1986), and to identify resource requirements of taxa. Even if several studies showed that both N and P could limit benthic algal growth in streams (Billen et al., 1994; Stevenson, 2009; Stevenson et al., 2006, 2012), nutrients are rarely expected to be a limiting factor for potamoplankton (Reynolds and Descy, 1996). Besides nutrient concentrations, changes in their ratio might also able to generate community shifts, if any of these resources is limiting (Reynolds, 2006; Naselli-Flores and Barone, 2011).

In the recent years, total P concentration has tended to decline in the River Loire, and in some cases reached levels at which may limit algal growth (Oudin et al., 2009). On the contrary, nitrate does not show such a clear tendency (Minaudo et al., 2013), but its attenuated seasonal oscillation is might be a sign of decline in primary production (Moatar and Meybeck, 2005). A possible phosphorus limitation of phytoplankton was recently emphasized by Descy et al. (2011), providing evidence for limited growth conditions especially for green algae.

In our study, nutrient ratios are used to characterize regional differences along the River Loire (see *Appendix IV*), where their changes might indicate considerable modifications in either natural or human mediated supplies. A specific feature of the River Loire is that P is in high availability upstream (between 200-300 km distance f.s.) according to human pressure of large cities while N increases continuously owing to agriculture, but becoming more relevant after the confluence of River Allier (Minaudo et al., 2014), and further downstream (Bouraoui and Grizzetti, 2008).

In 2009, low N:P values occurred in the upper Loire [between st. 2 - st. 4 - (st. 8)], where at Villerest dam (st. 4), Michard and her co-authors (1996) concluded that any kind of manipulation which lowered this ratio below 5 allowed *Microcystis* to become dominant. The lowest (< 10) N:P ratios coincided with cluster K2, and cluster R4, both of them containing eutrophic, limnophilic cyanobacteria. Even if the lowered N:P ratio and the potamoplankton composition cannot be directly related here, only the FG classification could display and separate this area based on functional composition (coda **P**, **M**). Besides physical reasons explained above, this regional summer occurrence of low N:P ratio might be indicative for the whole section, being either cause or consequence for the potamoplankton composition (Xie et al., 2003). The very distinct location of this low N:P ratio seems to delimit cyanobacterial blooms exceptionally in this upper Loire section, and thus only provide the possibility for its transport towards downstream river sections. This is contrasting in explanation to a recent study concluding possible cyanobacteria increase locally at the middle Loire (Larroudé et al., 2013).

In general, higher N:P ratios (> 200) were observed simultaneously with higher specific discharge, coupling hydrology and the unequivocal consequence of agriculture practices in the basin (Bouraoui and Grizzetti, 2008; Minaudo et al., 2013). Of the three functional approaches, only FGs provide trophic relationships and were characterized by mainly meso-

eutrophic taxa (coda **B**, **C** in R2; and codon **D** in R3). Decrease of centric cell size might be also an indicator of nutrient change, as reduced N:P ratio was already found to select for smaller centrics in lake ecosystems (Winder et al., 2009). However, regional differences in potamoplankton composition might only partly indicate nutrients, as the geological setting impacts agriculture, as well as determine hydrology; thus hydrology-determined composition only co-occur with similar regional scale differences, similarly to found in case of benthic diatoms (Rimet, 2009).

Besides N and P, silica is also a key nutrient in shaping phytoplankton composition (Sommer, 1988). In this study, Si to P ratio had considerable spatio-temporal changes in the River Loire (see *Appendix IV*). As silica takes a much longer regeneration time then either N or P (Sommer, 1988; Padisák et al., 2003b), its temporal and spatial relationship to P might be even more appropriate indicator of changes in chemical constraints than N:P ratio. Lower Si:P values, however, coincided with lower N:P ratio upstream; in other cases, it occurred exclusively at the middle Loire (st. 10 to st. 14) during the prevalence of spring centric bloom (S3, R2). SOM clusters representing remarkable differences in Si:P ratio were evidenced only based on the FG classification: (i) R1, reflecting a naturally high Si:P ratio of highland areas during flood, might be indicating a still lowered spring retention of dams, indicated by the dominance of benthic diatom in composition; (ii) R4, at the upper dam area in late summer (coda **P**, **M**). Some upstream planktonic taxa (*Fragilaria crotonensis*, *Asterionella formosa, Ulnaria delicatissima* var. *angustissima*) showed dominance at high (> 100) Si:P ratio. A possible explanation for these taxa distribution is once again the functioning of dams. Their presence explain the decreased Si content by the intensified sedimentation rate related to prolonged water retention time (Humborg et al., 2000; McGinnis et al., 2006), in this case by lowered specific discharge at high altitude, and also provides explication for the presence of good limnophilic Si competitors such as *Fragilaria crotonensis*. The low Si:P ratio, besides Si retention, might be also influenced by the increased P level in this upper Loire (Minaudo et al., 2013; Minaudo et al., 2014), which nutrient distribution seems to be human controlled according to dams' outflow (Abonyi et al., 2012). In other cases, if nutrient depletion or its ratios could not be able to generate any compositional changes, hydrology-based physical processes like sedimentation (Ha et al., 2002), or biological processes like new invaders (Floury et al., 2013; Pigneur et al., 2013) might became the driving forces for potamoplankton compositional change in all regions of rivers.

Functional approaches in water quality management

Besides theoretical overlaps between the three approaches (*Chapter 1.3.3.*), some advantages and disadvantages in river water quality management can be traced. Our results indicated the need for a fine functional resolution of pennate diatoms for reliable ecological surveys at a whole river scale. This might open a research field towards new benthic functional concepts like ecological guilds (Rimet and Bouchez, 2011; Stenger-Kovács et al., 2013), and their future inclusion into functional approaches, especially in the fields of potamoplankton ecology and river ecological status assessment.

The relevance of meso-eutrophic, limnophilic diatoms (codon **P**) in rivers indicating human impacts like damming evidences that neither only size pools of pennate diatoms (Salmaso and Padisák, 2007) nor the separation of large chain forming taxa (Tolotti et al., 2012) are satisfactory in rivers. In the River Loire, for example, potamoplankton contains taxa from both benthic (*Fragilaria construens*) and planktonic habitats (*F. crotonensis*), thus reflecting opposite environmental conditions.

Cyanobacteria are one of the most relevant components of water quality monitoring programs. Their dominance, however, only occasionally occurs in the River Loire; and is restricted to the upper two Loire dams (Michard et al., 1996; Bonnet and Poulin, 2002; Latour et al., 2004). Exclusively the **FG** classification separated these upstream stations (st. 2: Grangent, st. 4: Villerest) in one "clear" reservoir related cluster (R4). These assemblages from codon **P** and **M** might be affirming the relevance of a new functional group: $\mathbf{L_R}$, recently described for reservoirs by Hu and Xiao (2012).

Additionally, results from this Loire monitoring may emphasize the importance of temporal resolution of potamoplankton data in ecological researches and managements. As the composition of river phytoplankton highly depends on physical interactions (Reynolds et al., 1994; Reynolds, 2003), hydro-meteorological events may influence data representativeness according to specific environmental conditions, which effect should be taken into account. Autumn towards winter potamoplankton assemblages tended to display no major shifts in the functional composition along the Loire—as a consequence of homogenisation among habitats by increasing discharge (Reynolds and Descy, 1996; Descy et al., 2011). However, the spring to late summer period sustained at least four major shifts, while this period is the most affected by diverse hydro-meteorological conditions. Weekly to once a month sampling frequency is suggested in large rivers using taxa level resolution (Kiss et al., 1996), but based on functional group composition, once a month sampling seemed to be adequate, but during the whole vegetation period. Different sampling designs, however, might be defined according to regional location of each sampling station, as well as to specific local influential factors. A general four sampling per year strategy—international protocol is still being discussed—may not provide satisfactory results in all cases, and a more frequent sampling at few representative river sections should be privileged in ecology-based potamoplankton monitoring.

4.2. Phytoplankton functional groups as indicators of human impacts along the River Loire (France)[2]

Thesis Objective 2

[2] This chapter was presented at the 16th Workshop of the International Association of Phytoplankton Taxonomy and Ecology (IAP), San Michele all'Adige (Trento), Italy, 21-28 August 2011; and published in a slightly modified form in HYDROBIOLOGIA.

Abonyi, A., M. Leitão, A. M. Lançon & J. Padisák, 2012. Phytoplankton functional groups as indicators of human impacts along the River Loire (France). Hydrobiologia 698(1):233-249 doi:10.1007/s10750-012-1130-0.

4.2.1. Specific introduction

Water quality can be assessed in many ways according to the different metrics and human needs. One of the most relevant concepts of water quality assessment is the Water Framework Directive (Directive 2000/60/EC) of the European Parliament (WFD, 2000). The WFD has been stimulating a large number of researches to establish scientific basis to calibrate its assessment schemes and to define the so-called "Ecological Quality Ratios" (EQR) (Schimming et al., 2010). In order to manage the ecological status of rivers according to the WFD, human effects on rivers must be defined to achieve the good ecological status. Despite the great quantity of available data, some results appear to contradict each other (Bragg et al., 2005). At present, WFD recommends the use of quality assessment based on qualitative and quantitative phytoplankton data in rivers, without specific details. The need for understanding general background mechanisms (Welch, 1952; Vannote et al., 1980; Elwood et al., 1983; Minshall et al., 1985), for understanding phytoplankton related problems (Dokulil, 1996; Noppe and Prygiel, 1999) and to elaborate useful methods have been also emphasised in many papers (Borics et al., 2007; Trifonova et al., 2007; Friedrich and Pohlmann, 2009). Despite the need for holistic views to understand ecological processes in streams have been forced since the late 50's (Minshall et al., 1985), lotic environments have remained less frequently studied. Apart from their stochastic behaviour, difficulties arise on whole river scale (many organisms, several countries, limited accessibility of background data). Different river concepts (Vannote et al., 1980; Elwood et al., 1983; Thorp and Delong, 1994; Thorp et al., 2006) represent milestones in viewing rivers on ecosystem level, and such approaches are highly required by the WFD.

One of the most recent phytoplankton research interests is the application of the so-called phytoplankton functional groups. In a functional group, ecologically (Reynolds et al., 2002; Padisák et al., 2009), morphologically (Kruk et al., 2010), or morpho-functionally (Salmaso and Padisák, 2007) similar species are assembled together and they are expected to represent a more or less well defined functional trait. The usefulness of these concepts (Kruk et al., 2011; Stanković et al., 2012) is being tested.

Traditional phytoplankton monitoring is based on phytoplankton biomass or Chl-*a* (Mischke et al., 2011), in some cases on other accessory photosynthetic pigments or on these combinations (Friedrich and Pohlmann, 2009). As relationships between phytoplankton biomass and human impacts are often difficult to interpret, compositional changes seem to be better to fulfil the understanding of these relationships (Walsh et al., 2005). In addition, traditionally monitored variables are not able to reflect species or functional trait level properties, and their quantities are highly conditioned by the age and growth conditions of populations (Padisák, 2003).

The original idea of the phytoplankton functional group concept (Reynolds, 1984; Reynolds et al., 2002) was proposed as a new ecological status estimation method (Q index) for lake phytoplankton (Padisák et al., 2006), then for river potamoplankton ($Q_{(r)}$) (Borics et al., 2007). The use of this concept in this study relies on the fact, that phytoplankton composition is highly related to physical constraints (Reynolds, 1994; Naselli-Flores and Barone, 2011), and disturbances (Reynolds et al., 1993; Lindenschmidt and Chorus, 1998; Hambright and Zohary, 2000), both altering in time and space. Besides physical factors, trophic state also determines the relevant phytoplankton assemblages, altogether exhibiting quite similar dynamics in rivers and lakes (Reynolds et al., 1994).

The $Q_{(r)}$ index (Borics et al., 2007) is enabled to reflect human impacts at different scales by using specific F factor values for the different functional groups. These factor values were calculated using the following components: i) nutrient status (from values 0-hypertrophic to 5-oligotrophic), ii) turbulence (from values 0-standing waters to 5-highly lotic environment), iii) sufficient time for the development of the given assemblage (from values 0-climax to 5-pioneer assemblages), and iv) level of risk of functional traits (from values 0-high risk indicating pollution or being able to toxic to 5-low risk). The specified values of each component were summed, and then the F was calculated for each functional groups ranging between 0 and 5. The calculation of $Q_{(r)}$ is the following:

$$Q_{(r)} = \sum_{i=1}^{s} (p_i F),$$

where $p_i = n_i/N$, n_i is the biomass of the i-th group, while N is the total biomass. F is the factor number allowing the quality index to range between 0 (the worst) to 5 (the best). The method has been already tested on large rivers of the Hungarian great plain (Duna, Tisza), and the Estonian part of the river Narva (Piirsoo et al., 2010).

In this research, the continuity of longitudinal changes of Loire phytoplankton is studied at whole river scale, in relation to human influences at local- and regional scales. Thus, the phytoplankton composition is examined with the following specific objectives:

(i) Which are the dominant functional groups along the River Loire?

(ii) How natural is the seasonal succession of potamoplankton along the Loire?

(iii) Is it possible to define river sections by identifying corresponding phytoplankton patterns along the Loire?

(iv) Which kinds of relationships are recognized between the $Q_{(r)}$ index and species composition, and $Q_{(r)}$ and Shannon-Weaver diversity?

This study is opened towards requirements of the Water Framework Directive (WFD, 2000) and it is also suit for the more and more advised whole river scale investigations of lotic ecosystems (Schimming et al., 2010).

4.2.2. Specific methods

Phytoplankton diversity was calculated following Shannon and Weaver (Pielou, 1975) based on $\log_2$ base and all individuals counted including benthic taxa.

4.2.3. Results

Physical and chemical variables

Discharge values showed nival drainage regime with discharge maxima in February (Fig. 16a and *Appendix V*, Image 2a). While upstream stations showed sometimes uneven discharge fluctuations, between the two main confluents (River Allier and River Cher) discharge remained more or less constant in all seasons. Among *in situ* measurements, water temperature showed similar seasonal patterns along the whole Loire length, with a slightly prolonged spring cold period upstream. Maximum temperature levels were observed in late summer, where temperature maxima (up to 26°C) occurred at stations 3 and between st.11 to

st. 16. The pH values increased from the middle section to downstream between April and October. Conductivity showed increasing values both downstream and seasonally, with maxima between 200 and 400 µS cm^{-1} (Fig. 16b and *Appendix V*, Images 2b-c). In the middle section of the Loire (st. 11 to st. 16), dissolved oxygen reached supersaturated levels in summer (up to 170 %).

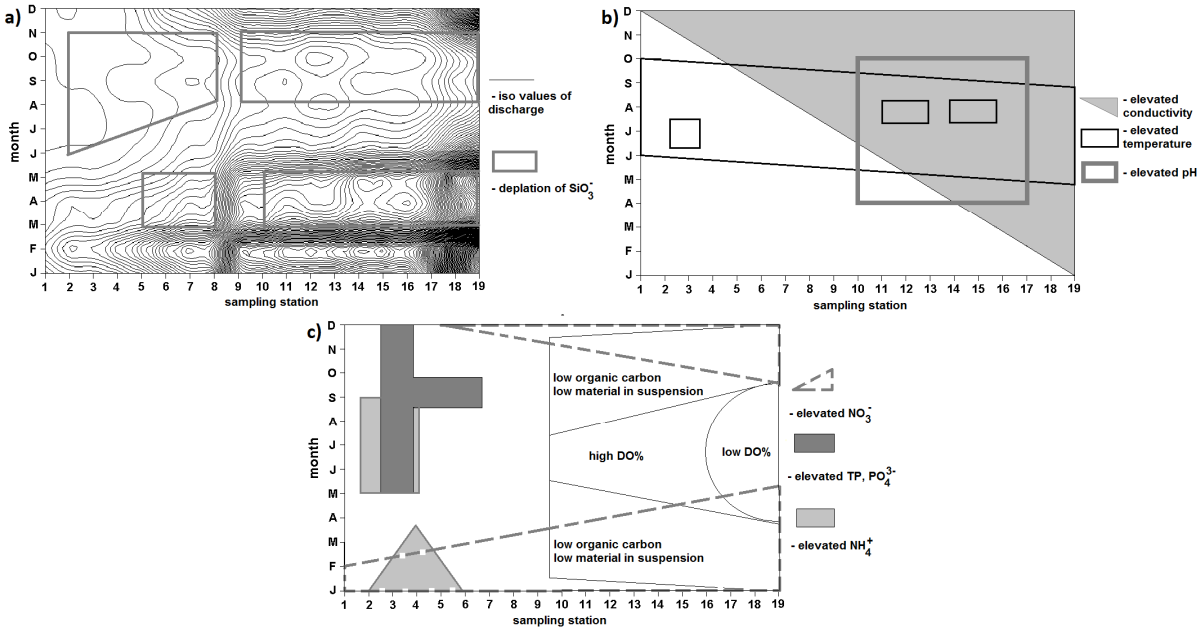

Fig. 16 *Patchiness of* **(a)** *iso-values of discharge and low soluble reactive silica;* **(b)** *temperature, conductivity and pH*; **(c)** *nitrate, TP, SRP, ammonium, DOC, dissolved oxygen (DO) saturation in the River Loire in 2009 (for more detailed information, see* Appendix V*, Images 3-6)*

Soluble reactive phosphorus and TP (st. 3), ammonium (between st. 2 to st. 4), and nitrite (st. 3 to st. 4) were higher at upstream stations. Values of organic carbon were low during spring and autumn at the downstream sections of the river, together with decreased suspended solid values. Nitrate showed significant increase downstream, with higher values in spring and autumn. Local increases in nitrate occurred at st. 10 and st.17. Amount of soluble reactive silica was low between st. 5 and st. 8 and st. 10 and st. 18 during spring, but absolute minimum values occurred upstream between st. 2 to st. 8 (< 2 mgL^{-1}) in late summer (Fig. 16c and *Appendix V*, Images 3-6).

Phytoplankton biomass and diversity

Most of the samples involved in this study were characterized by low biomass (Fig. 17a) and were mainly dominated by species belonging to diatoms, chlorococcalean green algae and Cyanobacteria. The total species number exceeded 300, of which the most abundant 161 taxa were converted to biomass (see electronic Spreadsheet), then classified into 23 different coda. The most frequent coda were **D** (37%), **J** (28%), $\mathbf{T_B}$ (11%), **C** (7%) and **B** (4%). The most species rich functional groups were $\mathbf{T_B}$ (39 spp.), **J** (25 spp.), **D** (15 spp.), **F** (15 spp.) and **X1** (14 spp.).

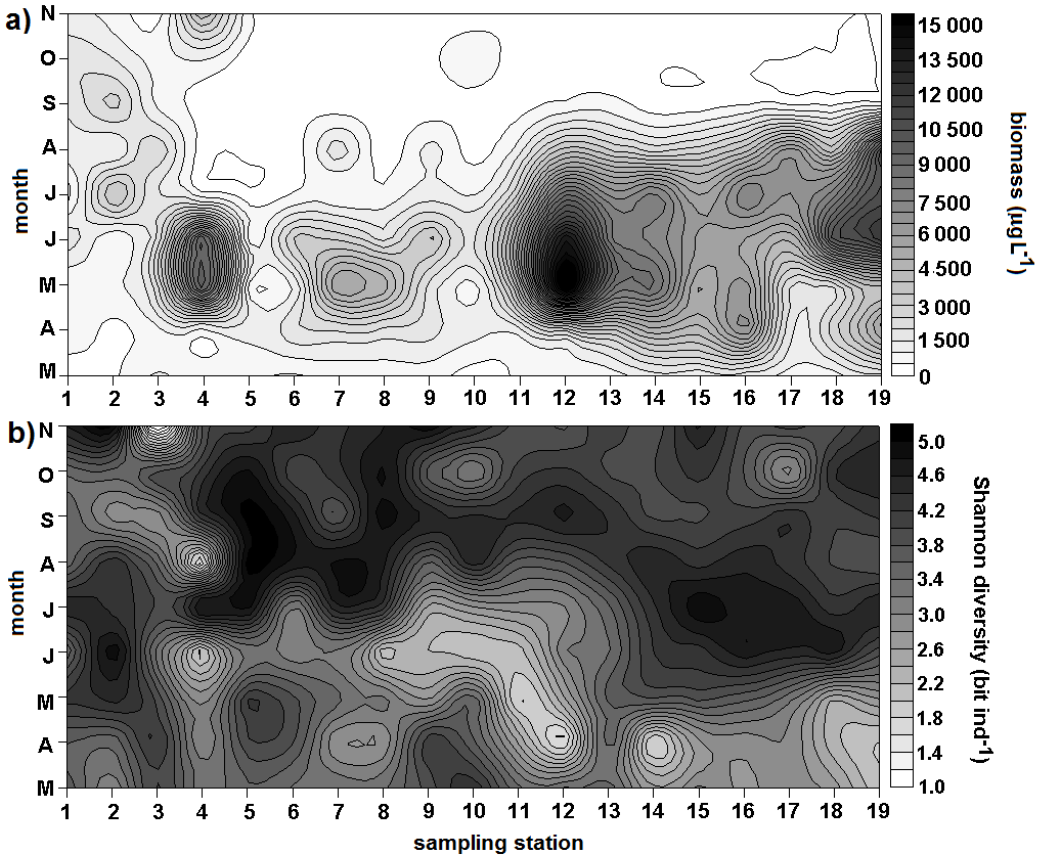

Fig. 17 *Distribution of* **(a)** *total phytoplankton biomass; and* **(b)** *Shannon-Weaver diversity in the River Loire in 2009*

Shannon-Weaver diversity showed relatively high values in general (>80% between 2.8-5.0 bits ind^{-1}), but reflected considerable seasonal and longitudinal differences (Fig. 17b). Minimum values of Shannon-Weaver diversity occurred in spring with some exceptions like upstream st. 2 to st. 4 and downstream at st. 17. Among patchiness of high diversity values, a late summer maxima between st. 5 and st. 8, and a midsummer maxima between st. 15 and st. 18 were observed. Species number (from 22 to 72) was highly related (R^2=0.45, n=170) with Shannon-Weaver diversity (1.28 to 5.37).

Seasonality in phytoplankton coda distribution

Benthic diatoms (**T_B**) were present during all seasons only at upstream stretches (*Nitzschia* spp., *Navicula* spp. and *Fragilaria construens* were the most frequent), while their distribution at other stations was mostly concentrated to spring and fall. At st. 9 to st. 10, they were highly represented even during summer. At st. 4 (Villerest), a biomass peak was formed by *Melosira varians* (**T_B**) in May with a biomass of 10,865 μgL^{-1}, then this species was replaced by coda **P** and **M**, in summer and autumn. The absolute biomass maximum (17,621 μgL^{-1}) was also found in May at the middle section of the Loire (st. 12), with the significant contribution of *Cyclotella meneghiniana* (**C**), *Cyclostephanos dubius* (**B**), and *Skeletonema potamos* (**D**). Centric diatoms were dominant in spring, being well represented at all sampling stations (Fig. 18a-c), but exhibiting a mismatch at st. 2 and st. 4. Here, *Fragilaria crotonensis*

(**P**) was dominant from May to August, where its contribution to the total biomass exceeded 50% around the year.

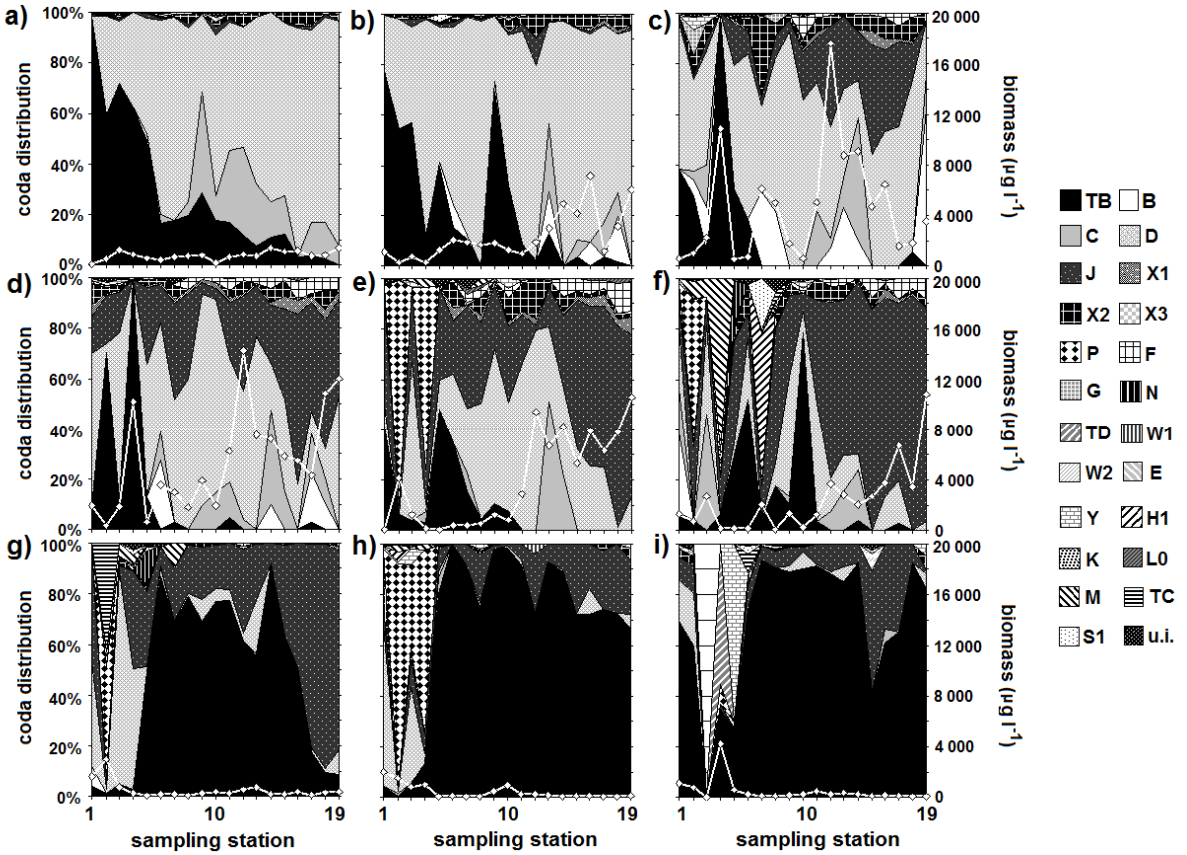

Fig. 18 *Relative biomass (%) of phytoplankton functional groups (*sensu *Reynolds et al, 2002; Borics et al., 2007; Padisák et al., 2009) from* **(a)** *March to* **(i)** *November in 2009 in the River Loire. Horizontal axes show sampling stations along the river from st. 1 to 19. White lines indicate total biomass values using identical scale during the nine months period*

Chlorococcalean algae played a key role in summer from st.11 towards downstream (Fig. 18d-g). Most of them were belonged to coda **J** (*Scenedesmus* group *Armati* and group *Desmodesmus*), **F** (*Dichotomococcus curvatus*, *Dictyosphaerium* spp., *Crucigeniella* spp., *Kirchneriella* spp., *Oocystis* spp.), **X1** (*Ankyra judayi*, *Didymocystis* spp., *Diplochloris* spp., *Monoraphidium* spp.). Members of codon **X2** (*Chlamydomonas* spp., *Plagioselmis* spp., *Spermatozopsis exsultans*) appeared only late spring and summer. At the downstream sections, coda **J** and **X1** showed a clear emergence between May and August (Fig. 18c-f), with the co-dominance of codon **F** (especially in June and July).

Cyanobacteria were only occasionally dominant in biomass, but well represented by species such as i) *Microcystis* spp. (**M**) between st. 2 and st. 4 and st. 7 and st. 8 late summer; ii) a not yet identified Stigonematales sp., ($\mathbf{T_C}$) at st. 2 in September and iii) *Dolichospermum spiroides* (**H1**) and *Planktothrix agardhii* (**S1**) at st. in August (Fig. 18e-f).

Longitudinal patterns by functional groups

While the distribution of coda $\mathbf{T_B}$, the sum of the centric diatoms (**B**+**C**+**D**) and **J** almost covered (around 90%) the whole the study period at almost all of the stations, these three

groups showed different longitudinal patterns. Codon $\mathbf{T_B}$ decreased downstream with two peaks: st. 4 and st. 10. Centric diatoms were present at all stations, being dominant between st. 6 and 14. Codon **J** increased its contribution continuously towards downstream (Fig. 19a).

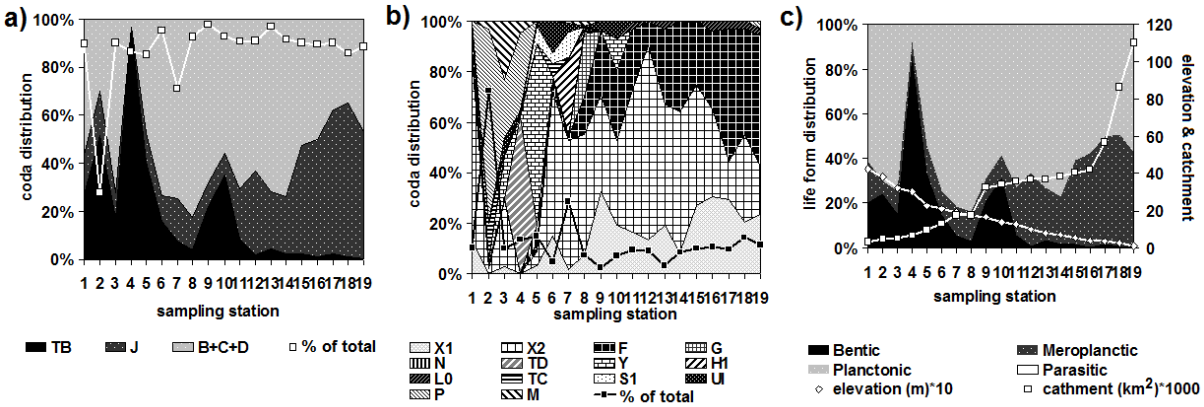

Fig. 19 *Distribution of* **(a)** *coda* $\boldsymbol{T_B}$, ***B+C+D*** *and* ***J*** *along sampling station in 2009, and their relative contribution to the total accumulated biomass (white line);* **(b)** *distribution of 'accessory coda' (UI means unidentified) and their contribution to the total accumulated biomass (black line);* **(c)** *biomass distribution of algae belonged to different life forms, elevation level and water catchment area along the River Loire in 2009*

"Accessory" coda (around 10 %) showed two markedly different distribution patterns upstream *vs*. downstream. While they were represented by a few numbers of taxa belonging to many different functional groups upstream (Fig. 19b), from the st. 10 downstream, their patchiness was designed by the fluctuations of only three functional groups: **X1**, **X2** and **F**. From the middle section of the River Loire, the contribution of coda **X1** and **F** increased on the account of codon **X2**. Though being characteristic at downstream stations, the above mentioned coda had some sporadic occurrences at upstream stations as well. In the distribution profile of life forms along the river (Fig. 19c), planktonic algae were dominant with the exceptions presented at st. 4 to st. 5 and st. 9 to st. 10. Meroplanktic species increased their quantity towards downstream, especially below the inflow of the River Allier.

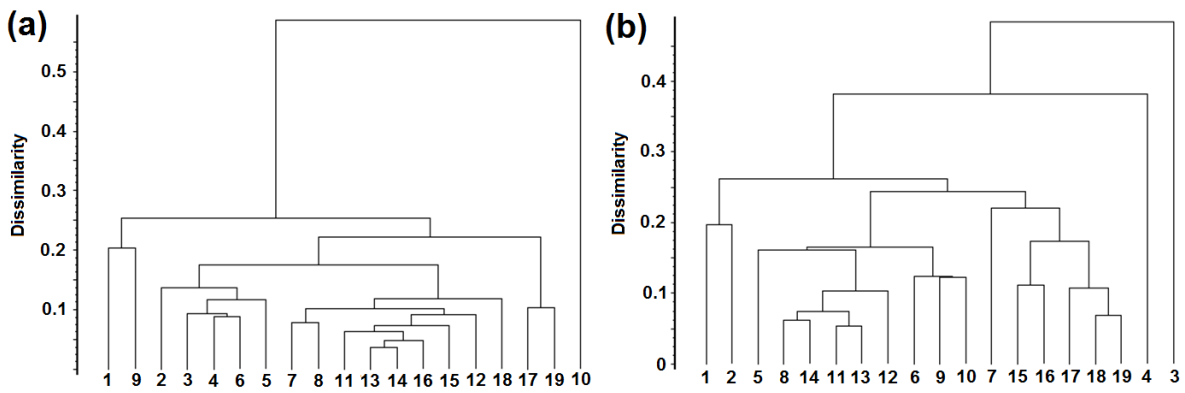

Fig. 20 *Cluster analysis of the sampling stations* **(a)** *based on phytoplankton nutrients (N-, and P-forms, DOC and SRSi);* **(b)** *based on* $Q_{(r)}$ *values*

Cluster analysis of the main phytoplankton nutrients (Fig. 20a) resulted in four groups (and a singlet: st. 10) at dissimilarity level of 0.15. Stations 1, 9, 10 were separated; the group of st. 2 to st. 6, and st. 7 to st. 18 were together, with the exception of st. 17 and st. 19.

Distribution of $Q_{(r)}$ *values*

Ecological status estimation based on Loire phytoplankton biomass for the year 2009 is shown at Fig. 21a. High $Q_{(r)}$ values were observed during spring and autumn, latter particularly in the middle section of the river. Low values characterized the late summer periods upstream (st. 2 to 4), and the summer periods downstream (st. 12 to st. 19). Minimum values occurred in August at st. 4 ($Q_{(r)}$=0.82) and st. 7 ($Q_{(r)}$=1.12). At whole river scale, the longer is the distance of stations from the source, the earlier is the seasonal decrease of $Q_{(r)}$.

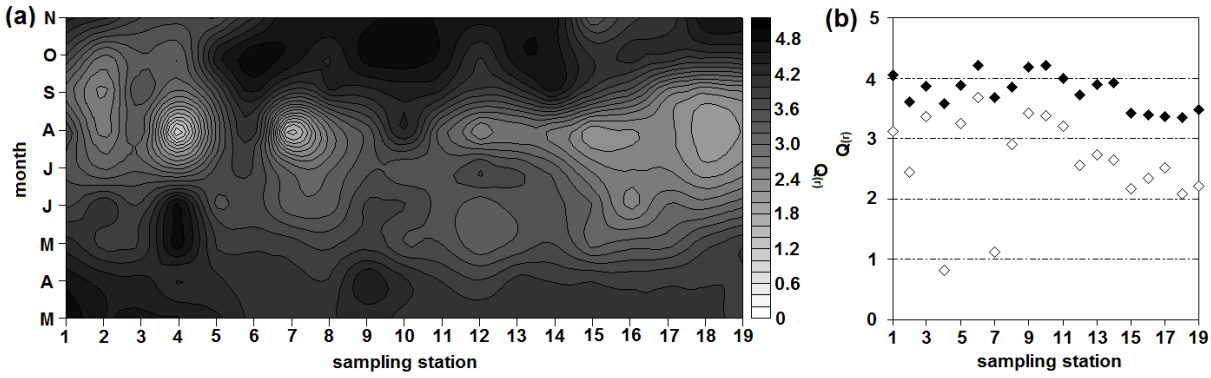

Fig. 21 (a) *Seasonal and longitudinal differences of the* $Q_{(r)}$ *index in 2009;* **(b)** *average (full circles) and minimum (open circles) values of* $Q_{(r)}$ *index along the Loire in 2009*

Average $Q_{(r)}$ index values varied around 4 at upstream and in the middle section of the River Loire, approximating value 3 downstreams. A clear decrease occurred at st. 2, 4 and 7, which was more markedly expressed in case of minimum index values (Fig. 21b). In both cases, index values showed progressive decrease from the st. 10 downstreams. Based on the cluster analysis of $Q_{(r)}$ index values, four main groups were formed at dissimilarity level of 0.2 (Fig. 20b). Individual stations were 3, 4, 7; but st. 1 to 2, 5 to st. 14 and st. 15 to st.19 were grouped together.

4.2.4. Discussion

Spatial gradients

Upstream sections of rivers have slight seasonality (Vannote et al. 1980), and the prevailing constant conditions select for algae belonging to benthic taxa (Leitão and Lepretre, 1998; Leland, 2003; Istvánovics et al., 2010). The more the sampling station is placed downstream, the more the seasonality overcomes. Changes in the river topography also require functional adaptations resulting zones *vs.* continuums by the best suited biota (Huet, 1959; Vannote et al., 1980). In long rivers (like the River Loire) source area is relatively small, and the catchment area increases by orders (Billen et al., 1994) providing evidence for longitudinal differences. Longitudinal succession of phytoplankton is redrawn by inflowing tributaries (Garnier et al., 1995; Istvánovics et al., 2010), by natural dead zones (Reynolds and Descy,

1996) or by human modifications on the river bed (dikes, reservoirs, flow modifications, stone disposal). Based on residence time, nutrient availability and light conditions, the maximum phytoplankton production occurs at middle sections of rivers (Reynolds and Descy, 1996) where phytoplankton is mainly dominated by centrics (Leitão and Lepretre, 1998; Bahnwart et al., 1999; Leland, 2003; Istvánovics et al., 2010). Downstream sections of different rivers are variable in the potamoplankton, dominated by centric diatoms, chlorococcalean colonial greens (Leitão and Lepretre, 1998; Bahnwart et al., 1999; Friedrich and Pohlmann, 2009; Tavernini et al., 2011), euglenophytes, cryptophytes (Bahnwart et al., 1999; Leland, 2003), colonial Cyanobacteria (Ibelings et al., 1998), chrysophytes (Istvánovics et al., 2010), all depending on season and site location.

The above longitudinal considerations serve as background data to understand spatial phytoplankton distribution along the River Loire. As $Q_{(r)}$ index is based on biomass data, and most of the samples are dominated by only a few coda, it is interesting to show the coda distribution of the most frequent taxa. At Fig. 22, the dominance of coda $\mathbf{T_B}$, **D** and **J** is reflected, where other type of dominances (**P**, **M**, **H1**) occur occasionally, but pre-indicating decreases in $Q_{(r)}$ values.

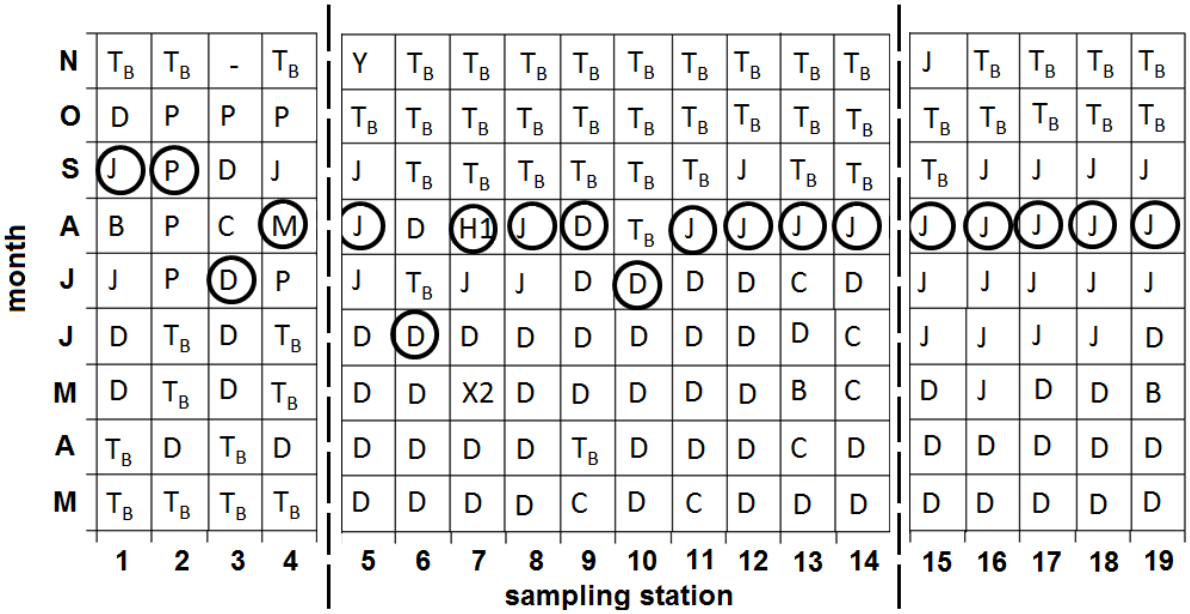

Fig. 22 *Coda distribution of the first species in biomass, where circles indicate the minimum values of* $Q_{(r)}$ *index along the River Loire in 2009*

Independently of sampling location, the lowest (worst) $Q_{(r)}$ values (circles on the Fig. 22) occurred in late summer, but different river stretches are identifiable:

(i) Upstream section of the Loire until Villerest dam (st. 1 to st. 4), which is dominated by benthic and centric unicellular diatoms which were replaced by lacustrine species (**P**, **M**) only in late summer;

(ii) After Villerest dam, where centric dominance was replaced by codon **J** only in late summer (st. 5 to st. 14, excepted st. 7), and dominated by benthic taxa autumn; and

(iii) From the st. 15 downstream, where the dominance of codon **J** on centrics appeared earlier, and stayed longer before changing to codon $\mathbf{T_B}$.

All taxa, contributing to this patchiness are common (Rojo et al., 1994; Reynolds and Descy, 1996) and are in agreement with dominance patterns described in the aforementioned publications. Exceptions are *Fragilaria crotonensis* (**P**), *Microcystis* spp. (**M**) and *Dolichospermum spiroides* (**H1**) in the upper part of the River Loire.

Temporal gradients

Seasonally changing parameters such as discharge (Schmidt, 1994; Centis et al., 2010; Salmaso and Zignin, 2010; Tavernini et al., 2011), water temperature (Leland, 2003; Salmaso and Braioni, 2008; Tavernini et al., 2011), light (Vörös et al., 2000) and nutrient availability (Wu et al., 2011b) have been in the focus of recent scientific research. In rivers, seasonality basically determines which species are able to maintain their population, selecting the most capable to dominate. While weak selective physical conditions may explain highly variable planktonic vegetation (Reynolds and Descy, 1996), low species diversity may reflect severely selective environments.

Using the above mentioned consideration, Fig. 23 visualizes the coda patchiness provided by the most frequent species in the samples. Like in Fig. 22, coda $\mathbf{T_B}$, **D** and **J** are frequent, but additional functional groups (coloured by gray background) occur: **X1** (*Chlorella*-like small greens, or isolated cells of *Dictyosphaerium* belonging to codon **F**), and **X2** (*Chlamydomonas* spp., *Spermatozopsis exsultans*).

month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
N	D	UI	-	T_B	X3	T_B	T_B	T_B	T_B	T_B	T_B	T_B	T_B	T_B	J	J	T_B	T_B	T_B
O	D	M	D	D	D	T_B	T_B	T_B	T_B	T_B	T_B	T_B	T_B	T_B	T_B	T_B	X2	TB	X2
S	D	M	D	D	X1	T_B	M	J	T_B	T_B	T_B	J	X2	J	X2	J	J	X2	X2
A	D	M	D	M	D	D	H1	X2	D	T_B	UI	D	D	J	UI	J	J	J	J
J	X1	P	D	P	T_B	UI	D	D	D	D	D	D	D	D	X1	UI	UI	UI	X1
J	X1	T_B	D	T_B	D	D	D	D	D	D	D	D	D	D	X1	X1	X1	X1	D
M	D	D	D	T_B	D	D	X2	D	D	D	D	D	B	C	D	D	D	D	B
A	D	TB	D	D	D	D	D	D	T_B	D	D	D	D	D	D	D	D	D	D
M	T_B	D	T_B	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D

sampling station

Fig. 23 *Coda distribution of the most abundant species, where circles indicate the minimum values of Shannon-Weaver diversity (UI means unidentified single greens of 2 - 5 µm) in the River Loire in 2009*

Using this coda patchiness of the most abundant species, the three investigated seasons can be characterized by three different coda distributions:

(i) Spring is almost invariably dominated by centric diatoms along the whole river length;

(ii) In summer, the Loire is divided into three parts: an upstream section with mixed coda distribution, including both benthic (*Melosira varians*), and planktonic (*Microcystis* spp.) species dominance, followed by a middle section dominated by centric diatoms, and then a downstream section with the co-dominance of codon **X1** *(Monoraphidium)* and small greens (**X1**/**F**) accompanying codon **J**;

(iii) In late summer, centrics *vs. Microcystis* dominance occur upstreams, bentic diatoms in the middle sections, and the dominance of codon **X2** (*Spermatozopsis exsultans)*, and $\mathbf{T_B}$ downstreams.

The minimum diversity values (circles in Fig. 23) change continuously among seasons along the Loire: they appear in late summer in the upper parts, and at the beginning of spring at the lower parts. Among these dominant taxa, only the centrics are reported commonly [see Table 3 in Rojo et al. (1994)].

Functional sections and human impacts

In the River Loire in 2009, benthic algae were more likely to dominate upstream, planktonic centrics in the middle part, and meroplanktic or metaphytic species downstream. Latter two life forms are described as strategies being fundamental for maintaining fluvial phytoplankton diversity (Stoyneva, 1994; Reynolds and Descy, 1996).

One of the most apparent human effect reflected by coda distribution is the influence of eutrophic reservoirs (Bonnet and Poulin, 2002; Latour et al., 2004; Briand et al., 2009) constructed in the upper part of the river. Dams modify the flowing regime, water residence time, nutrient distributions and light conditions (Hart et al., 2002; Palau, 2006), and therefore the seasonal succession of phytoplankton and species distribution. These can be identified on the Loire by the eutrophic, epilimnetic coda (**P**, **M**) resulting in lake type equilibrium assemblages (Naselli-Flores et al., 2003) in this area. The human controlled outlets of dams are reflected in the sporadic occurrence of lacustrine elements downstream: coda **M**, **P**, **Y**, $\mathbf{L_0}$, and by the uneven quantitative dominance of benthic (flashed *Melosira varians* with single cells) species. Despite the presence of the planktonic elements, they cannot maintain persistent dominance downstreams, as they are not adapted to survive in lotic environments (Reynolds and Descy, 1996), but are able to enrich river phytoplankton with species in additional habitats. This was also the case in the River Narva, sampled after the Narva Reservoir (Piirsoo et al., 2010).

This lake type succession is well reflected by the $Q_{(r)}$ index, emphasizing the lack of benthic diatoms dominance which is considered as natural in upstream sections of rivers. The upstream uneven distribution of physical and chemical components may also provide an example for effects of reservoirs in this part of the river. For example, very low soluble reactive silica concentrations (< 2 mgL^{-1}) might be related to prolonged residence time, and to the dominance of epilimnetic, eutrophic diatom species like *Fragilaria crotonensis* (codon **P**). It is interesting to note, that in spring at downstream sections, centric diatom maxima failed to result such a remarkable decrease (*Appendix V*, Image 6b). Controlled outlets from the reservoirs are also apparent in the distribution pattern of the water temperature, soluble reactive phosphorus, nitrite and discharge values (*Appendix V*, Image 2, 4, and 5). At Villerest dam (st. 4) for example, two types of outflow work: an upper outflow between May and July, which then changed to the underneath one between August and April. This lower outflow is

positioned at 8 m on the overall 24 m high dam, which allows emission of hypolimnetic water in late summers.

The middle part of the river is characterized by high $Q_{(r)}$ index values, reflecting the presence of benthic diatoms during high flow and the dominance of centrics all around the year. The spring centric dominances emphasize their resistance against this highly selective environment (Margalef, 1978) that favours species with low-light tolerance and fast growth (Reynolds, 1994; Reynolds and Descy, 1996). This can be attributed to the natural elevating effect of the River Allier on discharge. This section of the Loire can be compared to other large rivers of Europe, as the "Danube type" phytoplankton (Várbíró et al., 2007) dominated by coda **J**: *Scenedesmus* spp., **C**: *Cyclotella meneghiniana*, **D**: *Nitzschia acicularis*, *Skeletonema potamos*, *Stephanodiscus hantzschii*, that almost covers the main species occurring in the Loire.

The downstream increase of nitrate is a common human impact by agriculture (Strebel et al., 1989; Almasri and Kaluarachchi, 2004), and serves as a useful indicator of eutrophication in large rivers (Turner et al., 2003). The eutrophication in this middle part of the River Loire was demonstrated in the 1990s with elevated levels of Chl-*a* (Meybeck et al., 2003) up to 150 µg L^{-1} (the maximum in 2009 was around 90 µg L^{-1}). Besides the elevated level of nitrate, total phosphorus showed rather low values during spring at the whole river length, and also at the end of summer downstreams. In these cases, concentrations can be considered as background values (<0.05 mg P L^{-1}), as it was suggested for large German rivers (Mischke et al., 2011). The amount of total phosphorus is low enough for limiting algal growth (Descy et al., 2011), as it was recently concluded similarly in the downstream sections of the River Danube (Istvánovics and Honti, 2012).

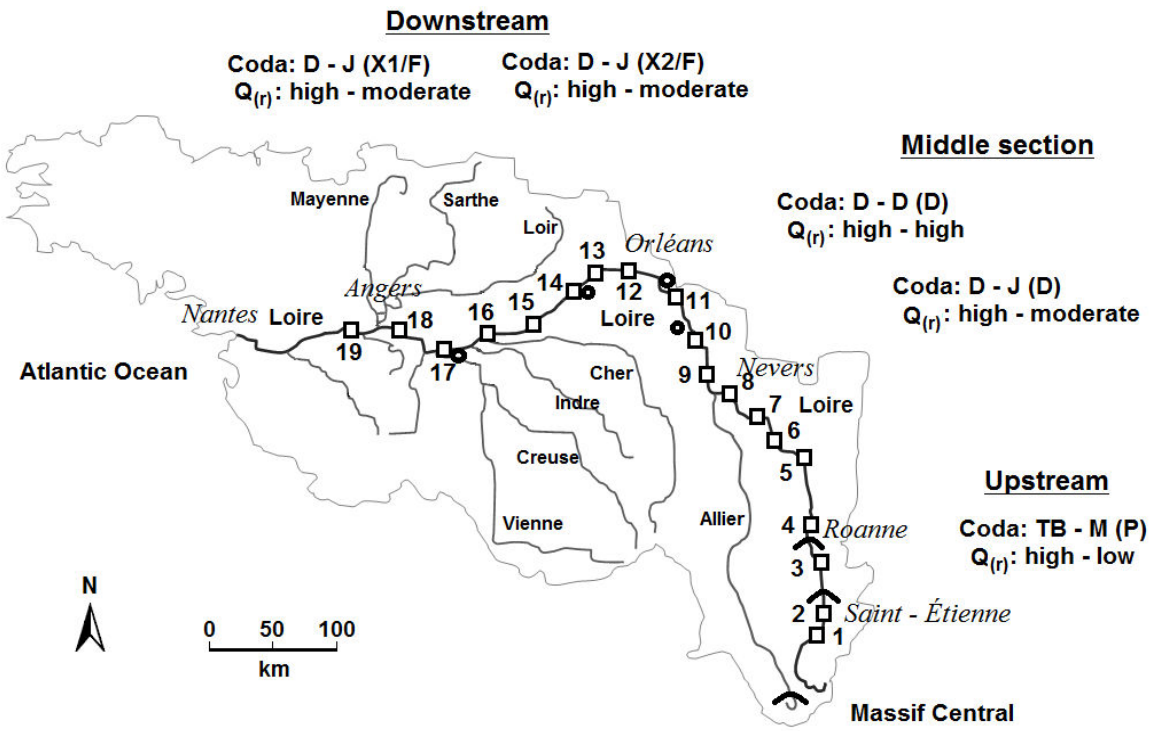

Fig. 24 *Coda patchiness [spring—late summer (intermediate phase)]* vs. $Q_{(r)}$ *index values along the River Loire in 2009*

The downstream decreasing $Q_{(r)}$ values reflected the increasing amount of codon **J,** indicating a switch in the primary energy source, as predicted by earlier studies (Borics et al., 2007). Besides the biomass dominance of codon **J** at the lower parts of the Loire, the change from codon **X2** to codon **X1** downstream also indicates an elevating trophic level. The uneven quantitative dominance of the volvocalean *Spermatozopsis exsultans* may require different assumptions i) this species is able to reflect high organic content (Várbíró et al., 2007); ii) may reflect uncommon environment, being dominant during downstream summer slow-flow, tolerating very high light availability; or iii) as it was observed in all Shannon-Weaver diversity maxima (66 species at st. 5: August, st. 7: July, st. 15: July), suggests evidence for some human induced species addition independently of river stretch. These longitudinal changes can be explained by low discharge (*Appendix V*, Image 2a) and the prolonged residence time, reflected also by higher Kjeldahl-N in some cases (*Appendix V*, Image 5a). An increasing downstream light availability was reflected by the increasing dominance of codon **F**, showing underwater light changes, which may influence the longitudinal switch between centric diatoms and green algae as well.

Using these results, the River Loire can be characterized in 2009 by the following river stretches (Fig. 24):

(i) Upper section (st. 1 to 4) reflects natural features by the presence of benthic diatoms dominance in spring, but with strong human impacts by dams (st. 2: Grangent and st. 4: Villerest), resulting in lake type succession with eutrophic, epilimnetic cyanobacterial 'climax';

(ii) Between Villerest dam, and the River Allier inflow, st. 5 to st. 8 represent an intermediate and functionally diverse river stretch, influenced by both natural and human impacts;

(iii) After the confluence of the River Allier, the Loire shows a prolonged dominance of centrics (st. 9 to st. 11), reflecting more permanent physical conditions by discharge;

(iv) Further downstream, the plankton is more and more enriched by meroplanktic taxa (st. 12 to st. 16), including species thought to indicate elevated trophic levels and a prolonged residence time. Despite the high species diversity values observed in summer, phytoplankton functional classification does not allow us to identify a functionally diverse river section here;

(v) The downstream section (st. 17 to st. 19) of the River Loire does not separate from its upper part, but has an increased light availability during summer owing to slow flow velocity and low discharge effects. The increasing population density of invasive Asian clams (*Corbicula* spp. - Mollusca, Bivalvia, Corbiculidae) in the Loire (Brancotte and Vincent, 2002; Chovet and Lécureuil, 2008) is supposed to affect quantitatively the phytoplankton by grazing (Descy et al., 2011), but their presence may also influence the phytoplankton composition as well.

This Loire survey, based on the phytoplankton functional group concept, can be used to obtain comprehensive information on ecological status differences along this Atlantic river, providing an example for "*phytoplankton response to human impact at different scales*".

4.3. The ecological state estimation of the River Loire (France) based on potamoplankton. A case study to compare species *vs.* functional groups in river water quality assessments[3]

Thesis Objective 3

[3] This chapter was presented at the 8th SEFS (Symposium for European Freshwater Sciences) meeting, held 1-5 July 2013, Münster, Germany; and it is being prepared for a future submission into ENVIRONMENTAL MONITORING AND ASSESSMENT.

Abonyi, A., U. Mischke, G. Borics, G. Várbíró & M. Leitão, (being prepared). The ecological state estimation of the River Loire (France) based on potamoplankton. A case study to compare species *vs.* functional groups in river water quality assessments.

4.3.1. Specific introduction

Water quality has been recognised to be a major issue connected to human water use, and has been argued along different problematic since the beginning of the last century (Meybeck and Helmer, 1989). However, the recognition of eutrophication processes delayed, and was only considered after understanding its direct effects on primary production (Blum, 1956), and the consequences of human mediated nutrient sources such as industrial and rural wastes, irrigation discharge, all contributing to an altered nutrient balance stimulating aquatic growths (Greene et al., 1975).

The water quality monitoring of the Loire basin - conducted by the Loire Bretagne Water Authority - was established in the 1970's, being among the first ones in France. The eutrophication of the river has been recognized in the 1980s, when the river was known as one of the most eutrophic European river (Meybeck et al., 2003). Since then, nitrate concentration does not show any decreasing trend (Minaudo et al., 2013), however, its seasonal oscillation seems to be attenuated, being a potential sign of decline in primary production (Moatar and Meybeck, 2005). Recently, groundwater origin of nutrient input was emphasized (Bouraoui and Grizzetti, 2008), paying the attention for the need of better farming practices. In contrast to nitrate, in recent years, TP concentration has tended to decline in the River Loire (Minaudo et al., 2013) reaching levels that might limit algal growth (Oudin et al., 2009). This potential phosphorus limitation was also explained by Descy and his co-authors (2011), however, the phytoplankton decline has not been yet clearly associated with neither nutrient decline nor other possible biotic factors such as the change of macrozoobenthos communities (Floury et al., 2013) in the Loire.

Conceptual framework of water quality approaches have been reconsidered by the implementation of the European official demand for ecological monitoring (WFD, 2000). The point of view has been turned towards ecological assessments, and it still motivates the scientific community to develop right methodologies and to establish well suited monitoring programs. New assessment schemes for both benthic and planktonic algae have been proposed (Padisák et al., 2006; Borics et al., 2007; Szilágyi et al., 2008; Mischke et al., 2011; Jüttner et al., 2012) in order to best meet with these requirements. While for lakes methodologies have been quickly evaluated (Reynolds, 2005; Padisák et al., 2006; Phillips et al., 2011; Pachés et al., 2012), reservoir phytoplankton (Sarmento and Descy, 2008; Cabecinha et al., 2009) and especially river potamoplankton assessments are being delayed. A further contrast is apparent, when contrasting the fast evaluation of benthic diatom assessments (Gomà et al., 2005; Tison et al., 2005; Kelly et al., 2009; Almeida and Feio, 2012; Novais et al., 2012; Rusanov et al., 2012), and of the potamoplankton, for which, only two methods have been proposed in Europe (Borics et al., 2007; Mischke et al., 2011).

At the moment, the WFD recommends the monitoring of potamoplankton in European rivers based on composition and biomass (Chl-*a*) metrics, without any further specific details (WFD, 2000).

Thus, this chapter is addressed to test the two existing potamoplankton assessments along the River Loire: the German PhytoFluss Index (Mischke et al., 2011) and the Hungarian River Phytoplankton Index—'HRPI' (Borics et al., 2009). The latter has been developed based on the $Q_{(r)}$ functional groups' index (Borics et al., 2007), taking a biomass (Chl-*a*) metric also into account. As French national potamoplankton assessment has not been developed yet, the national water quality classification system—'*SEQ*' of running waters (Oudin and Maupas, 2003) is used as a potential French reference tool for the qualification of the River Loire. The *SEQ* qualifies water into five classes being opened towards the WFD's

requirements. In this chapter, only one compartment of the SEQ connected to primary production is used, called SEQ-Eau (see *Appendix VI*). The SEQ-Eau contains five subclasses, and classifies each of them independently. For a final note, the worst seasonal case is considered for each parameter at each sampling station (if sample numbers exceed 12, the second worst case is considered). This method thus defines the worst water quality class occurring during a year.

According to the WFD, both German and Hungarian indices contain the compartments of biomass and composition metrics (Table 1), however, use different calculation processes. The PhytoFluss index runs with 5 independent metrics: "biomass based on Chl-*a*", "Pennales", "Chlorophyte", "Cyanobacteria" and "TIP-Indicator taxa". All metrics are assessed independently, and then averaged for the final PhytoFluss Index (Mischke et al., 2011). The HRPI uses two independent metrics: (i) a biomass one based on Chl-*a* and (ii) a composition metric based on the relative biomass of phytoplankton functional groups (Reynolds et al., 2002; Borics et al., 2007; Padisák et al., 2009). In the composition metric, each FG is weighted by a 'F' factor number, explained in *Chapter 4.2.1*. For the final HRPI, the two metrics are averaged using a multiple factor of 2 for the Chl-*a* metric (Borics et al., 2009). For both indices, different river typologies are assessed according to national river classification systems (see *Appendix VII*, Table 1). The final index values, as required by the WFD, correspond to five ecological status classes: "high", "good", "moderate", "poor" and "bad", and can be expressed as ecological quality ratios 'EQR' in both cases.

Therefore, our main objectives are to:

(i) Define merits and pitfalls in the use of both potamoplankton assessments along the River Loire.

(ii) Estimate the actual water quality state of the River Loire

(iii) Better understanding the two indices: in which cases, when, and why they perform better?

Table 7 *Metrics of the PhytoFluss (Mischke et al., 2011) and the HRPI (Borics et al., 2009) indices*

	PhytoFluss	**HRPI**
Biomass metric	Biomass Index: Chl-*a*	Chl-*a* Index
Composition metric	Pennales Index Chlorophyte Index Cyanobacteria Index Indicator taxa Index	FGs' Index
Final value of samples	mean of the 5 indices	weighted mean of the 2 indices
Scaling of quality classes	1 (high quality) to 5 (bad)	0 (bad) to 1 (high quality)
Final quality score of stations	seasonal mean of values	seasonal mean of values

4.3.2. Specific methods

Corresponding river typologies between the three countries

As both the PhytoFluss and the HRPI assessments require different normalization and calculation processes of data according to river typology, the correspondent or as similar as possible river types were chosen for each Loire sampling sites for our study (Table 8 and *Appendix VII*).

Table 8 *Corresponding river typology of sampling stations according to French (Wasson et al., 2004), German (Mischke et al., 2011) and Hungarian (Borics et al., 2009) river classifications. For details of German and Hungarian typologies, see* Appendix VII

Station	Hydro-ecoregion	Relief	Geology	Climate	Region	German type	Hungarian type
1	MASSIF CENTRAL	mountain	granite/metamorph	mountain humid	Mountain	9.2	3
2	DEPRESSIONS SEDIMENTAIRES	flat	detrital	southern oceanic	Mountain	9.2	3
3	MASSIF CENTRAL	mountain	granite/metamorph	mountain humid	Hilly	10.2	5
4	DEPRESSIONS SEDIMENTAIRES	flat	detrital	southern oceanic	Hilly	10.2	5
5	DEPRESSIONS SEDIMENTAIRES	flat	detrital	southern oceanic	Hilly	10.2	5
6	MASSIF CENTRAL NORD	mountain	granite/metamorph	temperate oceanic	Hilly	10.2	6
7	DEPRESSIONS SEDIMENTAIRES	flat	detrital	southern oceanic	Lowland	20.2	19
8	COTES CALCAIRES EST	broken	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
9	DEPRESSIONS SEDIMENTAIRES	flat	detrital	southern oceanic	Lowland	20.2	19
10	TABLES CALCAIRES	flat	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
11	TABLES CALCAIRES	flat	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
12	DEPOTS ARGILOSABLEUX	flat	detrital	temperate oceanic	Lowland	20.2	19
13	DEPOTS ARGILOSABLEUX	flat	detrital	temperate oceanic	Lowland	20.2	19
14	DEPOTS ARGILOSABLEUX	flat	detrital	temperate oceanic	Lowland	20.2	19
15	TABLES CALCAIRES	flat	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
16	TABLES CALCAIRES	flat	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
17	TABLES CALCAIRES	flat	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
18	TABLES CALCAIRES	flat	limestone/sedimentary	temperate oceanic	Lowland	20.2	19
19	ARMORICAIN	flat	granite/metamorph	temperate oceanic	Lowland	20.2	20

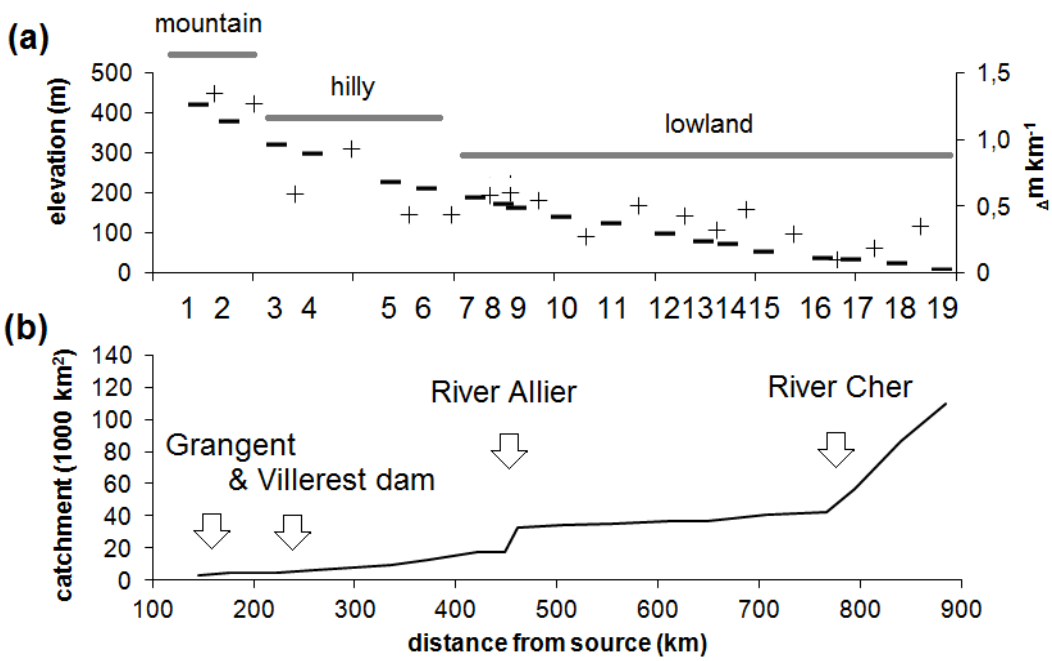

Fig. 25 *Geographical gradients along the River Loire sampling stations, 2009* **(a)** *elevation level (- symbol) and its specific change (+ symbol);* **(b)** *water catchment area. Figure also indicates the three main regions (mountain, hilly, lowland) according to elevation level and catchment size*

When difficulties appeared to identify the adequate river typology, the elevation level was first considered, and just then corresponded to further morphological characteristics. For data normalization process of each index, three main river sections were identified along the River Loire (Fig. 25):

(i)	Mountain area	(st. 1-2):	gravel river bad with medium catchment size
(ii)	Hilly region	(st. 3-6):	mostly gravel river bad, with large catchment
(iii)	Lowland section	(st. 7-19):	sandy river with large/very large catchment

Accordingly, both PhytoFluss and HRPI were run based on similar river typologies, however, using the original calculation and normalization processes of national methods (Borics et al., 2009; Mischke et al., 2011).

4.3.3. Results

Spatio-temporal patterns of quality index values

The ecological water quality values indicated by the two potamoplankton assessments showed considerable differences along the Loire (Fig. 26). Ecological classes according to the PhytoFluss assessment ranged almost in states of “good” to “moderate”; where “poor” water quality was only occasionally indicated at lowland river sections (st. 12 to st. 16) in May and June (Fig. 26a). Upstream mountain stations were mainly classified to “good” water quality through the whole growing season, as well as along the whole river length in spring.

The HRPI index showed more remarkable seasonal fluctuations in water quality classes. In general, “high” and “good” quality classes occurred during the spring and autumn periods. “Moderate” ecological state appeared even in some upstream cases (st. 1 to st. 3) in late summer. Further downstream, “poor” to “bad” conditions occurred at the middle Loire, and the lowermost river section (st. 10 to st. 19) in late spring and late summer (Fig. 26b). At a whole river scale, the longer was the distance from the source, the earlier was the seasonal decrease of both the PhytoFluss and the HRPI indices (more distinct feature in case of the HRPI).

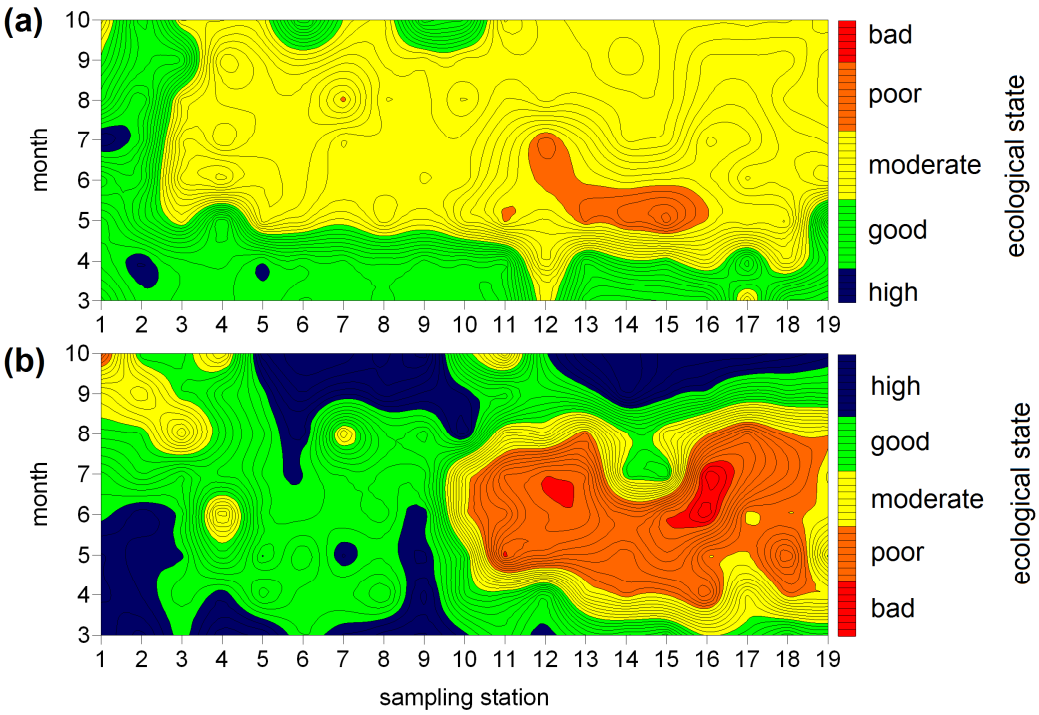

Fig. 26 *Spatio-temporal distribution of water quality classes by the* **(a)** *PhytoFluss (Mischke et al., 2011); and* **(b)** *the HRPI (Borics et al., 2009) indices along the River Loire, 2009*

Agreements vs. disagreements between the two indices

In spite of the different seasonal sensitivity of PhytoFluss and HRPI at a seasonal average level, the two assessments indicated similar ecological classes (Fig. 27). Differences occurred between st. 5 and st. 9, where HRPI systematically indicated better water quality by one quality class. The longitudinal distribution of both the seasonal average and of the worst quality values differed by the indices. PhytoFluss values tented to decrease almost the whole river length, but increased after the influence of the River Cher (st. 16). The HRPI showed increasing water quality until the confluence with the River Allier (st. 9), and then indicated rather "bad" and "poor" ecological water qualities further downward along the Loire.

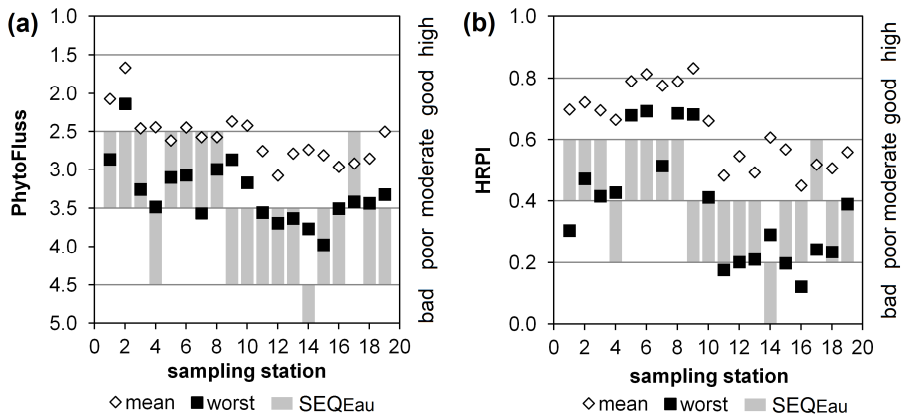

Fig. 27 *Seasonal average (open squares) and the seasonal worst (full squares) water quality classes at each sampling station along the River Loire, 2009 by* **(a)** *PhytoFluss (Mischke et al., 2011); and* **(b)** *HRPI (Borics et al., 2009). Grey colour indicates the seasonal worst water quality classes according to the French national running water quality classification, SEQ-Eau (Oudin and Maupas, 2003)*

Regional differences of water quality along the River Loire

Regional differences of quality values (median, Fig. 28) showed similar decreasing longitudinal profiles. In the mountain region, both indices indicated "good" water quality (median), however at the hilly and lowland sections they differed, where HRPI indicated one quality range higher in each case.

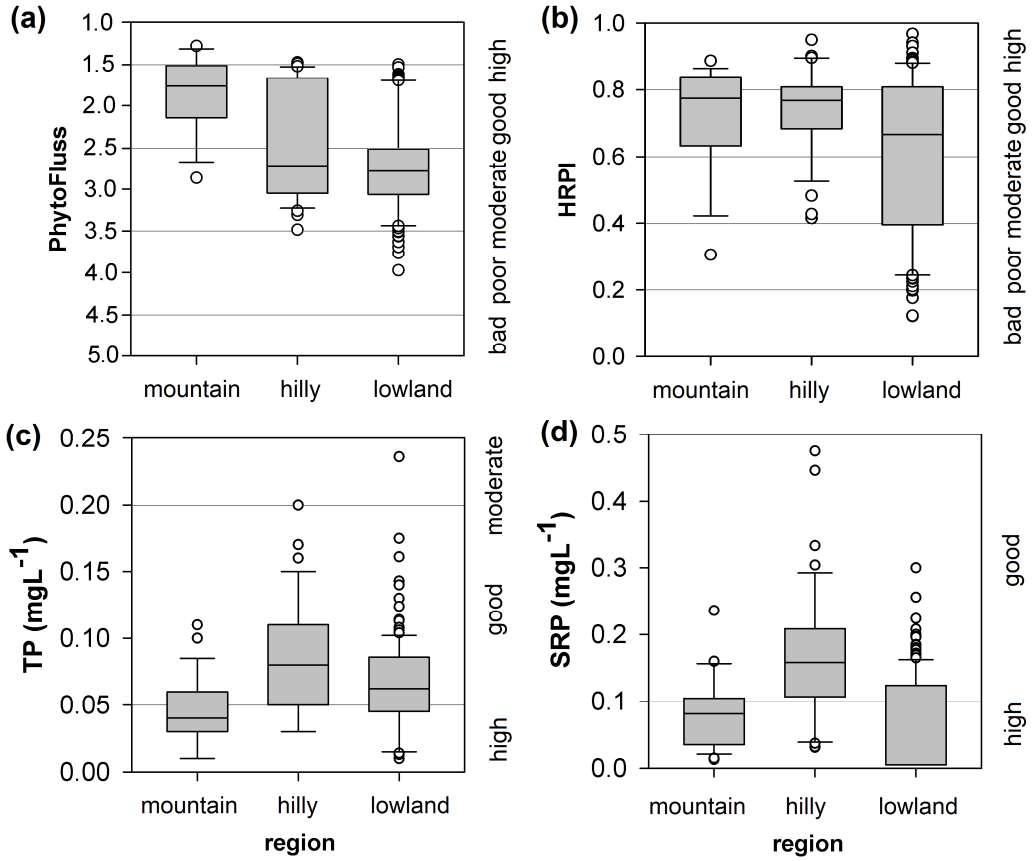

Fig. 28 *Box plot of ecological state values in the three Loire regions according to* **(a)** *PhytoFluss Index (Mischke et al., 2011);* **(b)** *HRPI Index (Borics et al., 2009);* **(c)** *TP and* **(d)** *SRP boundaries based on the SEQ-Eau system (Oudin and Maupas, 2003). Figures represent median values by solid black lines, and display each outlier. Number of data on* **(a-b)***: n=14 (mountain), n=31 (hilly), n=103 (lowland); while on* **(c-d)** *n=24 (mountain), n=48 (hilly), and n=156 (lowland)*

Index sensitivities on water quality parameters

The correlations between water quality indices and basic water quality parameters differed between the three geographical regions (Table 9). In the mountain area, both indices correlated with Chl-*a*, and only the HRPI with the relative biomass of benthic diatoms. In the hilly river section, only HRPI showed significant correlation with quantity parameters (total phytoplankton biomass, Chl-*a*) of the potamoplankton, while both indices significantly correlated with total P. At the lowland river section, both the PhytoFluss and the HRP Index were significant indicators of all the water quality parameters tested.

Table 9 *Correlation of index values with various water quality parameters in the* **(a)** *mountain area (st. 1 to 2);* **(b)** *in the hilly region (st. 3 to 6); and* **(c)** *at the lowland river section (st. 7 to 19). Bold, italic data indicate significant relationships between the two parameters.*

(a)

Parameter	Unit	PhytoFluss – r / p		HRPI – r / p	
Biomass	(µg L^{-1})	0.2909	p=0.313	-0.488	p=0.077
Chl-*a* + pheopigments	(µg L^{-1})	***0.7326***	***p=0.003***	***-0.7716***	***p=0.001***
Total P	(mg L^{-1})	0.1407	p=0.631	-0.1415	p=0.629
Benthic diatoms	%	-0.2797	p=0.333	***0.6711***	***p=0.009***
Planktonic diatoms	%	0.5009	p=0.068	-0.2075	p=0.477
Green algae	%	0.0903	p=0.759	-0.2079	p=0.476

(b)

Parameter	Unit	PhytoFluss – r / p		HRPI – r / p	
Biomass	(µg L^{-1})	-0.0071	p=0.970	***-0.5212***	***p=0.003***
Chl-*a* + pheopigments	(µg L^{-1})	0.194	p=0.296	***-0.5831***	***p=0.001***
Total P	(mg L^{-1})	***0.5049***	***p=0.004***	***-0.4676***	***p=0.008***
Benthic diatoms	%	-0.2703	p=0.141	0.2338	p=0.206
Planktonic diatoms	%	-0.1452	p=0.436	-0.0352	p=0.851
Green algae	%	***0.6953***	***p<0.001***	0.0581	p=0.756

(c)

Parameter	Unit	PhytoFluss – r / p		HRPI – r / p	
Biomass	(µg L^{-1})	***0.4581***	***p<0.001***	***-0.7123***	***p<0.001***
Chl-*a* + pheopigments	(µg L^{-1})	***0.5438***	***p<0.001***	***-0.8324***	***p<0.001***
Total P	(mg L^{-1})	***0.2913***	***p=0.003***	***-0.3252***	***p=0.001***
Benthic diatoms	%	***-0.2025***	***p=0.040***	***0.6284***	***p<0.001***
Planktonic diatoms	%	***-0.2723***	***p=0.005***	***-0.2463***	***p=0.012***
Green algae	%	***0.498***	***p<0.001***	***-0.3565***	***p<0.001***

4.3.4. Discussion

When compared to lake water qualification, river water quality might be more difficult to define due to the low level of predictability. In general, nutrients are highly available in large rivers (Reynolds and Descy, 1996), thus in most cases physical constraints are identified as major factors to control phytoplankton biomass and composition (Schmidt, 1994; Vörös et al., 2000; Leland, 2003; Salmaso and Braioni, 2008; Centis et al., 2010; Salmaso and Zignin, 2010; Tavernini et al., 2011). According to the WFD's requirements, habitat specific reference conditions should be defined by ecological states with minimised human impacts (Schimming et al., 2010). However, in Europe, the lack of these contemporary reference sites has been recognised, as most of the rivers show considerable degradation (Wehr and Descy, 1998; Borics et al., 2007; Schimming et al., 2010).

Besides the proposition of 'biotic integrity' as a potential potamoplankton assessment (Wu et al., 2012), reference conditions have been evaluated based on either TP concentration (Mischke et al., 2011), or the functional composition of potamoplankton (Borics et al., 2007). The German PhytoFluss index is normalized according to river typology based on specific response differences in the Chl-*a* to TP ratio. Pristine stage of German large rivers was defined in 0.05 mgL^{-1} TP (Mischke et al., 2011), indicating near natural conditions without anthropogenic inputs.

The HRP index has been based on the potamoplankton compositional response to environmental constraints, expressed by the relative biomass share among phytoplankton

functional groups. Pristine stage is defined by the overwhelmed dominance of benthic diatoms, reflecting fast flowing upland streams without long enough residence time for the development of true phytoplankton. However, further downstream with increasing WRT, the benthic diatom dominance is decreased by true planktonic elements, where the type and relative biomass share of each FG reflects some characteristics of both the chemical and the physical environmental. Thus, the HRPI's concept predicts the longitudinal decrease of water quality along rivers (Borics et al., 2007), while the specific biomass responses are normalized according to site-specific river typologies (Borics et al., 2009).

Besides the German and Hungarian potamoplankton indices, since 2000 (WFD, 2000) almost no river potamoplankton study was addressed to develop further potamoplankton assessment. The $Q_{(r)}$ functional group composition index (Borics et al., 2007) has been used to discriminate lentic and lotic sites in a German lowland system (Wu et al., 2011a, 2011b), to identify negative effects of damming in the River Narva (Piirsoo et al., 2010), as well as to indicate the major human impacts along the River Loire (Abonyi et al., 2012). In some other cases, river FGs described for the use of the $Q_{(r)}$ index have been preferred to interpret taxonomical data (Piirsoo et al., 2008; Devercelli, 2010; Cunha Pereira et al., 2011; Bovo-Scomparin et al., 2012).

In the River Loire, benthic diatom dominance was found to be a major characteristics of upstream sites (Descy et al., 2011) reflecting almost natural flowing conditions in spring (Abonyi et al., 2012). However, the seasonal succession of potamoplankton in this area indicates some major disturbance effects of dams. Their consequences might be reflected by (i) the possible dominance of true limnophilic taxa (*Fragilaria crotonensis*, *Aulacoseira granulata*) and (ii) uneven, point-like biomass peaks of either eutrophic benthic (*Melosira varians*, cf. *Batrachospermum*) or planktonic (*Microcystis*) taxa. While benthic biomass peaks might be directly related to flushing generated by the dams's outflow (Abonyi et al., 2012), presence of planktonic cyanobacteria is a clear indication of the eu-, hypertrophic conditions of both Grangent (Latour et al., 2004; Sabart et al., 2009) and Villerest reservoirs (Michard et al., 1996; Bonnet and Poulin, 2002). Despite the fragmentation of upper Loire by dams, water quality was qualified as "good" by both potamoplankton indices, as well as by the SEQ-Eau qualification system. The SEQ-Eau provided "moderate" water quality based on both N and P forms, as well as by Chl-*a*, algal number and pH. In this upper Loire, both the PhytoFluss and HRPI indices were significantly correlated only to Chl-*a*, but not well with the composition of potamoplankton. Exclusively, the HRPI seemed to be affected by compositional changes, as it was correlated to the relative biomass share of benthic diatoms. It was also able to indicate lake type succession stages by ecological state decrease at Grangent (st. 2) reservoir.

Further downstream, the hilly river section is might be the most affected by the controlled outflow, being influenced by the thermal stratification of Villerest dam (Bonnet et al., 2000). Several parameters such as low DO%, high Chl-*a* (*Melosira varians*, benthic peak) and pH indicates negative effects on water quality based on SEQ-Eau. PhytoFluss and HRPI indices are significantly correlated to TP, and the HRPI to algal biomass and Chl-*a*. While the increased TP and the lowered water temperature may be a sign of deep reservoir outflow (Abonyi et al., 2012), the potamoplankton composition tends to be decoupled from the spatio-temporal distribution of chemical parameters (Abonyi et al., 2014). Consequently, index values are not correlated to potamoplankton composition, only to chemical parameters such as TP by both indices; and to Chl-*a,* and total potamoplankton biomass by HRPI.

The discharge of the River Loire is mostly affected by the River Allier (inflow between st. 8 and st. 9) by doubling its water quantity through the whole year (Oudin et al., 2009). At

this section, the increased dominance of benthic diatoms might be a general feature of this river section (Abonyi et al., 2012), which effect was only reflected by the HRPI water quality Index (Fig. 26b).

As both indices have been developed to qualify large rivers with extended lowland areas, they performed the best in the middle and lower sections of the Loire (Table 9c). In this area, the SEQ-Eau system occasionally indicated "bad" water quality (st. 10) according to very high nitrate (up to 40 mgL^{-1}) but in general, all the downstream water quality classes were determined as "poor" by algae-related parameters (see *Appendix VII*, Table 3): both the PhytoFluss and the HRPI showed similarly "poor" quality classes in the seasonal worst cases, and responded similarly to the increased dominance of green algae, and the decreased relative biomass share of benthic diatoms (Table 9c).

The determination of water quality of downstream Loire sections requires further discussion. TP concentrations occurred around the German and French pristine states (~0.05 mgL^{-1}), while the SRP in most cases indicated "high" water quality (<0.1 mgL^{-1}) during the year 2009. Algae concentration by the SEQ-Eau, as well as by the two potamoplankton assessments indicate water quality states around "moderate" to "poor" classes. Even if algal, growth, especially green algae, might be P limited in some cases in the lower Loire (Descy et al., 2011), the species composition indicated by either the "indicator taxa list" of the PhytoFluss assessment, or the FG composition of HRPI prevail the overwhelming dominance of eutrophic taxa. These findings might allow supposing, that in case of favourable hydrological, physical, and biological (such as *Corbicula* spp.) conditions the potential for high algal concentration is still given in the Loire.

Despite the differences in characteristics of rivers and data used for the development of the potamoplankton water quality assessments in Germany and Hungary, both indices seemed to be applicable and provided valuable water quality indications on the largest Continental Atlantic River Loire.

Our results suggest that potamoplankton indices might be successfully used across different regions and countries, if normalization according to river typologies makes possible their site-specific harmonization. Some merits and pitfalls of both potamoplankton indices, as major outcomes of this study are provided in Table 10.

Table 10 *Summary of outcomes in testing PhytoFluss and HRPI along the River Loire, 2009*

	PhytoFluss (Mischke et al., 2011)	**HRPI (Borics et al., 2009)**
Chemical composition	Good indication of TP in hilly and lowland regions	Good indication of TP in hilly and lowland regions
Potamoplankton composition	Good indication mostly in lowlands	Good indication mostly in lowlands
	Might be slight indication on benthic diatoms dominance at upstream	Good indication on benthic diatoms dominance in mountain regions
Regional differences	Mostly influenced by Chl-*a* and photosynthetic pigments instead of composition	Mostly influenced by Chl-*a* and photosynthetic pigments instead of composition
Human impacts	Reliable indication on taxa dispersal at dams' area	Might be no indication on dam's influence in case of low Chl-*a* values

4.4. Inter-annual variation of phytoplankton functional groups along the River Loire. Do they appear similarly in each year? [4]

Thesis Objective 4

[4] This chapter was presented at the 32nd SIL (International Society of Limnology) Congress, held in Budapest, 4-9 August 2013, Hungary; and it is being prepared for a future submission into INLAND WATERS

Abonyi, A., F. Moatar, M. Leitão, J. Padisák, (being prepared). Inter-annual variation in phytoplankton functional group patchiness along the River Loire. Do they appear similarly in each year?

4.4.1. Specific introduction

River phytoplankton studies are often restricted to small river sections with a few sampling stations, or cover only one year, or even shorter periods. Potamoplankton taxa occurrence, accordingly, is thought to be highly stochastic in space and time, but regular annual successions might possibly occur among years (Köhler, 1994; Gosselain et al., 1994; Garnier et al., 1995; Ha et al., 2002). At a whole river scale, all influencial factors might be summarized in robust concepts such as the River Continuum Concept (Vannote et al., 1980), Flood Pulse Concept (Tockner et al., 2000), Riverine Ecosystem Synthesis (Thorp et al., 2006), or the Benthic Retention Hypothesis (Istvánovics and Honti, 2011). Furthermore, climate, geo- and hydro-morphological conditions affecting hydrological connectivity are the major factors to determine river biota worldwide (Sabater, 2008). Even if these biogeochemical (Meybeck and Helmer, 1989) and hydrological characteristics (Gasith and Resh, 1999) vary among rivers regarding whole river courses, their different reaches according to ecoregional or hydro-ecoregional scales might show similarities among years.

Potamoplankton may be less influenced by river typology along a river course (Borics et al., 2007) than benthic diatoms (Gosselain et al., 2005, Rimet, 2009), however, drastic changes of its composition might occur due to considerable changes in hydrology according to river order increase (Chételat et al., 2006), or morphology induced shifts like the lowland development of river side arms (Stoyneva, 1994; Lair and Reyes-Marchant, 1997). These geographical, geo-morphological and hydrological characteristics might then contribute to distinct river sections, which might function similarly in each year, and generate specific corresponding composition of biota (Thorp et al., 2006).

While the longitudinal occurrence of taxa might be hard to be predicted at each year (Reynolds and Descy, 1996), the functional grouping of taxa—as it collects functionally similar species to larger groups—might be more appropriate for this prediction. This chapter aims to compare the potamoplankton composition of the River Loire between the three consecutive years of 2009-2011 and, to provide a general longitudinal description of assemblages based on FGs. Specific questions of the chapter are the followings:

(i) What is the level of similarity in tendencies of FGs' occurrence between the three consecutive years along the River Loire?

(ii) What is the level of similarity in potamoplankton succession between the three years along the River Loire?

(iii) Which are the main physical and chemical factors controlling potamoplankton FG composition along the River Loire?

4.4.2. Specific methods

Succesion stages of potamoplankton composition are evaluated using the $Q_{(r)}$ potamoplankton index (Borics et al., 2007), already presented in the *Chapter 3.2.* in details. In order to identify the relevant controlling factors which determine potamoplankton functional composition in the River Loire, two distinc CCA analysis were performed using the same amount of data: (i) at the upper Loire part between Villerest dam (st. 4) and the River Allier inflow (st. 8); and (ii) at the downstream river reach between st. 11 and st. 15, before receiving its lowland inflows [3 year data of 5 sampling stations in each river section].

4.4.3. Results

Longitudinal trends in FG distribution

During the three consecutive years, functional group composition, and its longitudinal distribution provided regular and similar patterns along the River Loire (Fig. 29). Major coda, contributing up to ~80-90% of the seasonal average potamoplankton biomass were similar: $\mathbf{T_B}$, coda of centric diatoms: **B**, **C**, **D**, and codon **J** (Fig. 29a,c,e). Regression between FGs' distribution and distance from source indicated decrease for benthic diatoms, mainly increase for centric diatoms, while increase for chlorococcalean algae towards downstream sections in the three consecutive years (Table 11).

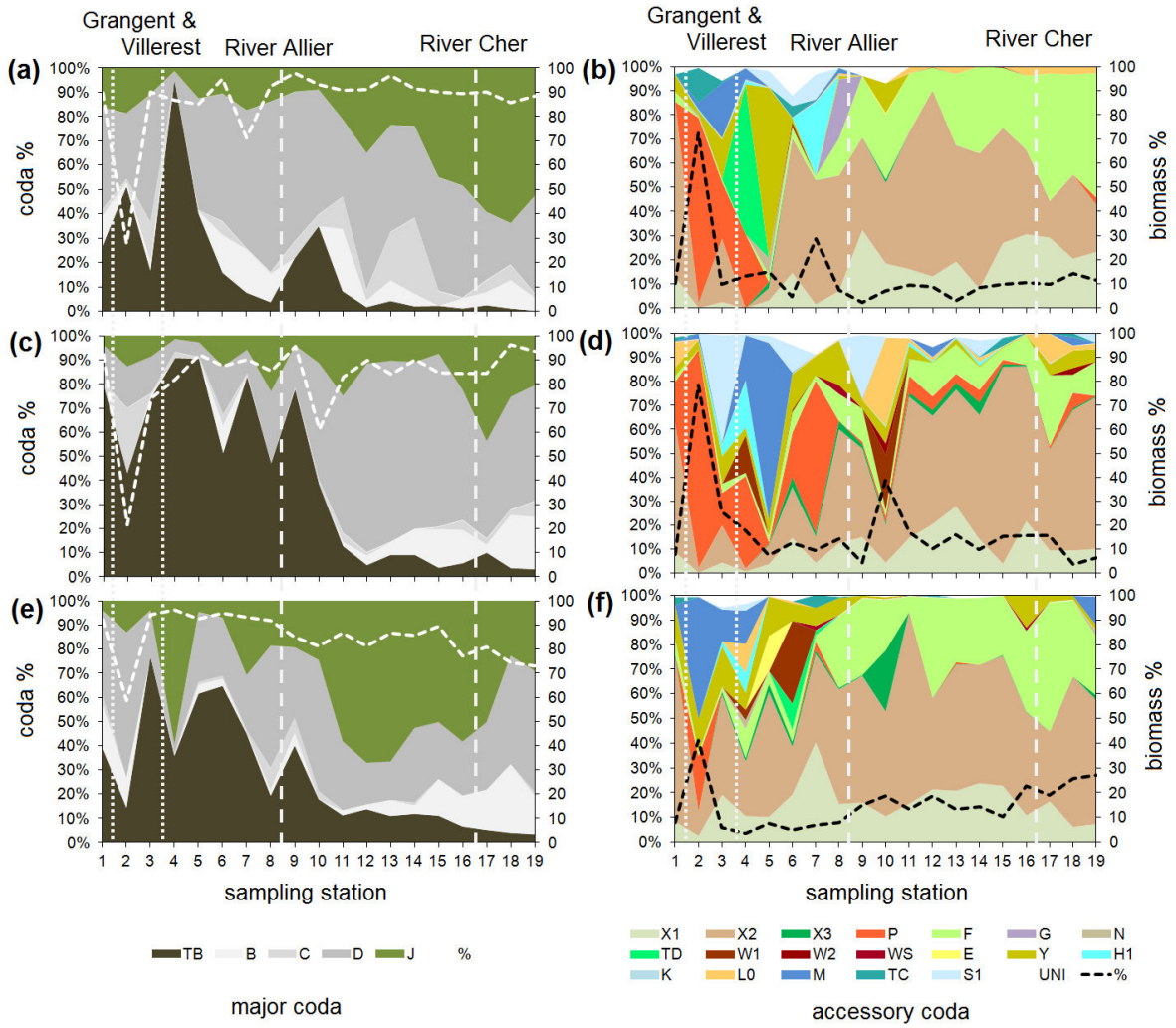

Fig. 29 *Longitudinal distribution of the major and the accessory phytoplankton functional group biomass along the River Loire based on seasonal averages at each sampling station. White (on the left) and black (on the right) dashed lines indicate contributions to the total seasonal average biomass at each station*

Table 11 *Linear regression between the seasonal average biomass contribution of each coda to the total biomass (%) and the distance from source (km) along the River Loire*

	2009		2010		2011	
TB	decrease	***P=0.005***	decrease	***P<0.001***	decrease	***P<0.001***
B+C+D	increase	P=0.483	increase	***P<0.001***	decrease	***P<0.001***
J	increase	***P<0.001***	increase	***P<0.001***	increase	***P<0.001***
X1	increase	***P=0.002***	decrease	P=0.807	increase	***P=0.013***
X2	increase	P=0.756	increase	P=0.100	increase	***P=0.005***
F	increase	***P<0.001***	increase	P=0.291	increase	***P<0.001***

Accessory coda, contributing almost ~10% to the seasonal average biomass displayed different functions at the up- and downstream river sections. Among them, however, the most important coda (**X1**, **X2**, **F**) showed similar, almost increasing biomass trends along the Loire in each year, and they provided the overwhelming biomass dominance besides codon **J** at the downstream river part. Contrary, at the upper Loire section—occasionally until the River Allier inflow (st. 8 to 9)—other assessor coda such as **P**, **S1**, **M**, $\mathbf{T_D}$**, Y**, **H1** were dominant, sometimes contributing up to ~70-80% of the seasonal average potamoplankton biomass (st. 2; Fig. 29b,d).

Succession differences of potamoplankton among years

At a spatio-temporal scale, both potamoplankton biomass, and the $Q_{(r)}$ composition metric showed considerable differences (Fig. 30). Higher biomass peaks occurred only occasionally upstream, and were displayed by algae of early or no plankton succession stages (see Mai-June, 2009 at st. 4—Villerest dam). In other cases, however, real limnophilic phytoplankton reflecting lake-type succession stages were dominant (coda **P**, **S1**, **M**, **H1**), repeatedly at late summer with low total phytoplankton biomass.

At the middle Loire, total biomass peaked due to centric diatom blooms in each spring, while the seasonal contribution of green algae was highly dependent and variant among years. The length of vegetation periods, and accordingly phytoplankton successional stages indicated by the $Q_{(r)}$ index differed significantly between the three years: intermediate in 2009 (Mai-September); very short in 2010 (Mai-July), and prolonged in 2011 (Mai-September)—(Fig. 30b,d,f).

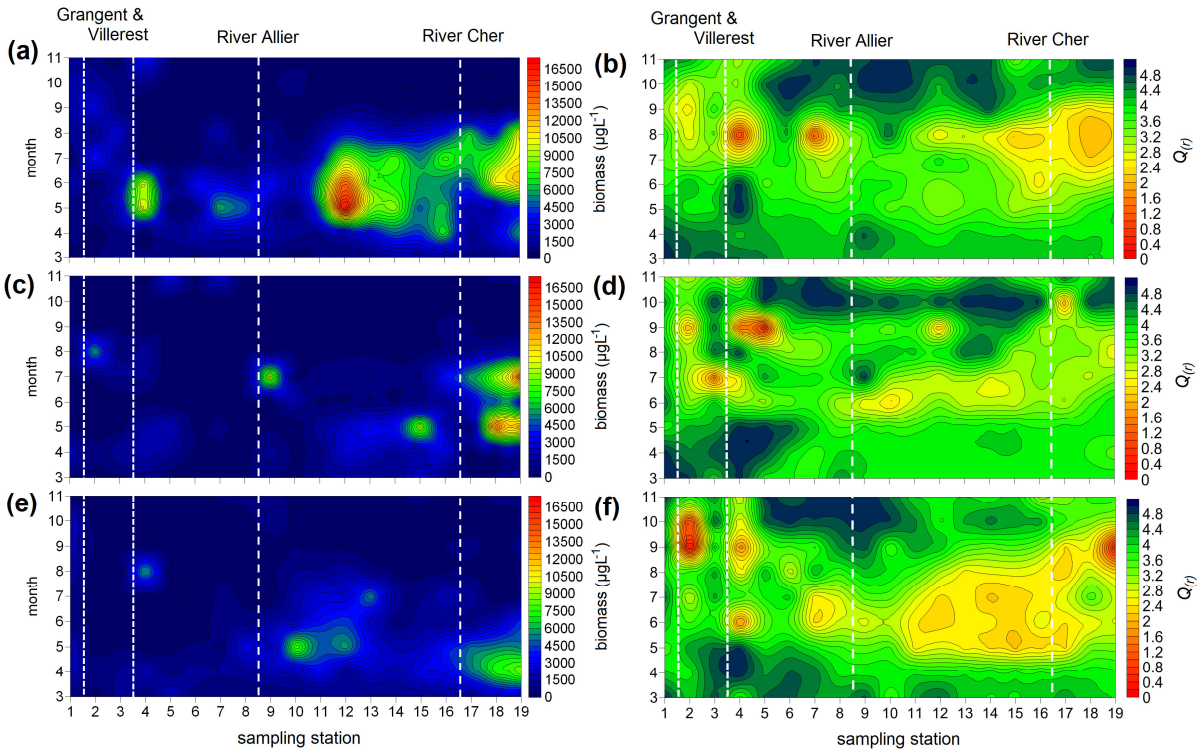

Fig. 30 *The spatio-temporal distribution of potamoplankton biomass and succession stages of the potamoplankton based on the $Q_{(r)}$ composition index in years* **(a**,**b)** *2009;* **(c**,**d)** *2010;* **(e**,**f)** *2011*

Physical and chemical controlling factors

At the upper Loire (st. 4 to st. 8), results of the CCA ordination on the 23 FGs and 12 environmental variables showed that the cumulative percentage variance of the FG-environmental parameters relation was 52.9%, with eigenvalues of 0.112 and 0.054. The first axis was closely related to TN (interset correlation, R= 0.643), while the second axis to specific discharge (R=0.631). Besides the first ordination axis which clearly reflected a gradient mostly related to TN, the second axis further indicated that DOC and T had also large effect on the occurrence of FGs. The Monte Carlo permutation test, in this upper region, failed to indicate significant ordinantion (p= 0.146).

Already at this upper Loire section, planktonic diatoms (coda **C**, **D**) were explained by specific discharge (SD) via turbidity, the amount of suspended solids and SRSi (Fig. 31a). The occurrence of coda **J** and **X1** were negatively correlated with the aforementioned parameters, but were more related to elevated water temperature and conductivity. Limnophilic taxa (coda **P**, $\mathbf{L_0}$, **M**, **S1**, **H1**) were positively correlated with DOC and TP, where the latter three coda were clearly grouped together.

At the downstream Loire section (st. 11 to st. 15), CCA ordination based on 19 FGs and 12 environmental variables showed that cumulative percentage variance of FG-environment relation for the first two axes was 59.4%, whith eigenvalues of 0.266 and 0.125, respectively. The first axis was mostly related to specific discharge (R=-0.581), while the second one to T (R=-0.856). In this case, the Monte Carlo permutation test of all canonical axes showed significant ordination result (p=0.002).

In this lower river section—contrary to upstream results—TP was found to be related to specific discharge. Phytoplankton coda of planktonic centric diatoms, as well of chlorococcalean alge were similarly controlled by environmental parameters as at the upper river section (Fig. 31b). A remarkable difference between the two river zones studied was that limnophilic taxa (coda **P**, **L_0**, **M**, **S1**, **H1**) were no more correlated and explained by any chemical or physical factor at the middle Loire, and they occurred with similar dispersing pattern found for benthic diatoms (**T_B**), or euglenoids taxa (**W1**, **W2**). The occurrence of limnophilic coda such as **L_0**, **P** and **K** depended mostly on water temperature, similarly to coda **F** and **X1**, which were also positively correlated to pH values.

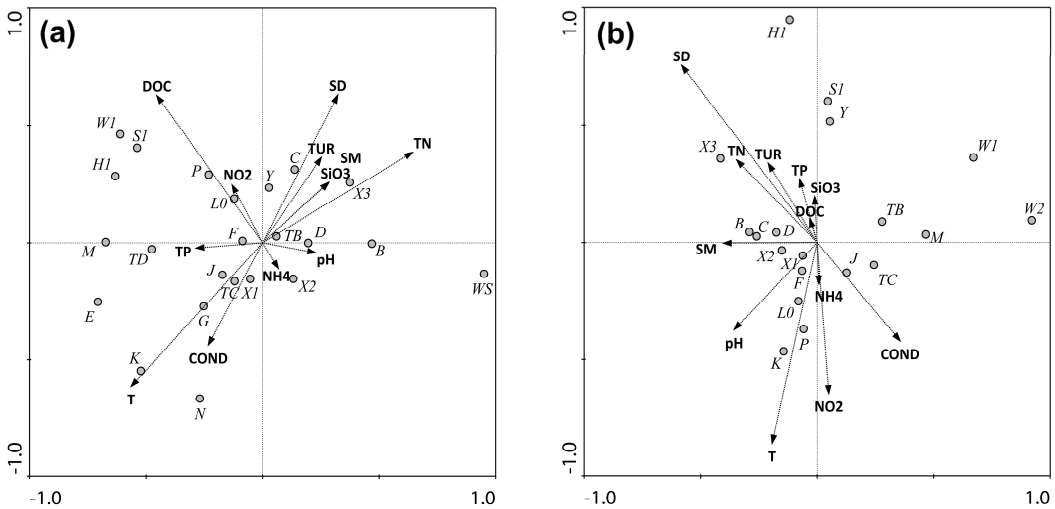

Fig. 31 *CCA analysis of physical, chemical and FGs data in the vegetation period of years 2009-2010-2011 at the* **(a)** *upper Loire (st. 4 to st. 8); and* **(b)** *at the middle Loire (st. 11 to st. 15). SD: specific discharge, TUR: turbidity, SM: suspended solids, TN: total nitrogen, TP: total phosphorus, DOC: dissolved organic carbon, SiO3: soluble reactive silica, NH4: ammonium, NO2: nitrite, COND: conductivity, T: water temperature; while other alphabetic letters are phytoplankton coda.*

4.4.4. Discussion

General trends in compositional continuity along the River Loire

The longitudinal shift of benthic coda to chlorococcalean greens via centric diatoms along the River Loire was already described along a few sampling stations by Leitão and Lepretre (1998), and recently by Descy et al. (2011). These compositional changes, however, display continuous shifts, and according to findings of the current chapter, occure repeatedly with similar longitudinal trends in all the three years studied. The potamoplankton composition at the upper Loire was found to depend on both natural (discharge) and human-mediated constraints (retention of dams) and, it displays a mix of taxa depending on seasonal river flow characteristics, and dams's functioning. Benthic diatoms, however, still frequently dominate the potamoplankton in this upper Loire section reflecting a general headwater environment or large rivers (Ács et al., 2006), or flows sustaining short water residence time (Holmes and Whitton, 1981; Reynolds and Descy, 1996). In these cases, benthic taxa are detached from the substratum, and thus occasionally occur in the plankton, like *Fragilaria construens*, *Fragilaria arcus*, *Navicula gregaria*, *N. lanceolata*, *N. tripunctata*, *Nitzschia dissipata*, *or N. linearis* at the upper Loire stations. Further downstream in the middle Loire, the occurrence of benthic diatom taxa are no more determined by environmental parameters in the plankton (indicated by the CCA analysis), but can be explained by dispersals from upstream habitats. This continuous decrease of benthic diatoms along the Loire might also demonstrate the importance of geographical location on benthic diatoms' composition, and of dispersals at larger spatial scales (Potapova and Charles, 2002; Soininen, 2007). Furthermore, it is provided, that codon $\mathbf{T_B}$ can be possibly used to indicate high flow rates and pristine source conditions in rivers (Borics et al., 2007). Such an example is the well known major influence of the River Allier on the Loire discharge, which prolong the dominance of codon $\mathbf{T_B}$ in all years at st. 9 to st. 10. However, smaller inflows like the River Aron seem to be also apparent, as indicated by the longitudinal distribution of codon $\mathbf{T_B}$, and of prolonged dominance at st. 7 in 2010.

While the contribution of benthic diatoms to potamoplankton biomass decreases along the Loire in all years, centric diatoms and coccal green algae depend more likely on specific annual river flow characteristics. Centric diatoms' dominance, as already described by former literatures, is basically determined by physical forces of the river flow, which relationship can be successfully studied by parameters such as suspended solids or turbidity (Krogstad and Løvstad, 1989; Reynolds et al., 1994; Salmaso and Zignin, 2010), as well as by silica content (Tavernini et al., 2011). This dependence on flow conditions are well indicated by the $Q_{(r)}$ composition index as well, which in medium (2009) and low flow years (2011) follows the seasonally earlier occurrence of spring blooms along the Loire. This observation might open towards a possible ecological indication of variability in spring river flow conditions, which is possibly related to recent climate change (Hardenbicker et al., 2014).

The dependence of green algae dominance on the length of vegetation period, meaning the length of low flow periods determining high light availability at lowland river sections is a well know process as well (Stoyneva, 1994; Leland, 2003). Besides variations between centrics and green algae dominances according to year specific flow conditions, codon **J** increase at longitudinal scale in the Loire independently of year. Its lowland dominance might allocate similar hydrological conditions as found in other large, lowland rivers (Ibelings et al., 1998; Stoyneva, 1994; Leland, 2003; Friedrich and Pohlmann, 2009). Further general pattern in the Loire is the co-dominance of coda **X2**, **X1**, and **F** along the River Loire. While coda **X2** (like *Chlamydomonas*, *Plagioselmis*) or **X1** (like *Monoraphidium*, *Scenedesmus*) often found

to be the most abundant and common summer riverine taxa worldwide (Peterson and Stevenson, 1989; Gosselain et al., 1994; Sabater et al., 2008; Devercelli, 2010; Wu et al., 2011b), the increase of codon **F** towards downstream sections might reflect a special Loire characteristic in recent years with high light availability in late summer. As indicated by the CCA analysis, coda **J**, **F**, **X1** are the most sensitive groups for the effects of timing in favourable hydrological conditions. Accordingly, in low water years, they development possibly start further upstream (example of year 2011), even if the continuous downstream biomass increase remains a repeated and general longitudinal pattern of each specific year.

The particularity of the River Loire is the relatively low level of regulation (two dams, and of one large occur in its upper river stretch), and the ~300 km free flow along its middle course without major inflow. Consequently, the high level of compositional connectivity in the Loire might not be observed, or at lower level in other large, more regulated and canalized rivers such as the River Seine (Billen et al., 1994), River Rhin (Scherwass et al., 2010), River Ebro (Sabater et al., 2008), or River Danube (Dokulil, 2013) in Europe; as well as elsewhere worldwide (Barbosa et al., 1999; Ha et al., 2002; Koch et al., 2004).

General trends in compositional discontinuity along the Loire

Independently of years, limnophilic taxa (coda **P**, $\mathbf{L_0}$, **M**, **S1**, **H1**) occur at upstream Loire sites, and are related to upstream dams' functioning: Grangent (st. 2) and Villerest (st. 4). This general pattern demonstrates that cyanobacteria still bloom in these reservoirs alike as described in the former literature (Michard et al., 1996; Latour et al., 2004; Sabart et al., 2009), and provides the evidence for limnophilic taxa dispersal similarly to observations found in case of other reservoir systems (Köhler, 1994; Piirso et al., 2010; Grabowska, 2012). It is important to note, however, that these taxa do not produce high biomass at further downstream, as they are not adapted to function in lotic conditions (Reynolds, 1994; Reynolds and Descy, 1996). Furthermore, taxa dispersal following this dams' upper section is might be a general consequence for further FGs' occurrence downstream ($\mathbf{T_C}$, $\mathbf{T_D}$, **W1**, **W2, WS**, **Y**), while the level of significance between upstream and middle Loire lateral sources for these coda still remains poorly understood. As both regions seem to be a possible and remarkable contributor to high potamoplankton richness of the Loire, they are further discussed in connection with their possible roles in ecosystem functioning in *Chapter 3.5.*

General patterns in potamoplankton succession along the Loire

According to distribution patterns of FGs described above, potamoplankton composition is expected to show similarly succession stages in the Loire among years. A more remarkable dependence on flow characteristics, however, occurs in the middle river section, especially for centric diatoms and green algae. The productive part of the composition—here based on biomass—might be fully covered by the major ($\mathbf{T_B}$, **B**, **C**, **D**, **J**) and the most abundant accessory coda (**X2**, **X1, F**). Consequently, high biomass is exclusively generated by taxa of early succession stages in the Loire. Dispersals of cyanobacteria, or other coda seem to be irrelevant as active components of the composition in the middle flow, in contrast to a recent finding at the middle section (Larroudé et al., 2013). High level of taxa dispersal might contribute to high taxonomical richness, but not as an active component of the Loire composition. Similarly, cyanobacteria may occur in late summer at the lowland river stations (September, 2011; st. 19), which can be, however, explained by the contribution of eutrophic lowland river inflows like the River Maine, instead of considering them as an autochthonous component of Loire potamoplankton.

4.5. Species *vs.* functional group richness of potamoplankton in the River Loire. Does the best ecosystem functioning occur under high richness in turbid environments?[5]

Thesis Objective 5

[5] This chapter is being prepared for a future submission into FRESHWATER BIOLOGY.

4.5.1. Specific introduction

The relationships between taxa number and ecosystem functioning has been studied in nutrient limited, clear water lentic (Ptacnik et al., 2008; Weyhenmeyer et al., 2013), but not yet in lotic systems. More and more studies provide data on potamoplankton taxa occurrence in a longitudinal context from rivers (Bahnwart et al., 1999; Sabater et al., 2008; Istvánovics et al., 2010; Descy et al., 2011), while further researches stress the controlling factors along even lateral axis (García de Emiliani, 1997; Devercelli, 2010; Mihaljević and Stević, 2011; Stević et al., 2013; Mihaljević et al., 2013). However, these descriptions do not consider differences in the level of significance of each taxon to ecosystem functioning when moved forward by the river flow. While dams' limnophilic taxa are not adapted to river conditions, and are not able to maintain considerable production further downstream (Reynolds and Descy, 1996; Reynolds, 2006), the dispersal-production relationships might display considerable changes according to timing, location and the occurring functional composition of potamoplankton taxa in other cases.

As summarized in the previous *Chapter 3.4.*, according to spatio-temporal differences of flow characteristics in one year, or of these variations among years, several taxa dispersal creating mixed potamoplankton compositions may occur along the Loire. These include the major- and the most relevant accessory taxa (*Chapter 4.2.*), while further species dispersals take place as well from additional habitats such as impoundments (Abonyi et al., 2012), or all kinds of lateral habitats like side arms or backwaters in the middle river section (Descy et al., 2011). These taxa dispersals sometimes largely contribute to the total occurring taxa number, and might signify different functioning in the composition. According to compositional differences found in previous chapters based on taxa richness and FG richness along the River Loire, we hypothesise that these approaches display different relationships with potamoplankton productivity and of ecosystem functioning measure in time and space. In the light of water quality management, we analyse the aforementioned relationships using the resource use efficiency—'RUE' ratio (Ptacnik et al.,2008), which involves the total phytoplankton biomass and TP water quality parameters.

Therefore, this chapter aims to study spatio-temporal differences in potamoplankton taxa and FG richness along the River Loire from three consecutive years (2009-2011), and answer how the relatively large species pool serves the functioning of the River Loire ecosystem with the following specific questions:

(i) How species and functional richness of potamoplankton are related to each other along the Loire?

(ii) How species and FG richness are related to ecosystem functioning, and at which richness the Loire ecosystem functions the most effectively?

(iii) How taxa and FG richness alter according to seasonal and inter-annual differences in flow characteristics?

4.5.2. Specific methods

The resource use efficiency—'RUE' was used to measure ecosystem functioning according to Ptacnik et al. (2008). Using their suggestions, two ratios were determined: (i) the fresh weight carbon phytoplankton biomass to TP (RUE_{carb}); and the Chl-*a* to TP (RUE_{chl}). Accordingly, the biomass is compared to the potentially available amount of resource—here P as the most

important trophic state indicator—in two independent way, and thus indicate the efficiency of ecosystem functioning.

Phytoplankton carbon biomass was determined according to Sournia (1978), based on phytoplankton biovolume determined according to *Chapter 2.2*.

4.5.3. Results

A general pattern of high potamoplankton diversity based on taxa number and FG number occurred on the river reaches between Villerest dam (st. 4) and the River Allier inflow (st. 8 to st. 9); as well as at the middle Loire (st. 11 to st. 15). In both cases, linear regression showed strong dependence between taxa and FG richness (upper Loire section: R=0.558, P<0.01; middle Loire section: R=0.604, P<0.01). However, differences occurred in the seasonal distribution of diversity between the two regions. In the upper Loire, maximum richness was mostly restricted to late summer periods (st. 3; st. 5), while in the middle Loire, it tended to occur during the period of late spring and summer. These patterns were similar in the three consecutive years studied, being the most remarkable in 2010, while the least pronounced in 2011 (Fig. 32).

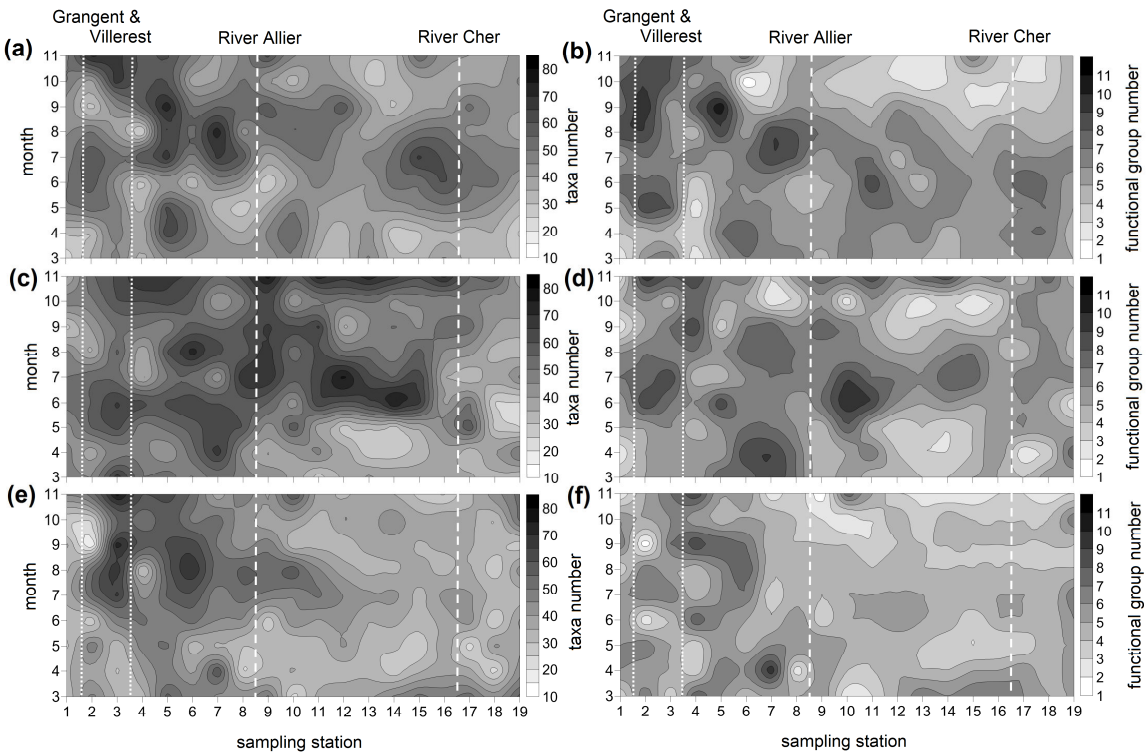

Fig. 32 *Spatio-temporal distribution of potamoplankton taxa- and FG-number in the River Loire in* **(a**, **b)** *2009;* **(c**, **d)** *2010; and* **(e**, **f)** *2011*

At a longitudinal scale, the most taxon rich sampling station was *La Motte Saint-Jean* (st. 5) in all the three years (Fig. 33a), while a second increase in total taxa number as well as in the newly arriving taxa occurred at the middle Loire (st. 11 to st. 13, Fig. 33b). At the upstream Loire stations (st.1 to st. 5), total taxa number increased sharply along a few stations, but was paralleled with an outstanding weaken of taxa pool by new arrivals. Between

the three years studied, 2009 and 2010 displayed a more diversified middle- and downstream Loire potamoplankton composition, while the least taxa rich one in 2011.

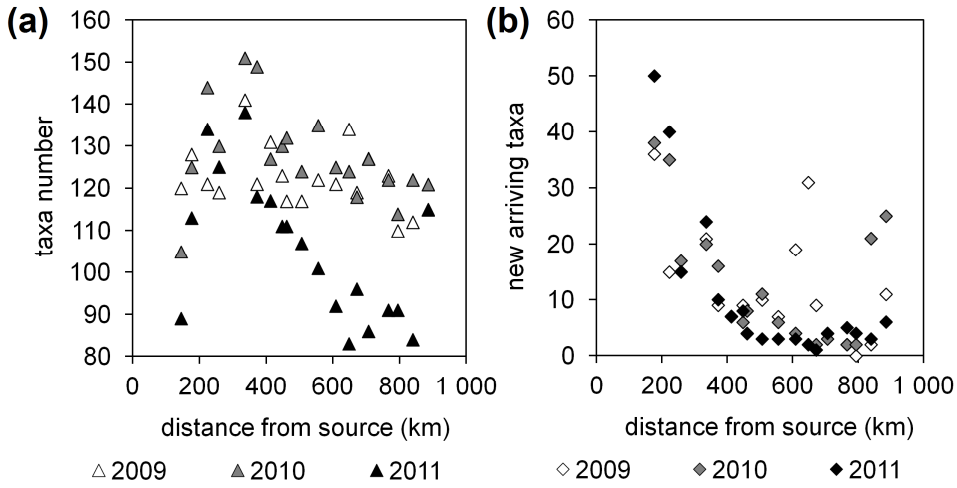

Fig. 33 *Longitudinal distribution of* **(a)** *the seasonal average of total taxa number; and* **(b)** *the number of new arriving taxa at each sampling station along the River Loire (2009-2011).*

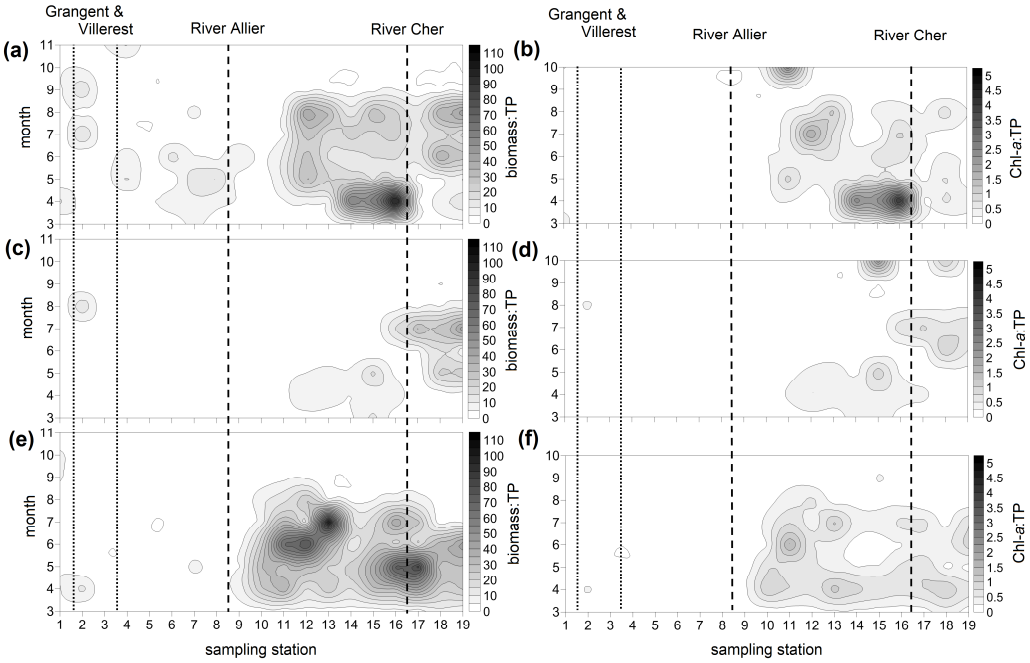

Fig. 34 *Spatio-temporal distribution of the resource use efficiency 'RUE' based on the biomass carbon:TP and the Chl-a:TP ratio in the River Loire in* **(a**, **b)** *2009;* **(c**, **d)** *2010; and* **(e**, **f)** *2011.*

At a spatio-temporal scale, the RUE peaked at the middle Loire based on both biomass and Chl-*a* data (Fig. 34). A second peak occurred further downstream in each year; however, it differed in both longitudinal positioning and timing. The less productive station was *La*

Motte Saint-Jean (st. 5) in all the three years. Besides a good linear correlation between RUE_{carb} and RUE_{chl} data (R^2=0.46), only RUE_{carb} displayed some upstream productive areas, while RUE_{chl} did not.

The RUE_{carb} and RUE_{chl} ratios displayed similar patterns along the gradient of taxa- and FG richness (Fig. 35 and Fig. 36). For all these parameters, the ordering of years along richness was 2010>2009>2011. Based on median values, taxa numbers differed significantly between all the three years (ANOVA, $p<0.001$), while FG numbers only between 2011 and the other two years.

Besides the significant differences between the three years in taxa- and FG-richness, the RUE displayed similar distribution patterns along the gradients of both richness parameters. Maxima of RUE occurred at low taxa number in each year (20-30 taxa), and showed a continuous decreasing trend with the increase of taxonomical richness. This relationship was more observable in years 2009 and 2010 (Fig. 35a,b,c and Fig. 36a,b,c).

The RUE values along FG richness stayed more or less stable between the 25-75% data range, but showed humped shaped distribution at a whole data distribution scale (Fig. 35d,e,f and Fig. 36d,e,f), where the RUE ratio increased continuously until ~six FGs, and then decreased with further rise in functional group richness.

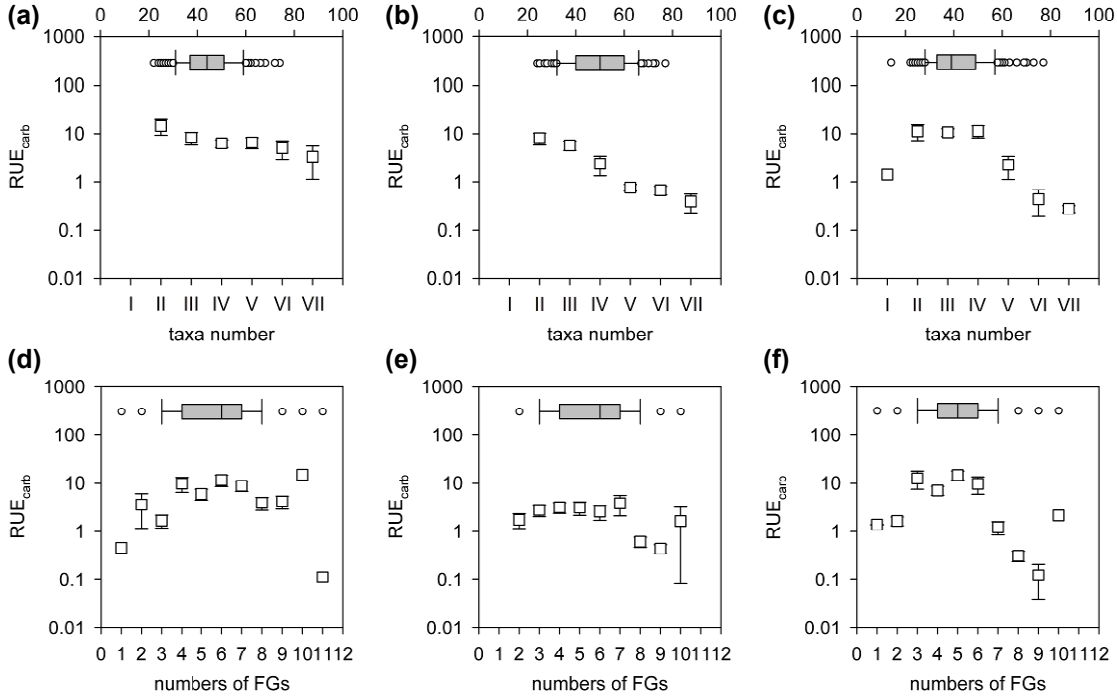

Fig. 35 *Resource use efficiency based on carbon content of freshweight potamoplankton biomass to TP ratio (RUE_{carb}), and its relate to taxa- and FG-richness. Mean ± SE of the years* **(a**, **d)** *2009;* **(b**, **e)** *2010;* **(c**, **f)** *2011. Taxa number classes on* **(a-c)***: I: 10-20 II: 20-30 III: 30-40 IV: 40-50 V: 50-60 VI: 60-70 VII: 70-80. Upper box plots represent the distribution of data, indicate median values by solid black lines, and display each outlier. (N=170 in 2009, 171 in 2010, and 170 in 2011)*

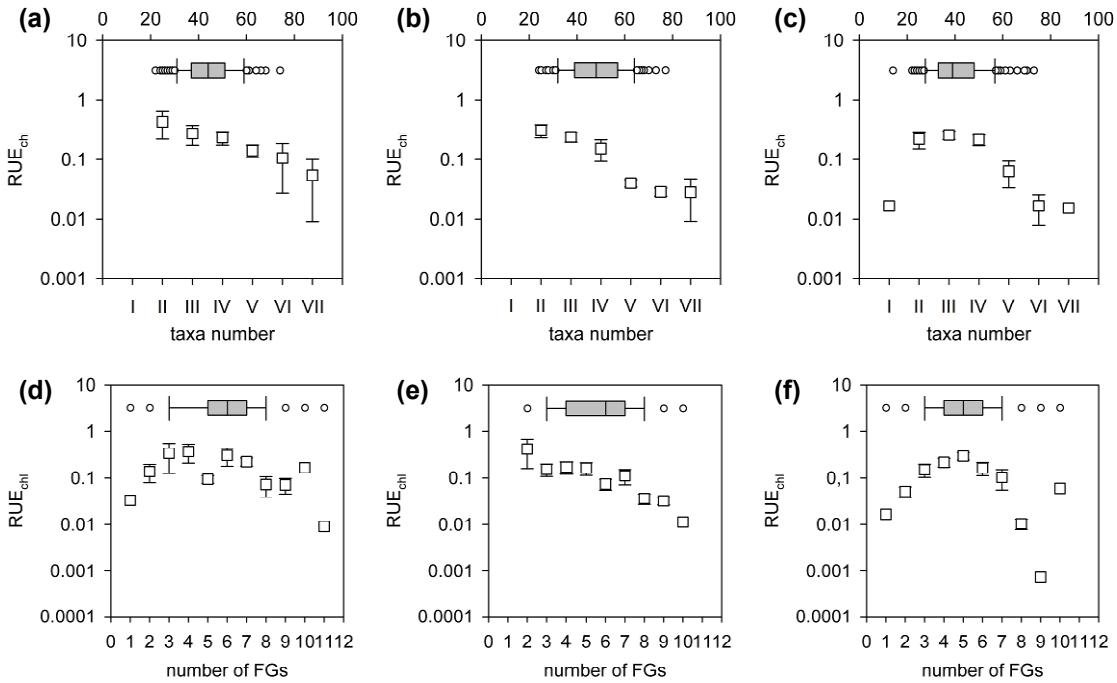

Fig. 36 *Resource use efficiency based on Chl-*a *to TP ratio (RUE$_{chl}$), and its relate to taxa- and FG-richness. Mean ± SE of the years* **(a**, **d)** *2009;* **(b**, **e)** *2010;* **(c**, **f)** *2011. Taxa number classes on* **(a-c)***: I: 10-20 II: 20-30 III: 30-40 IV: 40-50 V: 50-60 VI: 60-70 VII: 70-80. Upper box plots represent the distribution of data, indicate median values by solid black lines, and display each outlier. (N=170 in 2009, 171 in 2010, and 170 in 2011)*

4.5.4. Discussion

Low vs. *high taxa number in space and time along the Loire*

The number of coexisting phytoplankton species is known to be dependent on the periodicity of disturbances from both experimental (Gaedeke and Sommer, 1986) and field studies (Chorus and Schlag, 1993; Jacobsen and Simonsen, 1993). Growth of planktonic algae in rivers are determined by flow conditions (references in *Chapter 1.1.2.*), which govern patterns in taxa composition, and consequently, in richness/diversity as well (Carvajal-Chitty, 1993; Descy, 1993; Reynolds et al., 1993). Rivers remain to be rough and selective environment, where autochthonous growth requires special abilities like fast reproduction rate or the adaptation to narrow light conditions (Reynolds, 1994). A general consequence of large rivers is the alleviation of these pronounced selective conditions allowing autochthonous autotrophic production to increase at mainly middle river sections (Reynolds and Descy, 1996; Sabater et al., 2008; Dokulil, 2013).

In the previous chapter (*Chapter 3.4.*), differences in functional organization between the upper and the middle Loire potamoplankton composition was presented. Besides the major longitudinal sequences of benthic diatoms to planktonic ones, and then towards the dominance of meroplanktic greens, the upper and middle Loire both possibly sustain high species richness (diversity as well), however, owing to different determinant factors. At upstream, both physical (Bonnet et al., 2000; Bonnet and Poulin, 2002) and chemical disturbances (Minaudo et al., 2013; Minaudo et al., 2014) related to human impacts generate a

fast and significant increase in the total occurring taxa numbers reflecting a wide range of habitats. Already at the first few sampling stations (~ first 200 km distance f.s.), meroplanktonic and limnophilic phytoplankton taxa do occur (*Chapter 3.2.3.* and Fig. 29), and altogether display this river section as the most taxa rich and diversified, if the whole Loire river length is considered (st. 5: La Motte Saint-Jean, 336 km distance f.s.).

At the upper Loire section following dams (~340 km distance f.s.), potential for new taxa occurrence decrease sharply, but many scattered species occurrence might be further indicating modified river conditions such as high light availability by *Melosira varians*—$\mathbf{T_B}$ dominance (Hill et al., 2011), or dispersals from stagnant, stratified environment like *Ceratium*—$\mathbf{L_0}$, $\mathbf{L_M}$ (Köhler and Hoeg, 2000; Xiao et al., 2011). In this river section, the regulated outflow of dams may create high variance in connectivity between the main channel and of the lateral zones, resulting in irregular alternation of hydrological fluctuations, which might govern species occurrences reflecting also shallow, eutrophic conditions: *Cryptomonas*—**Y** (Crossetti and Bicudo, 2008; Devercelli, 2006, 2010), *Euglena* sp.—**W1** (Wu et al., 2011b), *Cylindrospermopsis*—$\mathbf{S_N}$ (Nixdorf et al., 2003; Soares et al., 2007; Mihaljević and Stević, 2011), or *Hydrodictyon africanum* ($\mathbf{T_D}$). The diversified hydrological patterns might also provide some prospects to explain taxa presences like *Gonyostomum semen* (**Q**) or cf. *Batrachospermum* ($\mathbf{T_D}$) in this river section.

At the middle Loire, total occurring taxa number further decreases in low flow years (example of 2011), while it stays constant during high flow examples like year of 2009 or 2010. This phenomenon might be explained by the following assumptions being all related to specific flow conditions:

(i) Significant taxa transport from upstream, highly diversified habitats, resulting in a more taxa rich—mixed—composition at the middle river section (presence of coda $\mathbf{L_0}$, **S1**, **M**, **P** on Fig. 29d);

(ii) Higher benthic diatom taxa number found in the plankton during high flow years (data not shown);

(iii) The further occurrence of new arriving taxa from middle Loire laterals, according to diverse river bed morphology and free connections among habitats such as oxbows, riparian forests in this section (Wisskirchen et al., 1998), braided meanders around sandy isles (Latapie, 2011) called also 'moving littorals' of the Loire (Lair and Reyes-Marchant, 1997; Lair, 2005). These morphologically diverse habitats are disconnected and function as 'dead zones' during low flow (Reynolds, 1994), and provide a wide range of inocula—possibly coda $\mathbf{L_0}$, **Y**, **E**, $\mathbf{T_C}$, $\mathbf{T_D}$, **W1**, **W2**, **S1**—to enrich the taxa composition of the Loire by later reconnections during higher flow, similarly as found in other large rivers (Devercelli, 2006, 2010; Istvánovics et al., 2010; Scherwass et al., 2010; Mihaljević et al., 2013).

Low taxa richness values might also provide further evidences for different functioning between the upper and middle Loire. Upstream, very low scores occur owing to limnophilic taxa dominances such as by *Fragilaria crotonensis* (**P**), *Microcystis* spp. ($\mathbf{L_M}$, **M**), *Dolichospermum* (**H1**); as well as by benthic—*Melosira varians* ($\mathbf{T_B}$) or meroplanktonic—*Coelastrum* spp. (**J**) taxa, being often related to reservoir conditions (Barone and Naselli-Flores, 1994; Unni and Pawar, 2000; Albay and Akçaalan, 2003; Sabater et al., 2008).

Middle stream low taxa richness values are displayed by single celled centric diatoms (*Chapter 3.1.* and *3.2.*), which provide the highest potamoplankton biomass with different

contribution patterns of taxa from coda **X1**, **X2**, depending in flow conditions of each specific year. This spring centric assemblage is, furthermore, often replaced by *Skeletonema potamos* and/or very small ~3-4 µm centrics—(cf. *Thalassiosira pseudonana*) dominance as a summer assemblage stage in the seasonal succession, sometimes resulting in relatively high biomass and low taxa richness/diversity as well.

The uneven late summer dominance of the volvocalean *Spermatozopsis exsultans* occurs regularly in recent years in the River Loire, resulting in low potamoplankton richness and very low biomass at lowland areas. This species might be able to reflect highly available organic compounds (Várbíró et al., 2007), and it might reflect uncommon environmental conditions by summer slow-flows (2009 example explained in *Chapter 3.2.*) with high light availability—independent study showed extreme late summer transparency with Secchi depths >3m, in 2011 at the lowland Loire section: Ponts-de-Cé—, and high water temperature.

Low taxa richness at effective ecosystem functioning in turbid environment

The seasonal pattern of discharge, consequently flow characteristics differed significantly between the three years studied (see *Chapter 1.2.2.*). The most reliable differences are the timing and lasting of spring and autumn floods, which created a very short vegetation period in 2010, a very long one in 2011, and an intermediate one in 2009. As a general consequence on taxa richness/diversity patterns is that both taxa and FG richness follow the same ordering: 2010>2009>2011, and thus support the dependence of potamoplankton richness on river flow conditions according to assumptions presented in the previous sub-chapter.

In the light of the fact that absolute maxima of richness occur as a consequence of species dispersals from human-mediated habitats at the upper Loire section, and that these taxa are not able to maintain significant production further downstream [similar examples are provided by Köhler (1994); Piirso et al. (2010); or Grabowska (2012)], it is obvious to conclude that the most effective ecosystem functioning could not co-occur and cannot be related with the highest potamoplankton richness in the Loire (Fig. 37a). However, according to rough and selective river conditions like continuous mixing, competitive and ruderal species dominate in assemblages being able to produce high potamoplankton biomass (Reynolds, 1997), by which composition, however, high taxa richness might be prevented (Lindenschmidt and Chorus, 1998). The most frequent competitive (*r*-selected) and thus also Loire taxa examples are single celled centric diatoms such as *Stephanodiscus hantzschii*, *Discostella pseudostelligera*, *D. stelligera*, *Cyclostephanos dubius*, *C. invisitatus*; single celled greens like *Monoraphidium*; and small flagellated species: *Chlamydomonas*, *Plagioselmis*. The total biomass is, however, highly affected by the contribution of ruderal taxa such as *Scenedesmus* spp., *Coelastrum* spp., or *Pediastrum* spp.—(literature examples are similar to those presented in *Chapter 3.4.4.*).

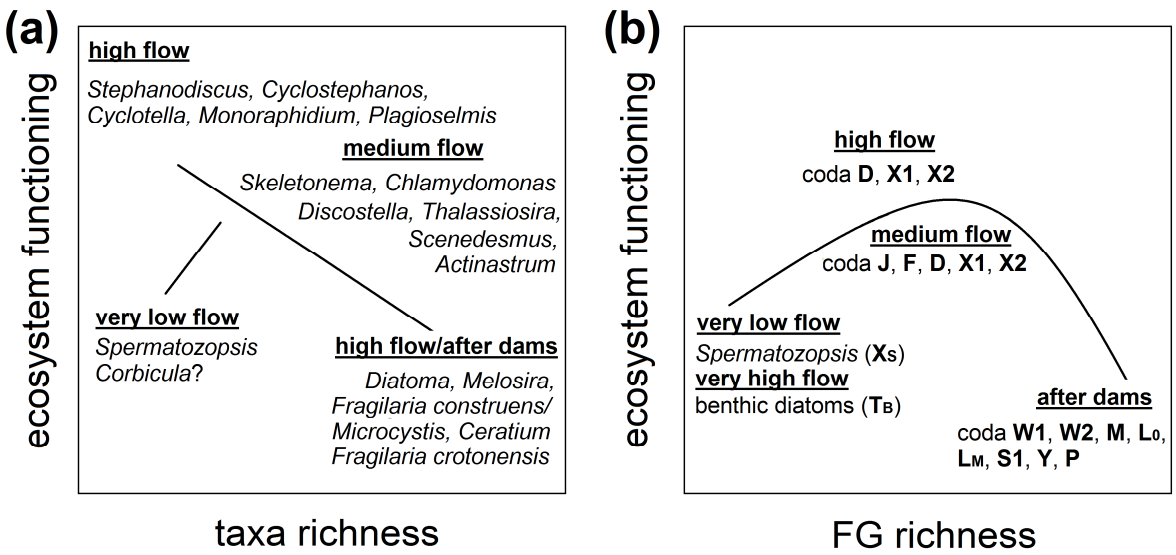

Fig. 37 *Ecosystem functioning along* **(a)** *taxa richness and* **(b)** *FG richness at whole river scale reflecting the flow dependence of potamoplankton composition*

Medium FG richness at effective ecosystem functioning in turbid environment

The FGs richness provides different relationships with ecosystem functioning, than based on taxa richness along the River Loire. While in the upper Loire, high taxa number signifies high functional diversity according to many, functionally different dispersed taxa, in the middle Loire part, the high taxa number is mainly due to some very taxa rich FGs such as codon **J**, **F**, or **X1**. Accordingly, while the spatio-temporal pattern of ecosystem functioning is still the same, the relationships based on taxa and FGs are displayed differently (Fig. 37b). The low richness *vs.* ecosystem functioning is further modified between the cases of taxa and FG richness by benthic diatom taxa, as all—occasionally very taxon rich— belong to the same FG, codon $\mathbf{T_B}$.

Based on our results, FG classification of potamoplankton reorganizes and clarifies compositional relationships between richness and ecosystem functioning: while based on taxa richness, low and high ecosystem functioning possibly occur at both low and high taxa number, FGs display the best ecosystem functioning more likely at medium FG richness. Additionally, these results might open towards a better understanding of still open questions like relationship between river water quality and phytoplankton richness/diversity, or effects of climate change- or altered hydromorphology-induced divergences in river ecosystem functioning (Elosegi and Sabater, 2013).

5. General discussion and perspectives

5.1. Phytoplankton functional zonation along the River Loire

5.1.1. Potamoplankton composition along the Loire

At a whole River Loire scale, longitudinal zonation has been studied on the riparian vegetation (Wisskirchen et al., 1998), fish (Lasne et al., 2007; Bergerot et al., 2008) or macro-invertebrates (Usseglio-Polatera et al., 2000), while the potamoplankton has been studied only along a few number of sampling stations earlier (Leitão and Lepretre, 1998; Descy et al., 2011). Functional composition of potamoplankton based on different approaches made possible to describe potamoplankton river zones along the largest, lowland Continental Atlantic River Loire (*Chapter 3.1.*). These river zones were relevant in all cases, but at different level in organization. While morphology-based functional groups (Kruk et al., 2010) were able to indicate only conditions being characteristic for the lowermost river section, zonation provided by the morpho-functional classification (Salmaso and Padisák, 2007) and the functional group concept (Reynolds et al., 2002) displayed a more detailed spatio-temporal patchiness.

The longitudinal shift of benthic diatoms (**T_B**) to chlorococcalean greens (**J**) via centric diatoms (coda **D**>**C**>**B**) was found to be a general and persistent feature of the River Loire in the three consecutive years studied (2009, 2010, 2011). This compositional sequence has been already highlighted along a few number of sampling stations (Leitão and Lepretre, 1998; Descy et al., 2011), and it is in accordance with former literature examples of longitudinal potamoplankton studies (Reynolds and Descy, 1996; Everbecq et al., 2001; Leland, 2003). Additional information obtained here is that the longitudinal shifts between these potamoplankton groups are continuous along the River Loire, and display similar longitudinal patterns/river zones among years (*Chapter 3.4.*). At the upper Loire, the overwhelming biomass dominance of benthic diatoms, however, depends on the interaction of both natural—discharge related physical factors—and human-mediated processes like damming (Abonyi et al., 2012). This latter influence has not been yet discussed in a longitudinal point of view, but explicitly studied at a local scale (Michard et al., 1996; Latour et al., 2004). Further general feature is the longitudinal patterns of accessory coda **X2**, **X1**, **F** along the River Loire, which groups in case of favourable hydrological conditions, start their development further upstream, but stay continuous in increase along the whole river independently of year. While codon **X2** (like *Chlamydomonas*, *Plagioselmis*) or **X1** (like *Monoraphidium*, *Scenedesmus*) often found to be the most abundant and most common summer riverine taxa worldwide (Peterson and Stevenson, 1989; Gosselain et al., 1994; Sabater et al., 2008; Devercelli, 2010; Wu et al., 2011b), the increase of codon **F** (like *Oocystis*, *Dictyosphaerium*) towards downstream sections might reflect a special Loire characteristic in recent years reflecting high light availability at lowland river sections in summer.

Limnophilic taxa (from coda **P**, **L_0**, **M**, **S1**, **H1**) occur regularly at the upper Loire, and are remarkable contributors to potamoplankton composition at Grangent (st. 2) and Villerest dam (st. 4) stations. Accordingly, while former Loire studies (Leitão and Lepretre, 1998; Descy et al., 2011) failed to detect high level of dispersals of limnophilic taxa from the two eutrophic dams, these taxa remains to be potential indicators of human impacts on this upper Loire section (~ 200-300 km from source). Besides the fact that the taxa composition of dam assemblages reflects high trophic states (Michard et al., 1996; Bonnet and Poulin, 2002), they also indicate physical modifications of stratifying water column conditions (Bonnet et al.,

2000). Furthermore, these upstream habitats as inocula sources might be also important contributors to taxonomical/functional richness towards downstream, similarly to other cases found elsewhere in rivers following river-lake systems (Köhler, 1994; Piirso et al., 2010; Grabowska, 2012).

5.1.2. Main physical and chemical constraints reflected by the potamoplankton composition

At the middle Loire, the River Allier has been already recognized to determine the seasonal distribution of discharge further downstream in the river (Oudien et al., 2009). However, our results demonstrated that even smaller river inflow like of the River Aron (st. 7) at the upper Loire section can be also a significant contributor (see characteristics of year 2010), and thus, it also determines the composition of potamoplankton.

Both at the upstream and middle river sections, flow characteristics are the main controlling factors on potamoplankton composition (*Chapter 3.4.*), as it has been found similarly in other large eutrophic rivers, where nutrients are less likely influence compositional patterns (references of *Chapter 1.1.1.* and *1.1.2.*). Accordingly, catchment area specific discharge was found to be related to suspended solids all along the river, affecting light conditions, as the most important, frequently limiting factor in large rivers (Prahl et al., 1997; Vörös et al., 2000). However, at the upstream Loire section, flow conditions explained only the distribution of N, while both N and P in the middle Loire course (*Chapter 3.4.*). This phenomenon might be explained by the specific nutrients' distribution, and of physical controlling factors in the Loire. Phosphorus is in high availability upstream (~ 200-300 km distance from source) owing to human pressures of large cities in the region (Minaudo et al., 2013, 2014), while the distribution of nutrients might be decoupled from natural hydrological patterns according to outflows' functioning of dams (Abonyi et al., 2012, 2014). Besides nutrients, the longitudinal distribution of major ion composition also displayed some possible sign of human impacts reflected by the maxima of Na^+, Cl^-, and SO_4^{3-} ion in the region (*Chapter 1.2.4.*). These ions might support the relevance of human sources such as domestic and industry sewage, or salting of upland ways (Cole, 1979).

Contrary to P, nitrogen—prevailingly nitrate—increases continuously along the Loire, owing to the growing percentage of agriculture area cover towards downstream river sections (Minaudo et al., 2014). This N increase becomes more relevant after the confluence of the River Allier (Minaudo et al., 2013), and even more at further downstream sections (Bouraoui and Grizzetti, 2008).

Even if the two upstream dams decouple the distribution of potamoplankton composition and nutrients according to outflows' functioning (Abonyi et al., 2012, 2014), their control on both chemical and biological elements is obvious (Villerest's outflows are explained in *Chapter 3.2.*). The controlled outflow is well reflected by late summer distribution patterns of TP, SRP, DO, pH, or water temperature, and contributes to indicate poor water quality in this Loire region (*Chapter 3.3.*, web[3]). Furthermore, flow might influence P availability further downstream (CCA in *Chapter 3.4.*), and might govern the potential for potamoplankton growth being related to annual patterns of hydrology, and to P transport from this upper Loire section. The upstream dams, additionally, might be expected to have some affects on potamoplankton composition towards downstream, as displayed by "unnatural" patterns in N:P and Si:P ratios (*Chapter 3.1.*). These ratios more likely function as indicators of the physically modified river flow—with of all consequences on nutrients'

distribution—, instead of being a direct determinant of the potamoplankton composition (*Chapter 3.1.* and *Appendix IV*).

5.2. Potamoplankton FGs in water quality management

5.2.1. River basin scale management still needs for fine functional resolution

Besides the fact that the river zones described based on three different functional classifications were consequent for each classification system, the levels of understanding provided were different. The simplest classification, the MBFG system (Kruk et al., 2010) containing only seven subsets was able to separate only conditions being characteristic for the lowermost lowland Loire section at a longitudinal scale, and failed to follow even basic ecological differences like benthic or planktonic diatoms dominance along the Loire. More complex classifications, MFGs (Salmaso and Padisák, 2007) and FGs (Reynolds et al., 2002) provided more detailed spatio-temporal river zonation in the River Loire.

In the both cases of MFGs and FGs, compositional changes among river zones coincided with the main geographical and climatic regions even in the upper and middle river sections (*Chapter 3.1.*), and thus functional composition of potamoplankton was also related to ecoregional setting, which had been elaborated based on lithodological differences (Wasson et al., 2004). This latter finding might provide a step towards a better understanding of large scale dependence in organization of primary producers—and the relevance of planktonic algae in water quality assessments—, being still a major challenge for benthic diatoms in connection with ecological state indication (Tison et al., 2005; Beltrami et al., 2012; Várbíró et al., 2012). Furthermore, geographical differences are highly implied in hydrology along the Loire, and some river zones based on the FG classification co-occurred with regional differences in nutrient ratios like N:P and Si:P (*Chapter 3.1.*). Obviously, the potamoplankton composition seemed to indicate both local physical modifications like damming, and diffuse, regional scale influential factors being connected to land use practices like agriculture. As the geological setting impacts agriculture, as well as determine hydrology, the hydrology-determined composition only co-occur with similar regional scale differences—in our case with nutrient ratios—, similarly to cases found for benthic diatoms (Rimet, 2009).

Our results indicate the need for fine functional resolutions of both benthic and planktonic diatoms for reliable ecological surveys at whole river basin scale. Apparently, this might also open a research field towards new benthic functional concepts like ecological guilds (Rimet and Bouchez, 2011; Stenger-Kovács et al., 2013), and for their possible inclusion into phytoplankton functional approaches. The relevance of meso-eutrophic, limnophilic diatoms (codon **P**) in rivers possibly indicating human impacts like damming evidences that neither only size pools of pennate diatoms (Salmaso and Padisák, 2007) nor the separation of large chain forming taxa proposed by Tolotti et al. (2012) are satisfactory in rivers. In the River Loire, for example, potamoplankton includes taxa from both benthic (*Fragilaria construens*) and planktonic habitats (*F. crotonensis*) with similar traits, however, the presence of one or the other reflects opposite environmental conditions.

Cyanobacteria are one of the most relevant components of water quality monitoring. Their dominance, however, only occasionally occurs in the River Loire, and is restricted to upper Loire dam stations (Michard et al., 1996; Bonnet and Poulin, 2002; Latour et al., 2004). The FG classification separated exclusively these upstream stations in one “clear” group by reservoir related assemblages from codon **P** and **M**, while MFGs and MBFGs did not.

As a conclusion, neither water quality management, nor assessments can fully omit traditional taxonomical identification, where functional systems might be used to understand and interpret the composition, but at a fine "functional resolution" scale.

5.2.2. FG *vs.* taxon-based potamoplankton indices

Despite differences in river characteristics and data used for the development of the two existing potamoplankton water quality assessments—in Germany (Mischke et al., 2011) and in Hungary (Borics et al., 2009)—, both the PhytoFluss and the HRPI indices seemed to be applicable and provided valuable water quality indications along the River Loire (*Chapter 3.3.*). Our results demonstrate, that potamoplankton indices—either based on FGs or taxa—may be successfully applied among similar regions of different countries, if their adequate normalization according to adequate river typologies makes possible the site-specific harmonization. As both indices have been developed to assess large lowland rivers, our results support their relevance to indicate major water quality parameters such as TP, Chl-*a*, and the overwhelming dominance of coccal green algae in the lowland river sections of the Loire.

While the PhytoFluss seemed to be more reliable to indicate negative effects at dam stations by taxa dispersal according to the 'indicator taxa' metric, the HRPI seemed to be more successful to indicate highland benthic diatoms dominance by the FG composition metric. This latter success can be explained by the separation of benthic and planktonic diatom taxa into different functional groups (*Chapter 3.3.*). An unfortunate feature of the $Q_{(r)}$ composition metric is—as part of the HRPI index— that it is not able to separate between natural and human-affected benthic diatom dominance, and does not penalize invasive (*Achnanthidium catenatum*, *Encyonema triangulum*—Coste and Ector, 2000) or brackish species (*Actinocyclus normanii*, *Bacillaria paxillifera*) existing also in the River Loire. This finding also supports the relevance of the 'indicator taxa metric' of PhytoFluss, and might further emphasize the need for the development of further sub-classification among benthic diatoms for potamoplankton assessments. Centric diatoms in rivers (coda **B**,**C**,**D**) might pose further difficulties, where sometimes, it is not possible to identify all taxa at species level. Even if size fractionating might be a possible tool (Mischke, 2007)—also found to be necessary according to the MFG classification in rivers (*Chapter 3.1.*)—, the FG system in its present form would be still biased by the overlapping size dimensions of species.

5.2.3. FGs of key potamoplankton taxa in the Loire

Potamoplankton taxa such as *Skeletonema potamos* or very small centrics like cf. *Thalassiosira pseudonana* are common and now characteristic species in recent years at the middle Loire. These taxa, therefore, might be also relevant indicators of specific environmental conditions (see discussion of *Chapter 3.2.*). Kiss et al. (1994) described *S. potamos* as a warm stenothermic species, with high light demand, and concluded its highest abundance to be related to low flow of the highly eutrophic River Danube. Further similarities occur in taxa composition between the middle Loire and the middle Danube (see Várbíró et al., 2007; and Abonyi et al., 2012), and might indicate similar trends in environmental parameters such as nutrients decrease (Istvánovics and Honti, 2012; Minaudo et al., 2013, 2014), or water temperature increase (Moatar and Gailhard, 2006; Verasztó et al., 2010). Besides the fact that *Thalassiosira pseudonana* (in the Loire, not yet determined) has been

already described from freshwater habitats, it is thought to be more relevant in coastal and brackish waters (Kiss et al., 2012); but it does occur in the middle Danube region as well. According to the special behaviour (possibly brackish, bloom forming), and late spring to late summer occurrence of both taxa, further studying their functional relevancies might be reasonable, and possibly opens towards a new large river potamoplankton functional group: provisionally $\mathbf{D_T}$.

Reservoir related potamoplankton composition in the Loire with *Microcystis* and *Aulacoseira* taxa (*A. granulata*, *A. ambigua, A. ambigua* f. *japonica*) from coda **P** and **M** might be affirming the relevance of the new codon: $\mathbf{L_R}$, already described for reservoir systems by Hu and Xiao (2012). In the River Loire, many scattered taxa occur neighbouring dams, such as *Melosira varians* ($\mathbf{T_B}$), *Euglena* sp. (**W1**), *Cryptomonas* (**Y**), *Ceratium* ($\mathbf{L_0}$, $\mathbf{L_M}$), *Cylindrospermopsis* ($\mathbf{S_N}$), *Gonyostomum semen* (**Q**), cf. *Batrachospermum* ($\mathbf{T_D}$), *Hydrodictyon africanum* ($\mathbf{T_D}$). These taxa, however, might provide evidence for only mixed assemblages from both human-mediated lentic (dam system), and higly disturbed lotic and lateral habitats owing to fluctuations between extreme low and high specific discharge (*Chapter 3.5.*).

The uneven dominance of the volvocalean *Spermatozopsis exsultans* in the Loire lowlands may also require some specific assumptions. This species is able to reflect high level of organic content (Várbíró et al., 2007), and it might reflect uncommon environmental conditions. It was found to be dominant during summer slow-flow with prolonged WRT, tolerating very high light availability, and high water temperature. Some point-like high Kjeldahl-N observation might confirm the presence of sewage inflows during this low flow periods in the Lowermost Loire, while the N:P ratio remains very high according to the possible late summer P limitation for green algae (Descy et al., 2011), and the very high nitrate availability according to agriculture (Bouraoui and Grizzetti, 2008). The high light availability was also indicated by the increasing downstream dominance of codon **F** in these lowland summer cases, while an independent study showed extreme transparencies with Secchi depths > 3m in the summer of 2011 at the lowland station of Ponts-de-Cé. Typical co-dominant taxa of *S. exsultans* were *Cocconeis placentula*, *Lagerheimia balatonica*, *Chlorogonium oogamum*, and sometimes *Plagioselmis nannoplanctica* in these cases. This assemblage has been observed in several other rivers recently like in the River Meuse, River Vienne, or in other downstream inflows of the Loire. Similar observations from other European rivers exist like in the River Kupa or River Sava in Croatia (Dr. Igor Stankovic, pers. comm.) or in River Fekete-Körös or River Hármas-Körös in Hungary (Dr. B-Béres Viktória, pers. comm.). The late summer dominance of *S. exsultans* thus might imply the relevance of a special new sub-codon, provisionally $\mathbf{X_S}$.

The increasing population density of invasive Asian clams (*Corbicula* spp. - Mollusca, Bivalvia, Corbiculidae) in the Loire (Brancotte and Vincent, 2002; Chovet and Lécureuil, 2008) and in almost all European large rivers (Pigneur et al., 2011, 2013) is supposed to affect quantitatively the phytoplankton by grazing (Descy et al., 2011), but their presence may also influence the phytoplankton composition as well. This latter impact, might be possibly reflected by the late summer dominance of the newly proposed codon $\mathbf{X_S}$. Apparently, the $\mathbf{X_S}$ assemblage seems to differ in functioning from codon $\mathbf{W_0}$ described for the mostly spring *S. exsultans* dominance (Borics et al., 2007), however, the late summer occurrences might do not invalidate former conclusions on ecological preferences, especially as for the composition of nutrients.

5.2.4. Potamoplankton sampling design

According to data presented from this traditional Loire monitoring program containing already nine sampling dates per year at nineteen stations along almost the whole river scale, the importance of the temporal resolution in phytoplankton sampling design must be particularly emphasized. According to thesis findings (especially in *Chaptar 3.1.* and *Chapter 3.3.*), four sampling per year—international protocol is being discussed—might not provide satisfactory results in all cases, depending on regional differences in station location, and on specific controlling factors of potamoplankton composition. Instead, the understanding of potamoplankton composition according to river zones might be preferred, where similar stations might be grouped together lowering site frequency, making possible to multiply the frequency of temporal resolution.

5.3. Some theoretical relevance of thesis findings

5.3.1. Potamoplankton zonation *vs.* potamoplankton continuum

Theoretical concepts developed to understand longitudinal patterns of biota predict either continuous (Vannote et al., 1980), or zone related (Huet, 1959) longitudinal compositional patterns. Besides the fact that several biological processes might change continuously along rivers (Vannote et al., 1980), the 'Riverine Ecosystem Synthesis model' (Thorp et al., 2006) presumes the existence of functionally different river zones, reflected also by the corresponding composition of biota.

Findings of the thesis on Loire potamoplankton might support both theories, in the sense that level of compositional continuity *vs.* zonation depends on study resolution in space (site frequency) as well as in time (sampling frequency). Further determinant factors are the level of connectivity according to discharge and the positioning of natural-disruptions like river inflows (Garnier et al., 1995; Istvánovics et al., 2010; Frenette et al., 2012), or human-mediated ones such as dams (Dauta et al., 1999; Hart et al., 2002; Moss, 2008) or groyne disposal (Belleudy, 2000; Engelhardt et al., 2004). Main functional groups and the most frequent accessory coda changed continuously along the River Loire, more precisely along the river zones displayed regarding geographical and climatic regions as natural gradients, and disruptions by dams and river inflows (*Chapter 3.1.* and *3.2.*). In case of long/large enough rivers—large might be understood and defined according to WRT or catchment area specific discharge—, river zones might be expected to occur with similar functional potamoplankton composition among years (*Chapter 3.4.*). The feature of the River Loire, however, is the relatively low level of regulation along its course—large dams occur exceptionally in its upper river stretch—, and a ~300 km free flow without major inflow in its middle river section. Consequently, in the Loire, higher level of connectivity and continuity might be observed compared to other large, more regulated and more canalized rivers such as the River Seine (Billen et al., 1994), River Rhin (Scherwass et al., 2010), River Ebro (Sabater et al., 2008), or River Danube (Dokulil, 2013) in Europe; as well as elsewhere worldwide (Barbosa et al., 1999; Ha et al., 2002; Koch et al., 2004).

Furthermore, river functional zones or similarities among potamoplankton samples might be more successfully organized and understood at a spatio-temporal scale (*Chapter 3.1.*), then exclusively based on space or on time (*Chapter 3.2.*). This is highly emphasized by compositional shifts in the middle Loire, where similar compositions—also single species—occurs with continuous seasonal lag towards upstream (same conditions occur later

on seasonally, providing similar composition accordingly), reflecting a flow-determined organization in the composition instead of by an internally driven phytoplankton succession. Accordingly, potamoplankton zones might be defined and studied in rivers, instead of simply follow data distribution at one single sampling station either in ecological research or monitoring programs (Additional information to *Chapter 4.2.4.*).

5.3.2. Potamoplankton composition and ecosystem functioning in a changing climate

Most of the European rivers are highly modified in flow characteristics as a consequence of canalization or regulation (Tockner et al., 2009), while a seasonally altered hydrology in quantity patterns is also observed in recent years, and it is also expected to occur in the near future (Nohara et al., 2006). Long term records of water flow in the River Ebro, for example, show decreasing trend by mean annual values for the last 50 years (Sabater et al., 2008); while in other cases (River Elbe, River Oder) winter flood patterns show similar trends (Mudelsee et al., 2003). Accordingly, the co-occurrence of some recent trends in European rivers might reflect some general consequences of climate change, reflected by trends in nutrient availability (Istvánovics and Honti, 2012; Minaudo et al., 2013, 2014), in physical parameters such as water temperature or conductivity (Moatar and Gailhard, 2006; Verasztó et al., 2010, Floury et al., 2012), or by the invasion of new arrivals like *Corbicula* spp. (Friedrich and Pohlmann, 2009; Bódis et al., 2011; Pigneur et al., 2011; Floury et al., 2013).

In connection with climate change, one of the most relevant ecological consequences is biodiversity loss (Butchart et al., 2010), and the invasion of new species (Keller and Lodge, 2009). These changes also contribute to determine freshwater ecosystem functioning besides all human pressures on river ecosystem structures (Sabater, 2008). As for the phytoplankton, the stability and productivity of communities are thought to depend on taxa richness in natural lentic communities (Ptacnik et al., 2008; Weyhenmeyer et al., 2013) and in culture conditions (Corcoran and Boeing, 2012), which findings have not been yet stressed on potamoplankton.

The Loire, flow according to annual discharge characteristics differed significantly between the three consecutive years studied. The most reliable differences were the timing and lasting of spring and autumn floods (*Chapter 1.2.3.*), which resulted in distinct hydrological conditions creating different length in vegetation periods (*Chaper 3.4.*). As a general consequence, taxa and FG richness of potamoplankton displayed similar ordering with hydrology at an annual scale, and thus provided high taxa richness in high flow year examples (2009, 2010), and low richness in low flow year (2011). At a longitudinal scale, however, the distribution of taxa richness showed similar patterns in each year, with maxima occurring (i) at the upper Loire section following dams and (ii) at the middle Loire. These two sections, however, differed in functional group composition of potamoplankton (*Chapter 3.4.*).

The RUE ratio (Ptacnik et al., 2008)—as an ecosystem functioning measure—adapted to the Loire resumed successfully these differences along the Loire, coupling all influential factors such as hydrology-determined light conditions or WRT into one metric, which might then reflect the effectiveness in the use of resources to build up phytoplankton biomass. As the upper Loire section (~ 200-300 km distance f.s.) receives severe human pressure that creates high nutrient availability—predominately P—(discussion of *Chapter 4.1.2.*), while the potamoplankton biomass and composition are decoupled from nutrients according to dams' functioning (*Chapter 3.2.* and *3.3.*), the RUE ratio under high taxonomical and functional richness (*Chapter 3.4.*) fails to appoint effective ecosystem functioning in the region. At the contrary, further downstream, continuous flow supposedly influence resource availability and

taxa composition at the same time, where the most effective production is displayed by competitive and the best adapted riverine taxa from coda **D** (like *Stephanodiscus* spp., *Discostella* spp.), **C** (like *Cyclostephanos* spp., *Asterionella*), **X1** (*Monoraphidium*, *Scenedesmus*), and **X2** (*Chlamydomonas*, *Plagioselmis*)—(*Chapter 3.4.4.*), resulting in a low taxonomical and medium FG richness (*Chapter 3.5.4.*).

As a consequence, FGs richness and taxa richness provide different relationships with ecosystem functioning along the River Loire. While in the upper Loire, high taxa number signifies high functional diversity according to many, functionally different dispersed taxa from diverse habitats, in the middle Loire section, the high taxa number is mainly due to some very taxa rich FGs such as codon **J**, **F**, or **X1**. Accordingly, while the spatio-temporal pattern of ecosystem functioning is still the same, the relationships based on taxa and FGs are displayed differently. Therefore, FG classification of potamoplankton reorganizes and clarifies compositional relationships between richness and ecosystem functioning: while based on taxa richness, low and high ecosystem functioning possibly occur at both low and high taxa number, FGs display the best ecosystem functioning more likely at medium FG richness. Therefore, absolute maxima of taxa and FG richness may occur owing to physical mixing among habitats in rivers, and thus higher taxa richness is not automatically related to more effective ecosystem functioning at a whole river basin scale (*Chapter 3.5.*).

The comparisons in FG composition between the three Loire years studied, and in the spatio-temporal distribution of FGs in each specific year open towards some general assumptions on potamoplankton richness distribution, being also connected to possible hydrological effects of climate change:

(i) The spring diatoms' bloom in large rivers is higly related to timing of lowering floods (Hardenbicker et al., 2014), when more favourable conditions might trigger the occurrence of a more diverse potamoplankton composition. In these cases, the overwhelming dominance of a few competitive taxa might be prevented by lowering nutrient concentrations (Bernal et al., 2013), or higher light availability. According to results of *Chapter 3.5.*, the lack of spring high flow, or less intensive floods would possibly trigger compositional changes (probably towards higher taxa number) with the effect of decreasing ecosystem functioning, as might be found recently by spring total algal biomass decrease in the River Rhin (Hardenbicker et al., 2014);

(ii) The increase in length of separation—prolonged vegetation periods—between eupotamal and para/paleopotamal zones might provide more distinct habitats (Thomaz et al., 2007), where local controlling factors may govern the composition adversely to eupotamal zones (Mihaljević et al., 2013); resulting in decrease of taxa richness in local, but in increase at a larger spatial scale;

(iii) Lowering inflow into reservoirs might result in a more stable water column or thermal stratification, which effect might evidence similar shifts in phytoplankton composition at long term scale as expected to occur in lakes (Winder and Sommer, 2012). Prolonged WRT, intensified sedimentation, and lowered nutrients in the upper water column would possibly affect local richness inside reservoirs, as well as along downstream river sections following dams.

The coupling of potamoplankton composition and their ecosystem functioning to clime change thus might be successfully studied in the future based on functional compositions and indices like the RUE ratio along/among rivers. A further deduction is that potamoplankton

taxa richness/diversity in rivers might not provide the automatic evidence for better ecosystem functioning, and cannot be a general objective, for example in water quality issues. Preferably, the understanding of the functional composition, and its natural *vs.* human-impacted controlling factors would be desirable at different scales; similarly to studies on other biota from individual river sites up to whole river basin scales (Allan et al., 1997; Chase and Leibold, 2002; Field et al., 2009).

Thesis findings might open towards a better understanding of still open questions like relationship between river water quality and phytoplankton diversity as well, or effects of climate change- or altered hydromorphology-induced divergences in river ecosystem functioning (Elosegi and Sabater, 2013).

5.4. Perspectives for future potamoplankton studies in the Loire

Based on the potamoplankton composition and nutrients' distribution at the two upper Loire dams—Grangent and Villerest—(*Chapter 3.1.4.* and *3.2.4.*), hydrology-induced patterns in phyto-, and potamoplankton diversity could be further evaluated. This is reasonable according to the highest taxa and FG diversity found in this river section (*Chapter 3.5.4.*), which diversity might be governed by the wide-ranging physical and chemical conditions created by different flow-connectivity levels. As both dams are in eutrophic/hypereutrophic state, their outflows' functioning as nutrient sources might be a major influential factor even further downstream in the River. This impact could be further modified according to alternation in the water column stability in their summer stratification, affecting all the above mentioned processes.

At the middle Loire, a second river section occurs with a very high potamoplankton diversity (*Chapter 3.4.4.*), which might function differently at "ecosystem scale" among hydrologically distinct years. Here, diversity could be further studied along connectivity gradients among diverse habitats from oxbow lakes, riparian forests, from patches of the braided meanders, as well as from small lakes created by groynes'disposal. In this point of view, the outcomes of an ongoing project 'OBLA' (Observatory of Biodiversity in the River Loire), governed by the University of Tours seems to be extremely important.

While the potamoplankton of other European rivers has been deeply studied at their lower parts, these detailed researches are still missing for the River Loire. A specific point could be the compositional change of potamoplankton and of functional response to recent trends in hydrological, chemical, and biological parameters detailed in the previous sub-*Chapter 4.3.2*. In this sense, the recent project on long term trends: 'Eutrophication trends in the River Loire' conducted by the University of Tours; as well as the Thesis of Camille Minaudo are expected to provide substantial details and results on the Loire.

The present Dissertation detailed the potamoplankton composition of the River Loire from very recent years. According to the available high quantity of long term data at the Bi-Eau Consultancy (see taxa list in *Appendix X*), produced by similar methodology and high level of competence during the last 20 years, the long term spatial analyse of potamoplankton taxa and of processes in connection with the aforementioned long term trends in environmental parameters should be privileged for future scientific works.

6. References

Abonyi, A., M. Leitão, A. M. Lançon & J. Padisák, 2012. Phytoplankton functional groups as indicators of human impacts along the River Loire (France). Hydrobiologia 698(1):233-249 doi:10.1007/s10750-012-1130-0.

Abonyi, A., M. Leitão, I. Stanković, G. Borics, G. Várbíró & J. Padisák, 2014. A large river (River Loire, France) survey to compare phytoplankton functional approaches: Do they display river zones in similar ways? Ecological Indicators 46(0):11-22 doi:http://dx.doi.org/10.1016/j.ecolind.2014.05.038.

Ács, É., K. Szabó, Á. K. Kiss, T. B., Z. Gy. & K. T. Kiss, 2006. Investigation of epilithic algae on the River Danube from Germany to Hungary and the effect of a very dry year on the algae of the River Danube. Archiv für Hydrobiologie 158(3):29.

Admiraal, W., A. Jacobs, P. Breugem & E. D. Steveninck, 1992. Effects of phytoplankton on the elemental composition (C, N, P) of suspended particulate material in the lower river Rhine. Hydrobiologia 235-236(1):479-489 doi:10.1007/bf00026236.

Akopian, M., J. Garnier, P. Testard & A. Ficht, 2001. Estimating the benthic population of *Dreissena polymorpha* and its impact in the lower Seine River, France. Estuaries and Coasts 24(6):1003-1014 doi:10.2307/1353013.

Albay, M. & R. Akçaalan, 2003. Factors influencing the phytoplankton steady state assemblages in a drinking-water reservoir (Ömerli reservoir, Istanbul). Hydrobiologia 502(1-3):85-95 doi:10.1023/B:HYDR.0000004272.38702.c3.

Allan, D., D. Erickson & J. Fay, 1997. The influence of catchment land use on stream integrity across multiple spatial scales. Freshwater Biology 37(1):149-161 doi:10.1046/j.1365-2427.1997.d01-546.x.

Allan, J. D. & M. M. Castillo, 2007. Stream Ecology: Structure and Function of Running Waters. Springer, The Netherlands. 436 pp.

Almasri, M. N. & J. J. Kaluarachchi, 2004. Assessment and management of long-term nitrate pollution of ground water in agriculture-dominated watersheds. Journal of Hydrology 295(1-4):225-245. doi:10.1016/j.jhydrol.2004.03.013

Almeida, S. P. & M. Feio, 2012. DIATMOD: diatom predictive model for quality assessment of Portuguese running waters. Hydrobiologia 695(1):185-197 doi:10.1007/s10750-012-1110-4.

Bahnwart, M., T. Hübener & H. Schubert, 1999. Downstream changes in phytoplankton composition and biomass in a lowland river–lake system (Warnow River, Germany). Hydrobiologia 391(1-3):99-111 doi:10.1023/a:1003558209411.

Barbosa, F. A. R., J. Padisák, E. L. G. Espíndola, G. Borics & O. Rocha, 1999. The cascading reservoir continuum concept (CRCC) and its application to the River Tietê-Basin, São Paolo State, Brazil. Theoretical Reservoir Ecology and its Applications:425-437.

Barone, R. & L. Naselli-Flores, 1994. Phytoplankton dynamics in a shallow, hypertrophic reservoir (Lake Arancio, Sicily). Hydrobiologia 289(1):199-214 doi:10.1007/bf00007421.

Becker, V., L. de Souza Cardoso & V. Huszar, 2009a. Diel variation of phytoplankton functional groups in a subtropical reservoir in southern Brazil during an autumnal stratification period. Aquatic Ecology 43(2):285-293 doi:10.1007/s10452-008-9164-0.

Becker, V., V. Huszar & L. Crossetti, 2009b. Responses of phytoplankton functional groups to the mixing regime in a deep subtropical reservoir. Hydrobiologia 628(1):137-151 doi:10.1007/s10750-009-9751-7.

Belleudy, P., 2000. Restoring flow capacity in the Loire River bed. Hydrological Processes 14(13):2331-2344 doi:10.1002/1099-1085(200009)14:13<2331::aid-hyp32>3.0.co;2-6.

Beltrami, M. E., F. Ciutti, C. Cappelletti, B. Lösch, R. Alber & L. Ector, 2012. Diatoms from Alto Adige/Südtirol (Northern Italy): characterization of assemblages and their application for biological quality assessment in the context of the Water Framework Directive. Hydrobiologia 695(1):153-170 doi:10.1007/s10750-012-1194-x.

Bergerot, B., E. Lasne, T. Vigneron & P. Laffaille, 2008. Prioritization of fish assemblages with a view to conservation and restoration on a large scale European basin, the Loire (France). Biodiversity and Conservation 17(9):2247-2262 doi:10.1007/s10531-008-9331-6.

Bernal, S., D. Schiller, F. Sabater & E. Martí, 2013. Hydrological extremes modulate nutrient dynamics in mediterranean climate streams across different spatial scales. Hydrobiologia 719(1):31-42 doi:10.1007/s10750-012-1246-2.

Bi-Eau, 1996. Synthese de l'étude du phytoplancton sur la Loire (1991-1994) pour l'Agence de l'Eau Loire-Bretagne. In: Leitão, M. (ed). Bi-Eau, Angers, 47 pp.

Billen, G., H. Décamps, J. Garnier, P. Boët, M. Meybeck & P. Servais, 2006. Atlantic river systems of Europe. In Cushing, C. E., K. W. Cummins & G. W. Minshall (eds) River and stream ecosystems of the World. University of California Press, London, England, 389-418.

Billen, G., J. Garnier & P. Hanset, 1994. Modelling phytoplankton development in whole drainage networks: the RIVERSTRAHLER Model applied to the Seine river system. Hydrobiologia 289(1-3):119-137 doi:10.1007/bf00007414.

Bioret, G., 1931. Catalogue des algues inférieures de l'Anjou. Bull Soc Etudes Sc d'Angers 60:33-48.

Blum, J., 1956. The ecology of river algae. The Botanical Review 22(5):291-341 doi:10.1007/bf02872474.

Bódis, E., J. Nosek, N. Oertel, B. Tóth & Z. Fehér, 2011. A Comparative study of two *Corbicula* Morphs (Bivalvia, Corbiculidae) inhabiting River Danube. International Review of Hydrobiology 96(3):257-273 doi:10.1002/iroh.201111344.

Bonnet, M. P. & M. Poulin, 2002. Numerical modeling of the planktonic succession in a nutrient-rich reservoir: environmental and physiological factors leading to *Microcystis aeruginosa* dominance. Ecological modelling 156(2-3):93-112. doi:10.1016/S0304-3800(02)00132-1

Bonnet, M.-P., M. Poulin & J. Devaux, 2000. Numerical modeling of thermal stratification in a lake reservoir. Methodology and case study. Aquatic Sciences - Research Across Boundaries 62(2):105-124 doi:10.1007/s000270050001.

Borics, G., G. Várbiró, I. Grigorszky, E. Krasznai, S. Szabó & T. Kiss Keve, 2007. A new evaluation technique of potamo-plankton for the assessment of the ecological status of rivers. Archiv für Hydrobiologie, Supplementband Large rivers 161(3-4):465-486.

Borics, G., J. Padisák, I. Grigorszky, G. Várbiró, G. Fehér & E. Krasznai, 2009. A fitoplankton minősítése [The qualification of phytoplankton]. p 5-31. In: Szilágyi, F. (ed) A felszíni vizek biológiai minősítésének továbbfejlesztése [Development of surface water quality assessments based on biological elements]. ÖKO Zrt., Budapest, 139 pp.

Bouraoui, F. & B. Grizzetti, 2008. An integrated modelling framework to estimate the fate of nutrients: Application to the Loire (France). Ecological Modelling 212(3–4):450-459 doi:10.1016/j.ecolmodel.2007.10.037.

Bovo-Scomparin, V., S. Train & L. Rodrigues, 2012. Influence of reservoirs on phytoplankton dispersion and functional traits: a case study in the Upper Paraná River, Brazil. Hydrobiologia:1-13 doi:10.1007/s10750-012-1313-8.

Bragg, O. M., A. R. Black, R. W. Duck & J. S. Rowan, 2005. Approaching the physical-biological interface in rivers: a review of methods for ecological evaluation of flow

regimes. Progress in Physical Geography 29(4):506-531. doi:10.1191/0309133305pp460ra

Brancotte, V. & T. Vincent, 2002. The invasion of French hydrographic system by the molluscs *Corbicula* spp. Details of settlement and main role of ship canals. Bulletin Français de la Pêche et de la Pisciculture 72(2-3):325-337. doi:10.1051/kmae:2002038

Briand, E., N. Escoffier, C. Straub, M. Sabart, C. Quiblier & J. F. Humbert, 2009. Spatiotemporal changes in the genetic diversity of a bloom-forming *Microcystis aeruginosa* (cyanobacteria) population. ISME J 3(4):419-29 doi:10.1038/ismej.2008.121.

Butchart, S. H. M., M. Walpole, B. Collen, A. van Strien, J. P. W. Scharlemann, R. E. A. Almond, J. E. M. Baillie, B. Bomhard, C. Brown, J. Bruno, K. E. Carpenter, G. M. Carr, J. Chanson, A. M. Chenery, J. Csirke, N. C. Davidson, F. Dentener, M. Foster, A. Galli, J. N. Galloway, P. Genovesi, R. D. Gregory, M. Hockings, V. Kapos, J.-F. Lamarque, F. Leverington, J. Loh, M. A. McGeoch, L. McRae, A. Minasyan, M. H. Morcillo, T. E. E. Oldfield, D. Pauly, S. Quader, C. Revenga, J. R. Sauer, B. Skolnik, D. Spear, D. Stanwell-Smith, S. N. Stuart, A. Symes, M. Tierney, T. D. Tyrrell, J.-C. Vié & R. Watson, 2010. Global biodiversity: Indicators of recent declines. Science 328(5982):1164-1168 doi:10.1126/science.1187512.

Cabecinha, E., R. Cortes, J. A. Cabral, T. Ferreira, M. Lourenço & M. Â. Pardal, 2009. Multi-scale approach using phytoplankton as a first step towards the definition of the ecological status of reservoirs. Ecological Indicators 9(2):240-255 doi:10.1016/j.ecolind.2008.04.006.

Caraco, N. F., J. J. Cole, P. A. Raymond, D. L. Strayer, M. L. Pace, S. E. G. Findlay & D. T. Fischer, 1997. Zebra mussel invasion in a large, turbid river: phytoplankton response to increased grazing. Ecology 78(2):588-602 doi:10.1890/0012-9658(1997)078[0588:zmiial]2.0.co;2.

Carvajal-Chitty, H., 1993. Some notes about the Intermediate Disturbance Hypothesis and its effects on the phytoplankton of the middle Orinoco river. Hydrobiologia 249(1-3):117-124 doi:10.1007/bf00008848.

Cellamare, M., 2009. Évaluation de l'Etat Ecologique des Plans d'Eau Aquitains à partir des Communautés de Producteurs Primaires [Doctoral Thesis]. Université Bordeaux 1, 334 pp. [in French]

CEN, 2003. Water quality – Guidance standard for the routine sampling and pre-treatment of benthic diatoms from rivers. European Standard: EN 13946:2003. Comité Européen de Normalisation.

Centis, B., 2011. Spatial patterns and ecological determinants of the diatom communities in an Alpine flow-regime river (Adige River, North-Eastern Italy). Implications for the ecological status' assessment [Doctoral Thesis] Università degli Studi di Parma, 199 pp. [in English]

Centis, B., M. Tolotti & N. Salmaso, 2010. Structure of the diatom community of the River Adige (North-Eastern Italy) along a hydrological gradient. Hydrobiologia 639(1):37-42 doi:10.1007/s10750-009-0019-z.

Chalon, E., 1979. Modèle d'eutrophisation de la Loire Moyenne / Eutrophication model for the middle reaches of the Loire. Hydrological Sciences Bulletin 24(2):189-198 doi:10.1080/02626667909491855.

Chase, J. M. & M. A. Leibold, 2002. Spatial scale dictates the productivity-biodiversity relationship. Nature 416(6879):427-430 doi:10.1038/416427a.

Chételat, J., F. R. Pick & P. B. Hamilton, 2006. Potamoplankton size structure and taxonomic composition : Influence of river size and nutrient concentrations. Limnology and Oceanography 51(2):681-689. doi:10.4319/lo.2006.51.1_part_2.0681

Chorus, I. & G. Schlag, 1993. Importance of intermediate disturbances for the species composition and diversity of phytoplankton in two very different Berlin lakes. Hydrobiologia 249(1-3):67-92 doi:10.1007/bf00008844.

Chovet, M. & J.-Y. Lécureuil, 2008. Les macroinvertébrés benthiques de la Loire moyenne (France) et leur évolution depuis 1977. Ephemera 10:103-122.

Cole, G. A., 1979. Textbook of Limnology, 2nd ed. C. V. Mosby, Saint Louis, USA. 426 pp.

Conley, D. J., 1997. Riverine contribution of biogenic silica to the oceanic silica budget. Limnology and Oceanography 42(4):774-777.

Corcoran, A. A. & W. J. Boeing, 2012. Biodiversity increases the productivity and stability of phytoplankton communities. PLoS ONE 7(11):e49397 doi:10.1371/journal.pone.0049397.

Costa, L. S., V. L. M. Huszar & A. R. Ovalle, 2009. Phytoplankton functional groups in a tropical estuary: Hydrological control and nutrient limitation. Estuaries and Coasts 32(3):508-521 doi:10.1007/s12237-009-9142-3.

Coste, M. & L. Ector, 2000. Diatomées invasives exotiques au rares en France: principales observations effectuées au cours des dernières décennies. Systematics and Geography of Plants 70:373-400.

Crossetti, L. & C. E. de M. Bicudo, 2008. Adaptations in phytoplankton life strategies to imposed change in a shallow urban tropical eutrophic reservoir, Garças Reservoir, over 8 years. Hydrobiologia 614(1):91-105 doi:10.1007/s10750-008-9539-1.

Crossetti, L. O. & C. E. de M Bicudo, 2005. Structural and functional phytoplankton responses to nutrient impoverishment in mesocosms placed in a shallow eutrophic reservoir (Garças Pond), São Paulo, Brazil. Hydrobiologia 541(1):71-85 doi:10.1007/s10750-004-4668-7.

Cunha Pereira, H., N. Allott, C. Coxon, O. Naughton, P. Johnston & L. Gill, 2011. Phytoplankton of turloughs (seasonal karstic Irish lakes). Journal of Plankton Research 33(3):385-403 doi:10.1093/plankt/fbq129.

Dauta, A., Y. Lapaquellerie & N. Maillet, 1999. Role of the dams on the River Lot on two types of pollution:point-sources (cadmium) and non-point sources (phosphorus). Hydrobiologia 410(0):325-329 doi:10.1023/a:1003799512666.

de M. Huszar, V. L. & C. S. Reynolds, 1997. Phytoplankton periodicity and sequences of dominance in an Amazonian flood-plain lake (Lago Batata, Pará, Brasil): responses to gradual environmental change. Hydrobiologia 346(1):169-181 doi:10.1023/a:1002926318409.

des Cilleuls, J., 1926. Le phytoplancton de Ia Loire. Comptes rendus de l'Académie des Sciences 182:649-651.

des Cilleuls, J., 1928. Le Phytoplancton de la Loire et de ses affluents dans la région saumuroise [Doctoral Thesis]. Faculté des Sciences, Paris [in French]

des Cilleuls, J., 1930. Le phytoplancton de Ia Loire au cours des étés 1928 et 1929. Comptes rendus de l'Académie des Sciences 190(13):817-819.

des Cilleuls, J., 1932. Contribution nouvelle à l'étude du phytoplancton de la Loire. Internationale Revue der Gesamten Hydrobiologie 27:120-129.

Descy, J. P. & C. Mouvet, 1984. Impact of the Tihange nuclear power plant on the periphyton and the phytoplankton of the Meuse River (Belgium). Hydrobiologia 119(2):119-128 doi:10.1007/bf00011951.

Descy, J. P., 1993. Ecology of the phytoplankton of the River Moselle: effects of disturbances on community structure and diversity. Hydrobiologia 249(1-3):111-116 doi:10.1007/bf00008847.

Descy, J.-P. & V. Gosselain, 1994. Development and ecological importance of phytoplankton in a large lowland river (River Meuse, Belgium). Hydrobiologia 289(1):139-155 doi:10.1007/bf00007415.

Descy, J.-P., 2009. Continental Atlantic Rivers. In Tockner, K., U. Uehlinger & C. T. Robinson (eds) Rivers of Europe. Elsevier, London, 151-199.

Descy, J.-P., M. Leitao, E. Everbecq, J. S. Smitz & J.-F. Deliège, 2011. Phytoplankton of the River Loire, France: a biodiversity and modelling study. Journal of Plankton Research 34:120-135 doi:10.1093/plankt/fbr085.

Devercelli, M. & I. O'Farrell, 2013. Factors affecting the structure and maintenance of phytoplankton functional groups in a nutrient rich lowland river. Limnologica - Ecology and Management of Inland Waters 43(2):67-78 doi:10.1016/j.limno.2012.05.001.

Devercelli, M., 2006. Phytoplankton of the middle Paraná river during an anomalous hydrological period: A morphological and functional approach. Hydrobiologia 563(1):465-478 doi:10.1007/s10750-006-0036-0.

Devercelli, M., 2008. Ecología del fitoplancton en la cuenca inferior del Río Salado (Santa Fe, Argentina). Desarrollo algal en zonas de retención hidráulica y gradiente fitoplanctónico en el flujo principal [Doctoral Thesis]. Universidad de Buenos Aires, 161 pp. [in Spanish]

Devercelli, M., 2010. Changes in phytoplankton morpho-functional groups induced by extreme hydroclimatic events in the Middle Paraná River (Argentina). Hydrobiologia 639(1):5-19 doi:10.1007/s10750-009-0020-6.

Doi, H., 2009. Spatial patterns of autochthonous and allochthonous resources in aquatic food webs. Population Ecology 51(1):57-64 doi:10.1007/s10144-008-0127-z.

Dokulil, M. T., 1996. Evaluation of eutrophication potential in rivers: The Danube example, a review. In Whitton, B. A. & E. Rott (eds) Use of algae for monitoring rivers II. Innsbruck, 173-178.

Dokulil, M., 2013. Potamoplankton and primary productivity in the River Danube. Hydrobiologia:1-19 doi:10.1007/s10750-013-1589-3.

Elosegi, A. & S. Sabater, 2013. Effects of hydromorphological impacts on river ecosystem functioning: a review and suggestions for assessing ecological impacts. Hydrobiologia 712(1):129-143 doi:10.1007/s10750-012-1226-6.

Elwood, J. W., J. D. Newbold, R. V. O'Neill & W. Van Winkle, 1983. Resource spiraling: an operational paradigm for analyzing lotic ecosystems. In Fontaine, T. D. & S. M. Bartell (eds) Dynamics of lotic ecosystems. Ann Arbor Science Publisher, Michigan, 3-27.

Engelhardt, C., A. Krüger, A. Sukhodolov & A. Nicklisch, 2004. A study of phytoplankton spatial distributions, flow structure and characteristics of mixing in a river reach with groynes. Journal of Plankton Research 26(11):1351-1366 doi:10.1093/plankt/fbh125.

Ettl, H., J. Gerloff & H. Hegnig, 1978. Xanthophyceae vol 1. Gustav Fischer Verlag, Stuttgart, 530 pp.

Ettl, H., J. Gerloff & H. Hegnig, 1985. Chrysophyceae und Haptophyceae. Gustav Fischer Verlag, Stuttgart, 515 pp.

Everbecq, E., V. Gosselain, L. Viroux & J. P. Descy, 2001. Potamon: a dynamic model for predicting phytoplankton composition and biomass in lowland rivers. Water Research 35(4):901-912 doi:10.1016/S0043-1354(00)00360-2.

Farahani, F., H. Korehi, S. Mollakarami & S. Skandari, 2006. Phytoplanton diversity and nutrients at the Jajerood River in Iran. Pakistan Journal of Biological Sciences 9(9):1787-1790.

Field, R., B. A. Hawkins, H. V. Cornell, D. J. Currie, J. A. F. Diniz-Filho, J.-F. Guégan, D. M. Kaufman, J. T. Kerr, G. G. Mittelbach, T. Oberdorff, E. M. O'Brien & J. R. G. Turner, 2009. Spatial species-richness gradients across scales: a meta-analysis. Journal of Biogeography 36(1):132-147 doi:10.1111/j.1365-2699.2008.01963.x.

Floury, M., C. Delattre, S. J. Ormerod & Y. Souchon, 2012. Global versus local change effects on a large European river. Science of the Total Environment 441(0):220-229 doi:10.1016/j.scitotenv.2012.09.051.

Floury, M., P. Usseglio-Polatera, M. Ferreol, C. Delattre & Y. Souchon, 2013. Global climate change in large European rivers: long-term effects on macroinvertebrate communities and potential local confounding factors. Global Change Biology 19(4):1085-1099 doi:10.1111/gcb.12124.

Fott, B., 1968. Cryptophyceae, Chloromonadophyceae, Dinophyceae, vol 3. E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart, 322 pp.

Fraisse, S., 2013. Structure de la communauté phytoplanctonique des fleuves côtiers en réponse aux contraintes hydrodynamiques : une approche basée sur les traits morpho-fonctionnels [Doctoral Thesis]. University of Rennes 1, 148 pp. [in French]

Fraisse, S., M. Bormans & Y. Lagadeuc, 2013. Morphofunctional traits reflect differences in phytoplankton community between rivers of contrasting flow regime. Aquatic Ecology 47(3):315-327 doi:10.1007/s10452-013-9446-z.

Francoeur, S. N., 2001. Meta-analysis of lotic nutrient amendment experiments: detecting and quantifying subtle responses. Journal of The North American Benthological Society 20(3):358-368 doi:10.2307/1468034.

French III, J. R. P., & D. W. Schloesser, 1991. Growth and overwinter survival of the Asiatic clam, Corbicula fluminea, in the St. Clair River, Michigan. Hydrobiologia 219(1):165-170 doi:10.1007/bf00024753.

Frenette, J.-J., P. Massicotte & J.-F. Lapierre, 2012. Colorful niches of phytoplankton shaped by the spatial connectivity in a large river ecosystem: A riverscape perspective. PLoS ONE 7(4):e35891 doi:10.1371/journal.pone.0035891.

Friedl, G., C. Teodoru & B. Wehrli, 2004. Is the Iron Gate I reservoir on the Danube River a sink for dissolved silica? Biogeochemistry 68(1):21-32 doi:10.1023/B:BIOG.0000025738.67183.c0.

Friedrich, G. & M. Pohlmann, 2009. Long-term plankton studies at the lower Rhine/Germany. Limnologica - Ecology and Management of Inland Waters 39(1):14-39 doi:10.1016/j.limno.2008.03.006.

Gaedeke, A. & U. Sommer, 1986. The influence of the frequency of periodic disturbances on the maintenance of phytoplankton diversity. Oecologia 71(1):25-28 doi:10.1007/bf00377315.

Gallego, I., T. A. Davidson, E. Jeppesen, C. Pérez-Martínez, P. Sánchez-Castillo, M. Juan, F. Fuentes-Rodríguez, D. León, P. Peñalver, J. Toja & J. J. Casas, 2012. Taxonomic or ecological approaches? Searching for phytoplankton surrogates in the determination of richness and assemblage composition in ponds. Ecological Indicators 18(0):575-585 doi:10.1016/j.ecolind.2012.01.002.

García de Emiliani, M. O., 1997. Effects of water level fluctuations on phytoplankton in a river-floodplain lake system (Paraná River, Argentina). Hydrobiologia 357(1-3):1-15 doi:10.1023/a:1003149514670.

Garnier, J., G. Billen & M. Coste, 1995. Seasonal succession of diatoms and Chlorophyceae in the drainage network of the Seine River: Observations and modeling. Limnology and Oceanography 40(4):750-765.

Gasith, A. & V. H. Resh, 1999. Streams in mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. Annual Review of Ecology and Systematics 30:51-81. doi:10.1146/annurev.ecolsys.30.1.51

Geitler, L., 1930-1932. Cyanophyceae von Europa. Koeltz Scientific Books, Koenigstein, 1196 pp.

Germain, H., 1935. Les lieux de developpement et de multiplication des diatomées d'eau douce. Contribution à l'écologie des diatomées [Doctoral Thesis]. Faculté des Sciences, Bordeaux [in French]

Giraudel, J. L. & S. Lek, 2001. A comparison of self-organizing map algorithm and some conventional statistical methods for ecological community ordination. Ecological Modelling 146(1–3):329-339 doi:10.1016/S0304-3800(01)00324-6.

Gomà, J., F. Rimet, J. Cambra, L. Hoffmann & L. Ector, 2005. Diatom communities and water quality assessment in mountain rivers of the upper Segre basin (La Cerdanya, Oriental Pyrenees). Hydrobiologia 551(1):209-225 doi:10.1007/s10750-005-4462-1.

Gosselain, V., J.-P. Descy & E. Everbecq, 1994. The phytoplankton community of the River Meuse, Belgium: seasonal dynamics (year 1992) and the possible incidence of zooplankton grazing. Hydrobiologia 289(1):179-191 doi:10.1007/bf00007419.

Gosselain, V., J.-P. Descy, L. Viroux, C. Joaquim-Justo, A. Hammer, A. Métens & S. Schweitzer, 1998. Grazing by large river zooplankton: a key to summer potamoplankton decline? The case of the Meuse and Moselle rivers in 1994 and 1995. Hydrobiologia 369-370(0):199-216 doi:10.1023/a:1017071909997.

Gosselain, V., M. Coste, S. Campeau, L. Ector, C. Fauville, F. Delmas, M. Knoflacher, M. Licursi, F. Rimet, J. Tison, L. Tudesque & J.-P. Descy, 2005. A large-scale stream benthic diatom database. Hydrobiologia 542(1):151-163. doi:10.1007/s10750-004-7423-1

Grabowska, M., 2012. The role of a eutrophic lowland reservoir in shaping the composition of river phytoplankton. Ecohydrology & Hydrobiology 12(3):231-242 doi:10.1016/S1642-3593(12)70206-9.

Greene, J. C., W. E. Miller, T. Shiroyama & T. E. Maloney, 1975. Utilization of algal assays to assess the effects of municipal, industrial, and agricultural wastewater effluents upon phytoplankton production in the Snake River system. Water, Air, and Soil Pollution 4(3-4):415-434 doi:10.1007/bf00280726.

Grime, J. P., 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. The American Naturalist 111:1169-1194.

Grosbois, C., P. Négrel, C. Fouillac & D. Grimaud, 2000. Dissolved load of the Loire River: chemical and isotopic characterization. Chemical Geology 170(1–4):179-201 doi:10.1016/s0009-2541(99)00247-8.

Guiry, M.D. & G. M. Guiry, 2013. *AlgaeBase*. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org; searched on 11 November 2013.

Guiry, M.D. & G.M. Guiry, 2014. *AlgaeBase*. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org; searched between 17-31 January 2014.

Ha, K., M.-H. Jang & G.-J. Joo, 2002. Spatial and temporal dynamics of phytoplankton communities along a regulated river system, the Nakdong River, Korea. Hydrobiologia 470(1):235-245 doi:10.1023/a:1015610900467.

Ha, K., M.-H. Jang & G.-J. Joo, 2003. Winter *Stephanodiscus* bloom development in the Nakdong River regulated by an estuary dam and tributaries. Hydrobiologia 506-509(1):221-227 doi:10.1023/B:HYDR.0000008564.64010.4c.

Hambright, K. D. & T. Zohary, 2000. Phytoplankton species diversity control through competitive exclusion and physical disturbances. Limnology & Oceanography 45(1):110-122.

Hardenbicker, P., S. Rolinski, M. Weitere & H. Fischer, 2014. Contrasting long-term trends and shifts in phytoplankton dynamics in two large rivers. International Review of Hydrobiology:n/a-n/a doi:10.1002/iroh.201301680.

Hart, D. D., T. E. Johnson, K. L. Bushaw-Newton, R. J. Horwitz, A. T. Bednarek, D. F. Charles, D. A. Kreeger & D. J. Velinsky, 2002. Dam removal: Challenges and opportunities for ecological research and river restoration. BioScience 52(8):669-682 doi:10.1641/0006-3568(2002)052[0669:drcaof]2.0.co;2.

Hecky, R. E. & P. Kilham, 1988. Nutrient limitation of phytoplankton in freshwater and marine environments: A review of recent evidence on the effects of enrichment1. Limnology & Oceanography 33(4/2):796-822.

Hill, W. R., B. J. Roberts, S. N. Francoeur & S. E. Fanta, 2011. Resource synergy in stream periphyton communities. Journal of Ecology 99(2):454-463 doi:10.1111/j.1365-2745.2010.01785.x.

Hindák, F. & J. Makovinská, 1999. Phytoplankton of the Danube from Bratislava (Slovakia) to Budapest (Hungary). In: Prygel, J., B. A. Whitton & J. Bukowska (eds) Use of algae for monitoring rivers. vol III, 188-193.

Holmes, N. T. H. & B. A. Whitton, 1981. Phytoplankton of four rivers, the Tyne, Wear, Tees and Swale. Hydrobiologia 80(2):111-127 doi:10.1007/bf00008430.

Holmes, R. W., R. Norris, T. Smayda & E. J. F. Wood, 1969. Collection, fixation, identification, and enumeration of phytoplankton standing stock, p. 17-46. In Anon. (ed) Recommended procedures for measuring the productivity of plankton standing stock and related oceanic properties. National Academy of Sciences, Washington, 1746 pp.

Hu, R. & L. Xiao, 2012. Functional classification of phytoplankton assemblages in reservoirs of Guangdong Province, South China. In Han, B.-P. & Z. Liu (eds) Tropical and Sub-Tropical Reservoir Limnology in China. Monographiae Biologicae, vol 91. Springer Netherlands, 59-70.

Hu, R., B. Han & L. Naselli-Flores, 2013. Comparing biological classifications of freshwater phytoplankton: a case study from South China. Hydrobiologia 701(1):219-233 doi:10.1007/s10750-012-1277-8. doi:10.1007/978-94-007-2007-7_4

Huber-Pestalozzi, G., 1955. Euglenophyceen, vol 4. E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart, 606 pp.

Hudson, A. R., N. F. Caraco, J. J. Cole & D. L. Strayer, 1996. Filtration of Hudson River water by the zebra Mussel (*Dreissena polymorpha*). Estuaries 19(4):824-832 doi:10.2307/1352300.

Huet, M., 1959. Profiles and biology of western European streams as related to fish management. Transactions of the American Fisheries Society 88(3):155-163 doi:10.1577/1548-8659(1959)88[155:pabowe]2.0.co;2.

Humborg, C., D. J. Conley, L. Rahm, F. Wulff, A. Cociasu & V. Ittekkot, 2000. Silicon Retention in River Basins: Far-reaching Effects on Biogeochemistry and Aquatic Food

Webs in Coastal Marine Environments. Ambio 29(1):45-50 doi:10.1579/0044-7447-29.1.45.
Hutchinson, G. E., 1957. A Treatise on Limnology. Vol. I., Geography, Physics, and Chemistry. John Wiley & Sons, Inc., New York. 1015 pp.
Hutchinson, G. E., 1961. The paradox of the plankton. The American Naturalist 95(885):137-145.
Ibelings, B., W. Admiraal, R. Bijkerk, T. Ietswaart & H. Prins, 1998. Monitoring of algae in Dutch rivers: does it meet its goals? Journal of Applied Phycology 10(2):171-181 doi:10.1023/a:1008049000764.
Ietswaart, T., L. Breebaart, B. van Zanten & R. Bijkerk, 1999. Plankton dynamics in the river Rhine during downstream transport as influenced by biotic interactions and hydrological conditions. Hydrobiologia 410(0):1-10 doi:10.1023/a:1003801110365.
Istvánovics, V. & M. Honti, 2011. Phytoplankton growth in three rivers: The role of meroplankton and the benthic retention hypothesis. Limnology & Oceanography 56(4):1439-1452. doi:10.4319/lo.2011.56.4.1439
Istvánovics, V. & M. Honti, 2012. Efficiency of nutrient management in controlling eutrophication of running waters in the Middle Danube Basin. Hydrobiologia 686(1):55-71 doi:10.1007/s10750-012-0999-y.
Istvánovics, V., M. Honti, L. Vörös & Z. Kozma, 2010. Phytoplankton dynamics in relation to connectivity, flow dynamics and resource availability—the case of a large, lowland river, the Hungarian Tisza. Hydrobiologia 637(1):121-141 doi:10.1007/s10750-009-9991-6.
Izaguirre, I., L. Allende, R. Escaray, J. Bustingorry, G. Pérez & G. Tell, 2012. Comparison of morpho-functional phytoplankton classifications in human-impacted shallow lakes with different stable states. Hydrobiologia 698(1):203-216 doi:10.1007/s10750-012-1069-1.
Jacobsen, B. A. & P. Simonsen, 1993. Disturbance events affecting phytoplankton biomass, composition and species diversity in a shallow, eutrophic, temperate lake. Hydrobiologia 249(1-3):9-14 doi:10.1007/bf00008838.
Jewson, D. H., 1992. Size reduction, reproductive strategy and the life cycle of a centric Diatom. Philosophical Transactions of the Royal Society of London Series B: Biological Sciences 336(1277):191-213 doi:10.1098/rstb.1992.0056.
Jüttner, I., P. J. Chimonides & S. J. Ormerod, 2012. Developing a diatom monitoring network in an urban river-basin: initial assessment and site selection. Hydrobiologia 695(1):137-151 doi:10.1007/s10750-012-1123-z.
Kalff, J., 2002. Limnology - Inland Water Ecosystems. Prentice Hall, New Jersey. 592 pp.
Keller, R. P. & D. M. Lodge, 2009. Invasive Species. In Likens, G. E. (ed) Encyclopedia of Inland Waters. vol 3. Elsevier, Oxford, 92-99.
Kelly, M., C. Bennett, M. Coste, C. Delgado, F. Delmas, L. Denys, L. Ector, C. Fauville, M. Ferréol, M. Golub, A. Jarlman, M. Kahlert, J. Lucey, B. Ní Chatháin, I. Pardo, P. Pfister, J. Picinska-Faltynowicz, J. Rosebery, C. Schranz, J. Schaumburg, H. Dam & S. Vilbaste, 2009. A comparison of national approaches to setting ecological status boundaries in phytobenthos assessment for the European Water Framework Directive: results of an intercalibration exercise. Hydrobiologia 621(1):169-182 doi:10.1007/s10750-008-9641-4.
Kiss, K. T., A. Schmidt, É. Ács, 1996. Sampling strategies for phytoplankton investigations in a large river (River Danube, Hungary), in: Whitton, B.A., Rott, E. (Eds.), Use of algae for monitoring rivers II. Institut für Botanik, Universität Innsbruck, pp. 179-185.

Kiss, K. T., É. Ács & A. Kovács, 1994. Ecological observations on *Skeletonema potamos* (Weber) Hasle in the River Danube, near Budapest (1991–92, daily investigations). Hydrobiologia 289(1-3):163-170 doi:10.1007/bf00007417.

Kiss, K. T., É. Ács, K. É. Szabó, B. Tóth & Á. K. Kiss, 2006. Alteration in the summer phytoplankton abundance from medium to low water level conditions in the River Danube. In: 36th International Conference of IAD Austrian Committee Danube Research/IAD, Vienna, 2006. vol 13. p 210-214.

Kiss, K. T., R. Klee, L. Ector & É. Ács, 2012. Centric diatoms of large rivers and tributaries in Hungary: morphology and biogeographic distribution. Acta Botanica Croatica 71(2):1-53 doi:10.2478/v10184-011-0067-0.

Koch, R. W., D. L. Guelda & P. A. Bukaveckas, 2004. Phytoplankton growth in the Ohio, Cumberland and Tennessee Rivers, USA: inter-site differences in light and nutrient limitation. Aquatic Ecology 38(1):17-26 doi:10.1023/b:aeco.0000021082.42784.03.

Köhler, J. & S. Hoeg, 2000. Phytoplankton selection in a river–lake system during two decades of changing nutrient supply. Hydrobiologia 424(1-3):13-24 doi:10.1023/a:1003988508599.

Köhler, J., 1994. Origin and succession of phytoplankton in a river-lake system (Spree, Germany). Hydrobiologia 289(1-3):73-83 doi:10.1007/bf00007410.

Komárek, J. & B. Fott, 1983. Chlorophyceae, vol 7, Chlorococcales. E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart, 1044 pp.

Komárek, J. & K. Anagnostidis, 1999. Cyanoprokaryota, vol 1, Chroococcales. Gustav Fischer Verlag, Stuttgart, 548 pp.

Komárek, J. & K. Anagnostidis, 2005. Cyanoprokaryota, vol 2, Oscillatoriales. Gustav Fischer Verlag, Stuttgart, 759 pp.

Krammer, K. & H. Lange-Bertalot, 1986. Bacillariophyceae, vol 1, Naviculaceae. Gustav Fischer Verlag, Stuttgart, 876 pp.

Krammer, K. & H. Lange-Bertalot, 1988. Bacillariophyceae, vol 2, Bacillariaceae, Epithemiaceae, Surirellaceae. Gustav Fischer Verlag, Stuttgart, 596 pp.

Krammer, K. & H. Lange-Bertalot, 1991a. Bacillariophyceae, vol 3, Centrales, Fragilariaceae, Eunotiaceae. Gustav Fischer Verlag, Stuttgart, 576 pp.

Krammer, K. & H. Lange-Bertalot, 1991b. Bacillariophyceae, vol 4, Achnanthaceae. Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema. Gustav Fischer Verlag, Stuttgart, 436 pp.

Krammer, K., 2002. Cymbella. In Lange-Bertalot, H. (ed) Diatoms of Europe. A.R.G. Gantner Verlag K. G., Königstein, 586 pp.

Krienitz, L. & C. Bock, 2012. Present state of the systematics of planktonic coccoid green algae of inland waters. Hydrobiologia 698(1):295-326 doi:10.1007/s10750-012-1079-z.

Krogstad, T. & Ø. Løvstad, 1989. Erosion, phosphorus and phytoplankton response in rivers of South-Eastern Norway. Hydrobiologia 183(1):33-41 doi:10.1007/bf00005968.

Kruk, C., 2010. Morphology captures function in phytoplankton. A large-scale analysis of phytoplankton communities in relation to their environment [Doctoral Thesis]. Wageningen University, 117 pp. [in English]

Kruk, C., E. T. H. M. Peeters, E. H. Van Nes, V. L. M. Huszar, L. S. Costa & M. Scheffera, 2011. Phytoplankton community composition can be predicted best in terms of morphological groups. Limnology & Oceanography 56(1):110-118. doi:10.4319/lo.2011.56.1.0110

Kruk, C., V. L. M. Huszar, E. T. H. M. Peeters, S. Bonilla, L. Costa, M. Lürling, C. S. Reynolds & M. Scheffer, 2010. A morphological classification capturing functional

variation in phytoplankton. Freshwater Biology 55(3):614-627 doi:10.1111/j.1365-2427.2009.02298.x.
Lair, N. & D. Sargos, 1981. Dynamique des populations planctoniques en Loire moyenne. Extrait des annales de la stations biologique de Besse-en-Chandesse 6:60-114.
Lair, N. & D. Sargos, 1993. A 10 year study at four sites of the middle course of the River Loire I - Patterns of change in hydrological, physical and chemical variables in relation to algal biomass. Hydroécologie Appliquée 5:1-27. doi: 10.1051/hydro:1993101
Lair, N. & P. Reyes-Marchant, 1997. The potamoplankton of the Middle Loire and the role of the 'moving littoral' in downstream transfer of algae and rotifers. Hydrobiologia 356(1):33-52 doi:10.1023/a:1003127230386.
Lair, N., 2005. Abiotic vs. biotic factors: Lessons drawn from Rotifers in the Middle Loire, a meandering river monitored from 1995 to 2002, during low flow periods. Hydrobiologia 546(1):457-472 doi:10.1007/s10750-005-4289-9.
Lair, N., G. Millerioux & F. Restituito, 1978. Examen physicochimique et répartition du plancton de la Loire, en période d'étiage (été 1976) au niveau de la centrale nucléaire de Saint-Laurent-des-Eaux. Cahiers du Laboratoire de Montereau 6:53-80.
Lair, N., V. Jacquet & P. Reyes-Marchant, 1999. Factors related to autotrophic potamoplankton, heterotrophic protists and micrometazoan abundance, at two sites in a lowland temperate river during low water flow. Hydrobiologia 394(0):13-28 doi:10.1023/a:1003552021726.
Lamberti, G. A. & A. D. Steinman, 1997. A comparison of primary production in stream ecosystems. Journal of the North American Benthological Society 16(1):95-104. doi: 10.2307/1468241
Lampert, W. & U. Sommer, 2007. Limnoecology: The Ecology of Lakes and Streams. Oxford University Press, USA. 324 pp.
Lange-Bertalot, H., 2001. Navicula sensu stricto: 10 genera separated from *Navicula* sensu lato *Frustulia*. In Lange-Bertalot, H. (ed) Diatoms of Europe. vol 2. A. R. G. Gantner Verlag K. G., Königstein, 526 pp.
Larroudé, S., N. Massei, P. Reyes-Marchant, C. Delattre & J. F. Humbert, 2013. Dramatic changes in a phytoplankton community in response to local and global pressures: a 24-year survey of the river Loire (France). Global Change Biology 19(5):1620-1631 doi:10.1111/gcb.12139.
Lasne, E., 2007. Connectivité hydrologique et distribution spatiale de l'ictyofaune dans le bassin versant de la Loire : de l'assemblage à la population (cas de l'anguille européenne) [Doctoral Thesis]. Université de Rennes [in French]
Lasne, E., B. Bergerot, S. Lek & P. Laffaille, 2007. Fish zonation and indicator species for the evaluation of the ecological status of rivers: example of the Loire basin (France). River Research and Applications 23(8):877-890 doi:10.1002/rra.1030.
Latapie, A., 2011. Modelisation de l'evolution morphologique d'un lit alluvial : application à la Loire moyenne [Doctoral Thesis]. Université François - Rabelais, Tours, 279 pp. [in French].
Latour, D., H. Giraudet & J.-L. Berthon, 2004. Frequency of dividing cells and viability of *Microcystis aeruginosa* in sediment of a eutrophic reservoir. Aquatic Microbial Ecology 36(2):6. doi: 10.3354/ame036117
Leitão, M. & A. Lepretre, 1998. The phytoplankton of the River Loire, France: a typological approach. Verhandlungen des Internationalen Vereinigung für theoretische und angewandte Limnologie 26:1050-1056.

Leitao, M. & V. Rouquet, 2002. Algal monitoring in the Seine and two tributaries near Paris. Verhandlungen des Internationalen Vereinigung für theoretische und angewandte Limnologie 28:892-896.

Leland, H. V., 2003. The influence of water depth and flow regime on phytoplankton biomass and community structure in a shallow, lowland river. Hydrobiologia 506-509(1-3):247-255 doi:10.1023/b:hydr.0000008596.00382.56.

Leopold, L. B. & T. Maddock, Jr., 1953. The hydraulic geometry of stream channels and some physiographic implications. USGPO, Geological Survey Professional Paper 252.

Leopold, L. B. & W. B. Langbein, 1962. The concept of entropy in landscape evolution. Geological Survey Professional Paper 500-A.

Leopold, L. B., M. G. Wolman & J. P. Miller, 1995. Fluvial Processes in Geomorphology. Dover Publ., 522 pp.

Lercari, D. & L. Bergamino, 2011. Impacts of two invasive mollusks, *Rapana venosa* (Gastropoda) and *Corbicula fluminea* (Bivalvia), on the food web structure of the Río de la Plata estuary and nearshore oceanic ecosystem. Biological Invasions 13(9):2053-2061 doi:10.1007/s10530-011-0023-x.

Lindenschmidt, K.-E. & I. Chorus, 1998. The effect of water column mixing on phytoplankton succession, diversity and similarity. Journal of Plankton Research 20(10):1927-1951 doi:10.1093/plankt/20.10.1927.

Litchman, E. & C. A. Klausmeier, 2008. Trait-based community ecology of phytoplankton. Annual Review of Ecology, Evolution, and Systematics 39(1):615-639 doi:doi:10.1146/annurev.ecolsys.39.110707.173549.

Litchman, E., C. A. Klausmeier, O. M. Schofield & P. G. Falkowski, 2007. The role of functional traits and trade-offs in structuring phytoplankton communities: scaling from cellular to ecosystem level. Ecology Letters 10(12):1170-1181 doi:10.1111/j.1461-0248.2007.01117.x.

Livingstone, D. A., 1963. Chemical composition of rivers and lakes. In Fleischer, M. (ed) Data of geochemistry, 6th ed, Geological Survey Professional Paper 440-G Chap G. U.S. Government Printing Office, Washington, G1-G64.

Lund, J. W. G. & J. F. Talling, 1957. Botanical limnological methods with special reference to the algae. The Botanical Review 23(8-9):489-583 doi:10.1007/bf02870144.

Lund, J. W. G., C. Kipling & E. D. Cren, 1958. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia 11(2):143-170 doi:10.1007/bf00007865.

Margalef, R., 1958. Temporal succession and spatial heterogeneity in phytoplankton. In Buzzati-Traverso, A. A. (ed) Perspectives in marine biology. University of California Press, Berkeley, 323-349.

Margalef, R., 1978. Life-forms of phytoplankton as survival alternatives in an unstable environment. Oceanologica Acta 1(4):493–509.

Martí, E., F. Sabater, J. L. Riera, G. C. Merseburger, D. von Schiller, A. Argerich, F. Caille & P. Fonollà, 2006. Fluvial nutrient dynamics in a humanized landscape. Insights from a hierarchical perspective. Limnetica 25(1-2):513-526.

McGinnis, D. F., S. Bocaniov, C. Teodoru, G. Friedl, A. Lorke & A. Wüest, 2006. Silica retention in the Iron Gate I reservoir on the Danube River: the role of side bays as nutrient sinks. River Research and Applications 22(4):441-456 doi:10.1002/rra.916.

Meybeck, M. & R. Helmer, 1989. The quality of rivers: from pristine stage to global pollution. Global and Planetary Change 1(4):283-309 doi:10.1016/0921-8181(89)90007-6.

Meybeck, M., 2003a. Global analysis of river systems: from Earth system controls to Anthropocene syndromes. Philosophical Transactions of the Royal Society of London Series B: Biological Sciences 358(1440):1935-1955 doi:10.1098/rstb.2003.1379.

Meybeck, M., 2003b. Global occurrence of major elements in rivers. Treatise on Geochemistry. Elsevier Ltd., Paris, 207-223.

Meybeck, M., J. Vogler, F. Moatar, H. Duerr, L. Laroche & L. Lachartre, 2003. Analysis of temporal variability in river systems. E. C. Report EUROCAT Program, W P 51.

Michard, M., L. Aleya & J. Verneaux, 1996. Mass occurrence of the cyanobacteria *Microcystis aeruginosa* in the hypereutrophic Villerest reservoir (Roanne, France) : usefulness of the biyearly examination of N/P (nitrogen phosphorous) and P/C (protein/carbohydrate) couplings. Archiv für Hydrobiologie 135(3):337-359.

Mihaljević, M. & F. Stević, 2011. Cyanobacterial blooms in a temperate river-floodplain ecosystem: the importance of hydrological extremes. Aquatic Ecology 45(3):335-349 doi:10.1007/s10452-011-9357-9.

Mihaljević, M., D. Špoljarić, F. Stević & T. Žuna Pfeiffer, 2013. Assessment of flood-induced changes of phytoplankton along a river–floodplain system using the morpho-functional approach. Environ Monit Assess 185(10):8601-8619 doi:10.1007/s10661-013-3198-z.

Minaudo, C., F. Moatar, M. Meybeck, F. Curie, N. Gassama & M. Leitão, 2013. Loire River eutrophication mitigation (1981–2011) measured by seasonal nutrients and algal pigments In Arheimer, B. (ed) Understanding Freshwater Quality Problems in a Changing World. vol 361. IAHS Publication, Wallingford, UK, 167-174.

Minaudo, C., M. Meybeck, F. Moatar, O. Coulon, F. Curie, P. Gosse, 2014. Hypertrophication in the Loire River basin (France) since the 1970s: control of river biogeochemistry and organic pollution export to the estuary. Science of the Total Environment (Submitted)

Minshall, G. W., K. W. Cummins, R. C. Petersen, C. E. Cushing, D. A. Bruns, J. R. Sedell & R. L. Vannote, 1985. Developments in stream ecosystem theory. Canadian Journal of Fisheries and Aquatic Sciences 42(5):1045-1055 doi:10.1139/f85-130.

Mischke, U., Distribution of pelagic Centrales and their value to index trophic status in German rivers: Dominant, but not relevant? In: Kusber, W.-H. & R. Jahn (eds) Proceedings of the 1st Central European Diatom Meeting, Berlin, 2007. p 117-120.

Mischke, U., M. Venohr & H. Behrendt, 2011. Using phytoplankton to assess the trophic status of German rivers. International Review of Hydrobiology 96(5):578-598 doi:10.1002/iroh.201111304.

Moatar, F. & J. Gailhard, 2006. Water temperature behaviour in the River Loire since 1976 and 1881. Comptes Rendus Geoscience 338(5):319-328 doi:10.1016/j.crte.2006.02.011.

Moatar, F. & M. Meybeck, 2005. Compared performances of different algorithms for estimating annual nutrient loads discharged by the eutrophic River Loire. Hydrological Processes 19(2):429-444 doi:10.1002/hyp.5541.

Moatar, F., A. Ducharne, D. Thiéry, V. Bustillo, E. Sauquet & J.-P. Vidal, 2010. La Loire à l'épreuve du changement climatique. Geosciences 12:78-87.

Moss, B., 2008. The kingdom of the shore: achievement of good ecological potential in reservoirs. Freshwater Reviews 1(1):29-42 doi:10.1608/frj-1.1.2.

Mudelsee, M., M. Borngen, G. Tetzlaff & U. Grunewald, 2003. No upward trends in the occurrence of extreme floods in central Europe. Nature 425(6954):166-169 doi:http://www.nature.com/nature/journal/v425/n6954/suppinfo/nature01928_S1.html.

Naselli-Flores, L. & R. Barone, 2011. Fight on plankton! or, phytoplankton shape and size as adaptive tools to get ahead in the struggle for life. Cryptogamie, Algologie 32(2):157-204 doi:10.7872/crya.v32.iss2.2011.157.

Naselli-Flores, L., J. Padisák, M. T. Dokulil & I. Chorus, 2003. Equilibrium/steady-state concept in phytoplankton ecology. Hydrobiologia 502(1):395-403 doi:10.1023/b:hydr.0000004297.52645.59.

Newbold, J. D., J. W. Elwood, R. V. O'Neill & W. V. Winkle, 1981. Measuring nutrient spiralling in streams. Canadian Journal of Fisheries and Aquatic Sciences 38(7):860-863 doi:10.1139/f81-114.

Nilsson, C., C. A. Reidy, M. Dynesius & C. Revenga, 2005. Fragmentation and flow regulation of the world's large river systems. Science 308(5720):405-408 doi:10.1126/science.1107887.

Nixdorf, B., M. Ute & J. Rücker, 2003. Phytoplankton assemblages and steady state in deep and shallow eutrophic lakes – an approach to differentiate the habitat properties of Oscillatoriales. Hydrobiologia 502:111-121 doi:10.1023/B:HYDR.0000004274.65831.e5.

Nohara, D., A. Kitoh, M. Hosaka & T. Oki, 2006. Impact of climate change on river discharge projected by multimodel ensemble. Journal of Hydrometeorology 7(5):1076-1089 doi:10.1175/jhm531.1.

Noppe, K. & J. Prygiel, 1999. Phytoplankton as an eutrophication indicator for the main watercouses of the Artois-Picardie water basin (France). In Prygiel, J., B. A. Whitton & J. Bukowska (eds) Use of algae for monitoring rivers III. Agence de l'Eau Artrois-Picardie, 194-205.

Novais, M., S. Blanco, C. Delgado, M. Morais, L. Hoffmann & L. Ector, 2012. Ecological assessment of Portuguese reservoirs based on littoral epilithic diatoms. Hydrobiologia 695(1):265-279 doi:10.1007/s10750-012-1197-7.

Oudin, L.-C. & D. Maupas, 2003. System d'évaluation de la qualité de l'eau des cours d'eau (SEQ-Eau). Rapport de présentation de la V2. MEDD & Agences de l'eau, 106 pp.

Oudin, L.-C., N. Lair, M. Leitão, P. Reyes-Marchant, J. F. Mignot, P. Steinbach, T. Vigneron, J.-P. Berton, M. Bacchi, J. E. Roché & J.-P. Descy, 2009. The Loire Basin. In Tockner, K., U. Uehlinger & C. T. Robinson (eds) Rivers of Europe. Elsevier, London, 167-181.

Pacheco, J., C. Iglesias, M. Meerhoff, C. Fosalba, G. Goyenola, F. Teixeira-de Mello, S. García, M. Gelós & F. García-Rodríguez, 2010. Phytoplankton community structure in five subtropical shallow lakes with different trophic status (Uruguay): a morphology-based approach. Hydrobiologia 646(1):187-197 doi:10.1007/s10750-010-0180-4.

Pachés, M., I. Romero, Z. Hermosilla & R. Martinez-Guijarro, 2012. PHYMED: An ecological classification system for the Water Framework Directive based on phytoplankton community composition. Ecological Indicators 19(0):15-23 doi:10.1016/j.ecolind.2011.07.003.

Padisák, J., 2003. Phytoplankton. In O'Sullivan, P. E. & C. S. Reynolds (eds) The Lakes Handbook. vol 1: Limnology and Limnetic Ecology. Blackwell Science Ltd, Malden, MA, USA, 251-307.

Padisák, J., G. Borics, G. Fehér, I. Grigorszky, I. Oldal, A. Schmidt & Z. Zámbóné-Doma, 2003a. Dominant species, functional assemblages and frequency of equilibrium phases in late summer phytoplankton assemblages in Hungarian small shallow lakes. Hydrobiologia 502(1-3):157-168 doi:10.1023/b:hydr.0000004278.10887.40.

Padisák, J., G. Borics, I. Grigorszky & É. Soróczki-Pintér, 2006. Use of phytoplankton assemblages for monitoring ecological status of lakes within the Water Framework Directive: The assemblage index. Hydrobiologia 553(1):1-14 doi:10.1007/s10750-005-1393-9.

Padisák, J., L. Crossetti & L. Naselli-Flores, 2009. Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. Hydrobiologia 621(1):1-19 doi:10.1007/s10750-008-9645-0.

Padisák, J., W. Scheffler, C. Sípos, P. Kasprzak, R. Koschel & L. Krienitz, 2003b. Spatial and temporal pattern of development and decline of the spring diatom populations in Lake Stechlin in 1999. Arch Hydrobiol Spec Issues Advanc in Limnol 58:135-155.

Palau, A., 2006. Integrated environmental management of current reservoirs and regulated rivers. Limnetica 25(1-2):287-302.

Park, Y.-S., J. Tison, S. Lek, J.-L. Giraudel, M. Coste & F. Delmas, 2006. Application of a self-organizing map to select representative species in multivariate analysis: A case study determining diatom distribution patterns across France. Ecological Informatics 1(3):247-257 doi:10.1016/j.ecoinf.2006.03.005.

Pérez, M. D. C., N. I. Maidana & A. Comas, 2009. Phytoplankton composition of the Ebro river estuary, Spain. Acta Botanica Croatica 68(1):11-27.

Peterson, C. G. & R. J. Stevenson, 1989. Seasonality in river phytoplankton: multivariate analyses of data from the Ohio River and six Kentucky tributaries. Hydrobiologia 182(2):99-114 doi:10.1007/bf00006036.

Phillips, G., G. Morabito, L. Carvalho, A. L. Solheim, B. Skjelbred, J. Moe, T. Andersen, U. Mischke, C. de Hoyos & G. Borics, 2011. WISER: water bodies in Europe: Integrative systems to assess ecological status and recovery. Report on lake phytoplankton composition metrics, including a common metric approach for use in intercalibration by all GIGs. Norwegian Institute for Water Research (NIVA), 61 pp.

Picard, V. & N. Lair, 2005. Spatio-temporal investigations on the planktonic organisms of the middle Loire (France), during the low water period: Biodiversity and community dynamics. Hydrobiologia 551(1):69-86 doi:10.1007/s10750-005-4451-4.

Pielou, E. C., 1975. Ecological Diversity. Wiley Interscience, New York, 165 pp.

Pigneur, L.-M., E. Falisse, K. Roland, E. Everbecq, J.-F. Deliège, J. S. Smitz, K. Van Doninck & J.-P. Descy, 2013. Impact of invasive Asian clams, *Corbicula* spp., on a large river ecosystem. Freshwater Biology doi:10.1111/fwb.12286.

Pigneur, L.-M., J. Marescaux, K. Roland, E. Etoundi, J.-P. Descy & K. Van Doninck, 2011. Phylogeny and androgenesis in the invasive *Corbicula* clams (Bivalvia, Corbiculidae) in Western Europe. BMC Evolutionary Biology 11:147 doi:10.1186/1471-2148-11-147.

Piirsoo, K., 2001. Phytoplankton of Estonian rivers in midsummer. Hydrobiologia 444(1-3):135-146 doi:10.1023/a:1017515132718.

Piirsoo, K., P. Pall, A. Tuvikene & M. Viik, 2008. Temporal and spatial patterns of phytoplankton in a temperate lowland river (Emajõgi, Estonia). Journal of Plankton Research 30(11):1285-1295 doi:10.1093/plankt/fbn082.

Piirsoo, K., P. Pall, A. Tuvikene, M. Viik & S. Vilbaste, 2010. Assessment of water quality in a large lowland river (Narva, Estonia/Russia) using a new Hungarian potamoplanktic method. Estonian Journal of Ecology 59(4):243-258 doi:10.3176/eco.2010.4.01.

Podani, J., 1988. Syn-Tax III. User's manual. Abstracta Botanica 12:1-183.

Popovský, J. & L. A. Pfiester, 1990. Dinophyceae (Dinoflagellida). Gustav Fischer Verlag, Stuttgart, 272 pp.

Prahl, F. G., L. F. Small, B. A. Sullivan, J. Cordell, C. A. Simenstad, B. C. Crump & J. A. Baross, 1997. Biogeochemical gradients in the lower Columbia River. Hydrobiologia 361(1):37-52 doi:10.1023/a:1003129124747.

Ptacnik, R., A. G. Solimini, T. Andersen, T. Tamminen, P. Brettum, L. Lepistö, E. Willén & S. Rekolainen, 2008. Diversity predicts stability and resource use efficiency in natural

phytoplankton communities. Proceedings of the National Academy of Sciences 105(13):5134-5138 doi:10.1073/pnas.0708328105.
Ramos, J. & J. Gracia, 2012. Spatial–temporal fluvial morphology analysis in the Quelite river: It's impact on communication systems. Journal of Hydrology 412–413(0):269-278 doi:10.1016/j.jhydrol.2011.05.007.
Reynolds, C. S. & J. P. Descy, 1996. The production, biomass and structure of phytoplankton in large rivers. Archiv für Hydrobiologie Supplementband Large rivers 10(1-4):161-187.
Reynolds, C. S., 1984. The ecology of freshwater phytoplankton. Cambridge University Press, Cambridge, 384 pp.
Reynolds, C. S., 1987. Community organization in the freshwater plankton. In Gee, J. H. R. & P. S. Giller (eds) Organization of communities, past and present. Blackwell Scientific Publications, Oxford, 297-325.
Reynolds, C. S., 1994. The long, the short and the stalled: on the attributes of phytoplankton selected by physical mixing in lakes and rivers. Hydrobiologia 289(1-3):9-21 doi:10.1007/bf00007405.
Reynolds, C. S., 1997. Vegetation processes in the pelagic: a model for ecosystem theory. Ecology Institute, Oldendorf/Luhe, Germany. 371 pp.
Reynolds, C. S., 2003. Planktic community assembly in flowing water and the ecosystem health of rivers. Ecological Modelling 160(3):191-203 doi:10.1016/S0304-3800(02)00252-1.
Reynolds, C. S., 2005. Expert judgement of phytoplankton composition - functional groups. In Solheim, A. L. (ed) Reference conditions of European lakes: Indicators and methods for the Water Framework Directive assessment of reference conditions. REBECCA, version 5: 2005/30/12, 90-104.
Reynolds, C. S., 2006. The Ecology of Phytoplankton. Cambridge University Press, 535 pp.
Reynolds, C. S., J. P. Descy & J. Padisák, 1994. Are phytoplankton dynamics in rivers so different from those in shallow lakes? Hydrobiologia 289(1):1-7 doi:10.1007/bf00007404.
Reynolds, C. S., J. Padisák & U. Sommer, 1993. Intermediate disturbance in the ecology of phytoplankton and the maintenance of species diversity: a synthesis. Hydrobiologia 249(1-3):183-188 doi:10.1007/bf00008853.
Reynolds, C. S., V. Huszar, C. Kruk, L. Naselli-Flores & S. Melo, 2002. Towards a functional classification of the freshwater phytoplankton. Journal of Plankton Research 24(5):417-428 doi:10.1093/plankt/24.5.417.
Richardson, J. S. & R. J. Mackay, 1991. Lake outlets and the distribution of filter feeders: An assessment of hypotheses. Oikos 62(3):370-380 doi:10.2307/3545503.
Rimet, F. & A. Bouchez, 2011. Use of diatom life-forms and ecological guilds to assess pesticide contamination in rivers: Lotic mesocosm approaches. Ecological Indicators 11(2):489-499 doi:10.1016/j.ecolind.2010.07.004.
Rimet, F., 2009. Benthic diatom assemblages and their correspondence with ecoregional classifications: case study of rivers in north-eastern France. Hydrobiologia 636(1):137-151 doi:10.1007/s10750-009-9943-1.
Rimet, F., L. Ector, H. M. Cauchie & L. Hoffmann, 2004. Regional distribution of diatom assemblages in the headwater streams of Luxembourg. Hydrobiologia 520(1-3):105-117 doi:10.1023/B:HYDR.0000027730.12964.8c.
Rojo, C., M. A. Cobelas & M. Arauzo, 1994. An elementary, structural analysis of river phytoplankton. Hydrobiologia 289(1):43-55 doi:10.1007/bf00007407.

Rott, E., 1981. Some results from phytoplankton counting intercalibrations. Schweiz Z Hydrologie 43(1):34-62 doi:10.1007/bf02502471.

Rusanov, A. G., E. V. Stanislavskaya & É. Ács, 2012. Periphytic algal assemblages along environmental gradients in the rivers of the Lake Ladoga basin, Northwestern Russia: implication for the water quality assessment. Hydrobiologia 695(1):305-327 doi:10.1007/s10750-012-1199-5.

Sabart, M., D. Pobel, D. Latour, J. Robin, M.-J. Salençon & J.-F. Humbert, 2009. Spatiotemporal changes in the genetic diversity in French bloom-forming populations of the toxic cyanobacterium, *Microcystis aeruginosa*. Environmental Microbiology Reports 1(4):263-272 doi:10.1111/j.1758-2229.2009.00042.x.

Sabater, S., 2008. Alterations of the global water cycle and their effects on river structure, function and services. Freshwater Reviews 1(1):75-88 doi:10.1608/frj-1.1.5.

Sabater, S., H. Guasch, I. Muñoz & A. Romaní, 2006. Hydrology, light and the use of organic and inorganic materials as structuring factors of biological communities in Mediterranean streams. Limnetica 25(1-2):335-348.

Sabater, S., J. Artigas, C. Durán, M. Pardos, A. M. Romaní, E. Tornés & I. Ylla, 2008. Longitudinal development of chlorophyll and phytoplankton assemblages in a regulated large river (the Ebro River). Science of the Total Environment 404(1):196-206 doi:10.1016/j.scitotenv.2008.06.013.

Salençon, M. J., 2004. Ecosystème de la retenue de Grangent, Présentation générale, EDF R&D, Laboratoire Nationale d'hydaulique et environnement, Projet E3-98-03 I, rapport interne. Chatou: 18.

Salmaso, N. & A. Zignin, 2010. At the extreme of physical gradients: phytoplankton in highly flushed, large rivers. Hydrobiologia 639(1):21-36 doi:10.1007/s10750-009-0018-0.

Salmaso, N. & J. Padisák, 2007. Morpho-Functional Groups and phytoplankton development in two deep lakes (Lake Garda, Italy and Lake Stechlin, Germany). Hydrobiologia 578(1):97-112 doi:10.1007/s10750-006-0437-0.

Salmaso, N. & M. G. Braioni, 2008. Factors controlling the seasonal development and distribution of the phytoplankton community in the lowland course of a large river in Northern Italy (River Adige). Aquatic Ecology 42(4):533-545 doi:10.1007/s10452-007-9135-x.

Salmaso, N., L. Naselli-Flores & J. Padisák, 2012. Impairing the largest and most productive forest on our planet: how do human activities impact phytoplankton? Hydrobiologia 698(1):375-384 doi:10.1007/s10750-012-1253-3.

Salmaso, N., L. Naselli-Flores & J. Padisák, submitted. Functional classifications in phytoplankton ecology: a comparative review of approaches and experiences. Freshwater Biology.

Sarmento, H. & J.-P. Descy, 2008. Use of marker pigments and functional groups for assessing the status of phytoplankton assemblages in lakes. Journal of Applied Phycology 20(6):1001-1011 doi:10.1007/s10811-007-9294-0.

Scherwass, A., T. Bergfeld, A. Schöl, M. Weitere & H. Arndt, 2010. Changes in the plankton community along the length of the River Rhine: Lagrangian sampling during a spring situation. Journal of Plankton Research 32(4):491-502 doi:10.1093/plankt/fbp149.

Schiemer, F., H. Keckeis, W. Reckendorfer & G. Winkler, 2001. The inshore retention concept and its significance for large rivers. Archiv für Hydrobiologie Supplementband 135(2-4):509-516.

Schimming, C.-G., S. Augustin & R. Karez, 2010. The Scientific Potential of Environmental Monitoring, p 39-57. In Müller, F., C. Baessler, H. Schubert & S. Klotz (eds) Long-term ecological research. Springer, Dordrecht, 456.

Schmidt, A., 1994. Main characteristics of the phytoplankton of the Southern Hungarian section of the River Danube. Hydrobiologia 289(1-3):97-108 doi:10.1007/bf00007412.

Schöl, A., V. Kirchesch, T. Bergfeld & D. Müller, 1999. Model-based analysis of oxygen budget and biological processes in the regulated rivers Moselle and Saar: modelling the influence of benthic filter feeders on phytoplankton. Hydrobiologia 410(0):167-176 doi:10.1023/a:1003858713999.

Schöl, A., V. Kirchesch, T. Bergfeld, F. Schöll, J. Borcherding & D. Müller, 2002. Modelling the Chlorophyll a Content of the River Rhine –Interrelation between Riverine Algal Production and Population Biomass of Grazers, Rotifers and the Zebra Mussel, *Dreissena polymorpha*. International Review of Hydrobiology 87(2-3):295-317 doi:10.1002/1522-2632(200205)87:2/3<295::aid-iroh295>3.0.co;2-b.

Segura, A. M., C. Kruk, D. Calliari & H. Fort, 2013. Use of a morphology-based functional approach to model phytoplankton community succession in a shallow subtropical lake. Freshwater Biology 58(3):504-512 doi:10.1111/j.1365-2427.2012.02867.x.

Sellers, T. & P. A. Bukaveckas, 2003. Phytoplankton production in a large, regulated river: A modeling and mass balance assessment. Limnology and Oceanography 48(4):1476-1487.

Shanmuganathan, S., P. Sallis & J. Buckeridge, 2006. Self-organising map methods in integrated modelling of environmental and economic systems. Environmental Modelling & Software 21(9):1247-1256 doi:10.1016/j.envsoft.2005.04.011.

Silvia, P. J., 2007. How to Write a Lot: A Practical Guide to Productive Academic Writing. American Psychological Association, Washington, DC, 149 pp.

Soares, M. C. S., V. L. M. Huszar & F. Roland, 2007. Phytoplankton dynamics in two tropical rivers with different degrees of human impact (southeast Brazil). River Research and Applications 23(7):698-714 doi:10.1002/rra.987.Sommer, U., 1983. Algal nutrient competition in continuous culture. Hydrobiological Bulletin 17(1):21-27 doi:10.1007/bf02255189.

Søballe, D. M. & B. L. Kimmel, 1987. A large-scale comparison of factors influencing phytoplankton abundance in rivers, lakes, and impoundments. Ecology 68(6):1943-1954. doi: 10.2307/1939885

Sommer, U., 1983. Algal nutrient competition in continuous culture. Hydrobiological Bulletin 17(1):21-27 doi:10.1007/bf02255189.

Sommer, U., 1986. Phytoplankton competition along a gradient of dilution rates. Oecologia 68(4):503-506 doi:10.1007/bf00378762.

Sommer, U., 1988. Growth and survival strategies of planktonic diatoms. In Sandgren, C. D. (ed) Growth and reproduction strategies of freshwater phytoplankton. Cambridge University Press, New York, 227-260.

Sommer, U., R. Adrian, L. De Senerpont Domis, J. J. Elser, U. Gaedke, B. Ibelings, E. Jeppesen, M. Lürling, J. C. Molinero, W. M. Mooij, E. van Donk & M. Winder, 2012. Beyond the plankton ecology group (PEG) model: Mechanisms driving plankton succession. Annual Review of Ecology, Evolution, and Systematics 43(1):429-448 doi:10.1146/annurev-ecolsys-110411-160251.

Sommer, U., Z. M. Gliwicz, W. Lampert & A. Duncan, 1986. The PEG-model of seasonal succession of planktonic event in fresh waters. Archiv für Hydrobiologie 106(4):433-471.

Sournia, A., 1978. Phytoplankton manual. UNESCO, Paris, France, 337 pp.

Sousa, R., C. Antunes & L. Guilhermino, 2008. Ecology of the invasive Asian clam *Corbicula fluminea* (Müller, 1774) in aquatic ecosystems: an overview. Annales de

Limnologie - International Journal of Limnology 44(02):85-94 doi:10.1051/limn:2008017.
Soylu, E. N. & A. Gönülol, 2003. Phytoplankton and seasonal variations of the River Yeşihrmak, Amasya, Turkey. Turkish Journal of Fisheries and Aquatic Sciences 3:17-24.
Stanković, I., 2013. Fitoplankton kao pokazatelj ekološkoga. Stanja velikih nizinskih rijeka hrvatske [Phytoplankton as indicator of ecological status of large lowland rivers in Croatia—Doctoral Thesis]. University of Zagreb [in Croatian]
Stanković, I., T. Vlahović, M. Gligora Udovič, G. Várbíró & G. Borics, 2012. Phytoplankton functional and morpho-functional approach in large floodplain rivers. Hydrobiologia 698(1):217-231 doi:10.1007/s10750-012-1148-3.
Starmach, K., 1985. Chrysophyceae und Haptophyceae. Gustav Fischer Verlag, Stuttgart, 515 pp.
Stenger-Kovács, C., E. Lengyel, L. O. Crossetti, V. Üveges & J. Padisák, 2013. Diatom ecological guilds as indicators of temporally changing stressors and disturbances in the small Torna-stream, Hungary. Ecological Indicators 24(0):138-147 doi:10.1016/j.ecolind.2012.06.003.
Stenger-Kovács, C., L. Tóth, F. Tóth, É. Hajnal & J. Padisák, 2014. Stream order-dependent diversity metrics of epilithic diatom assemblages. Hydrobiologia 721(1):67-75 doi:10.1007/s10750-013-1649-8.
Stevenson, R. J., 2009. Algae in river ecosystems. In Likens, G. E. (ed) Enyclopedia of Inland Waters. Academic Press, 114-122.
Stevenson, R. J., B. J. Bennett, D. N. Jordan & R. D. French, 2012. Phosphorus regulates stream injury by filamentous green algae, DO, and pH with thresholds in responses. Hydrobiologia 695(1):25-42 doi:10.1007/s10750-012-1118-9.
Stevenson, R. J., S. T. Rier, C. M. Riseng, R. E. Schultz & M. J. Wiley, 2006. Comparing effects of nutrients on algal biomass in streams in two regions with different disturbance regimes and with applications for developing nutrient criteria. Hydrobiologia 561(1):149-165 doi:10.1007/s10750-005-1611-5.
Stević, F., M. Mihaljević & D. Špoljarić, 2013. Changes of phytoplankton functional groups in a floodplain lake associated with hydrological perturbations. Hydrobiologia 709(1):143-158 doi:10.1007/s10750-013-1444-6.
Stoyneva, M. P., 1994. Shallows of the lower Danube as additional sources of potamoplankton. Hydrobiologia 289(1):171-178 doi:10.1007/bf00007418.
Strebel, O., W. H. M. Duynisveld & J. Böttcher, 1989. Nitrate pollution of groundwater in Western Europe. Anglais 26(3-4):189-214.
Szilágyi, F., É. Ács, G. Borics, B. Halasi-Kovacs, P. Juhász, B. Kiss, T. Kovács, Z. Müller, G. Lakatos, J. Padisák, P. Pomogyi, C. Stenger-Kovács, K. E. Szabó, E. Szalma & B. Tóthmérész, 2008. Application of water framework directive in Hungary: development of biological classification systems. Water Science & Technology 58(11):2117-2125 doi:10.2166/wst.2008.565.
Tánago, M. G. & D. G. Jalón, 2006. Attributes for assessing the environmental quality of riparian zones. Limnetica 25(389-402).
Tavernini, S., E. Pierobon & P. Viaroli, 2011. Physical factors and dissolved reactive silica affect phytoplankton community structure and dynamics in a lowland eutrophic river (Po river, Italy). Hydrobiologia 669(1):213-225 doi:10.1007/s10750-011-0688-2.
ter Braak, C. J. F. & P. Šmilauer, 2002. CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, NY, USA, 500 pp.

Thomaz, S., L. Bini & R. Bozelli, 2007. Floods increase similarity among aquatic habitats in river-floodplain systems. Hydrobiologia 579(1):1-13 doi:10.1007/s10750-006-0285-y.

Thorp, J. H. & M. D. Delong, 1994. The riverine productivity model: an heuristic view of carbon sources and organic processing in large river ecosystems. Oikos 70(2):305-308. doi:10.2307/3545642

Thorp, J. H., M. C. Thoms & M. D. Delong, 2006. The riverine ecosystem synthesis: biocomplexity in river networks across space and time. River Research and Applications 22(2):123-147 doi:10.1002/rra.901.

Tilman, D., S. S. Kilham & P. Kilham, 1982. Phytoplankton community ecology: the role of limiting nutrients. Annual Review of Ecology and Systematics 13:349-372. doi:10.1146/annurev.es.13.110182.002025

Tison, J., Y. S. Park, M. Coste, J. G. Wasson, L. Ector, F. Rimet & F. Delmas, 2005. Typology of diatom communities and the influence of hydro-ecoregions: A study on the French hydrosystem scale. Water Research 39(14):3177-3188 doi:10.1016/j.watres.2005.05.029.

Tockner, K. & J. A. Stanford, 2002. Riverine flood plains: present state and future trends. Environmental Conservation 29(3):308-330 doi:10.1017/S037689290200022X.

Tockner, K., F. Malard & J. V. Ward, 2000. An extension of the flood pulse concept. Hydrological Processes 14(16-17):2861-2883 doi:10.1002/1099-1085(200011/12)14:16/17<2861::aid-hyp124>3.0.co;2-f.

Tockner, K., U. Uehlinger & C. T. Robinson, 2009. Rivers of Europe. Elsevier Science, London, 728 pp.

Tolotti, M., A. Boscaini & N. Salmaso, 2010. Comparative analysis of phytoplankton patterns in two modified lakes with contrasting hydrological features. Aquatic Sciences 72(2):213-226 doi:10.1007/s00027-009-0124-0.

Tolotti, M., H. Thies, U. Nickus & R. Psenner, 2012. Temperature modulated effects of nutrients on phytoplankton changes in a mountain lake. Hydrobiologia 698(1):61-75 doi:10.1007/s10750-012-1146-5.

Trifonova, I. S., O. A. Pavlova & A. G. Rusanov, 2007. Phytoplankton as an indicator of water quality in the rivers of the Lake Ladoga basin and its relation to environmental factors. Archiv für Hydrobiologie Supplementband Large rivers 17(3-4):527-549.

Turner, R. E., N. N. Rabalais, D. Justic & Q. Dortch, 2003. Global patterns of dissolved N, P and Si in large rivers. Biogeochemistry 64(3):297-317 doi:10.1023/a:1024960007569.

Uherkovich, G., 1971. A Tisza lebegő paránynövényei : a Tisza fitoszesztonja [Planktonic photo-microorganisms of the River Tisza]. Damjanich János Museum, Szolnok [in Hungarian].

Unni, K. S. & S. Pawar, 2000. The phytoplankton along a pollution gradient in the river Mahanadi (M.P. state) India – a multivariate approach. Hydrobiologia 430(1-3):87-96 doi:10.1023/a:1004025231206.

Usseglio-Polatera, P., M. Bournaud, P. Richoux & H. Tachet, 2000. Biomonitoring through biological traits of benthic macroinvertebrates: how to use species trait databases? Hydrobiologia 422-423(0):153-162 doi:10.1023/a:1017042921298.

Utermöhl, H., 1958. Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Mitteilunger der internationale Vereinigunk für theoretische und angewandte Limnologie 9:1-38 doi:citeulike-article-id:377423.

Üveges, V. & J. Padisák, 2012. Photosynthetic activity of epilithic algal communities in sections of the Torna stream (Hungary) with natural and modified riparian shading. Hydrobiologia 679(1):267-281 doi:10.1007/s10750-011-0891-1.

van der Wateren-de Hoog, B., 1995. The effects of climate variability on discharge as dependent on catchment characteristics in the Upper Loire basin, France. Hydrological Sciences Journal 40(5):633-646 doi:10.1080/02626669509491449.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37(1):130-137 doi:10.1139/f80-017.

Várbíró, G., É. Ács, G. Borics, K. Érces, G. Fehér, I. Grigorszky, T. Japport, G. Kocsis, E. Krasznai, K. Nagy, Z. Nagy-László, Z. Pilinszky & K. T. Kiss, 2007. Use of self organizing maps (SOM) for characterization of riverine phytoplankton associations in Hungary. Archiv für Hydrobiologie 161(3-4):383-394.

Várbíró, G., G. Borics, B. Csányi, G. Fehér, I. Grigorszky, K. T. Kiss, A. Tóth & É. Ács, 2012. Improvement of the ecological water qualification system of rivers based on the first results of the Hungarian phytobenthos surveillance monitoring. Hydrobiologia 695(1):125-135 doi:10.1007/s10750-012-1120-2.

Verasztó, C., K. T. Kiss, C. Sipkay, L. Gimesi, C. Vadadi-Fülöp, D. Türei & L. Hufnagel, 2010. Long-term dynamic patterns and diversity of phytoplankton communities in a large eutrophic river (The case of River Danube, Hungary). Applied Ecology and Environmental Research 8(4):329-349.

Violle, C., M.-L. Navas, D. Vile, E. Kazakou, C. Fortunel, I. Hummel & E. Garnier, 2007. Let the concept of trait be functional! Oikos 116(5):882-892 doi:10.1111/j.0030-1299.2007.15559.x.

Viroux, L., 2002. Seasonal and longitudinal aspects of microcrustacean (Cladocera, Copepoda) dynamics in a lowland river. Journal of Plankton Research 24(4):281-292 doi:10.1093/plankt/24.4.281.

Vörös, L., K. V.-Balogh, S. Herodek & K. T. Kiss, 2000. Underwater light conditions, phytoplankton photosynthesis and bacterioplankton production in the Hungarian section of the River Danube. Archiv für Hydrobiologie Supplementband Large rivers 11(4):511-532.

Walsh, C. J., A. H. Roy, J. W. Feminella, P. D. Cottingham, P. M. Groffman & R. P. Morgan, 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of The North American Benthological Society 24(3):706-723. doi:10.1899/0887-3593(2005)024\[0706:TUSSCK\]2.0.CO;2

Ward, J. V. & J. A. Stanford, 1982. The serial discontinuity concept of river ecosystems. In Fortaine, T. H. & S. M. Bartell (eds) Dynamics of Lotic Ecosystems. Ann. Arbor. Science Publications, Michigan, 29-42.

Ward, J. V., F. Malard & K. Tockner, 2002. Landscape ecology: a framework for integrating pattern and process in river corridors. Landscape Ecology 17(1):35-45 doi:10.1023/a:1015277626224.

Wasson, J., G., A. Chandesris, H. Pella & L. Blanc, 2004. Les hydro-écoregions : une approache fonctionnelle de la typologie des rivières pour la Directive cadre eurpéenne sur l'eau. Ingénieries 40:3-10.

web[1], Osur Web: Mesures de la qualité des eaux de surface, Agence de l'eau Loire-Bretagne. http://osur.eauloire-bretagne.fr/exportosur/Accueil, (accessed: 12/11/2010).

web[2], Banque Hydro. eaufrance, Ministère de l'Ecologie et du Développement Durable 2007. http://www.hydro.eaufrance.fr/, (accessed: 07/04/2011).

web[3], EP Loire. Suivi de la qualité des eaux des retenues de Villerest et de Naussac. In: 5ème journée technique EP Loire/DREAL, le 26 juin 2013. http://www.eptb-loire.fr/wp-content/uploads/2013/09/4-7-Qualite_des_eaux_Villerest_Naussac.pdf, (accessed: 18/03/2014)

Wehr, J. D. & J.-P. Descy, 1998. Use of phytoplankton in large river management. Journal of Phycology 34(5):741-749 doi:10.1046/j.1529-8817.1998.340741.x.

Weithoff, G., 2003. The concepts of 'plant functional types' and 'functional diversity' in lake phytoplankton – a new understanding of phytoplankton ecology? Freshwater Biology 48(9):1669-1675 doi:10.1046/j.1365-2427.2003.01116.x.

Welch, P. S., 1952. Limnology. McGraw-Hill Book Company, New York. 538 pp.

Weyhenmeyer, G. A., H. Peter & E. V. A. Willén, 2013. Shifts in phytoplankton species richness and biomass along a latitudinal gradient – consequences for relationships between biodiversity and ecosystem functioning. Freshwater Biology 58(3):612-623 doi:10.1111/j.1365-2427.2012.02779.x.

WFD, 2000. Directive of the European Parliament and of the Council 2000/60/EC. Establishing a framework for community action in the field of water policy. Official Journal of the European Union L327, 1-72.

Winder, M. & U. Sommer, 2012. Phytoplankton response to a changing climate. Hydrobiologia 698(1):5-16 doi:10.1007/s10750-012-1149-2.

Winder, M., J. E. Reuter & S. G. Schladow, 2009. Lake warming favours small-sized planktonic diatom species. Proceedings of the Royal Society B: Biological Sciences 276(1656):427-435 doi:10.1098/rspb.2008.1200.

Wisskirchen, R., S. Kisteneich & S. Krause, 1998. Analysis of floristical and environmental gradients in the longitudinal profile of the Loire (France). The use of riparian plant species for a biotypological river-zone classification. Feddes Repertorium 109(3-4):291-312 doi:10.1002/fedr.19981090311

Wu, N., B. Schmalz & N. Fohrer, 2011a. A comparison of phytoplankton assemblages generated by two sampling protocols in a German lowland catchment. Annales de Limnologie - International Journal of Limnology 47(04):313-323. doi: 10.1051/limn/2011045

Wu, N., B. Schmalz & N. Fohrer, 2011b. Distribution of phytoplankton in a German lowland river in relation to environmental factors. Journal of Plankton Research 33(5):807-820 doi:10.1093/plankt/fbq139.

Wu, N., B. Schmalz & N. Fohrer, 2012. Development and testing of a phytoplankton index of biotic integrity (P-IBI) for a German lowland river. Ecological Indicators 13(1):158-167 doi:10.1016/j.ecolind.2011.05.022.

Xiao, L. J., T. Wang, R. Hu, B. P. Han, S. Wang, X. Qian & J. Padisák, 2011. Succession of phytoplankton functional groups regulated by monsoonal hydrology in a large canyon-shaped reservoir. Water Research 45(16):5099-109 doi:10.1016/j.watres.2011.07.012.

Xie, L., P. Xie, S. Li, H. Tang & H. Liu, 2003. The low TN:TP ratio, a cause or a result of *Microcystis* blooms? Water Research 37(9):2073-2080 doi:10.1016/S0043-1354(02)00532-8.

Yvon-Durocher, G., J. M. Montoya, M. Trimmer & G. U. Y. Woodward, 2011. Warming alters the size spectrum and shifts the distribution of biomass in freshwater ecosystems. Global Change Biology 17(4):1681-1694 doi:10.1111/j.1365-2486.2010.02321.x.

Zapomělová, E., O. Skácelová, P. Pumann, R. Kopp & E. Janeček, 2012. Biogeographically interesting planktonic Nostocales (Cyanobacteria) in the Czech Republic and their polyphasic evaluation resulting in taxonomic revisions of *Anabaena bergii* Ostenfeld 1908 *Chrysosporum* gen. nov.) and *A. tenericaulis* Nygaard 1949 (*Dolichospermum tenericaule* comb. nova). Hydrobiologia:1-13 doi:10.1007/s10750-012-1034-z.

Zhu, K., Y. Bi & Z. Hu, 2013. Responses of phytoplankton functional groups to the hydrologic regime in the Daning River, a tributary of Three Gorges Reservoir, China.

Science of the Total Environment 450–451(0):169-177 doi:10.1016/j.scitotenv.2013.01.101.
Zimmermann-Timm, H., H. Holst & H. Kausch, 2007. Spatial dynamics of rotifers in a large lowland river, the Elbe, Germany: How important are retentive shoreline habitats for the plankton community? Hydrobiologia 593(1):49-58 doi:10.1007/s10750-007-9046-9.

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Bi-Eau is a private consultancy specialized in freshwater phycology, created in 1988 by *Dr. Maria Leitão*. The profile of the society includes both field and laboratory work, with all necessary tasks to identify algal taxa, and then to interpret them in their ecological contexts. The society works for industries, state institutions, as well as for research departments; proposing practical and theoretical guidance in phycology to solve particular problems, or to interpret data at different spatial and temporal scales.

Some of the studies revealed new species or provided original data, which were further interpreted in scientific publications or congresses communications. As each customer has a particular problem to solve or a new question to be answered, Bi-Eau maintains and welcomes each request as a possible new challenge in France, as well as abroad.

The Department of Limnology at the University of Pannonia was established as the first limnological department in Hungary by *Prof. Dr. Judit Padisák* in 2002. The department has been successfully contributing to freshwater sciences at both international and national level, and has been training several BSc, MSc, and PhD students in different fields of both applied and theoretical limnology. Plenty of the department's students have been awarded by National Student Competitions in Biology and Environmental Sciences and by the Hungarian Hydrological Society, or prized at National Meetings of Hydrobiologists, or elsewhere.

In 2013, a Limnoecology Research Groups was established at the department, and acknowledged and assigned in the same year as part of the Hungarian Academy of Sciences.

Further acknowledgements:

Thesis points

1st Thesis point: Reliable potamoplankton river zones can be defined based on different functional approaches along the River Loire. (Chapter 3.1.)

Lentic phytoplankton functional approaches are able to provide reliable river zones based on functional group composition of potamoplankton. The level of understanding provided by the approaches, however, depends on the taxonomical and ecological resolution of classifications. For river ecosystems, no satisfactory water quality management can be built based on functional approaches without fine taxonomical, then functional resolution of benthic and planktonic diatoms, as well as of cyanobacterial taxa. Furthermore, thesis results emphasize the relevance of the 'Riverine Ecosystem Synthesis model' presuming the existence of functionally different river zones based on hydro-morphological and geo-morphological differences along large rivers.

2nd Thesis point: The phytoplankton functional groups approach can be used as an ecological indicator of human impacts along the River Loire. (Chapter 3.2.)

The FG classification is able to delimit natural- and human-mediated factors to determine compositional changes of potamoplankton along the River Loire. These changes can be successfully followed by the $Q_{(r)}$ potamoplankton composition index, which accurately indicates local morphological alternations like damming, or regional scale differences in nutrient availability according to land use practices.

3rd Thesis point: Potamoplankton water quality assessments can be based either on taxa-level or on FG-level resolution. (Chapter 3.3.)

The German PhytoFluss based on taxa level resolution, and the Hungarian HRPI index based on FGs, both provide comparable and reliable water quality indications along the River Loire. In case of adequate implementation of these indices according to site-specific river types, the two national potamoplankton assessments can be successfully compared or implemented at international level, as it is also required by the European Water Framework Directive.

4th Thesis point: FGs display similar river zones in hydrologically different years along the River Loire. (Chapter 3.4.)

Functional group composition of potamoplankton displays similar river zonation in each year along the River Loire. Besides quantitative differences, the distribution of main FGs and the dominant accessory FGs follow similar regional patterns at whole river scale, while further FGs were identified to reflect specific annual hydrological regimes.

5th Thesis point: Low species and medium functional group richness provide the most effective ecosystem functioning in the River Loire. (Chapter 3.5.)

In the River Loire, ecosystem functioning—based on biomass:TP ratio—displays different relationships with taxa number and FG richness. The highest potamoplankton richness was identified as a consequence of physically mixed habitats from either natural or human-mediated sources, where the best functioning occurred at low taxa number and at medium FG richness. Accordingly, high taxa richness/diversity in large rivers might not provide the automatic evidence for better ecosystem functioning, and cannot be a general water quality objective without understanding its functional composition and controlling factors at different scales.

Curriculum Vitae

András Abonyi (born 1984) was graduated at the University of Pannonia, Veszprém, Hungary in 2009, under the supervision of Prof. Dr. Judit Padisák. His Master thesis aimed to understand stratification patterns of some Hungarian deep pit lakes and oxbows, and to relate differences in mixing behaviours and the vertical patterns of phytoplankton composition and chemicals.

In 2009, he started to work in the society Bi-Eau, Angers, France. In a scientific collaboration, he started his PhD Thesis in the same year under the supervision of Prof. Dr. Judit Padisák and under the mentorship of Dr. Maria Leitão. His doctoral thesis purposed the understanding of longitudinal processes of potamoplankton composition along the River Loire (France), with special interest in phytoplankton functional approaches as potential ecological indicators of natural *vs.* human-mediated controlling factors.

His research interest is phytoplankton ecology, especially the use of phytoplankton functional classifications to better understanding compositional behaviours in different aquatic ecosystems. He is particularly interested in the physical structuring of the environment (lake mixing, river zonation), as well as in trait- and functional group-based organization of phytoplankton communities.

He has gained several experiences from different freshwater ecosystems such as oxbow lakes, pit lakes, as well as from monitoring programs of almost all temperate lake and river types. Since his Master Thesis, he has been involved in several projects outside of the university environment as well. These included the long term monitoring of the Lake Erken phytoplankton (Erken Limnological Field Station, Sweden), the establishment of a cyanobacteria monitoring in the region of Dordogne (LDAR 24, France), and the phyto- and potamoplankton monitoring of numerous waters at regional and national scale at the Bi-Eau Society, Angers, France.

He has been accomplished many practical experiences at the Bi-Eau Society, and acquired deep theoretical knowledge at the University of Pannonia, gaining wide knowledge in limnological research, phytoplankton ecology, and phytoplankton taxonomy.

His recent scientific interests are (i) the functional group and trait dependence of phyto- and potamoplankton diversity, and the combination of scale-dependent controlling factors with ecological theories towards a better understanding of ecosystem functioning; (ii) mixing behaviour of lakes, and their responses to climate change according to characteristics of lake size, morphology, geographical and climatic locations.

List of publications

International papers in phytoplankton ecology and limnology

Abonyi, A., M. Leitão, I. Stanković, G. Borics, G. Várbíró & J. Padisák, 2014. A large river (River Loire, France) survey to compare phytoplankton functional approaches: Do they display river zones in similar ways? Ecological Indicators 46(0):11-22 doi:http://dx.doi.org/10.1016/j.ecolind.2014.05.038.

Abonyi, A., M. Leitão, A. M. Lançon & J. Padisák, 2012. Phytoplankton functional groups as indicators of human impacts along the River Loire (France). Hydrobiologia 698(1):233-249 doi:10.1007/s10750-012-1130-0.

Borics, G., **A. Abonyi**, E. Krasznai, G. Várbíró, I. Grigorszky, S. Szabó, C. Deák & B. Tóthmérész, 2011. Small-scale patchiness of the phytoplankton in a lentic oxbow. Journal of Plankton Research 33(6):973-981 doi:10.1093/plankt/fbq166.

Krasznai, E., G. Borics, G. Várbíró, **A. Abonyi**, J. Padisák, C. Deák & B. Tóthmérész, 2010. Characteristics of the pelagic phytoplankton in shallow oxbows. Hydrobiologia 639(1):173-184 doi:10.1007/s10750-009-0027-z.

International congress attendances

Sarmento, H., **A. Abonyi**, S. Jati, A.M. Lançon, M. Leitão, L. C. Rodrigues, S. Train, A comparative study of potamoplankton community and size structure in large temporal and geographical scales: The tropical river Parana (Brazil) and the temperate river Loire (France). 17th Workshop of the International Association of Phytoplankton Taxonomy and Ecology (IAP), Kastoria (Greece), 14-21 September 2014. **(oral presentation)**

Stanković, I., A. Rimac & **A. Abonyi**, Phytoplankton functional groups of planktonic diatoms in karstic barrage lakes (Plitvice lakes, Croatia). In: Ljubešić, Z., et al. (eds) 8th Central European Diatom Meeting, Zagreb, Croatia, 10-13 April 2014. **(poster)**

Abonyi, A., F. Moatar, M. Leitão & J. Padisák, Functional groups of river phytoplankton are reflecting longitudinal processes along the River Loire (France). In: Tóth, V., Z. Heiszler & R. Hohol (eds) 32nd Congress of the International Society of Limnology (SIL), Budapest, Hungary, 4-9 August 2013. Balaton Limnological Institute, Hungarian Academy of Sciences, Centre for Ecological Research, p 96. **(oral presentation)**

Abonyi, A., M. Leitão, I. Stanković, G. Borics, G. Várbíró & J. Padisák, Comparing phytoplankton functional classifications along the River Loire. In: Meyer, E. (ed) 8th Symposium for European Freshwater Sciences, Münster, Germany, 1-5 July 2013. **(poster)**

Leitão, M., **A. Abonyi**, U. Mischke, G. Borics & G. Várbíró, Applying phytoplankton indices along the River Loire (France). In: Meyer, E. (ed) 8th Symposium for European Freshwater Sciences, Münster, Germany, 1-5 July 2013. **(poster)**

Abonyi, A., M. Leitão & J. Padisák, Phytoplankton functional properties along the River Loire continuum (France). In: Bengtsson, M., et al. (eds) Fresh Blood for Fresh Water, Young Aquatic Science, WasserCluster, Lunz am See, Austria, February 27th – March 1st 2013. p 24. **(poster)**

Leitão, M., **A. Abonyi** & A. Lançon, The phytoplankton monitoring of the river Loire (France). In: Ortega, P. M., F. F. Piñas, E. P. Urízar, R. R. García, E. G. Calvo & S. S. Cortés (eds) Use of Algae for Monitoring Rivers, Alcalá de Henares, 2012. Madrid, p 35. **(oral presentation)**

Abonyi, A., M. Leitão, A.-M. Lançon & J. Padisák, Application of the phytoplankton functional group concept for the characterization of functional sections and

anthropogenic impacts in the River Loire (France). In: Salmaso, N., et al. (eds) 16th Workshop of the International Association of Phytoplankton Taxonomy and Ecology (IAP), San Michele all'Adige (Trento), Italy, 21-28 August 2011. p 21. **(oral presentation)**

Grigorszky, I., G. Borics, E. Krasznai, **A. Abonyi**, V. Béres, C. Schnitchen, B. Tóthmérész, J. Padisák, G. Dévai, S. A. Nagy & G. Várbíró, *Peridinium palatinum* (Dinophyta) as a possible winter water quality indicator of standing waters. In: 1st International Symposium of Winter Limnology, Kilpisjarvi Biological Station, Kilpisjarvi, Finnland, 24-28 May 2008. **(poster)**

Hungarian papers in phytoplankton ecology and limnology

Abonyi, A., G. Borics, G. Várbíró, E. T-Krasznai, J. Görgényi, G. Selmeczy & J. Padisák, 2014. Magyarországi holtágak morfológiája II.: A medermorfológia és a keletkezés természetvédelmi vonatkozásai [Morphology classes of Hungarian oxbow lakes II.: The influence of lake origin and morphology on the natural conservation value]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 94(6):x-y [in Hungarian with English summary].

Abonyi, A., G. Borics, G. Várbíró, E. T-Krasznai, J. Görgényi, G. Selmeczy & J. Padisák, 2014. Magyarországi holtágak morfológiája I.: A természetes, a mesterséges, az ártéri és a mentett oldali [Morphology classes of Hungarian oxbow lakes I.: The natural, the artificially separated, the flooded and the isolated]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 94(6):x-y [in Hungarian with English summary].

T-Krasznai, E., **A. Abonyi** & J. Görgényi, 2014. A Malom-Tisza holtág epi- és metalimnetikus fitoplanktonjának vertikális mintázata (2007-2009) [Epi- and metalimnetic profile of phytoplankton in a stratifying shallow oxbow between 2007 and 2009 (Malom-Tisza, Hungary)]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 94(6):x-y [in Hungarian with English summary].

Görgényi, J., **A. Abonyi**, E. Krasznai, V. Pozderka, Á. Bolgovics, G. Várbíró & G. Borics, 2014. A habitat diverzitás hatása az aktuális fitoplankton fajszámra egy sekély eutróf állóvíz esetén [Effects of habitat diversity on phytoplankton taxa numbers in a shallow eutrophic oxbow (Hungary)]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 94(6):x-y [in Hungarian with English summary].

T-Krasznai, E., **A. Abonyi** & J. Görgényi, 2013. A Malom-Tisza holtág nyári rétegződési stabilitása és oxigénviszonyai 2007-2010-ben [Characteristics of the summer thermal stratification and the vertical distribution of oxygen in the Malom-Tisza oxbow]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 93(6):81-83. [in Hungarian with English summary]

Abonyi, A., E. Krasznai & J. Padisák, 2011. Rétegződő fitoplankton és a funkcionális csoport koncepció néhány hazai mély bányató esetében [Phytoplankton functional groups and the vertical distribution of phytoplankton in some Hungarian deep pit lakes]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 91(6):7-11 [in Hungarian with English summary].

Krasznai, E., G. Borics, G. Várbíró, C. Deák, **A. Abonyi**, B. Tóthmérész & J. Padisák, 2010. A fitoplankton vertikális mintázata egy sekély holtágban [Vertical distribution of phytoplankton in a shallow oxbow]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 90(6):81-83 [in Hungarian with English summary].

Abonyi, A., E. Krasznai, G. Borics, G. Várbíró, I. Grigorszky, B. Tóthmérész & J. Padisák, 2009. Két Tisza-menti holtág rétegződési sajátságai [Stratification patterns of two

oxbows nearby the River Tisza]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 89(6):196-198 [in Hungarian with English summary].

Abonyi, A., E. Krasznai & J. Padisák, 2009. Hazai mély bányatavaink rétegződési sajátosságai [Stratification patterns of deep Hungarian pit lakes]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 89(6):80-84 [in Hungarian with English summary].

Borics, G., E. Krasznai, G. Várbíró, **A. Abonyi**, I. Grigorszky & S. Szabó, 2008. Néhány Tisza-menti holtág jellegzetes fitoplankton asszociációi [Characteristic phytoplankton associations of some oxbows in the Middle Tisza valley]. Hidrológiai Közlöny [Journal of the Hungarian Hydrological Society] 88(6):34-36 [in Hungarian with English summary].

Abonyi, A., E. Krasznai, K. Kovács, J. Padisák, 2008. Az édesvízi medúza (*Craspedacusta sowerbii* LANKESTER, 1880) magyarországi előfordulása [The freshwater jellyfish (*Craspedacusta sowerbii* Lankester, 1880) in Hungarian waters]. A Bakonyi Természettudományi Múzeum Közleményei [Folia Musei Historico-Naturalis Bakonyiensis] 25:19-24 [in Hungarian with English summary].

Additional information

Personal Home Page: http://abonyiandras.blogspot.com/p/publications.html

Google Scolar Profile: http://scholar.google.com/citations?user=4PSamIoAAAAJ

Appendix

List of Appendix

Appendix I Contributions to the Thesis

Table 1 *Division of labour in Loire phytoplankton counting*

	2009	n°	2010	n°	2011	n°	Total counted
András ABONYI	st. 1-11 st. 13-14 st. 16-18	**98** **18** **27**	st. 1-17	**153**	st. 1-19	**170**	**466**
Anne-Marie LANÇON	st. 12 st. 19	**18**	-	**-**	-	**-**	**18**
Maria LEITÃO	st. 15	**9**	st. 18 st. 19	**18**	-	**-**	**27**
Total n°		***170***		***171***		***170***	***511***

Table 2 *Division of labour in background data organization*

	2009—2010—2011
András ABONYI	Download and data organization from official pages: 'OSUR'—http://osur.eauloire-bretagne.fr/exportosur/Accueil' 'Banque Hydro'—http://www.hydro.eaufrance.fr/'

Table 3 *Contributions to Thesis chapters I.: General parts*

	1. Introduction	2. Material & Methods	4. General Discussion
András ABONYI	Reviewing literature Chapter writing	Chapter writing	Chapter writing
Judit PADISÁK	Corrections	Corrections	Corrections
Maria LEITÃO	Reflections	Reflections	Reflections

Table 4 *Contributions to Thesis chapters II.: Scientific parts*

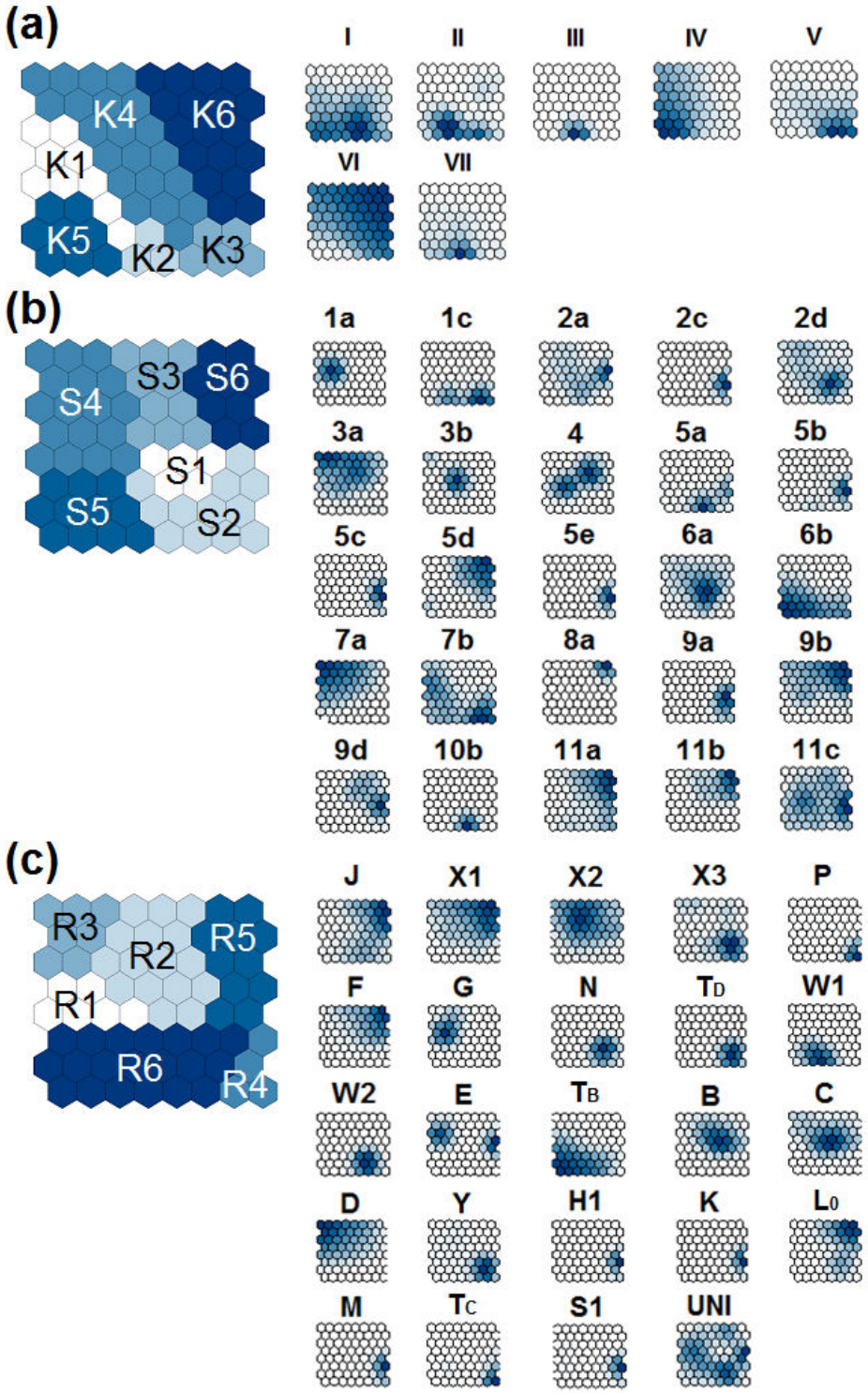
	Results 3.1.	3.2.	3.3.	3.4.	3.5.
A. ABONYI	Chapter writing	Chapter writing	Chapter writing	Chapter writing	Chapter writing
J. PADISÁK	Corrections	Corrections	Corrections	Corrections	Corrections
M. LEITÃO	Reflections	Reflections	Reflections	Reflections	Reflections
A.M. LANÇON	-	Reflections	-	-	-
G. BORICS	SOM statistics Reflections	-	Run of HRPI index Reflections	-	-
U. MISCHKE	-	-	Run of Phytofluss index Reflections	-	-
G. VÁRBÍRÓ	SOM statistics	-	Run of HRPI index	-	-
I. STANKOVIC	Fig. 11 Reflections	-	-	Fig. 31	-

Appendix II *Major ion content of the River Loire (all data of years 2004-2008)* **(a)** *cations,* **(b)** *anions. Station numbers indicate the same sampling stations through the Thesis*

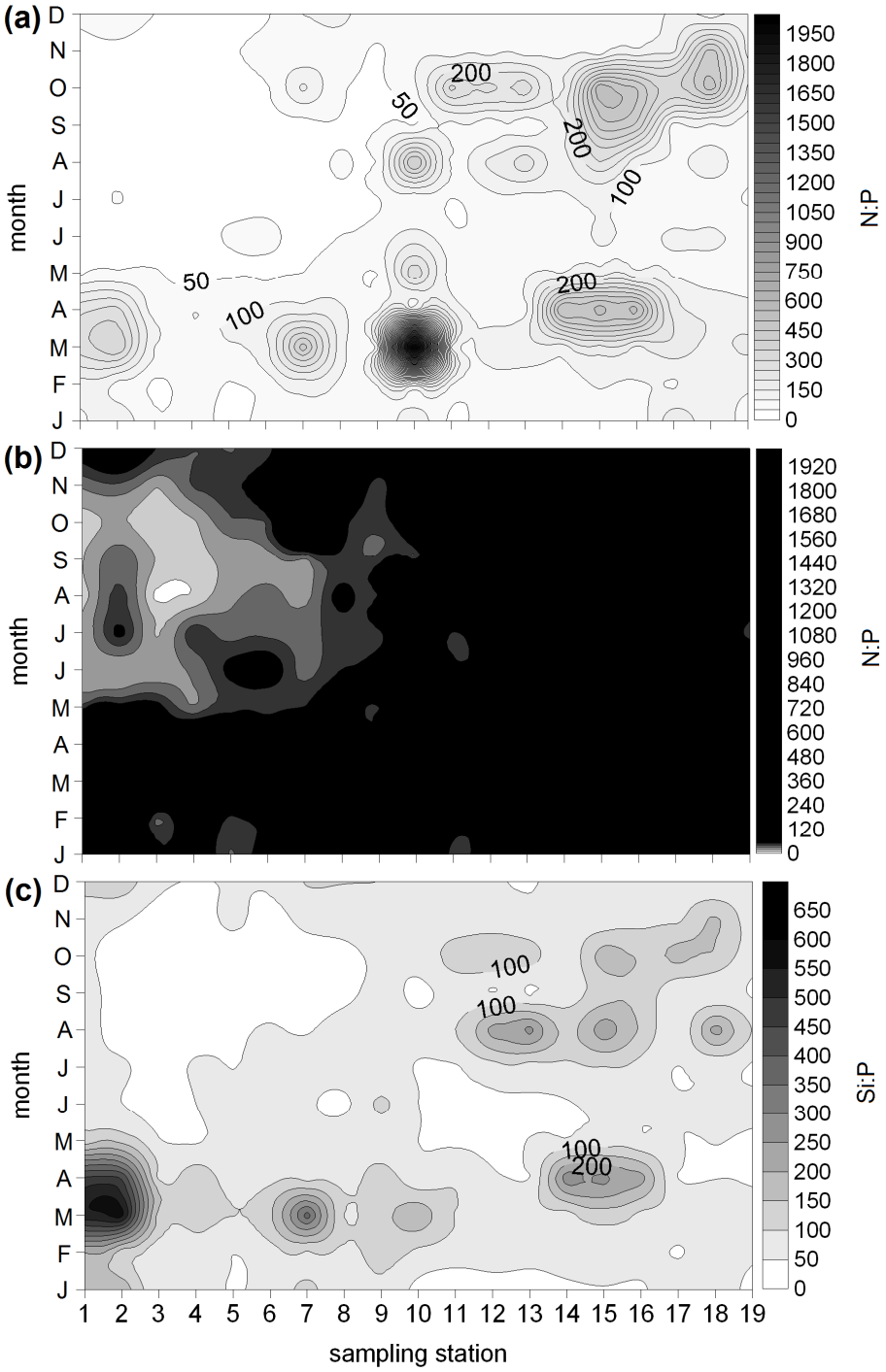
(a)	Ca^{2+}			Na^{+}			Mg^{2+}			K^{+}			$\Sigma^{(+)}_{med}$
Station	*n°*	*ave*	*med*	*n°*	*ave*	*med*	*n°*	*ave*	*med*	*n°*	*ave*	*med*	
1	43	11.2	11.0	21	12.1	12.0	43	4.3	4.3	20	3.0	3.2	
2	25	13.1	13.0	7	12.0	12.1	25	4.8	4.8	7	3.1	2.7	
3	41	17.3	16.0	11	16.1	14.9	41	5.6	5.2	11	3.6	3.2	
4	41	16.4	16.0	11	16.6	15.8	41	5.1	5.1	11	3.7	3.4	
5	41	25.1	24.0	11	11.3	10.6	41	3.8	3.7	11	3.4	3.0	
6	41	24.0	23.8	11	13.8	13.6	41	4.2	4.1	11	4.0	3.6	
7	41	22.6	23.0	11	13.8	12.6	41	4.2	4.2	11	3.6	3.1	
8	59	41.6	41.0	11	12.2	10.8	59	3.6	3.6	11	3.4	3.0	
9	41	25.9	25.0	11	12.8	11.1	41	5.8	5.7	11	3.7	3.1	
10	42	31.4	29.5	12	12.7	12.9	42	5.2	5.4	12	3.5	3.5	
11	41	32.6	32.0	11	12.6	12.0	41	4.9	4.9	11	3.5	3.0	
12	64	31.9	31.0	11	12.4	12.0	64	5.2	5.0	12	3.6	3.1	
13	5	31.1	29.7	5	10.1	10.5	5	4.1	4.4	5	3.4	3.1	
14	42	37.8	37.0	11	12.8	13.0	42	5.2	5.3	11	3.6	3.2	
15	42	37.8	37.0	11	12.8	13.0	42	5.2	5.3	11	3.6	3.2	
16	61	36.4	35.0	11	13.9	12.0	61	5.0	4.8	11	3.7	3.2	
17	41	44.6	42.0	11	13.2	12.0	41	5.2	5.0	11	3.6	3.2	
18	41	41.3	40.3	11	13.5	12.2	41	5.2	5.2	11	3.7	3.9	
19	77	45.2	44.6	11	14.4	14.1	77	5.3	5.3	11	3.9	3.9	
Σ	829			210			829			210			
ave (mgL^{-1})		29.9	29.0		13.1	12.5		4.8	4.8		3.5	3.2	
ave in (mEq)		1.5	1.4		0.6	0.5		0.4	0.4		0.1	0.1	
med (mgL^{-1})			**29.7**			**12.1**			**5.0**			**3.2**	**50.0**
med (mEq)			**1.5**			**0.5**			**0.4**			**0.1**	**2.5**
% mgL^{-1}			**59.4**			**24.2**			**10.0**			**6.4**	**100.0**
% mEq			**59.2**			**21.0**			**16.4**			**3.3**	**100.0**

(b)	HCO_3^-			Cl^-			SO_4^{2-}			NO_3^-			$\Sigma^{(-)}_{med}$
Station	*n°*	ave	med	*n°*	ave	med	*n°*	ave	med	*n°*	ave	med	
1	43	47.6	47.0	43	14.3	14.0	21	8.3	8.0	60	3.9	3.8	
2	25	53.0	55.7	25	17.2	16.9	7	12.3	12.3	50	4.8	4.6	
3	41	62.9	64.0	41	23.0	21.8	11	16.1	14.5	61	7.0	6.7	
4	41	57.2	52.9	41	21.6	21.5	11	17.1	16.5	61	7.1	7.0	
5	41	65.1	64.7	41	20.6	18.2	11	15.2	14.5	61	7.2	6.2	
6	41	67.7	66.7	41	20.9	20.9	11	16.9	18.2	61	8.1	7.3	
7	41	66.8	65.6	41	20.2	19.6	11	15.5	14.8	61	8.1	7.2	
8	59	119.2	118.0	59	16.8	15.1	11	16.0	15.3	61	9.1	8.5	
9	41	89.9	89.7	41	17.6	17.6	11	14.1	14.3	61	8.3	7.7	
10	42	98.6	94.6	42	17.9	18.0	12	17.4	18.7	61	9.7	9.1	
11	41	104.0	100.0	41	17.8	18.1	11	16.2	17.0	61	9.8	9.3	
12	64	100.5	96.9	64	18.4	17.8	11	16.6	17.0	61	9.4	8.6	
13	5	97.9	94.0	5	14.4	15.0	5	13.8	14.3	61	12.3	9.8	
14	42	115.6	114.5	42	19.7	19.0	11	16.7	18.0	43	9.4	8.6	
15	42	115.6	114.5	42	19.7	19.0	11	16.7	18.0	61	11.1	11.2	
16	61	107.6	108.0	61	19.6	18.3	11	17.2	17.8	61	10.7	9.8	
17	41	125.1	130.0	41	20.4	19.1	11	19.1	19.9	61	12.5	12.0	
18	41	117.1	113.0	41	20.3	19.8	11	20.6	20.4	61	12.0	11.3	
19	77	117.4	118.0	77	22.3	21.6	11	23.4	22.3	61	12.7	12.9	
Σ	829			829			210			1129			
ave (mgL^{-1})		91.0	89.9		19.1	18.5		16.3	16.4		9.1	8.5	
ave in (mEq)		1.5	1.5		0.5	0.5		0.3	0.3		0.1	0.1	
med (mgL^{-1})			**94.6**			**18.3**			**17.0**			8.6	**129.9**
med (mEq)			**1.5**			**0.5**			**0.4**			0.1	**2.4**
% mgL^{-1}			**72.8**			**14.1**			**13.1**				**100.0**
% mEq			**64.0**			**21.3**			**14.6**				**100.0**

Appendix III *SOM clusters based on different functional approaches* **(a)** *morphology-based functional groups (Kruk et al., 2010);* **(b)** *morpho-functional groups (Salmaso and Padisák, 2007);* **(c)** *phytoplankton functional groups (Reynolds et al., 2002; Borics et al., 2007; Padisák et al., 2009). First letter of clasters indicate the first author of the original papers describing approaches.*



Appendix IV *Spatio-temporal distribution of* **(a**,**b)** *N:P molar ratio at two different colour scales; and* **(c)** *Si:P molar ratio in the River Loire, 2009*



Appendix V *Distribution of potamoplankton coda and chemicals in 2009 along the Loire*

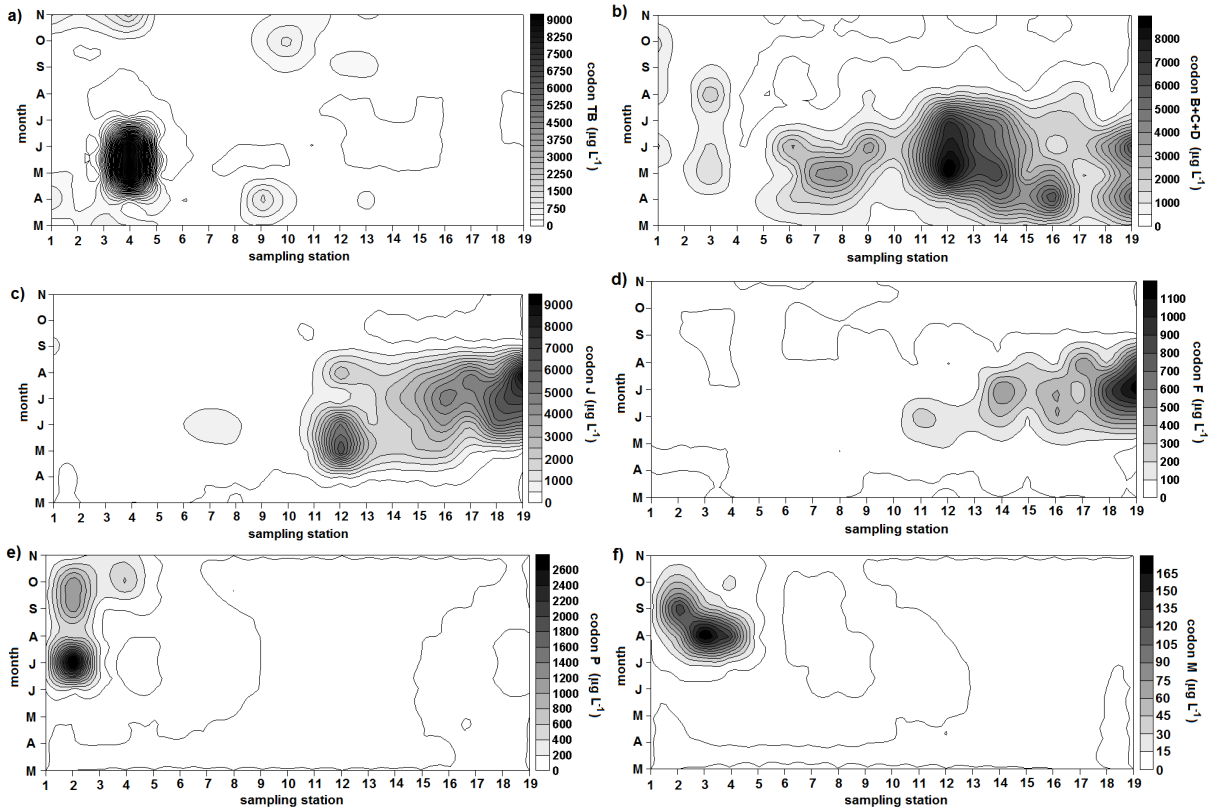


Image 1 *Spatio-temporal distribution of* **(a)** *codon* T_B*;* **(b)** *coda* ***B+C+D****;* **(c)** *codon* ***J****;* **(d)** *codon* ***F****;* **(e)** *codon* ***P****; and* **(f)** *codon* ***M*** *in the River Loire, 2009*

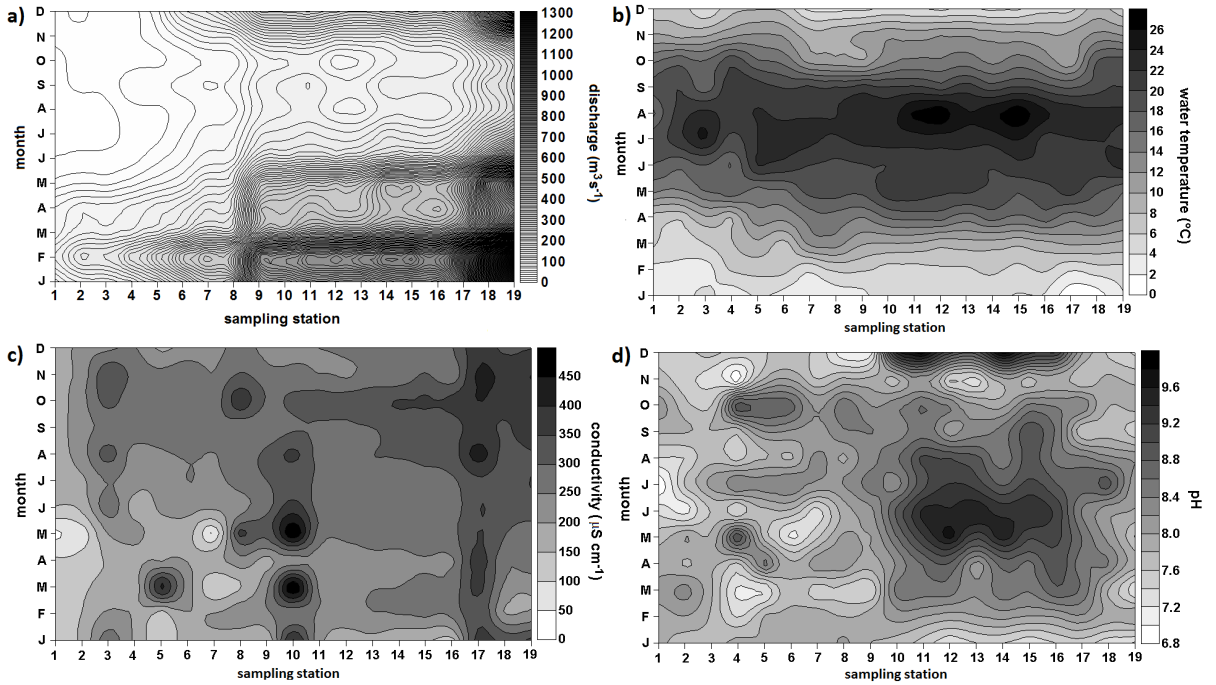


Image 2 *Spatio-temporal distribution of* **(a)** *discharge;* **(b)** *water temperature;* **(c)** *conductivity;* **(d)** *pH in the River Loire, 2009*

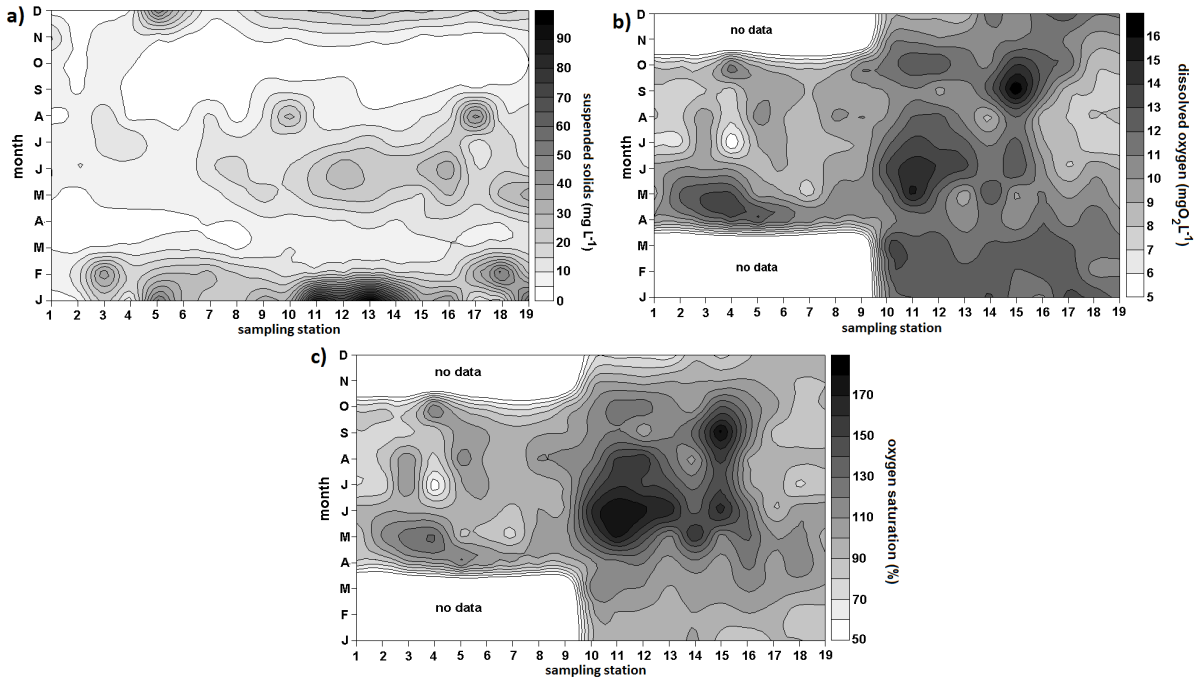


Image 3 *Spatio-temporal distribution of* **(a)** *suspended solids;* **(b)** *dissolved oxygen;* **(c)** *DO saturation in the River Loire, 2009*

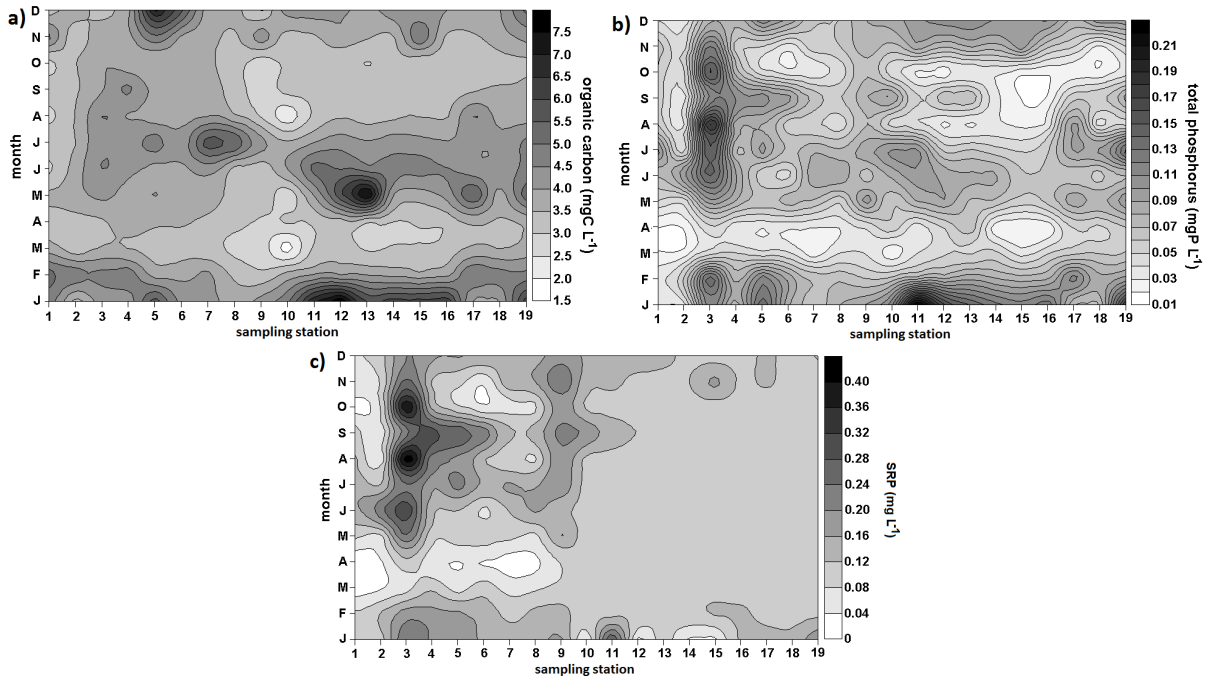


Image 4 *Spatio-temporal distribution of* **(a)** *total dissolved organic carbon;* **(b)** *TP;* **(c)** *SRP in the River Loire, 2009*

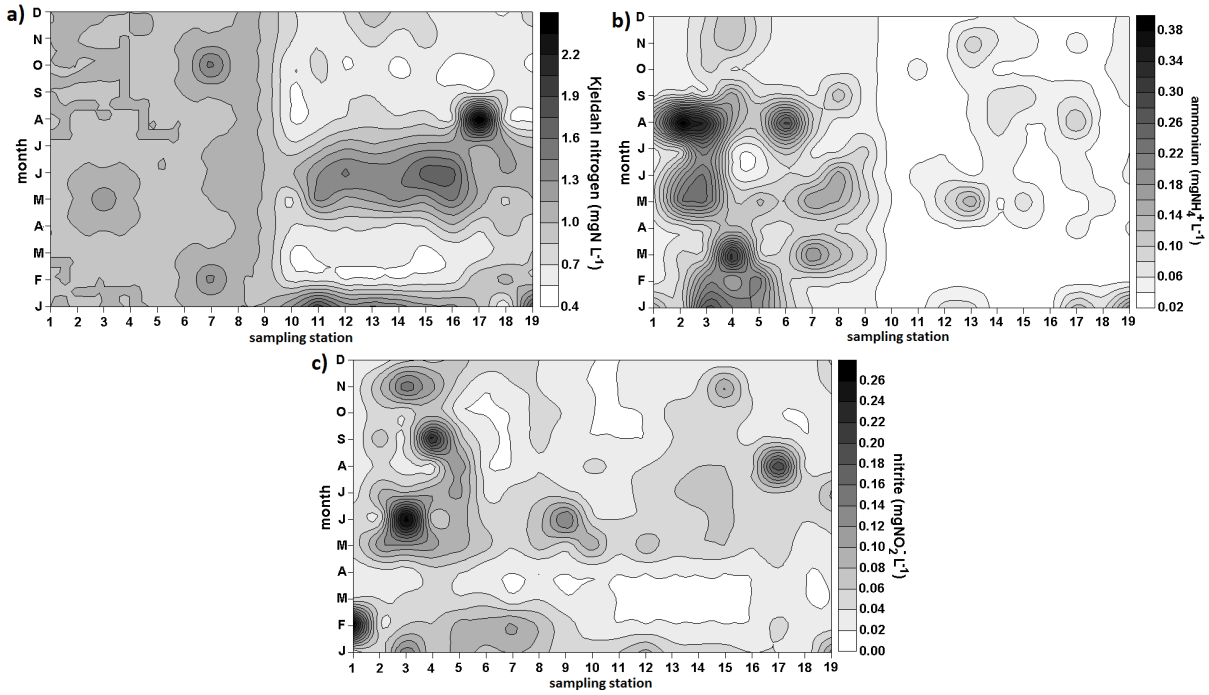


Image 5 *Spatio-temporal distribution of* **(a)** *Kjeldahl-N;* **(b)** *ammonium;* **(c)** *nitrite in the River Loire, 2009*

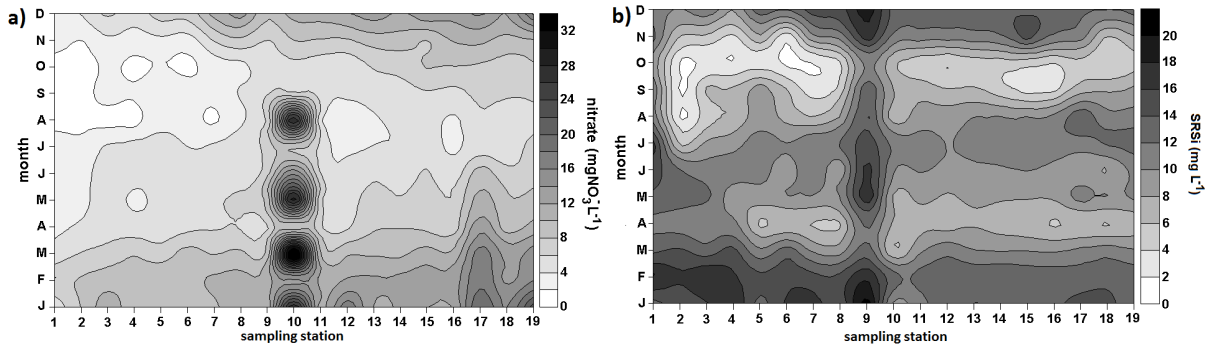


Image 6 *Spatio-temporal distribution of* **(a)** *nitrate;* **(b)** *SRSi in the River Loire, 2009*

Appendix VI *Water quality parameters according to the French national running water qualification system–SEQ-Eau (Oudin and Maupas, 2003)*

Quality class	High	Good	Moderate	Poor	Bad
1) Organic material					
Dissolved oxygen (mgL^{-1})	8	6	4	3	< 3
Oxygen saturation (%)	90	70	50	30	< 30
DBO_5 (mgL^{-1} O_2)	3	6	10	25	> 25
DCO (mgL^{-1} O_2)	20	30	40	80	> 80
DOC (mgL^{-1} C)	5	7	10	12	> 12
NH_4^+ (mgL^{-1})	0,5	1,5	2,8	4	> 4
N_{Kj} (mgL^{-1})	1	2	4	6	> 6
2) Nitrogen forms without nitrate					
NH_4^+ (mgL^{-1})	0.1	0.5	2	5	> 5
N_{Kj} (mgL^{-1})	1	2	4	10	> 10
NO_2^- (mgL^{-1})	0.03	0.1	0.5	1	> 1
3) Nitrate					
NO_3^- (mgL^{-1})	2	10	25	50	>50
4) Phoshorus forms					
PO_4^{3-} (mgL^{-1})	0.1	0.5	1	2	> 2
Total P (mgL^{-1})	0.05	0.2	0.5	1	> 1
5) Primary production					
Chl-a + Phep. (μgL^{-1})	10	60	120	240	> 240
Algae ($indL^{-1}$)	2,500	25,000	50,000	500,000	> 500,000
Oxygen saturation (%)	110	130	150	200	> 200
pH	8.0	8.5	9.0	9.5	> 9.5

Appendix VII *Harmonization of German and Hungarian national river typologies*

Table 1 *Numerical codes, names and major characteristics of river types in Germany selected for potamoplankton assessment according to Mischke et al. (2011)*

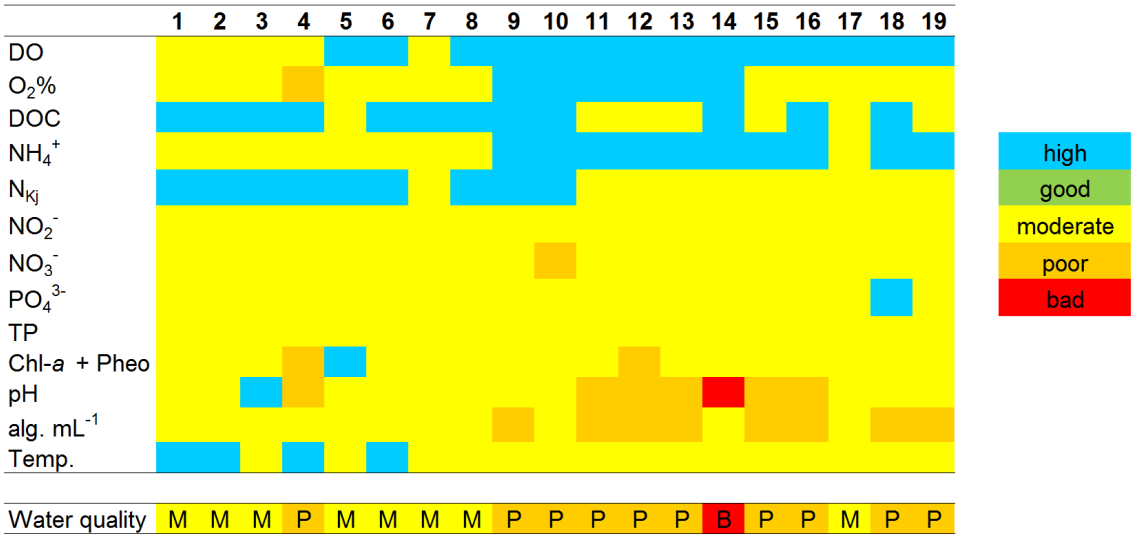
Type code	Aquatic landscape		Catchment size	Typology name
	Sub-ecoregion	Substratum		
15.1+17.1	lowland (< 200 m)	sand, clay, gravel	small catchment (1,000-5,000 km^2)	lowland river with small catchment
15.2+17.2	lowland (< 200 m)	sand, clay, gravel	large catchment (> 5,000 km^2)	lowland rivers with large catchment
20.1	lowland (< 200 m)	sand, clay, gravel	very large catchment (> 10,000 km^2)	streams in lowland with high area specific runoff
20.2	lowland (< 200 m)	sand, clay, gravel	very large catchment (> 10,000 km^2)	streams in lowland with low area specific runoff
9.2	hilly region (200-400 m)	gravel	medium catchment (>1,000 km^2)	large gravel rich rivers
10.1	hilly region (200-400 m)	gravel	large catchment (> 5,000 km^2)	gravel rich streams with high area specific runoff
10.2	hilly region (200-400 m)	gravel	large catchment (> 5,000 km^2)	gravel rich streams with low area specific runoff
23	lowland (< 200 m)	-	small catchment (> 500 km^2)	Baltic sea tributaries

Table 2 *Numerical codes, names and major characteristics of river types in Hungary selected for potamoplankton assessment according to Borics et al. (2009)*

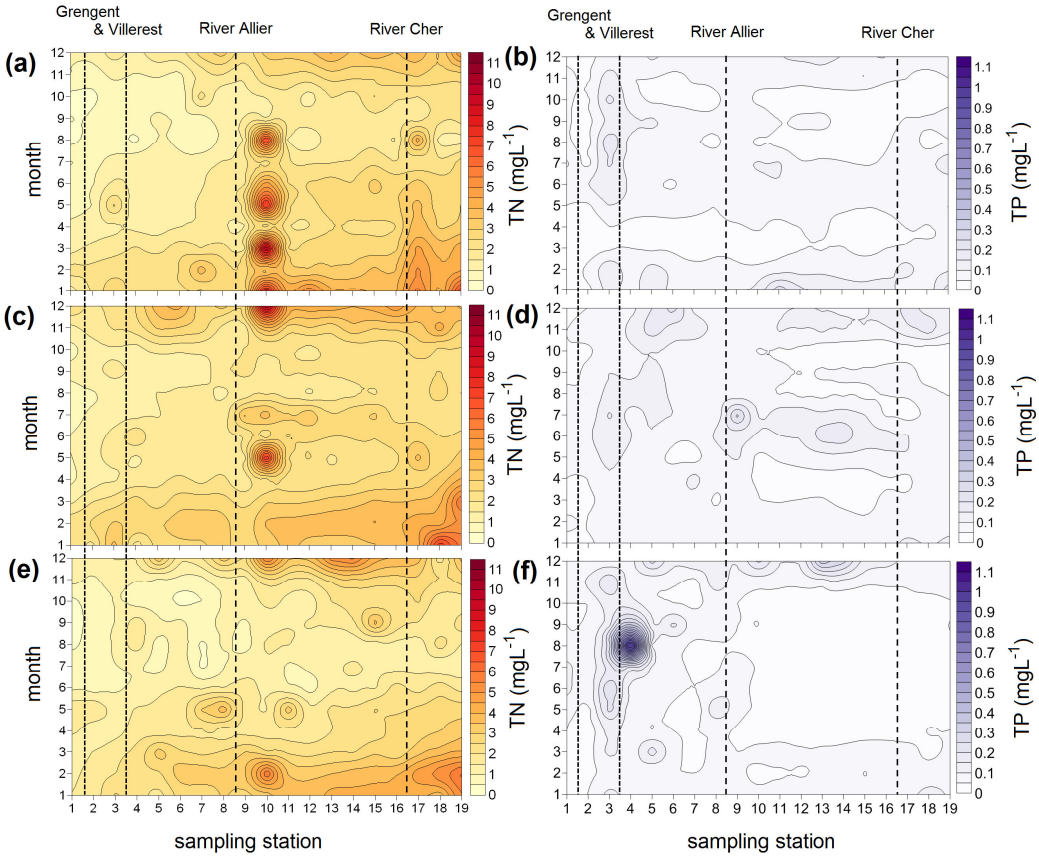
Type code	Aquatic landscape			Catchment size	Typology name
	Sub-ecoregion	Hydrogeochemical characteristics	Substratum		
1	mountainous region	siliceous	coarse	small*	stream
2	(>350 m)	calcareous	coarse	small	stream
3				Middle*	small river
4	hilly region	calcareous	coarse	small	stream
5	(200-350 m)			middle	small river
6				large*	middle sized river
7				very large*	large river
8			medium-fine	small	brook
9				middle	small river
10				large	middle sized river
11	plains	calcareous	coarse	small	
12	(< 200 m)			middle	small river
13				large	middle sized river
14				very large	large river
15			medium-fine	small	brook
16				small in very flat area	brook
17				middle in flat area	
18				middle	small river
19				large	middle sized river
20				very large	large river
21		organic		small	
22				medium	
23	Danube upstream from Gönyű				
24	Danube, between Gönyű and Baja				
25	Danube, downstream from Baja				

*small: 10-100 km^2, middle 100-1,000 km^2, large: 1,000-10,000 km^2, very large: >10,000km^2

Table 3 *Summary of water quality classification obtained by the seasonal worst cases in the SEQ-Eau water quality classification system (Oudin and Maupas, 2003) along the River Loire, 2009*



Appendix VIII *Spatio-temporal distribution of TN and TP in the River Loire in* **(a, b)** *2009;* **(c, d)** *2010; and* **(e, f)** *2011*



Appendix IX *Potamoplankton taxa list of the River Loire (2009-2011) according to the following river zones: 1) upper Loire between st.1-4; 2) upper Loire between st. 5-8; 3) middle Loire between st. 9-12; 4) middle Loire between st. 13-16; and 5) lowland Loire between st. 17-19. Taxa contributions are based on ind.mL^{-1} in each river zone. Taxa names are updated according to AlgaeBASE (Guiry and Guiry, 2014)*

0 - 1 % at the river zone based on ind.mL^{-1}
1 - 10 % at the river zone based on ind.mL^{-1}
10 - 100 % at the river zone based on ind.mL^{-1}

	River zone														
	2009					2010					2011				
Taxa list	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Chlorophyceae															
Acanthosphaera zachariasii Lemmermann															
Actinastrum Lagerheim															
Actinastrum hantzschii Lagerheim															
Ankistrodesmus Corda															
Ankistrodesmus gracilis (Reinsch) Korshikov															
Ankistrodesmus spiralis (W.B. Turner) Lemmermann															
Ankyra Fott															
Ankyra judayi (G.M. Smith) Fott															
Botryococcus Kützing															
Carteria Diesing															
Characium A. Braun in Kützing															
Chlamydomonas Ehrenberg															
Chlamydomonas pseudopertusa Ettl															
Chloroidium saccharophilum (W. Krüger) Darienko, Gustavs, Mudimu, Menendez, Schumann, Karsten, Friedl & Proschold															
Chlorogonium Ehrenberg															
Chlorogonium hiemale J. Schiller															
Chlorogonium oogamum Pascher															
Chlorolobion Korshikov															
Closteriopsis Lemmermann															
Closteriopsis longissima (Lemmermann) Lemmermann															
Coelastrum Nägeli															
Coelastrum astroideum De Notaris															
Coelastrum microporum Nägeli															
Coelastrum polychordum / Hariotina polychorda (Korshikov) E. Hegewald															
Coelastrum pseudomicroporum Korshikov															
Coelastrum reticulatum / Hariotina reticulata P.A. Dangeard															
Coenochloris Korshikov															
Coronastrum R.H. Thompson															
Coronastrum ellipsoideum Fott															
Crucigenia Morren															
Crucigenia fenestrata (Schmidle) Schmidle															
Crucigenia lauterbornii (Schmidle) Schmidle															
Crucigenia quadrata Morren															
Crucigenia tetrapedia (Kirchner) Kuntze															
Crucigeniella Lemmermann															
Crucigeniella apiculata (Lemmermann) Komárek															
Crucigeniella crucifera (Wolle) Komárek															
Crucigeniella neglecta (B. Fott & H. Ettl) J.Komárek															
Crucigeniella pulchra (West & G.S. West) Komárek															
Crucigeniella rectangularis (Nägeli) Komárek															
Crucigeniella truncata (G.M. Smith) J. Komárek															
Diacanthos belenophorus / Micractinium belenophorum (Korshikov) T. Proschold, C. Block, W. Luo & L. Kreinitz															
Dicellula planktonica D.O. Svirenko															
Dichotomoccocus Koršikov															
Dichotomococcus curvatus Koršikov															
Dictyosphaerium Nägeli															
Dictyosphaerium pulchellum / Mucidosphaerium pulchellum (H.C. Wood) C. Bock, Proschold & Krienitz															
Dictyosphaerium subsolitarium Van Goor															
Dictyosphaerium tetrachotomum / Hindakia tetrachotoma (Printz) C. Bock, Pröschold & Krienitz															
Didymocystis Korshikov															
Didymocystis bicellularis (R. Chodat) Komárek															
Didymocystis comasii Komárek															

continuing...

...continued

	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Chlorophyceae															
Didymocystis fina / Pseudodidymocystis fina (Komárek) E. Hegewald & Deason															
Didymocystis inermis (Fott) Fott															
Didymocystis planktonica / Pseudodidymocystis planktonica (Korshikov) E. Hegewald & Deason															
Didymogenes Schmidle															
Didymogenes anomala (G.M. Smith) Hindák															
Didymogenes palatina Schmidle															
Diplochloris Korschikov															
Diplochloris decussata Korschikov															
Diplochloris raphidioides F. Fott															
Eudorina Ehrenberg															
Franceia Lemmermann															
Franceia ovalis (Francé) Lemmermann															
Golenkinia Chodat															
Golenkinia radiata Chodat															
Golenkiniopsis Korshikov															
Gonium O.F. Müller															
Gonium pectorale O.F. Müller															
Granulochloris Pascher & Jahoda															
Granulocystis Hindák															
Granulocystopsis Hindák															
Granulocystopsis coronata (Lemmermann) Hindák															
Haematococcus Flotow															
Hydrodictyon Roth															
Kirchneriella Schmidle															
Kirchneriella contorta / Pseudokirchneriella contorta (Schmidle) F.Hindák															
Kirchneriella contorta var. elongata / Pseudokirchneriella elongata (G.M. Smith) F.Hindák															
Kirchneriella incurvata J.H. Belcher & Swale															
Kirchneriella irregularis (G.M. Smith) Korshikov															
Kirchneriella lunaris (Kirchner) K. Möbius															
Kirchneriella obesa (West) West & G.S. West															
Korshikoviella P.C. Silva															
Korshikoviella limnetica (Lemmermann) P.C. Silva															
Lagerheimia R. Chodat															
Lagerheimia balatonica (Scherffel) Hindák															
Lagerheimia ciliata (Lagerheim) Chodat															
Lagerheimia genevensis (Chodat) Chodat															
Lagerheimia quadriseta (Lemmermann) G.M. Smith															
Lagerheimia wratislaviensis Schröder															
Lobomonas P.-A. Dangeard															
Micractinium Fresinius															
Micractinium pusillum Fresenius															
Monoraphidium Komárková-Legnerová															
Monoraphidium arcuatum (Korshikov) Hindák															
Monoraphidium circinale (Nygaard) Nygaard															
Monoraphidium contortum (Thuret) Komárková-Legnerová															
Monoraphidium convolutum (Corda) Komárková-Legnerová															
Monoraphidium griffithii (Berkeley) Komárková-Legnerová															
Monoraphidium irregulare (G.M. Smith) Komárková-Legnerová															
Monoraphidium komarkovae Nygaard															
Monoraphidium minutum (Nägeli) Komárková-Legnerová															
Monoraphidium subclavatum Nygaard															
Monoraphidium tortile (West & G.S. West) Komárková-Legnerová															
Neodesmus danubialis Hindák															
Nephrochlamys Korshikov															
Nephrochlamys subsolitaria (G.S. West) Korshikov															
Nephroselmis Stein															
Nephroselmis olivacea F. Stein															
Oocystis Nägeli ex A. Braun															
Oocystis lacustris Chodat															
Oocystis marsonii Lemmermann															
Pandorina Bory de Saint-Vincent															
Pandorina morum (O.F. Müller) Bory de Saint-Vincent															
Pediastrum Meyen															
Pediastrum biradiatum / Parapediastrum biradiatum (Meyen) E. Hegewald															
Pediastrum biradiatum var. longecornutum / Parapediastrum biradiatum var. longecornutum (Gutwinski) Tsarenko															
Pediastrum boryanum / Pseudopediastrum boryanum (Turpin) E. Hegewald															
Pediastrum privum / Stauridium privum (Printz) Hegewald															

continuing...

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	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Chlorophyceae															
Pediastrum duplex Meyen															
Pediastrum duplex var. gracillimum West & G.S. West															
Pediastrum simplex / Monactinus simplex (Meyen) Corda															
Pediastrum simplex var. biwaense Fukushima															
Pediastrum simplex var. echinulatum Wittrock in Wittrock & Nordstedt															
Pediastrum tetras / Stauridium tetras (Ehrenberg) E. Hegewald															
Phacotus Perty															
Planktosphaeria gelatinosa G. M. Smith															
Polyedriopsis spinulosa (Schmidle) Schmidle															
Pteromonas Seligo															
Pteromonas aculeata Lemmermann															
Pteromonas angulosa Lemmermann															
Pteromonas cordiformis Lemmermann															
Quadricoccus Fott															
Quadricoccus ellipticus Hortobágyi															
Quadricoccus laevis Fott															
Raphidocelis Hindák															
Scenedesmus [2 cells] Meyen															
Scenedesmus [gr. Abundantes/ Spinosi] Meyen															
Scenedesmus [gr. Acutodesmus] Meyen															
Scenedesmus [gr. Armati] Meyen															
Scenedesmus [gr. Desmodesmus] Meyen															
Scenedesmus [gr. Scenedesmus sensu stricto] Meyen															
Schroederia Lemmermann															
Schroederia setigera (Schröder) Lemmermann															
Schroederia spiralis (Printz) Korshikov															
Siderocelis (Naumann) Fott															
Siderocelis ornata (Fott) Fott															
Spermatozopsis exsultans Korshikov															
Sphaerocystis R. Chodat															
Sphaerocystis planktonica (Korshikov) Bourrelly															
Tetrachlorella Korshikov															
Tetrachlorella alternans (G.M. Smith) Korshikov															
Tetraedron Kützing															
Tetraedron caudatum (Corda) Hansgirg															
Tetraedron incus (Teiling) G. M. Smith															
Tetraedron minimum (A.Braun) Hansgirg															
Tetraëdriella regularis (Kützing) Fott															
Tetraedron triangulare Korshikov															
Tetraselmis F. Stein															
Tetrastrum Chodat															
Tetrastrum elegans Playfair															
Tetrastrum heteracanthum (Nordstedt) Chodat															
Tetrastrum punctatum / Lemmermannia punctata (Schmidle) C. Bock & Krienitz															
Tetrastrum staurogeniiforme (Schröder) Lemmermann															
Tetrastrum triacanthum Korshikov															
Tetrastrum triangulare (Chodat) Komárek															
Treubaria C. Bernard															
Treubaria euryacantha (Schmidle) Korshikov															
Treubaria triappendiculata C. Bernard															
Volvulina Playfair															
Westella botryoides (West) De Wildeman															
Ulothricophyceae															
Catena viridis Chodat															
Elakatothrix Wille															
Elakatothrix gelatinosa Wille															
Gloeotila Kützing															
Gloeotila contorta (Lemmermann) Chodat															
Stichococcus pelagicus (Nygaard) Hindák															
Koliella Hindák															
Koliella longiseta (Vischer) Hindák															
Koliella spiralis Kuosa															
Koliella spirotaenia (G.S. West) Hindák															
Prasiola Meneghini															
Ulothrix Kützing															
Zygophyceae															
Closterium Nitzsch ex Ralfs															
Cosmarium Corda ex Ralfs															
Euastrum Ehrenberg ex Ralfs															

continuing...

...continued	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Zygophyceae															
Mougeotia C. Agardh															
Spirogyra Link															
Staurastrum Meyen ex Ralfs															
Staurodesmus Teiling															
Xanthidium Ehrenberg ex Ralfs															
Euglenophyceae															
Anisonema Dujardin															
Astasia Dujardin															
Colacium Ehrenberg															
Cryptoglena pigra Ehrenberg															
Entomoneis Ehrenberg															
Euglena Ehrenberg															
Lepocinclis acus (O.F. Müller) Marin & Melkonian															
Lepocinclis Perty															
Phacus Dujardin															
Phacus longicauda (Ehrenberg) Dujardin															
Strombomonas Deflandre															
Trachelomonas Ehrenberg															
Trachelomonas hispida (Perty) F. Stein															
Trachelomonas volvocina (Ehrenberg) Ehrenberg															
Trachelomonas volvocinopsis Svirenko															
Chrysophyceae															
Bicosoeca H.J. Clark															
Chromulina L. Cienkowsky															
Chrysochromulina Lackey															
Chrysochromulina parva Lackey															
Chrysococcus G.A. Klebs															
Chrysococcus biporus Skuja															
Chrysococcus rufescens Klebs															
Chrysococcus triporus Mack															
Desmarella W.S. Kent															
Dinobryon Ehrenberg															
Dinobryon bavaricum Imhof															
Dinobryon crenulatum West & G.S. West															
Dinobryon divergens O.E. Imhof															
Dinobryon sertularia Ehrenberg															
Dinobryon sociale (Ehrenberg) Ehrenberg															
Dinobryon sociale (Ehrenberg) Ehrenberg															
Dinobryon suecicum Lemmermann															
Dinobryon suecicum var. longispinum Lemmermann															
Kephyrion Pascher															
Kephyrion rubri-claustri Conrad															
Mallomonas Perty															
Mallomonas akrokomos Ruttner															
Ochromonas Vysotskii [Wysotzki]															
Pseudokephyrion Pascher															
Pseudokephyrion conicum Schiller															
Salpingoeca H.J. Clark															
Synura Ehrenberg															
Synura uvella Ehrenberg															
Xanthophyceae															
Centritractus E. Lemmermann															
Characiopsis Borzì															
Chloridella Pascher															
Gloeobotrys Pascher															
Goniochloris Geitler															
Goniochloris fallax Fott															
Goniochloris mutica (A. Braun) Fott															
Nephrodiella Pascher															
Nephrodiella lunaris Pascher															
Ophiocytium capitatum Wolle															
Pseudostaurastrum R. Chodat															
Tetraëdriella Pascher															
Tetraplektron Fott															
Trachydiscus Ettl															
Bacillariophyceae															
Acanthoceras zachariasii (Brun) Simonsen															
Achnanthes Bory de Saint-Vincent															
Achnanthidium minutissimum (Kützing) Czarnecki															
Achnanthidium catenatum (Bily & Marvan) Lange-Bertalot															

continuing...

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	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Bacillariophyceae															
Actinocyclus normanii (Gregory) Hustedt															
Amphora Ehrenberg ex Kützing															
Amphora ovalis (Kützing) Kützing															
Amphora pediculus (Kützing) Grunow ex A. Schmidt															
Asterionella formosa Hassall															
Aulacoseira Thwaites															
Aulacoseira ambigua (Grunow) Simonsen															
Aulacoseira ambigua f. japonica Tuji & D. M. Williams															
Aulacoseira granulata (Ehrenberg) Simonsen															
Aulacoseira granulata f. spiralis (Hustedt) D.B. Czarnecki & D.C. Reinke															
Aulacoseira granulata var. angustissima (O.F. Müller) Simonsen															
Aulacoseira muzzanensis (Meister) Krammer															
Aulacoseira pusilla (F. Meister) Tuji & Houki															
Aulacoseira subarctica (O.F. Müller) E.Y. Haworth															
Bacillaria paxillifera (O.F. Müller) T. Marsson															
Caloneis Cleve															
Caloneis schumanniana (Grunow) Cleve															
Caloneis silicula f. claviceps Hustedt															
Cocconeis pediculus Ehrenberg															
Cocconeis placentula Ehrenberg															
Craticula ambigua (Ehrenberg) D.G. Mann															
Cyclostephanos dubius (Fricke) Round															
Cyclostephanos invisitatus (Hohn & Hellermann) Theriot, Stoermer & Håkasson															
Cyclotella (Kützing) Brébisson															
Cyclotella atomus Hustedt															
Cyclotella atomus var. gracilis Genkal & Kiss															
cf. *Cyclotella nana* / cf. *Thalassiosira oceanica* Hasle															
Cyclotella meduanae Germain															
Cyclotella meneghiniana Kützing															
Discostella pseudostelligera (Hustedt) Houk & Klee															
Cyclotella radiosa / Puncticulata radiosa (Grunow) H.Hakansson															
Cymatopleura solea (Brébisson) W.Smith															
*Cymbella C.*Agardh															
Cymbella affinis Kützing															
Cymbella lanceolata / Brebissonia lanceolata (C. Agardh) Mahoney & Reimer															
Cymbella tumida (Brébisson) van Heurck															
Denticula Kützing															
Diatoma Bory de St-Vincent															
Diatoma mesodon (Ehrenberg) Kützing															
Diatoma problematicum Lange-Bertalot															
Diatoma tenuis C. Agardh															
Diatoma vulgaris Bory de Saint-Vincent															
Diatoma vulgaris var. linearis Grunow															
Discostella stelligera (Cleve & Grunow) Houk & Klee															
Encyonema prostratum (Berkeley) Kützing															
Encyonema persilesiacum Krammer															
Encyonema triangulum (Ehrenberg) Kützing															
Eolimna Lange-Bertalot & W.Schiller in W. Schiller & H. Lange-Bertalot															
Eolimna minima (Grunow) Lange-Bertalot & W.Schiller															
Fragilaria Lyngbye [planktonic]															
Fragilaria Lyngbye [benthic]															
Fragilaria arcus / Hannaea arcus (Ehrenberg) R.M. Patrick															
Fragilaria capucina Desmazières															
Fragilaria construens (Ehrenberg) Grunow															
Fragilaria crotonensis Kitton															
Fragilaria nanana Lange-Bertalot															
Fragilaria tenera (W. Smith) Lange-Bertalot															
Frustulia Rabenhorst															
Geissleria Lange-Bertalot & Metzeltin															
Geissleria decussis (Østrup) Lange-Bertalot & Metzeltin															
Gomphonema Ehrenberg															
Gomphonema olivaceum (Hornemann) Brébisson															
Gyrosigma Hassall															
Gyrosigma acuminatum (Kützing) Rabenhorst															
Gyrosigma attenuatum (Kützing) Rabenhorst															
Gyrosigma nodiferum (Grunow) Reimer															
Gyrosigma parkerii (M.B.Harrison) Boyer															
Hantzschia amphioxys (Ehrenberg) Grunow															
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski															

continuing...

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	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Bacillariophyceae															
Luticola D.G. Mann															
Luticola ventricosa (Kützing) D.G. Mann															
Mayamaea Lange-Bertalot															
Melosira varians C. Agardh															
Meridion circulare (Greville) C. Agardh															
Navicula Bory de Saint-Vincent															
Navicula antonii Lange-Bertalot															
Navicula capitatoradiata Germain															
Navicula cryptotenella Lange-Bertalot															
Navicula viridula var. germainii (Wallace) Lange-Bertalot															
Navicula gregaria Donkin															
Navicula lanceolata / Cymbella lanceolata (C.Agardh) C. Agardh															
Navicula minima Grunow															
Navicula rhynchocephala Kützing															
Navicula viridula var. rostellata (Kützing) Cleve															
Navicula tripunctata (O.F.Müller) Bory de Saint-Vincent															
Navicula trivialis Lange-Bertalot															
Navicula viridula (Kützing) Ehrenberg															
Nitzschia Hassall															
Nitzschia acicularis (Kützing) W. Smith															
Nitzschia agnewii Choln.															
Nitzschia capitellata Hustedt															
Nitzschia dissipata (Kützing) Grunow															
Nitzschia flexa Schumann															
Nitzschia fruticosa Hustedt															
Nitzschia heufleriana Grunow															
Nitzschia intermedia Hantzsch ex Cleve & Grunow															
Nitzschia linearis (C.Agardh) W. Smith															
Nitzschia palea (Kützing) W. Smith															
Nitzschia palea var. debilis (Kützing) Grunow															
Nitzschia paleacea Grunow															
*Nitzschia recta H*antzsch ex Rabenhorst															
Nitzschia sigmoidea (Nitzsch) W. Smith															
Palibellus protracta (Grunow) Witkowski, Lange-Bertalot & Metzeltin															
Pinnularia Ehrenberg															
Pinnularia lundii Hustedt															
Pinnularia rupestris Hantzsch															
Planothidium frequentissimum (Lange-Bertalot) Round & L. Bukhtiyarova															
Puncticulata radiosa (Grunow) H. Hakansson															
Reimeria J.P. Kociolek & E.F. Stoermer															
Rhoicosphenia abbreviata (C. Agardh) Lange-Bertalot															
*Rhopalodia gibba (*Ehrenberg) Otto Müller															
Sellaphora Mereschowsky															
Sellaphora bacillum (Ehrenberg) D.G. Mann															
*Sellaphora pupula (*Kützing) Mereschkovsky															
Sellaphora seminulum (Grunow) D.G. Mann															
Skeletonema potamos (C.I. Weber) Hasle															
Stephanodiscus hantzschii Grunow															
Stephanodiscus hantzschii f. tenuis (Hustedt) H. Håkansson & E.F. Stoermer															
Stephanodiscus minutulus (Kützing) Cleve & Möller															
Surirella Turpin															
Surirella angusta Kützing															
Surirella brebissonii Krammer & Lange-Bertalot															
Surirella linearis W. Smith															
Thalassiosira bramaputrae (Ehrenberg) Håkansson & Locker															
Tryblionella levidensis W. Smith															
Ulnaria ulna (Nitzsch) P. Compère															
Ulnaria ulna var. acus (Kützing) Lange-Bertalot															
Ulnaria delicatissima var. angustissima (Grunow) M. Aboal & P.C. Silva															
Cryptophyceae															
Chroomonas Hansgirg															
Cryptomonas Ehrenberg															
Plagioselmis Butcher ex G. Novarino, I.A.N. Lucas & S. Morrall															
Plagioselmis lacustris (Pascher & Ruttner) P. Javornick															
Plagioselmis nannoplanctica (H.Skuja) G. Novarino, I.A.N. Lucas & S. Morrall															
Dinophyceae															
Ceratium Schrank															
Ceratium hirundinella (O.F. Müller) Dujardin															
Gymnodinium Stein															

continuing...

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	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Dinophyceae															
Peridiniopsis Lemmermann															
Peridiniopsis corillionii M. Leitao, L.Ten-Hage, G. Mascarell, & A. Couté															
Peridinium Ehrenberg															
Cyanobacteria															
Anabaena / Dolichospermum (Ralfs ex Bornet & Flahault) P. Wacklin, L. Hoffmann & J. Komárek															
Anabaena spiroides / Dolichospermum spiroides (Klebhan) Wacklin, L. Hoffmann & Komárek															
Anabaenopsis V.V. Miller															
Anabaenopsis elenkinii V.V. Miller															
Aphanizomenon A.Morren ex Bornet & Flahault															
Aphanizomenon issatschenkoi (Usacev) Proshkina-Lavrenko															
Aphanocapsa Nägeli															
Aphanothece Nägeli															
Chroococcus Nägeli															
Clastidium setigerum Kirchner															
Coelomoron Buell															
Coelomoron pusillum (Van Goor) Komárek															
Cuspidothrix P. Rajaniemi, J. Komárek, R. Willame, P. Hrouzek, K. Kastovská, L. Hoffmann & K. Sivonen															
Cuspidothrix issatschenkoi (Usachev) Rajaniemi, Komárek, Willame, Hrouzek, Ka															
Cyanogranis Hindák															
Cyanogranis ferruginea (F.Wawrik) Hindák															
Cyanogranis libera Hindák															
Cylindrospermopsis G. Seenayya & N. Subba Raju in T.V. Desikachary															
Eucapsis Clements & Shantz															
Geitlerinema (Anagnostidis & Komárek) Anagnostidis															
Geitlerinema splendidum (Greville ex Gomont) Anagnostidis															
Gloeocapsopsa Kützig															
Gloeocapsopsis Geitler ex Komárek															
Gloeocapsopsis dvorakii (Novácek) J. Komárek & K. Anagnostidis															
Jaaginema Anagnostidis & Komárek															
Jaaginema subtilissimum (Kützing ex De Toni) Anagnostidis & Komárek															
Komvophoron Anagnostidis & Komárek															
Leptolyngbya Anagnostidis & Komárek															
Leptolyngbya subtilis (West) Anagnostidis															
Limnothrix Meffert															
Limnothrix redekei (van Goor) Meffert															
Merismopedia Meyen															
Merismopedia glauca (Ehrenberg) Kützing															
Merismopedia punctata Meyen															
Merismopedia tenuissima Lemmermann															
Merismopedia trolleri Bachmann															
Microcystis Kützing ex Lemmermann															
Microcystis wesenbergii (Komárek) Komárek															
Nostoc Vaucher ex Bornet & Flahault															
Oscillatoria Vaucher ex Gomont															
Phormidium Kützing ex Gomont															
Planktolyngbya Anagnostidis & Komárek															
Planktolyngbya limnetica (Lemmermann) J. Komárková-Legnerová & G. Cronberg															
Planktothrix agardhii (Gomont) Anagnostidis & Komárek															
Pseudanabaena Lauterborn															
Pseudanabaena limnetica (Lemmermann) Komárek															
Pseudanabaena mucicola (Naumann & Huber-Pestalozzi) Schwabe															
Romeria Koczwara															
Snowella Elenkin															
Snowella lacustris (Chodat) Komárek & Hindák															
Synechococcus Nägeli															
Synechococcus capitatus A.E. Bailey-Watts & J. Komárek															
Woronichinia naegeliana (Unger) Elenkin															
Raphidophyceae															
Gonyostomum semen (Ehrenberg) Diesing															
Rhodophyceae															
Batrachospermum Roth															
Unidentified															
Chlorococcales															
Volvocales															
Ulothricophyceae															
Zygophyceae															

continuing...

...continued	River zone														
	2009					2010					2011				
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*	*1*	*2*	*3*	*4*	*5*
Unidentified															
Euglenophyceae															
Chrysophyceae															
Xanthophyceae															
Centrales															
Pennales															
Dinophyceae															
Cyanobacteria															
Rhodophyceae															
algae															

Appendix X *Presence of potamoplankton taxa in the River Loire observed at whole river scale (24 locations) since 1991; and during the three years (2009-2011) studied in the Dissertation along 19 sampling sites. Taxonomical groups are: CHL: Chlorophyceae, ULO: Ulothricophyceae, ZYG: Zygophyceae, EUG: Euglenophyceae, CHR: Chrysophyceae, XAN: Xanthophyceae, BAC: Bacillariophyceae, CRY: Cryptophyceae, DIN: Dinophyceae, CYA: Cyanobacteria, RHO: Rhodophyceae, RAP: Raphidophyceae*

Taxa list	Algal group	1991-2011	2009-2011
Acanthoceras zachariasii (Brun) Simonsen	CHL	+	+
Acanthosphaera Lemmermann	CHL	+	
Acanthosphaera zachariasii Lemmermann	CHL	+	+
Achnanthes Bory de Saint Vincent	BAC	+	+
Achnanthidium catenatum (Bílý et Marvan) Lange-Bertalot	BAC	+	+
Achnanthidium minutissimum (Kützing) Czarnecki	BAC	+	+
Actinastrum hantzschii Lagerheim	CHL	+	+
Actinastrum hantzschii var. *subtile* J.Woloszynska	CHL	+	
Actinastrum Lagerheim	CHL	+	+
Actinocyclus normanii (Gregory ex Greville) Hustedt	BAC	+	+
Acutodesmus bernardii (G.M. Smith) E. Hegewald, C. Bock & Krienitz	CHL	+	
Acutodesmus dimorphus (Turpin) Tsarenko	CHL	+	
Amphora Ehrenberg ex Kützing	BAC	+	
Amphora libyca Ehrenberg	BAC	+	+
Amphora ovalis (Kützing) Kützing	BAC	+	+
Amphora pediculus (Kützing) Grunow	BAC	+	+
Anabaena Bory de Saint-Vincent	CYA	+	+
Anabaena spiroides Klebahn	CYA	+	+
Anabaenopsis (Woloszynska) Miller	CYA	+	
Anabaenopsis cunningtonii Taylor	CYA	+	+
Anabaenopsis elenkinii Miller	CYA	+	+
Anisonema Dujardin	EUG	+	+
Ankistrodesmus bibraianus (Reinsch) Korshikov	CHL	+	
Ankistrodesmus Corda	CHL	+	+
Ankistrodesmus fusiformis Corda	CHL	+	
Ankistrodesmus gracilis (Reinsch) Korshikov	CHL	+	+
Ankistrodesmus spiralis (W.B. Turner) Lemmermann	CHL	+	+
Ankyra Fott	CHL	+	+
Ankyra judayi (G.M.Smith) Fott	CHL	+	+
Ankyra lanceolata (Korshikov) Fott	CHL	+	
Apatococcus F. Brand	CHL	+	
Aphanizomenon aphanizomenoides (Forti) Horecká & Komárek	CYA	+	
Aphanizomenon flos-aquae Ralfs ex Bornet & Flahault	CYA	+	
Aphanizomenon Morren ex Bornet & Flahault	CYA	+	+
Aphanocapsa elachista W. West & G.S. West	CYA	+	
Aphanocapsa Nägeli	CYA	+	+
Aphanothece Nägeli	CYA	+	+
Astasia Dujardin	EUG	+	+
Asterionella formosa Hassall	BAC	+	+
Aulacoseira ambigua (Grunow) Simonsen	BAC	+	+
Aulacoseira ambigua fo. *curvata* Skabicevsky	BAC	+	+
Aulacoseira granulata (Ehrenberg) Simonsen	BAC	+	+
Aulacoseira granulata fo. *curvata* (Ehrenberg) Simonsen	BAC	+	+
Aulacoseira granulata var. *angustissima* (O.F. Müller) Simonsen	BAC	+	+
Aulacoseira muzzanensis (Meister) Krammer	BAC	+	+
Aulacoseira pusilla (Meister) Tuji et Houki	BAC	+	+
Aulacoseira subarctica (O.F. Müller) E.Y. Haworth	BAC	+	+
Aulacoseira Thwaites	BAC	+	+
Bacillaria paxillifera (O.F. Müller) Hendey	BAC	+	+
Batrachospermum A.W. Roth	RHO	+	+
Bicosoeca H.J. Clark	CHR	+	+
Bicosoeca campanulata (Lackey) Bourrelly	CHR	+	
Botryococcus Kützing	CHL	+	+
Caloneis bacillum (Grunow) P.T. Cleve	BAC	+	
Caloneis P. Cleve	BAC	+	+
Caloneis schumanniana (Grunow) Cleve	BAC	+	+
Caloneis silicula (Ehrenberg) P.T. Cleve	BAC	+	+
Carteria Diesing	CHL	+	+
Catena viridis Chodat	ULO	+	+
Centritractus dubius Printz	XAN	+	
Centritractus ellipsoideus Starmach	XAN	+	
Centritractus Lemmermann	XAN	+	+
Centritractus belonophorus (Schmidle) Lemmermann	XAN	+	
Ceratium hirundinella (O.F. Müller) Dujardin	DIN	+	+
Ceratium Schrank	DIN	+	+
Characiopsis A. Borzi	CHL	+	+
Characium A. Braun inKützing	CHL	+	+
Chlamydocapsa B. Fott	CHL	+	
Chlamydomonas Ehrenberg	CHL	+	+

continuing...

...continued	Algal group	1991-2011	2009-2011
Chlamydomonas cf. *gyroides* A. Pascher	CHL	+	
Chlamydomonas pseudopertusa Ettl	CHL	+	+
Chlorella M. Beijerinck	CHL	+	
Chlorella saccharophila (Kruger) Migula	CHL	+	+
Chlorhormidium Fott	ULO	+	
Chloridella Pascher	XAN	+	+
Chloroceras Schiller	CHL	+	
Chlorogonium Ehrenberg	CHL	+	+
Chlorogonium oogamum Pascher	CHL	+	+
Chlorogonium hiemale J.Schiller	CHL	+	+
Chlorogonium intermedium Skuja	CHL	+	
Chlorolobion Korshikov	CHL	+	+
Chlorotetraedron F.J. MacEntee, H.C. Bold & P.A. Archibald	CHL	+	
Chromulina Cienkowski	CHR	+	+
Chromulina freiburgensis Doflein	CHR	+	
Chromulina parvula Conrad	CHR	+	
Chroococcus cf. *planctonicus* Bethge	CYA	+	
Chroococcus limneticus Lemmermann	CYA	+	
Chroococcus Nägeli	CYA	+	+
Chroomonas acuta Utermohl	CRY	+	
Chroomonas coerulea (Geitler) Skuja	CRY	+	
Chroomonas Hansgirg	CRY	+	+
Chrysamoeba Klebs	CHR	+	
Chrysochromulina Cienkowski	CHR	+	+
Chrysochromulina parva Lackey	CHR	+	+
Chrysococcus biporus Skuja	CHR	+	+
Chrysococcus G.A. Klebs	CHR	+	+
Chrysococcus rufescens G.A. Klebs	CHR	+	+
Chrysococcus cordiformis Naumann	CHR	+	
Chrysococcus triporus Mack	CHR	+	+
Chrysosaccus Pascher	CHR	+	
Chrysostephanosphaera Scherffel	CHR	+	
Clastidium Kirchner	CYA	+	
Clastidium setigerum Kirchner	CYA	+	+
Closteriopsis Lemmermann	CHL	+	+
Closteriopsis longissima (Lemmermann) Lemmermann	CHL	+	+
Closterium J. Ralfs	ZYG	+	+
Cocconeis Ehrenberg	BAC	+	
Cocconeis pediculus Ehrenberg	BAC	+	+
Cocconeis placentula Ehrenberg	BAC	+	+
Codosiga botrytis (Ehrenberg) Kent	CHR	+	
Coelastrum astroideum De Notaris	CHL	+	+
Coelastrum microporum Nägeli	CHL	+	+
Coelastrum Nägeli	CHL	+	+
Coelastrum pseudomicroporum Korshikov	CHL	+	+
Coelastrum polychordum (Korshikov) Hindák	CHL	+	+
Coelastrum reticulatum (Dangeard) Senn	CHL	+	+
Coelastrum sphaericum Nägeli	CHL	+	
Coelomoron Buell	CHL	+	+
Coelomoron pusillum (Van Goor) Komárek	CHL	+	+
Coelosphaerium Nägeli	CYA	+	
Coenochloris helvetica Hindák	CHL	+	
Coenochloris Korshikov	CHL	+	+
Coenocystis Korshikov	CHL	+	
Colacium Ehrenberg	EUG	+	+
Coronastrum ellipsoideum Fott	CHL	+	+
Coronastrum R.H. Thompson	CHL	+	+
Coscinodiscus Ehrenberg	BAC	+	
Cosmarium margaritifeum Meneghini ex Ralfs	ZYG	+	
Cosmarium Ralfs	ZYG	+	+
Craticula ambigua (Ehrenberg) D.G. Mann	BAC	+	+
Craticula cuspidata (Kützing) Mann	BAC	+	
Craticula Grunow	BAC	+	
Crucigenia fenestrata (Schmidle) Schmidle	CHL	+	+
Crucigenia lauterbornii (Schmidle) Schmidle	CHL	+	+
Crucigenia Morren	CHL	+	+
Crucigenia quadrata Morren	CHL	+	+
Crucigenia tetrapedia (Kirchner) W.G.S. West	CHL	+	+
Crucigenia truncata G.M. Smith	CHL	+	
Crucigeniella apiculata (Lemmermann) Komárek	CHL	+	+
Crucigeniella crucifera (Wolle) Komárek	CHL	+	+
Crucigeniella Lemmermann	CHL	+	+
Crucigeniella neglecta (B. Fott & H. Ettl) J. Komárek	CHL	+	+
Crucigeniella pulchra (West & G.S.West) Komárek	CHL	+	+
Crucigeniella quadrata (Morren) Gaillon	CHL	+	
Crucigeniella rectangularis (Nägeli) Komárek	CHL	+	+
Crucigeniella truncata (G.M.Smith) J.Komárek	CHL	+	+
Cryptoglena pigra Ehrenberg	CRY	+	+
Cryptomonas Ehrenberg	CRY	+	+
Cryptomonas erosa Ehrenberg	CRY	+	
Cryptomonas reflexa Skuja	CRY	+	
Cryptomonas tetrapyrenoidosa Skuja	CRY	+	

continuing...

...continued	Algal group	1991-2011	2009-2011
Cuspidothrix issatschenkoi (Usacev) Rajaniemi, Komárek, Willame, *et al.*	CYA	+	+
Cuspidothrix Rajaniemi, Komárek, Willame, *et al.*	CYA	+	+
Cyanogranis ferruginea (F. Wawrik) Hindák	CYA	+	+
Cyanogranis Hindák	CYA	+	+
Cyanogranis libera Hindák	CYA	+	+
Cyanosarcina Kováčik	CYA	+	
Cyanosarcina parthenonensis Anagnostidis	CYA	+	
Cyclostephanos dubius (Fricke) Round	BAC	+	+
Cyclostephanos invisitatus (Hohn & Hellerman) Theriot Stoermer & Håkasson	BAC	+	+
Cyclostephanos Round	BAC	+	
Cyclotella (Kützing) Brébisson	BAC	+	+
Cyclotella atomus Hustedt	BAC	+	+
Cyclotella atomus var. gracilis Genkal & Kiss	BAC	+	+
Cyclotella cf. *nana* Hustedt	BAC	+	+
Cyclotella cf. *scaldensis* K. Muylaert & K. Sabbe	BAC	+	
Cyclotella cyclopuncta Håkansson & J.R. Carter	BAC	+	
Cyclotella meduanae Germain	BAC	+	+
Cyclotella meneghiniana Kützing	BAC	+	+
Cyclotella ocellata Pantocsek	BAC	+	
Cyclotella woltereckii Hustedt	BAC	+	
Cylindrospermopsis Seenayya and N. Subba Raju	CYA	+	+
Cymatopleura elliptica (Brébisson ex Kützing) W. Smith	BAC	+	
Cymatopleura solea (Brebisson) W. Smith	BAC	+	+
Cymatopleura W. Smith	BAC	+	
Cymbella affinis Kützing	BAC	+	+
Cymbella Agardh	BAC	+	+
Cymbella lanceolata (Agardh) Agardh	BAC	+	+
Cymbella protracta Østrup	BAC	+	
Cymbella tumida (Brebisson) Van Heurck	BAC	+	+
Denticula Kützing	BAC	+	+
Desmarella Kent	CHR	+	+
Desmarella moniliformis W.S. Kent	CHR	+	
Desmodesmus intermedius (Chodat) E. Hegewald	CHL	+	
Desmodesmus opoliensis (P.G. Richter) E. Hegewald	CHL	+	
Diacanthos belenophorus Korshikov	CHL	+	+
Diatoma Bory de Saint Vincent	BAC	+	+
Diatoma mesodon (Ehrenberg) Kützing	BAC	+	+
Diatoma problematica Lange-Bertalot	BAC	+	+
Diatoma tenuis Agardh	BAC	+	+
Diatoma vulgaris Bory de Saint Vincent	BAC	+	+
Diatoma vulgaris fo. *lineare* (Grunow in V.Heurck) Bukhtiyarova	BAC	+	+
Dicellula planctonica Svirenko	CHL	+	+
Dicellula Svirenko	CHL	+	
Dichotomococcus curvatus Korshikov	CHL	+	+
Dichotomococcus Korshikov	CHL	+	+
Dictyosphaerium ehrenbergianum Nägeli	CHL	+	
Dictyosphaerium elongatum F. Hindák	CHL	+	
Dictyosphaerium Nägeli	CHL	+	+
Dictyosphaerium pulchellum Wood	CHL	+	+
Dictyosphaerium subsolitarium Van Goor	CHL	+	+
Dictyosphaerium tetrachotomum Printz	CHL	+	+
Didymocystis bicellularis (R. Chodat) J. Komárek	CHL	+	+
Didymocystis comasii Komárek	CHL	+	+
Didymocystis inermis (Fott) Fott	CHL	+	+
Didymocystis Korshikov	CHL	+	+
Didymocystis lineata Korshikov	CHL	+	
Didymogenes anomala (G.M. Smith) Hindák	CHL	+	+
Didymogenes palatina Schmidle	CHL	+	+
Didymogenes Schmidle	CHL	+	+
Dinobryon bavaricum Imhof	CHR	+	+
Dinobryon crenulatum W. West & G.S. West	CHR	+	+
Dinobryon divergens Imohf	CHR	+	+
Dinobryon Ehrenberg	CHR	+	+
Dinobryon sertularia Ehrenberg	CHR	+	+
Dinobryon sociale Ehrenberg	CHR	+	+
Dinobryon suecicum Lemmermann	CHR	+	+
Dinobryon suecicum var. *longispinum* Lemmermann	CHR	+	+
Diplochloris decussata Korshikov	CHL	+	+
Diplochloris hortobagyi B. Fott	CHL	+	
Diplochloris Korshikov	CHL	+	+
Diplochloris lunata (Fott) Fott	CHL	+	
Diplochloris raphidioides F. Fott	CHL	+	+
Diploneis Ehrenberg ex P.T. Cleve	BAC	+	
Discostella pseudostelligera (Hustedt) Houk & Klee	BAC	+	+
Discostella stelligera (Cleve & Grunow) Houk & Klee	BAC	+	+
Echinosphaerella G.M. Smith	CHL	+	
Elakatothrix gelatinosa Wille	ULO	+	+
Elakatothrix Wille	ULO	+	+
Encyonema minutum (Hilse in Rabh.) D.G. Mann	BAC	+	
Encyonema prostratum (Berkeley) Kützing	BAC	+	+
Encyonema silesiacum (Bleisch) D.G. Mann in Round, Crawford & Mann	BAC	+	+
Encyonema triangulum (Ehrenberg) Kützing	BAC	+	+

continuing...

...continued	Algal group	1991-2011	2009-2011
Entomoneis Ehrenberg	BAC	+	+
Eolimna Lange-Bertalot & Schiller	BAC	+	+
Eolimna minima (Grunow) Lange-Bertalot	BAC	+	+
Epithemia Brébisson ex Kützing	BAC	+	
Epithemia sorex Kützing	BAC	+	
Euastrum C.G. Ehrenberg ex Ralfs	ZYG	+	+
Eucapsis Clements et Shantz	CYA	+	+
Eudorina Ehrenberg ex Ralfs	CHL	+	+
Eudorina elegans Ehrenberg	CHL	+	
Eudorina illinoisensis (Kofoid) Pascher	CHL	+	
Eudorina indica Iyengar	CHL	+	
Eudorina unicocca G.M. Smith	CHL	+	
Euglena acus Ehrenberg	EUG	+	+
Euglena Ehrenberg	EUG	+	+
Euglena tripteris (Dujardin) Klebs	EUG	+	
Eunotia Ehrenberg	BAC	+	
Eutetramorus fottii (Hindák) Komárek	CHL	+	
Eutetramorus Walton	CHL	+	
Fallacia Stickle & D.G. Mann	BAC	+	
Fallacia subhamulata (Grunow in V. Heurck) D.G. Mann	BAC	+	
Fragilaria arcus (Ehrenberg) Cleve	BAC	+	+
Fragilaria berolinensis (Lemmermann) Lange-Bertalot	BAC	+	
Fragilaria capucina Desmazieres	BAC	+	+
Fragilaria capucina var. *vaucheriae* Desmazieres (Kützing) Lange-Bertalot	BAC	+	
Fragilaria construens (Ehrenberg) Grunow	BAC	+	+
Fragilaria crotonensis Kitton	BAC	+	+
Fragilaria Lyngbye	BAC	+	+
Fragilaria nanana Lange-Bertalot	BAC	+	+
Fragilaria parasitica (W. Smith) Grunow	BAC	+	
Fragilaria parasitica var. *subconstricta*	BAC	+	
Fragilaria pinnata Ehrenberg	BAC	+	
Fragilaria rumpens (Kützing) Carlson	BAC	+	
Fragilaria tenera (W. Smith) Lange-Bertalot	BAC	+	+
Fragilaria virescens Ralfs	BAC	+	
Franceia ovalis (France) Lemmermann	CHL	+	+
Franceia Lemmermann	CHL	+	+
Frustulia Rabenhorst	BAC	+	+
Frustulia rhomboides (Ehrenberg) De Toni	BAC	+	
Frustulia vulgaris (Thwaites) De Toni	BAC	+	
Geissleria decussis (Oestrup) Lange-Bertalot & Metzeltin	BAC	+	+
Geissleria Lange-Bertalot & Metzeltin	BAC	+	+
Geitlerinema (Anagnostidis & Komárek) Anagnostidis	CYA	+	+
Geitlerinema splendidum (Greville) Anagnostidis	CYA	+	+
Gloeobotrys Pascher	XAN	+	+
Gloeocapsa cf. *alpina* (Nägeli) Brand	CYA	+	
Gloeocapsa Kützing	CYA	+	+
Gloeocapsopsis dvorakii (Nováček) Komárek et Anagnostidis	CYA	+	+
Gloeocapsopsis Geitler ex Komárek	CYA	+	+
Gloeocystis Nägeli	CHL	+	
Gloeotila Kützing	ULO	+	+
Gloeotila pelagica (Nygaard) Skuja	ULO	+	+
Gloeotila contorta (Lemmermann) Chodat	ULO	+	+
Golenkinia Chodat	CHL	+	+
Golenkinia radiata Chodat	CHL	+	+
Golenkinia brevispina Korshikov	CHL	+	
Golenkiniopsis Korshikov	CHL	+	+
Gomphoneis minuta (Stone) Kociolek & Stoermer	BAC	+	
Gomphoneis P.T. Cleve	BAC	+	
Gomphoneis eriense var. *variabilis* Kociolek & Stoermer	BAC	+	
Gomphonema acuminatum Ehrenberg	BAC	+	
Gomphonema augur Ehrenberg	BAC	+	
Gomphonema clavatum Ehrenberg	BAC	+	
Gomphonema Ehrenberg	BAC	+	+
Gomphonema olivaceum (Hornemann) Brebisson	BAC	+	+
Gomphonema parvulum (Kützing) Kützing	BAC	+	
Gomphonema truncatum Ehrenberg	BAC	+	
Gomphosphaeria Kützing	CYA	+	
Goniochloris fallax Fott	XAN	+	+
Goniochloris Geitler	XAN	+	+
Goniochloris mutica (A. Braun) Fott	XAN	+	+
Gonium O.F. Müller	CHL	+	+
Gonium pectorale O.F. Müller	CHL	+	+
Gonyostomum K. Diesing	RAP	+	
Gonyostomum semen (Ehrenberg) Diesing	RAP	+	+
Granulochloris Pascher & Jahoda	CHL	+	+
Granulocystis F. Hindák	CHL	+	+
Granulocystis helenae Hindák	CHL	+	
Granulocystopsis coronata (Lemmermann) Hindák	CHL	+	+
Granulocystopsis Hindák	CHL	+	+
Gymnodinium Stein	DIN	+	+
Gyrosigma acuminatum (Kützing) Rabenhorst	BAC	+	+
Gyrosigma attenuatum (Kützing) Cleve	BAC	+	+

continuing...

...continued	Algal group	1991-2011	2009-2011
Gyrosigma Hassall	BAC	+	+
Gyrosigma nodiferum (Grunow) Reimer	BAC	+	+
Gyrosigma parkerii (Harrison) Elmore	BAC	+	+
Gyrosigma scalproides (Sullivan & Wormley) Boyer	BAC	+	
Haematococcus Agardh	CHL	+	+
Hafniomonas Ettl & Moestrup	CHL	+	
Hantzschia abundans Lange-Bertalot	BAC	+	
Hantzschia amphioxys (Ehrenberg) Grunow	BAC	+	+
Hantzschia Grunow	BAC	+	
Heterodesmus Ettl	XAN	+	
Heterodesmus multicellularis Wawrik	XAN	+	
Hippodonta capitata (Ehrenberg) Lange-Bertalot, Metzeltin & Witkowski	BAC	+	+
Hyalocardium H. Ettl	CHL	+	
Hydrodictyon Roth	CHL	+	+
Hydrurus foetidus (Villars) Trevisan	CHR	+	
Jaaginema Anagnostidis & Komárek	CYA	+	+
Jaaginema subtilissimum (Kützing ex De Toni) Anagnostidis & Komárek	CYA	+	+
Kephyrion Pascher	CHR	+	+
Kephyrion rubri-claustri Conrad	CHR	+	+
Keratococcus Pascher	CHL	+	
Keratococcus suecicus Hindák	CHL	+	
Keratococcus braunii (Nägeli) Hindák	CHL	+	
Kirchneriella contorta (Schmidle) Bohlin	CHL	+	+
Kirchneriella contorta var. *gracillima* (Bohlin) Chodat	CHL	+	
Kirchneriella incurvata Belcher & Swale	CHL	+	+
Kirchneriella irregularis (G.M. Smith) Korshikov	CHL	+	+
Kirchneriella lunaris (Kirchner) Möbius	CHL	+	+
Kirchneriella obesa (W. West) Schmidle	CHL	+	+
Kirchneriella Schmidle	CHL	+	+
Kirchneriella contorta var. *elongata* (G.M. Smith) Komárek	CHL	+	+
Koliella Hindák	ULO	+	+
Koliella longiseta (Vischer) Hindák	ULO	+	+
Koliella spiralis Kuosa	ULO	+	+
Koliella spirotaenia (G.S.West) Hindák	ULO	+	+
Komarekia appendiculata (Chodat) Fott	CHL	+	
Komarekia Fott	CHL	+	
Komvophoron Anagnostidis & Komárek	CYA	+	+
Korshikoviella limnetica (Lemmermann) P.C. Silva	CHL	+	+
Korshikoviella P.C. Silva	CHL	+	+
Lagerheimia balatonica (Scherffel) Hindák	CHL	+	+
Lagerheimia Chodat	CHL	+	+
Lagerheimia chodatii C. Bernard	CHL	+	
Lagerheimia ciliata (Lagerheim) Chodat	CHL	+	+
Lagerheimia citriformis (J. Snow) Collins	CHL	+	
Lagerheimia genevensis (Chodat) Chodat	CHL	+	+
Lagerheimia longiseta (Lemmermann) Wille	CHL	+	
Lagerheimia marssonii Lemmermann	CHL	+	
Lagerheimia quadriseta (Chodat) Chodat	CHL	+	+
Lagerheimia subsalsa Lemmermann	CHL	+	
Lagerheimia wratislaviensis Schröder	CHL	+	+
Lemmermanniella Geitler	CYA	+	
Lepocinclis Perty	EUG	+	+
Leptolyngbya Anagnostidis & Komárek	CYA	+	+
Leptolyngbya subtilis (W. West) Anagnostidis	CYA	+	+
Limnothrix Meffert	CYA	+	+
Limnothrix planctonica (Woloszynska) Meffert	CYA	+	
Limnothrix redekei (Van Goor) Meffert	CYA	+	+
Lobocystis planctonica (Tiffany & Ahlstrom) Fott	CHL	+	
Lobocystis R.H. Thompson	CHL	+	
Lobomonas ampla Pascher	CHL	+	
Lobomonas Dangeard	CHL	+	+
Luticola Mann	BAC	+	+
Luticola ventricosa (Kützing) D.G. Mann	BAC	+	+
Lyngbya Agardh ex Gomont	CYA	+	
Mallomonas akrokomos Ruttner	CHR	+	+
Mallomonas Perty	CHR	+	+
Mayamaea Lange-Bertalot	BAC	+	+
Melosira varians Agardh	BAC	+	+
Meridion circulare (Greville) C.Agardh	BAC	+	+
Merismopedia glauca (Ehrenberg) Kützing	CYA	+	+
Merismopedia Meyen	CYA	+	+
Merismopedia punctata Meyen	CYA	+	+
Merismopedia tenuissima Lemmermann	CYA	+	+
Merismopedia trolleri Bachmann	CYA	+	+
Merismopedia warmingiana Lagerheim	CYA	+	
Micractinium bornhemiense (Conrad) Korshikov	CHL	+	
Micractinium Fresenius	CHL	+	+
Micractinium pusillum Fresenius	CHL	+	+
Micractinium quadrisetum (Lemmermann) G.M. Smith	CHL	+	
Microcystis Kützing ex Lemmermann	CYA	+	+
Microcystis protocystis Crow	CYA	+	
Microcystis wesenbergii Komárek	CYA	+	+

continuing...

...continued	Algal group	1991-2011	2009-2011
Monoraphidium arcuatum (Korshikov) Hindák	CHL	+	+
Monoraphidium circinale (Nygaard) Nygaard	CHL	+	+
Monoraphidium contortum (Thuret) Komárková-Legnerová	CHL	+	+
Monoraphidium convolutum (Corda) Komárková-Legnerová	CHL	+	+
Monoraphidium griffithii (Berkeley) Komárková-Legnerová	CHL	+	+
Monoraphidium indicum Hindák	CHL	+	
Monoraphidium irregulare (G.M. Smith) Komarkova-Legnerova	CHL	+	+
Monoraphidium komarkovae Nygaard	CHL	+	+
Monoraphidium Komárková-Legnerová	CHL	+	+
Monoraphidium minutum (Nägeli) Komárková-Legnerová	CHL	+	+
Monoraphidium mirabile (West et G.S. West) Pankow	CHL	+	
Monoraphidium nanum (Ettl) Hindák	CHL	+	
Monoraphidium pseudobraunii (Belcher & Swale) Heynig	CHL	+	
Monoraphidium tortile (W.et G.S.West) Komárková-Legnerová	CHL	+	+
Monoraphidium subclavatum Nygaard	CHL	+	+
Monosiga W.S. Kent	CHR	+	
Mougeotia C.A. Agardh	ZYG	+	+
Navicula antonii Lange-Bertalot	BAC	+	+
Navicula Bory de Saint Vincent	BAC	+	+
Navicula capitatoradiata Germain	BAC	+	+
Navicula cf. *menisculus* Schumann	BAC	+	
Navicula cryptocephala Kützing	BAC	+	
Navicula cryptotenella Lange-Bertalot	BAC	+	+
Navicula germainii Wallace	BAC	+	+
Navicula gregaria Donkin	BAC	+	+
Navicula halophila (Grunow ex Van Heurck) P.T. Cleve	BAC	+	
Navicula lanceolata (Agardh) Ehrenberg	BAC	+	+
Navicula minima Grunow in Van Heurck	BAC	+	+
Navicula protracta (Grunow) Witkowski Lange-Bertalot & Metzeltin	BAC	+	+
Navicula radiosa Kützing	BAC	+	
Navicula rhynchocephala Kützing	BAC	+	+
Navicula rostellata Kützing	BAC	+	+
Navicula tripunctata (O.F. Müller) Bory de Saint Vincent	BAC	+	+
Navicula trivialis Lange-Bertalot	BAC	+	+
Navicula viridula (Kützing) Ehrenberg	BAC	+	+
Neidium dubium (Ehrenberg) P.T. Cleve	BAC	+	
Neidium Pfitzer	BAC	+	
Neodesmus danubialis F. Hindák	CHL	+	+
Neodesmus F. Hindák	CHL	+	
Nephrochlamys Korshikov	CHL	+	+
Nephrochlamys rostrata Nygaard, Komárek, J. Kristiansen & O.M. Skulberg	CHL	+	
Nephrochlamys subsolitaria (G.S.West) Korshikov	CHL	+	+
Nephrocytium Nägeli	CHL	+	
Nephrodiella lunaris Pascher	XAN	+	+
Nephrodiella Pascher	XAN	+	+
Nephroselmis F. Stein	CHL	+	+
Nephroselmis olivacea F.Stein	CHL	+	+
Nitzschia acicularis (Kützing) W.M. Smith	BAC	+	+
Nitzschia acula Hantzsch ex Cleve & Grunow	BAC	+	
Nitzschia agnewii Cholnoky	BAC	+	+
Nitzschia amphibia Grunow	BAC	+	
Nitzschia brevissima Grunow	BAC	+	
Nitzschia brunoi Lange-Bertalot	BAC	+	
Nitzschia capitellata Hustedt	BAC	+	+
Nitzschia cf. *pumila* Hustedt	BAC	+	
Nitzschia constricta (Kützing) Ralfs	BAC	+	
Nitzschia debilis (Arnott) Grunow	BAC	+	
Nitzschia dissipata (Kützing) Grunow	BAC	+	+
Nitzschia dubia W. Smith	BAC	+	
Nitzschia flexa Schumann	BAC	+	+
Nitzschia fonticola Grunow	BAC	+	
Nitzschia frustulum (Kützing) Grunow	BAC	+	
Nitzschia fruticosa Hustedt	BAC	+	+
Nitzschia graciliformis Lange-Bertalot & Simonsen	BAC	+	
Nitzschia gracilis Hantzsch	BAC	+	
Nitzschia hantzschiana Rabenhorst	BAC	+	
Nitzschia Hassall	BAC	+	+
Nitzschia heufleriana Grunow	BAC	+	+
Nitzschia inconspicua Grunow	BAC	+	
Nitzschia intermedia Hantzsch ex Cleve & Grunow	BAC	+	+
Nitzschia linearis (Agardh) W. Smith	BAC	+	+
Nitzschia palea (Kützing) W. Smith	BAC	+	+
Nitzschia palea var. *debilis* (Kützing) Grunow	BAC	+	+
Nitzschia paleacea Grunow	BAC	+	+
Nitzschia recta Hantzsch ex Rabenhorst	BAC	+	+
Nitzschia sigmoidea (Nitzsch) W.M. Smith	BAC	+	+
Nitzschia sociabilis Hustedt	BAC	+	
Nitzschia subacicularis Hustedt	BAC	+	
Nitzschia supralitorea Lange-Bertalot	BAC	+	
Nostoc Vaucher ex Bornet & Flahault	CYA	+	+
Ochromonas Wyssotski	CHR	+	+
Oedogonium Link ex Hirn	CHL	+	

continuing...

...continued	Algal group	1991-2011	2009-2011
Oocystis lacustris Chodat	CHL	+	+
Oocystis marssonii Lemmermann	CHL	+	+
Oocystis Nägeli ex A. Braun	CHL	+	+
Ophiocytium capitatum Wolle	XAN	+	+
Ophiocytium Nägeli	XAN	+	
Oscillatoria princeps Vaucher	CYA	+	
Oscillatoria Vaucher Ex Gomont	CYA	+	+
Pandorina Bory de Saint Vincent	CHL	+	+
Pandorina morum (O.F. Müller) Bory de Saint Vincent	CHL	+	+
Paradoxia multiseta Sirvenko	CHL	+	
Paulschulzia Skuja	CHL	+	
Pediastrum angulosum Ehrenberg ex Meneghini	CHL	+	
Pediastrum biradiatum Meyen	CHL	+	+
Pediastrum biradiatum var. *longicornutum* Gutwinski	CHL	+	+
Pediastrum boryanum (Turpin) Meneghini	CHL	+	+
Pediastrum duplex Meyen	CHL	+	+
Pediastrum Meyen	CHL	+	+
Pediastrum privum (Printz) Hegewald	CHL	+	+
Pediastrum simplex Meyen	CHL	+	+
Pediastrum tetras (Ehrenberg) Ralfs	CHL	+	+
Pediastrum duplex var. *gracillimum* West & G.S. West	CHL	+	
Pediastrum simplex var. *biwaense* Fukushima	CHL	+	+
Pediastrum simplex var. *echinulatum* Wittrock	CHL	+	+
Pediastrum simplex var. *sturmii* (Reinsch) Wolle	CHL	+	
Peranema Dujardin	EUG	+	
Peridiniopsis corillionii M. Leitao, L. Ten-Hage, G. Mascarell, & A. Couté	DIN	+	+
Peridiniopsis Lemmermann	DIN	+	+
Peridinium Ehrenberg	DIN	+	+
Phacotus Perty	CHL	+	+
Phacus Dujardin	EUG	+	+
Phacus longicauda (Ehrenberg) Dujardin	EUG	+	+
Phacus pusillus Lemmermann	EUG	+	
Phacus pyrum (Ehrenberg) Stein	EUG	+	
Phacus suecicus Lemmermann	EUG	+	
Phormidium cf. *chlorinum* (Kützing ex Gomont) Umezaki & Watanabe	CYA	+	
Phormidium granulatum (N.L. Gardner) Anagnostidis	CYA	+	
Phormidium Kützing ex Gomont	CYA	+	+
Phormidium tenue (C. Agardh ex Gomont) Anagnostidis & Komárek	CYA	+	
Pinnularia Ehrenberg	BAC	+	+
Pinnularia lundii Hustedt	BAC	+	+
Pinnularia microstauron (Ehrenberg) Cleve	BAC	+	
Pinnularia rupestris Hantzsch	BAC	+	+
Pinnularia subgibba Krammer	BAC	+	
Plagioselmis Butcher ex G. Novarino, I.A.N. Lucas & S. Morrall	CRY	+	+
Plagioselmis lacustris (Pascher & Ruttner) P. Javornick	CRY	+	+
Plagioselmis nannoplanctica (H. Skuja) G. Novarino, I.A.N. Lucas & S. Morrall	CRY	+	+
Planctonema lauterbornii Schmidle	ULO	+	
Planctonema Schmidle	ULO	+	
Planktolyngbya Anagnostidis & Komárek	CYA	+	+
Planktolyngbya limnetica (Lemmermann) Komárková-Legnerová & Cronberg	CYA	+	+
Planktolyngbya subtilis (W. West) Anagnostidis & Komárek	CYA	+	
Planktosphaeria gelatinosa G.M. Smith	CHL	+	+
Planktothrix agardhii (Gomont) Anagnostidis & Komárek	CYA	+	+
Planktothrix Anagnostidis & Komárek	CYA	+	
Planothidium frequentissimum (Lange-Bertalot) Lange-Bertalot	BAC	+	+
Pleodorina californica W.R. Shaw	CHL	+	
Polyedriopsis Schmidle	CHL	+	
Polyedriopsis spinulosa (Schmidle) Schmidle	CHL	+	+
Prasiola (C. Agardh) Meneghini	CHL	+	+
Pseudanabaena amphigranulata (Van Goor) Anagnostidis	CYA	+	
Pseudanabaena catenata Lauterborn	CYA	+	
Pseudanabaena Lauterborn	CYA	+	+
Pseudanabaena limnetica (Lemmermann) Komárek	CYA	+	+
Pseudanabaena mucicola (Naumann et Huber-Pestalozzi) Schwabe	CYA	+	+
Pseudanabaena tenuis Koppe	CYA	+	
Pseudodidymocystis fina (Komárek) E. Hegewald & Deason	CHL	+	+
Pseudodidymocystis planctonica (Korshikov) Hegewald et Deason	CHL	+	+
Pseudokephyrion conicum (Schiller) Schmide	CHR	+	+
Pseudokephyrion cyclindricum (Lackey) Bourrelly	CHR	+	
Pseudokephyrion Pascher	CHR	+	+
Pseudokirchneriella danubiana (F. Hindák) F. Hindák	CHL	+	
Pseudokirchneriella elongata (G.M. Smith) F. Hindák	CHL	+	
Pseudoquadrigula E.N. Lacoste de Díaz	CHL	+	
Pseudostaurastrum Chodat	XAN	+	+
Pseudostaurosira subsalina (Hustedt) Morales	BAC	+	
Pseudotetrastrum Hindák	CHL	+	
Pteromonas aculeata Lemmermann	CHL	+	+
Pteromonas angulosa Lemmermann	CHL	+	+
Pteromonas cordiformis Lemmermann	CHL	+	+
Pteromonas Seligo	CHL	+	+
Puncticulata radiosa (Grunow) Håkansson	BAC	+	+
Pyramimonas Schmarda	CHL	+	

continuing...

...continued	Algal group	1991-2011	2009-2011
Quadricoccus ellipticus Hortobagyi	CHL	+	+
Quadricoccus Fott	CHL	+	+
Quadricoccus laevis Fott	CHL	+	+
Quadrigula Printz	CHL	+	
Radiococcus Schmidle	CHL	+	
Raphidiopsis F.E. Fritsch & F. Rich	CYA	+	
Raphidocelis Hindák	CHL	+	+
Raphidocelis mucosa (Korshikov) Komarek	CHL	+	
Reimeria Kociolek & Stoermer	BAC	+	+
Reimeria sinuata (Gregory) Kociolek & Stoermer	BAC	+	
Reimeria uniseriata S.E. Sala, J.M. Guerrero & M.E. Ferrario	BAC	+	
Rhipidodendron F. Stein	CHR	+	
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot	BAC	+	+
Rhopalodia gibba (Ehrenberg) O.F. Müller	BAC	+	+
Romeria Koczwara	CYA	+	+
Salpingoeca H.J. Clark	CHR	+	+
Scenedesmus abundans (Kirchner) Chodat	CHL	+	
Scenedesmus aculeolatus Reinsch	CHL	+	
Scenedesmus armatus (R. Chodat) R. Chodat	CHL	+	
Scenedesmus bellospinosus Hortobagyi	CHL	+	
Scenedesmus bicaudatus Dedusenko	CHL	+	
Scenedesmus denticulatus Lagerheim	CHL	+	
Scenedesmus disciformis (Chodat) Fott & Komárek	CHL	+	
Scenedesmus dispar (Brébisson) Rabenhorst	CHL	+	
Scenedesmus ecornis (Ehrenberg) Chodat	CHL	+	
Scenedesmus gr. *Abundantes/ Spinosi* Meyen	CHL	+	+
Scenedesmus gr. *Acutodesmus* Meyen	CHL	+	+
Scenedesmus gr. *Armati* Meyen	CHL	+	+
Scenedesmus gr. *Desmodesmus* Meyen	CHL	+	+
Scenedesmus gr. *Scenedesmus sensu stricto* Meyen	CHL	+	+
Scenedesmus granulatus West & G.S. West	CHL	+	
Scenedesmus gutwinskii Chodat	CHL	+	
Scenedesmus insignis (West et G.S. West) Chodat	CHL	+	
Scenedesmus longispina Chodat	CHL	+	
Scenedesmus Meyen	CHL	+	+
Scenedesmus obtusus Meyen	CHL	+	
Scenedesmus pseudoopoliensis Hortobagyi	CHL	+	
Scenedesmus quadricauda (Turpin) Brébisson	CHL	+	
Scenedesmus smithii Teiling	CHL	+	
Scenedesmus spinosus Chodat	CHL	+	
Scenedesmus acuminatus (Lagerheim) Chodat	CHL		
Scenedesmus acuminatus (Lagerheim) Chodat	CHL	+	
Scenedesmus acutus Meyen	CHL	+	
Scenedesmus linearis Komárek	CHL	+	
Schroederia Lemmermann	CHL	+	+
Schroederia robusta Korshikov	CHL	+	
Schroederia setigera (Schroeder) Lemmermann	CHL	+	+
Schroederia spiralis (Printz) Korshikov	CHL	+	+
Selenastrum Reinsch	CHL	+	
Selenodictyon G. Uherkovich et A. Schmidt	CHL	+	
Selenodictyum brasiliense G. Uherkovich et A. Schmidt	CHL	+	
Sellaphora bacillum (Ehrenberg) D.G. Mann	BAC	+	+
Sellaphora Mereschowsky	BAC	+	+
Sellaphora pupula (Kützing) Mereschkowksy	BAC	+	+
Sellaphora seminulum (Grunow) D.G. Mann	BAC	+	+
Siderocelis Naumann (Fott)	CHL	+	+
Siderocelis ornata (Fott) Fott	CHL	+	+
Skeletonema potamos (Weber) Hasle	BAC	+	+
Snowella Elenkin	CYA	+	+
Snowella lacustris (Chodat) Komárek et Hindák	CYA	+	+
Spermatozopsis exsultans Korshikov	CHL	+	+
Sphaerellopsis Korshikov	CHL	+	
Sphaerobotrys Butcher	CHL	+	
Sphaerobotrys fluviatilis Butcher	CHL	+	
Sphaerocystis Chodat	CHL	+	+
Sphaerocystis planctonica (Korshikov) Bourrelly	CHL	+	+
Spirogyra Link In C.G. Nees	ZYG	+	+
Spondylosium Brébisson ex Kützing	ZYG	+	
Staurastrum Meyen Ex J. Ralfs	ZYG	+	+
Staurodesmus Teiling	ZYG	+	+
Stauroneis Ehrenberg	BAC	+	
Staurosira construens var. *binodis* (Ehrenberg) Hamilton	BAC	+	
Staurosira venter (Ehrenberg) Cleve & Moeller	BAC	+	
Stelexomonas dichotoma Lackey	CHR	+	
Stephanodiscus Ehrenberg	BAC	+	
Stephanodiscus hantzschii Grunow	BAC	+	+
Stephanodiscus hantzschii var. *tenuis* (Hustedt) Håkansson et Locker	BAC	+	+
Stephanodiscus minutulus (Kützing) Cleve & Möller	BAC	+	+
Stephanodiscus neoastraea Håkansson & Hickel	BAC	+	
Stephanodiscus parvus Stoermer & Håkansson	BAC	+	
Stichococcus Nägeli	CHL	+	
Strombomonas Deflandre	EUG	+	+

continuing...

...continued	Algal group	1991-2011	2009-2011
Surirella angusta Kützing	BAC	+	+
Surirella brebissonii Krammer & Lange-Bertalot	BAC	+	+
Surirella linearis W.M. Smith	BAC	+	+
Surirella minuta Brébisson in Kützing	BAC	+	
Surirella ovalis Brébisson	BAC	+	
Surirella solea (Brébisson) Brébisson	BAC	+	
Surirella Turpin	BAC	+	+
Syncrypta Ehrenberg	CHR	+	
Synechococcus capitatus A.E. Bailey-Watts & J. Komárek	CYA	+	+
Synechococcus elongatus (Nägeli) Nägeli	CYA	+	
Synechococcus Nägeli	CYA	+	+
Synura Ehrenberg	CHR	+	+
Synura uvella Ehrenberg	CHR	+	+
Tabellaria C.G. Ehrenberg ex F.T. Kützing	BAC	+	
Tabellaria flocculosa (Roth) Kützing	BAC	+	
Teilingia Bourrelly	ZYG	+	
Tetrabaena socialis (Dujardin) H. Nozaki & M. Itoh	CHL	+	
Tetrachlorella alternans (G.M. Smith) Korshikov	CHL	+	+
Tetrachlorella Korshikov	CHL	+	+
Tetradesmus G.M. Smith	CHL	+	
Tetraedriella Pascher	XAN	+	+
Tetraedriella spinigera Skuja	XAN	+	
Tetraedron caudatum (Corda) Hansgirg	CHL	+	+
Tetraedron incus (Teiling) G.M. Smith	CHL	+	+
Tetraedron Kützing	CHL	+	+
Tetraedron minimum (A. Braun) Hansgirg	CHL	+	+
Tetraedron regulare Kützing	CHL	+	+
Tetraedron triangulare Korshikov	CHL	+	+
Tetrallantos lagerheimii Teiling	CHL	+	
Tetraplektron Fott	XAN	+	+
Tetraselmis F. Stein	CHL	+	+
Tetrastrum Chodat	CHL	+	+
Tetrastrum elegans Playfair	CHL	+	+
Tetrastrum heteracanthum (Nordstedt) Chodat	CHL	+	+
Tetrastrum punctatum (Schmidle) Ahlstrom & Tiffany	CHL	+	+
Tetrastrum staurogeniaeforme (Schroeder) Lemmermann	CHL	+	+
Tetrastrum triacanthum Korshikov	CHL	+	+
Tetrastrum triangulare (Chodat) Komárek	CHL	+	+
Thalassiosira bramaputrae (Ehrenberg) Håkansson & Locker	BAC	+	+
Thalassiosira pseudonana Hasle & Heimdal	BAC	+	
Thalassiosira weissflogii (Grunow) Stachura-Suchoples & Williams	BAC	+	
Trachelomonas Ehrenberg	EUG	+	+
Trachelomonas hispida (Perty) F. Stein	EUG	+	+
Trachelomonas volvocina (Ehrenberg) Ehrenberg	EUG	+	+
Trachelomonas volvocinopsis Swirenko	EUG	+	+
Trachydiscus Ettl	XAN	+	+
Trachydiscus sexangulatus Ettl	XAN	+	
Treubaria Bernard	CHL	+	+
Treubaria planctonica (G.M. Smith) Korshikov	CHL	+	
Treubaria quadrispina (G.M. Smith) Fott et Kovácik	CHL	+	
Treubaria setigera (W. Archer) G.M. Smith	CHL	+	
Treubaria triappendiculata Bernard	CHL	+	+
Tribonema Derbes and Solier	XAN	+	
Trochiscia Kützing	CHL	+	
Tryblionella levidensis W. Smith	BAC	+	+
Tychonema Anagnostidis & Komárek	CYA	+	
Ulnaria delicatissima var. *angustissima* (Grunow) Aboal & Silva	BAC	+	+
Ulnaria ulna (Nitzsch) Compère	BAC	+	+
Ulnaria ulna var. *acus* (Kützing) Lange-Bertalot	BAC	+	+
Ulothrix Kützing	ULO	+	+
Urosolenia longiseta (Zacharias) Bukhtiyarova	BAC	+	
Urosolenia Round & Crawford	BAC	+	
Volvulina Playfair	CHL	+	+
Westella botryoides (W.West) De Wild	CHL	+	+
Willea Schmidle	CHL	+	
Woronichinia Elenkin	CYA	+	
Woronichinia naegeliana (Unger) Elenkin	CYA	+	+
Xanthidium Ehrenberg ex Ralfs	XAN	+	+
Total number of taxa		**710**	**440**