Events and calls for input

ESPC4 and PERM5, Vienna, 20-22 June 2022

The 4th European Sustainable Phosphorus Conference (ESPC4) will be the biggest phosphorus stakeholder meeting globally for 4 years (since ESPC3 Helsinki, with 300 participants from 30 countries, see SCOPE Newsletter n°127).

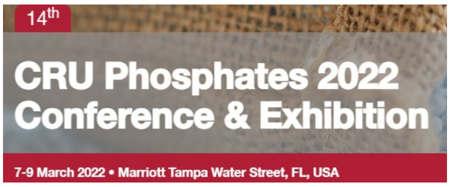
ESPC4, Monday 20th and Tuesday 21st June 2022, will be followed by **PERM5, the 5th Phosphorus in Europe Research Meeting**, Wednesday 22nd June 2022 (summary of PERM4, June 2021, online, coming soon here).

ESPC4 will include a **Nutrient Recovery Technology Fair**, with stands, presentations and possibility to meet technology suppliers presented in the ESPP-DPP-NNP Catalogue of Nutrient Recovery Technologies, currently being updated (see below).

ESPC4 - PERM5 will be both physical and accessible online.
Updated outline programmes of ESPC4 and PERM5, and a call for abstracts for presentations and posters for ESPC4 are now online *https://phosphorusplatform.eu/espc4*

Phosphates 2022

7 – 9 March 2022, Tampa, Florida. This is "the" phosphate industry professional conference, with over 400 participants.



Phosphates 2022 will be in-person (with an online option), and a major chance to re-connect with the phosphate industry, from mining through rock and acid processing, to fertilisers, feed phosphates and technical phosphates. The two-day conference will have a dual agenda: commercial - market – regulatory, and technical and industry operational.

CRU Phosphates 2022: https://events.crugroup.com/phosphates/home

Baltic Nutrient Recycling Strategy implementation webinar

Monday 22 November 2021, 9h00 – 12h45 CET. This webinar will address challenges and opportunities in implementation of the HELCOM Nutrient Recycling Strategy, with the Finland Ministry of the Environment, UBA Germany, Lithuania Ministry for Agriculture, HELCOM, European Commission DG Agriculture and DG GROW, Swedish Water, etc.

Webinar "PA Nutri and PA Bioeconomy webinar on the implementation of the HELCOM Baltic Sea Regional Nutrient Recycling Strategy", Monday 22 November 2021, 9h00 – 12h45 CET, registration HERE.

Update and new entries for Catalogue of Nutrient Recovery Technologies

ESPP, DPP and NNP are updating the Catalogue of Nutrient Recovery Technologies summarising processes for recovery of nutrients from sewage, manure or other sources. Information is invited on technologies to be added. To be included, technologies should be operational or demonstrated at full-scale or pilot scale, and should recover phosphorus, nitrogen, potassium and/or micro-nutrients. The catalogue provides practical data and information on: technology supplier(s) (website, contact), process input materials (sewage sludge, ash, manure, etc.), output products (nutrient content, organic carbon content and other properties), process description (in particular indicating fate of contaminants), current operating status (number and capacity of plants operating, capacity of pilots and duration of continuous operation) and photos of installations.

***To include further technologies in the Catalogue**: send information, as specified above and if possible in the format of (column titles) the Catalogue as currently online here to info@phosphorusplatform.eu*
ESPP - DPP - NNP Catalogue of Nutrient Recovery Technologies: http://www.phosphorusplatform.eu/p-recovery-technology-inventory

Call for abstracts: “Legacy Phosphorus” in agricultural soils

ESPP, with BOKU, are organising a webinar 2nd February 2022, 13h – 17h CET, on relationships between draw-down of “Legacy P”, crop yield and P losses, see below. Abstracts are invited by 30th November 2021

Webinar website, call for abstracts, registration www.phosphorusplatform.eu/LegacyP

Call for abstracts: ESPC4, Vienna 2022

A new call for abstracts for presentations and posters is now open for the 4th European Sustainable Phosphorus Conference, Vienna 20-22 June 2022. Deadline 30th November 2021. Proposed presentations should address the conference parallel session themes (see updated programme here): policy tools and business models, climate change links to phosphorus management, new fertilisers for nutrient sustainability, P-recycling R&D and new technologies, regions in action for phosphorus sustainability. Posters can address any theme relating to phosphorus sustainability. Abstract submission instructions are on the conference website here.

ESPC4 – PERM5 website: https://phosphorusplatform.eu/espc4

Call for information on P flows and resources for EU Critical Raw Material assessment

The EU-funded SCRREEN2 project has launched the re-assessment of materials on the EU’s Critical Raw Materials (CRM) list, and is looking for information on phosphorus resources, uses, flows, and LCAs.

The European Commission published the 4th version of the Critical Raw Materials List (CRM) in September 2020. The CRM list currently includes 30 materials, including both Phosphate Rock (in effect: phosphorus in any form: rock, fertiliser, chemicals, biological materials, etc.) and “Phosphorus” (in effect: P_4 and derivatives).

The EU is now supporting the “SCRREEN2” project with 3 million € EU funding (following on from SCRREEN1, which also received 3 million € EU funding) led by the French atomic energy agency CEA, to develop information and an expert network to support the EU decision making process for critical raw materials.

SCRREEN will update the European Commission’s “Fact Sheets” (September 2020). In particular, a first EU experts’ workshop on 22nd October 2021 (ESPP participated) recognised the need to separate the Fact Sheets for “Phosphate Rock” (all forms of P) and “Phosphorus” (P_4 and derivates), which are currently confused into one.

For “Phosphate Rock” (which in effect concerns all uses and flows of P in any form, mineral or organic/biological: mined phosphate rock, secondary P resources, animal feed and food, etc.), **please provide information (data, publications or links to studies, reports, etc.) as follows:**

- Recent studies on potential secondary P resources in Europe (quantities, flows, etc..)
- Recent papers or studies on P-rock resources, P supply geopolitics
- Recent overviews or studies on P-uses, markets and trade, in Europe or worldwide (phosphate rock and P-acid, fertilisers, P in animal fodder and feeds, P in food, industrial uses, etc..)
- LCAs of P-recovery, P-fertilisers, other P products or uses
- comments on the 2020 Fact Sheets (“Phosphate Rock and Phosphorus”, pages 525-546).

For the second Critical Raw Material, P4 and derivates (CRM “Phosphorus”), ESPP has indicated to SCRREEN that full up-to-date information was developed in the joint workshop organised by ESPP and the European Commission on 9th July 2020 (with participation of nearly all concerned companies in Europe) presented in detail (after technical validation) in ESPP’s SCOPE Newsletter n°136 and then used in the EU JRC MSA (Material System Analysis) for P_4 published in 2021 (http://dx.doi.org/10.2760/677981)

Please send your input to info@phosphorusplatform.eu and we will input to the SCRREEN process, for which ESPP is a registered expert.

EU consultations and tenders

EU public consultations open

Air quality. Revision of EU rules**. Open to 16th December 2021.** Consultation**.**

Pharmaceuticals: Revision of the EU general pharmaceuticals legislation. Open to 21st December 2021. Consultation.

EU tender on fertilising products technical documentation

The European Commission has published a tender (low value contracts procedure) to develop a 'Guidance Document' for companies placing products on the market, to provide information on technical documentation for EU Fertilising Products. **Deadline 12 November 2021** for submission of interest.

"Study in support of a guidance document for the elaboration of the technical documentation of EU fertilising products"
https://ec.europa.eu/growth/low-value-contracts-procedures_en

Nutrient recycling

Recycled nutrients in Organic Farming

FiBL has published a "reflections" paper on the acceptability of recycled phosphorus fertilisers in European Organic Agriculture, providing possible criteria for which recycled nutrient products are likely to be accepted. The paper "provides only the personal opinion of the authors" but is coherent with discussions ongoing in the Organic Farming movement and via the EU-funded project RELACS (see ESPP eNews n°53). The paper takes as starting point Annex II of EU Regulation 2021/1165, that is the updated list of products and substances authorised in Organic Production in the EU (public consultation, April 2021, see ESPP eNews n°53).

This paper addresses only recovered phosphorus products, but notes that other recycled plant nutrients (e.g. nitrogen) could be discussed in the future. ESPP also notes that Regulation 2021/1165 already authorises (subject to EU fertilisers regulation contaminant limits), be they recycled or otherwise, "Inorganic micronutrient fertilisers" (e.g. iron) and "Elemental sulphur".

The FiBL paper notes that certain input materials are already considered acceptable in this Regulation: manure (but **NOT manure from factory farming**), food industry wastes, source separated household organic waste, bones. Sewage sludge is currently not listed, but the EU expert committee for Organic Farming (EGTOP) has given positive opinions on struvite and calcined phosphates (both) recovered from municipal sewage, and more widely on all products from municipal sewage if the production process ensures pathogen safety and minimises contaminants (all three in EGTOP Opinion of 2/2/2016).

A key point indicated by FiBL is that the EU Organic Farming regulation requires only "**low solubility**" mineral fertilisers, and the paper suggests that a criterion could be < 25% P water solubility.

Use of nitric acid in the recovery process is questioned, because the Organic Farming movement would regard this as "synthetic nitrogen". The use of other synthetic reagents in recovery processes is considered acceptable, with preference to natural origin materials and with health and environmental impacts avoided.

The paper suggests that, for recycled fertilisers, the contaminant limits of the EU Fertilising Products Regulation should be considered as providing adequate environmental protection, but that products with low contaminant levels should be preferred, and lower contaminant levels could be fixed in the EU Organic Farming Regulation.

This document provides a valuable starting point to identify which recycled phosphorus products can be appropriately proposed for inclusion into the Organic Farming Regulation and to support such proposals. ESPP will now propose to our members, to wider stakeholders and to the Organic Farming movement (IFOAM, RELACS, FiBL) to define a short list of corresponding recycled P products and to develop dossiers for submission (via Member States) for consideration by the European Commission (DG AGRI) and by EGTOP.

"Reflections on the acceptability of recycled P fertilisers for European organic agriculture", 29 September 2021, V. Leschenne, B. Speiser, FiBL
https://www.betriebsmittelliste.ch/fileadmin/bml-ch/documents/stellungnahmen/Recycled_P_fertilisers_v2_Sept_2021.pdf
FiBL is the Swiss Organic Farming research institute.

EGTOP Opinion of 2/2/2016 on recovered struvite, calcined phosphates and products from municipal sewage
https://ec.europa.eu/agriculture/organic/eu-policy/expert-advice/documents/final-reports/final-report-egtop-on-fertilizers-2_en.pdf

EU Organic Farming inputs list Regulation 2021/1126 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1165&from=EN

Updated overview of phosphorus recovery and/or recycling facilities

Both the inventory list of operating full-scale P -recovery / -recycling installations worldwide (Christian Kabbe, P-REX Environment) and the ESPP – DPP - NNP catalogue of nutrient recycling technologies are updated online here. The inventory list has been fully updated, and indicates some 120 installations operating worldwide, specifying the technology supplier, the location, operating since, the recovered phosphate material/product and the annual tonnage of product output. The technology catalogue is in the process of updating (see call for input above) and has been updated to already include information received.

Online here: https://www.phosphorusplatform.eu/activities/p-recovery-technology-inventory
Information for updates of the inventory and catalogue are welcome: to info@phosphorusplatform.eu

Swiss update report on P-recovery technologies

The Swiss Federal Environment Office published in 2017 an overview report comparing 20 P-recovery technologies. A 2019 update compares 8 technologies adapted to the Swiss P-recovery obligation: ExtraPhos (Budenheim), EuPhoRe*, Pyrophos*, ZAB (Glatt Phos4Green)*, CleanMAP (EasyMining)*, EcoPhos (now Prayon), Phos4Life (ZAR – Técnicas Reunidas), Tetraphos (Remondis) [* = not covered in the 2017 report, summarised in ESPP eNews n°12]. The eight technologies are assessed on the basis of 13 criteria, in three thematic groups: Closing the Loop (input flexibility, degree of recovery), Environment (chemical use, energy, waste), Product (P content, plant availability, pollutant content, product yield). A third update of the report is currently under preparation and is expected to be published in 2022.

"Technologien zur Phosphor-Rückgewinnung. Bewertung von Technologien für die Schweiz bezogen auf den Entwicklungsstand", EBP for BAFU (Swiss Federal Office for the Environment), April 2019, in German LINK.
The Swiss Government has also published (2020) a document on implementation of the national P-recovery regulation, see ESPP SCOPE Newsletter n°141.

LCA and greenhouse gas benefits of recycled nitrogen

Energy use and greenhouse emissions were compared using several LCA methods, calculated according to field trial crop yields, and modelled field N losses. The recycled N fertilisers tested were digestate from anaerobic digestion of wastes, meat and bone meal (combined with oat hulls, chicken manure and vinasse) and ammonium sulphate from nylon product. For the mineral fertiliser, data for calcium ammonium nitrate from Ecoinvent was used. The authors note that results vary considerably depending on whether recycled raw materials are allocated as "waste" or "by-product" (i.e. with economic value allocation). LCAs using both ISO 14040:2006 and European Commission Environmental Footprint project methods were calculated. Field trials were carried out using the three recycled N fertilisers, mineral fertiliser and no fertiliser (control), using spring sown oats near Helsinki, Finland. Yields with the recycled fertilisers were not statistically significantly different from yields with the mineral fertiliser (whereas control yield was significantly lower than all fertiliser treatments), but nonetheless the somewhat lower average yields with the recycled fertilisers were used in the LCA calculation (-7% to -15%). Atmospheric and leaching N emissions from fields were estimated based on N inputs, crop yield and coefficients for organic (digestate, meal and bone meal) or mineral (mineral fertiliser, ammonium sulphate) N fertilisers. Energy use and GHG emissions were lower for the recycled N fertilisers than for mineral fertilisers, whatever the calculation method, with differences between the recycled N fertilisers varying depending on the calculation method.

"Carbon footprint and energy use of recycled fertilizers in arable Farming", V. Kyttä et al., J. Cleaner Production, Volume 287, 10 March 2021, 125063 DOI.

Pathogens in struvite from poultry manure digestate

Struvite precipitated in batch lab tests from poultry slurry digestate (mesophilic, 37°C) showed significant levels of foodborne pathogens, depending on precipitation pH and post-treatment: *E. coli, Streptococcus, Clostridium*. The batch struvite precipitation tests involved 40 minutes reaction time and 30 minutes settling, at pH 9, 10 or 11. The struvite was settled and recovered by filtration, but not washed. Pathogen levels in the struvite were significant, but lower with increasing pH. *E. coli* was 10-40% higher than the EU STRUBIAS criteria limit (for precipitated phosphates) of 1 000 CFU/g when struvite was precipitated at pH9, but lower at pH 10 or 11. Pathogen inactivation technologies were tested on the recovered struvite: drying (35 – 55 °C), high humidity hot air impingement blanching (HHAIB, 110 – 130 °C), cold plasma (30 – 60 seconds). These technologies significantly reduced pathogens to "very low" levels, lower than natural soil levels. They did not modify the struvite crystal structure, but they did reduce metal-oxygen functional group abundance, and treatments > 55°C would lead to ammonia loss. This study confirms the need for further investigation of pathogens in recovered struvites and approaches to reduce these, including in continuous precipitation installations (rather than batch tests), as well as testing of washing and low temperature drying – storage for pathogen reduction. ESPP notes that the anaerobic digestion, depending on operating temperature and conditions, can also ensure sanitary safety of the digestate, upstream of the struvite recovery.

"Quantitative characterization and effective inactivation of biological hazards in struvite recovered from digested poultry slurry", A. Muhmood et al., Water Research 204 (2021) 117659 DOI.

Fertilisers from spent fire extinguisher power

End-of-life powder from ABC fire extinguishers, containing MAP* and ammonium sulphate was combined with compost (of municipal solid organic waste) and fibres to produce pellets. Fire extinguishers must be emptied and the powder renewed every three years. The spent powder is very fine (90% of particles < 0.25 mm, 40% < 0.04 mm) so posing risks of inhalation and accidental pollution. The powder contains 40-50% MAP* and additives for flow / anti-caking, colour or water repellence (in particular, silicones). After removal of these additives (using specific technology under patenting), the spent extinguisher powder was combined with dried compost and fibres (wood chips or Jatropha seed cake), in five different combinations, each with 10% spent extinguisher powder, in a rotary 6 mm die pressing machine (using no heat or additives, only mechanical pressure). Lignin in the wood chips showed to be an effective binder and pellets showed mechanical resistance (necessary for handling) and water uptake (necessary to render nutrients plant available) compatible with agricultural use. Further work is needed to assess the fertiliser value (especially crop nutrient availability) of the pellets, to test their handling and resistance in agricultural equipment (verify no dusting) and to ensure no risk of dust release to the environment or inhalation during spent extinguisher powder preparation, handling and pelletising.

** MAP = mono ammonium phosphate*
Work carried out as part of the "FIRECOMPOST" project, funded by the Calabria Region POR FESR-FSE 2014-2020
"Pelletization of Compost from Different Mixtures with the Addition of Exhausted Extinguishing Powders", S. Papandrea et al., Agronomy 2021, 11, 1357, DOI.

P-fertiliser and lithium recovery from batteries

Lithium iron phosphate (LFP) batteries represent over 1/3 of the world market for lithium ion batteries. A process to recover lithium and a phosphate fertiliser is presented. Currently LFP batteries are difficult to recycle: regeneration leads to battery quality deterioration and strong acid dissolution results in large quantities of wastewater and loss of the phosphorus. In this lab study, the batteries were shredded, then the cathode material separated (from aluminium foils) by ultrasound in 0.4 mol NaOH. The extracted cathode material is then reacted with $Na_2S_2O_8$ to recover lithium sulphate solution (for lithium recovery). The remaining material is then reacted with Na_2S resulting in a phosphate solution (HPO_4 / H_2PO_4), which is then reacted with urea, N,N'-methylenebisacrylamide, acrylic acid and potassium persulphate, then dried. This results in an N-P-K slow-release fertiliser material, containing approx. 18%N, 6.5%P, and some K. Recovery of both lithium and phosphorus > 99% could be achieved. This recovered fertiliser material was tested in pot trials with maize, showing significantly increased growth compared to control (no comparison was made to commercial fertiliser). Tested heavy metals (Cd, As, Pb, Cr, Hg) were below detection limit in the recovered N-P-K fertiliser, as were iron and sulphur. Residues from the process were mainly $NaFeS_2$ (used as a catalyst for degradation of methylene blue and indigo carmine) and Na_2SO_4 (a commodity chemical). The authors conclude that the process would offer significantly better profitability than recovery of lithium only (lithium is <2% of LFP battery weight, whereas phosphorus (as P) is c. 17%).

"Recycling phosphorus from spent $LiFePO_4$ battery for multifunctional slow-release fertilizer preparation and simultaneous recovery of Lithium", H-H. Yue et al., Chemical Engineering Journal 426 (2021) 131311, DOI.

Sewage sludge incineration ash (SSIA) shows limited P fertiliser efficiency

Pot trials of twelve SSIAs show P effectiveness 5% - 46% compared to mineral P fertiliser TSP (comparable to 24% for phosphate rock). NAC P-solubility only explained around 50% of variation in effectiveness. Random forest analysis of the three parameters oxalate extractable aluminium, phosphorus and iron was the best indicator of P-fertiliser effectiveness, predicting c. 80% of variability. The greenhouse pot trials used rye grass grown for twelve weeks, in two soils (clay and sandy loam), pH 6 – 7. The SSIAs came from 11 municipal sewage sludge mono-incinerators in Canada and the USA, and one agri-food processing plant incinerator, with several different types of incinerator, operating at different temperatures (8 out of 12 at lower temperatures than the EU IED requirement of 850°C). Ten of the eleven municipal plants used iron and/or aluminium coagulants. Data for P, Fe, Al and other minerals in the twelve ashes are provided, as are data for inorganic contaminants. The authors conclude that levels of heavy metals in the SSIAs "do not appear to be of concern for agricultural use", whereas six of the eleven municipal sewage SSIAs show copper levels higher than the new EU Fertilising Products Regulation (FPR) 2019/1009 limit of 600 mgCu/kg limit for mineral fertilisers, two show zinc levels higher than the FPR limit (1500 mgZn/kg) and three show lead levels higher than the FPR limit (120 mgPb/kg).

"Assessing and predicting phosphorus phytoavailability from sludge incineration ashes", C-A. Joseph et al., Chemosphere 288 (2022) 132498 DOI and "Influence of Sludge Incineration Ash on Ryegrass Growth and Soil Phosphorus Status", C-A. Joseph et al., Pedosphere 29(1): 70–81, 2019 DOI. These publications present the same study. The study was part funded by the participating incinerators.

Potential for P-recovery from meat processing

Data from a meat processing company and lab tests suggest that c. 13 ktP/y could be recovered from meat processing in Poland, by calcining, to high quality hydroxyapatite (calcium phosphate, human food or animal feed grade). ESPP notes that currently this recovered phosphate cannot be used in Europe because the European Commission DG SANTE and EFSA have not yet defined an Animal By Products Regulation 'End Point'. The experimental work tested calcining (at 600°C – 950°C) of bone sludge and of bone waste (from pigs and cattle). Bone sludge is produced by hydrolysis of bones, to remove proteins, and showed 12 – 16% P-content and 12 – 20% organics. After calcining, hydroxyapatite (mainly $Ca_5(PO_4)_3OH$) was produced with c. 17% P, low levels of silicon and iron, aluminium, cadmium and manganese considerably lower than in phosphate rock. The authors estimate that waste from slaughterhouses and meat processing in Poland is around 230 000 t/y, that is c. 24% of the meat processed, and that some 70 000 t/y of hydroxyapatite could be recovered, worth c. 10 million €/y based on the price of phosphate rock.

"Quantification of material recovery from meat waste incineration – An approach to an updated food waste hierarchy", Z. Kowalski et al., J. Hazardous Materials 416 (2021) 126021 DOI.

Impacts of ferric on anaerobic digestion

Lab tests of five forms of ferric phosphate in sewage sludge fermentation suggest that amorphous iron(III) phosphate reduced to vivianite, releasing soluble P. Most forms inhibited VFA production, and so potentially methane production. Five forms of iron(III) phosphate which can be found in sewage sludge after use of ferric salts for P-removal were tested: anhydrous ferric-phosphate (FePO4), ferric-phosphate dihydrate ($FePO_4{\cdot}2H_2O$), ferric-phosphate trihydrate ($FePO_4{\cdot}3H_2O$), ferric-phosphate tetrahydrate ($FePO_4{\cdot}4H_2O$), Giniite ($Fe_5(PO_4)_4(OH)3{\cdot}2H_2O$). The ferric phosphates were added to WAS sludge from a laboratory anaerobic-anoxic-oxic (AAO) reactor at 2.6 mmol Fe/g VSS in 600 ml bottles, air was removed, then the bottles were closed and fermented in a shaker at 35°C for 7 days. All the ferric [i.e. Fe(III)] phosphates except Giniite (that is, all the $FePO_4{\cdot}nH_2O$ ferric phosphates, n=0-4) released soluble P during fermentation, due to reduction to Fe(II) phosphate, with the reduction rate of hexagonal FePO4 being highest. All the Fe(III) phosphates had negative impacts on fermentation of sludge, reducing specific hydrolysis rate constant and volatile fatty acid yield (VFA) by around -40% for amorphous ferric-phosphate trihydrate (this confirms results from Kim and Chung 2015). ESPP comment: overall this study suggests that further work is needed on how iron dosing may impact anaerobic digestion, depending on different forms of iron phosphate present, but it is not clear how sewage works or digester operators can influence the forms of iron phosphate.

"Effects of ferric-phosphate forms on phosphorus release and the performance of anaerobic fermentation of waste activated sludge", Z. Zhang et al., Bioresource Technology 323 (2021) 124622 DOI.

Eutrophication and nutrient losses

Wisconsin's nutrient pollution trading system

Analysis of the three market-like phosphorus credit programmes, providing opportunities for reduced P discharge compliance costs for funding of reduction of diffuse (agricultural) P losses, in the State of Wisconsin (USA). 84% of US phosphorus pollution is from diffuse "non-point" sources (mainly agriculture). Point sources are highly regulated through water quality permits whereas policy on non-point sources is incentive or voluntary. The US EPA formalised its policy for guidance water quality trading in 2003. Wisconsin enacted restrictive numeric water quality standards for P in 2010 (ambient P of 0.015 - 0.1 mg/L), and shortly after launched three P credit programmes. The three components of Wisconsin's Water Quality Trading Programme for phosphorus (1) enables permitted point sources to purchase discharge credits from other point sources or from (non-regulated) non-point sources, (2) allows all nutrient sources in a watershed to coordinate efforts to meet the water body P standard ("Adaptive Management"), and (3) allows small point sources to purchase credits by paying a fixed price in to a fund for agricultural pollution control ("Multi-Discharger Variance"). This has resulted in a significant number of P credit trading transactions. As of mid 2021, more than 140 point sources have participated in these market-like options. Analysis shows that decisions are influenced by stringent water body P standards and credit trades and coordination are more likely in larger municipalities, who show more institutional preparedness for such engagement. The authors conclude that nutrient credit markets move slowly and that the urban – rural stakeholder relationship is critical to uptake.

"Key Elements of Nutrient Credit Markets: An Empirical Investigation of Wisconsin's Market-like Phosphorus Control Policy", Z. Wu thesis University of Wisconsin-Madison 2021 LINK.

Climate change, eutrophication and algal toxins

This book reviews science on links between climate change and marine and freshwater toxins. These are released mainly from "blue-green algae" (cyanobacteria) and which can impact humans e.g. by accumulation in shellfish or fish. Previously unreported toxin events are now occurring including in Europe tetrodotoxin intoxications from shellfish and ostreocin in aerosols on Mediterranean beaches. There are some 2 000 cyanobacteria species identified worldwide, of which 50 are today known to produce natural toxins. Climate change is expected to benefit bloom-forming cyanobacteria, increasing growth rates, with more severe and longer blooms and shifts in geographical distribution, but the impact of climate change on toxin production is likely to be variable (Kelly et al., ch. 5). Climate change impacts (analysed in detail in Reichwaldt et al., ch. 6) include higher temperatures, leading to warmer water (faster algal growth), stratification and evaporation (so increasing nutrient concentrations), increased occurrence of high rainfall events (accentuating nutrient losses to waters, especially after droughts), The authors identify as emerging toxins related to climate change, in particular in the Mediterranean: tetrodotoxin, palytoxin, cyclic imines (gymondimine, spirolides, pinnatoxins), ciguatoxins, brevetoxin. Toxins can impact global food supply, by food safety of fisheries and aquaculture (Carmen Louzao et al., ch. 14): amnesic shellfish poisoning (the toxin domoic acid produced by *Pseudo-nitzschia* is accumulated in shellfish), ciguatera fish poisoning (*Gambierdiscus* produce ciguatoxins, which accumulate or are metabolised to other toxins in fish), diarrheic shellfish poisoning (dinophysistoxins produced by *Dinopysis*), neurotoxic shellfish poisoning (brevotoxins from *Karenia brevis*), palytoxin poisoning (from *Ostreopsis*), paralytic shellfish poisoning (often from *Alexandriuim*), yessotoxin shellfish poisoning, etc. National and international regulations and safety limits for different toxins are listed as well as detection methods (Vilariño et al., ch. 15), underlining the current limitations to detecting and determining toxins, the challenges of adapting to emerging toxins and the need for updated monitoring programmes.

"Climate change and marine and freshwater toxins", L. Botana, M. Carmen Louzao and N. Vilariño editors, 668 pages, 2021 ISBN 978-3-11-062292-8

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