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Pesticide prioritization approaches and limitations in environmental monitoring studies: From Europe to Latin America and the Caribbean

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A R T I C L E I N F O

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A B S T R A C T

Assessment and management of issues related to pesticide residues, such as environmental fate, monitoring and toxicity, are complex and, in many cases, require costly studies. The early establishment of a priority list of pesticides that should be monitored and assigned to a restricted-use policy is an important issue of post-registration Risk Assessment (RA). Various pesticide registration approaches have been adopted by different countries with those from Europe and the USA being the most popular, constituting the major prototypes for registration approaches in other countries. Adoption of pesticide registration and monitoring systems developed in Europe or USA by Latin American and Caribbean countries may underestimate factors affecting the environmental fate and toxicity of pesticides in their own countries. Incentive for this short review was the activities undertaken during the three KNOWPEC workshops held in Costa Rica, Argentina and Bolivia where European pesticide experts met Latin American experience in the form of Costa Rica's exceptional environmental conditions and ecology, Argentina's and Uruguay's soyisation and Bolivia's contrasting climate and agricultural zones. During the parallel activities of the workshop - including scientific presentations, field trips, interviews and meetings among European partners and pesticide stakeholders in Latin America, - the whole pesticide chain (import-export, trade, application, plant protection-efficacy, residues, monitoring, remediation and risk) was studied and clarified. Recently-published chemical prioritization studies were reviewed to consider their use as a tool to support risk assessments. Differences in regional practices are highlighted as regards to the establishment of RA or prioritization strategy in European and Latin American regimes. General guidance of establishing a cost-effective pesticide monitoring scheme in water bodies of Latin America and the Caribbean (LAC) is also proposed. Moreover, we summarize the most important factors that should be taken into consideration for prioritization approaches and categorization used in pesticide environmental monitoring studies. Consideration of current RA approaches and limitations, and pesticide prioritization exercises highlighted in this Commentary could assist in the management of pesticides in Latin America and Caribbean.

1. Pesticide registration and risk assessment in Europe and USA and their limitations

Pesticides are cited as being essential to prevent food shortages in support of an ever-increasing global population (Carvalho, 2006). The inherent toxicity of pesticides and their intentional release into the environment requires significant steps to be taken to ensure that they do not pose an unacceptable risk to the environment or human health.

Abbreviations: AHAW, Panel on Animal Health and Welfare; ANS, Panel on Food Additives and Nutrient Sources Added to Food; BIOHAZ, Panel on Biological Hazards; CEF, Panel on Food Contact Materials, Enzymes, Flavourings and Processing Aids; CONTAM, Panel on Contaminants in the Food Chain; EU, European Union; EFSA, European Food Safety Authority; FEEDAP, Panel on Additives and Products or Substances used in Animal Feed; FIFRA, Federal Insecticide, Fungicide, and Rodenticide Act; FFDCA, Federal Food, Drug, and Cosmetic Act; FOCUS, FOrum for Co-ordination of pesticide fate models and their USe; GM, Genetically Modified; GMO, Panel on Genetically Modified Organisms; KNOWPEC, Knowledge for pesticides control; LAC, Latin America and the Caribbean; LAPRW, Latin American Pesticide Residue Workshop; LOD, Limit of Detection; NDA, Panel on Dietetic Products, Nutrition and Allergies; PLH, Panel on Plant Health; PPR, Panel on Plant Protection Products and their Residues; QSAR, Quantitative Structure-Activity Relationship; RA, Risk Assessment; USA, United States of America; USEPA, United States Environmental Protection Agency; WFD, Water Framework Directive

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This typically includes using models prior to registration to predict concentrations in the environment (exposure) in order to avoid approving compounds that could pose unacceptable environmental or human health risks; the same RA can be used to identify mitigation measures that could be employed to reduce risk to an acceptable level. Although the European Union's (EU) and North American legislation relating to pesticide registration, use, environmental risk, human risk and remediation are among the strictest in the world, because the legislation has to be applied at a national/large-scale, the supporting methodology is, necessarily, somewhat generic and therefore has some limitations, as discussed below.

Environmental RA of pesticides is usually conducted by applying pre-registration methodologies (toxicity tests and fate assessment using predictive models) and post-registration methodologies (toxicity tests and measured concentrations from monitoring studies). However, the risk status (un/acceptable) depends on the methodology utilized, current knowledge, choice of representative most-sensitive organism, environmental quality standards and the policy of each authority. Moreover, risk assessments continue to evolve in light of new knowledge e.g. the toxicity of relevant and non-relevant metabolites, cumulative toxicity, mixtures and the hypersensitive biological effects of extremely low concentrations of some pesticides. Prioritization approaches and hierarchy is another option to categorize the effects and/or occurrence of pesticides according to specific criteria. Pesticide monitoring studies are often underutilized as a means of supporting such prioritization exercises. Categorization of pesticides and receptors (e.g. surface water, groundwater) by giving the appropriate weighting factor to the monitoring results and associated chemometrics, agricultural practices, soil characteristics, weather conditions, landscape, sensitivity of non-target organisms and agroecosystem services/functions is extremely difficult to manage especially when taking into consideration the necessity of ensuring crop production.

The pesticide registration process in the European Union involves a scientifically-based evaluation of the data provided by the pesticide company, legal requirements, administrative procedures and finally a policy decision based on prevailing safety standards (Storck et al. 2017). There are two parts to the EU pesticide approval process: the active substance(s) must be approved at EU level, and the formulated product must be authorized at Member State level. Before being placed on the market, all active substances are evaluated by experts in one of the EU's national regulatory authorities; their preliminary results are then peer reviewed by the European Food Safety Authority (EFSA), before the active ingredient is considered for approval by the European Commission. Once an active substance has been approved at EU level, the formulated product containing it must then be registered in each Member State. The pesticide registration process in the USA involves data evaluation by scientists at the United States Environmental Protection Agency (USEPA) according to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Federal Food, Drug, and Cosmetic Act (FFDCA). These laws have been amended by the Food Quality Protection Act and the Pesticide Registration Improvement Act. Current EU and USA pesticide RAs rely on laboratory-based toxicity studies focused on groups of individual organisms without directly assessing the toxicological endpoints for populations or communities.

Recently, Storck et al. (2017) have highlighted the disadvantages and limitations of the existing EU pesticide registration process and they have proposed relevant actions to improve the overall procedure. A similar approach is followed in USA pesticide registration process where companies that want to produce the pesticide must provide data from studies that comply with USEPA testing guidelines. The main criticism of the existing RA methodology is focused on the fact that data used to assess the risk are mainly produced by the directly-involved pesticide manufacturers (PAN, 2011). However, the fact that these data must be generated in compliance with Good Laboratory Practice should provide confidence in the data, plus it is difficult to see who else would fund the work necessary to generate the compound-specific data, other than the manufacturer or consortiums of the same. Another criticism is that EU legislation relating to registration of pesticides includes exceptions and "loopholes" that allow banned pesticides and biocides to be used under specific conditions. Although environmental awareness in the EU has been guaranteed by the European acquis, there are external political pressures to maintain business growth and to provide a cheap, stable food supply for consumers. The time-frame generally associated with politics (< 5 years) is much shorter than the typical time-frame in which adverse environmental and health impacts become evident (Gupta 2004; Lydy et al. 2004), thus political pressures regarding pesticide use and food supply can outweigh long-term environmental concerns. Moreover, companies' lobbying in European Commission (European interest representation) is a well-known and fair fact according to many parties that may affect or even determine the existing safety standards and policy decision (McGrath 2014).

Environmental RA for pesticides in the EU and USA is typically evaluated on a pesticide-by-pesticide basis for registration of new pesticidal products based on crop/soil/climate scenarios representative of the region of intended use. Risk management decisions derived from RA for single pesticides are difficult to interpret in isolation, and restricting the use of any one pesticide may result in increased usage of other registered pesticides labeled for use on the same crop, which has its own set of risk (Etterson et al. 2017). This phenomenon would be far more impactful in cases of huge areas of monocultures as those observed in some countries of LAC, such as Brazil and Argentina. Although maize and soya monocultures are also observed in USA and to a lesser extent in EU, monoculture expansion in LAC has coincided with a vast increase of pesticide quantities used (Fig. 1 and Table 1). The soyisation we observed in Argentina, Uruguay and Bolivia during our KNOWPEC workshops and field trips, strongly influenced our perspectives about the RA process highlighting the need to fully embrace the context of use if attempting to apply RA learnings from the EU, particularly given that soy, maize (and cotton) crops in LAC are commonly genetically modified (GM) allowing for different usage of pesticides compared to the EU, where GM crops are restricted.

Environmental fate, ecotoxicity and pre-/post-registration RA of pesticides are compound-specific excluding, or at least underestimating, the mixture (cocktail) effects, and/or non-relevant transformation product effects (EU-Regulation 283/2013/EC; Fenner et al. 2013); synergism or other interactions are not considered. Although EFSA's scientific committee and panels (AHAW, ANS, BIOHAZ, CEF, CONTAM, FEEDAP, GMO, NDA, PLH, PPR) have conducted separate RAs for many biotic and abiotic potential stressors such as pesticides, genetically modified organisms, feed additives, allergens, pathogens, and invasive alien species, co-occurrence of these stressors is not routinely assessed. Similarly, whilst pesticides can have multiple modes of action, their toxicity is mainly examined according to the principal mode of action and the most sensitive species. Environmental RA processes employed by authorities focus on requirements of a pesticide to be registered according to the existing legislation and not to assess the cumulative risk to non-target organisms. Also, the whole process has high uncertainty which increases from contamination source to receptor, and from field to catchment and regional scale. Confidence in the risk estimate can be lowered by the uncertainties during the process of environmental RAs and uncertainty determination is not included in most pesticide RA processes. The main uncertainties in environmental RA are identified in its constituent dimensions, namely, its *location*, its *nature*, and its *level*. In order to manage uncertainty effectively, all the compartments in its dimension should be identified and characterized and actions then implemented to reduce the uncertainty. Skinner at al. (2016) presented a detailed approach, based on subject-matter experts' opinion, to define the sources of uncertainty in pesticide RA. The limitations in current RA approaches, combined with weaknesses in the enforcement of the pesticide policy could partly explain the detection of pesticides in the environment above agreed water quality standards, indicating that the RA employed has failed in its role to protect the

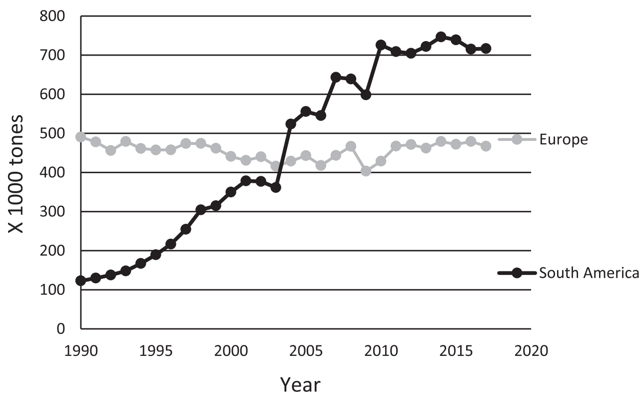

Fig. 1. Total pesticides used per year.[1]

Table 1
Comparison of crops consistently in the top 10 in 1990, 2000, 2010, 2018 by area harvested for Europe and South America/the Caribbean, and the % change (1990 to 2018).

Caribbean		South America		Europe	
	% change		% change		% change
Sugar cane (0.67)[*]	−62.4	**Soybeans (57)**	222.2	**Wheat (61)**	−19.8
Maize	57.4	Maize	70.5	Barley	−46.1
Rice	27.3	Sugar cane	116.2	Oats	−58.4
Coffee	−37.9	Wheat	−1.5	Maize	31.2
Cassava	60.2	Rice	−22.4	Potatoes	−54.4
Cocoa beans	16.7	Beans	−32.1	Sunflower	117.0
Bananas	0.0	Coffee	−31.6	Grapes	−34.5
		Cassava	−28.7		
		Sunflower	−34[b].8		

* The crop in bold was the largest by area harvested in 2018 with approximate area (million ha) in parentheses.
[b] Data source: http://www.fao.org/faostat/en/#data/QC.

environment and, potentially, human health (Vryzas et al., 2012). Moreover, the global dispersion of pesticides over the past 7 decades has given rise to their dominance as a threat to ecosystems and human health (Sharma et al., 2019; FAO, 2019).

Another important issue that is often not considered during evaluation of risk is that RAs may be conducted by scientists having different background and experience and/or having different priorities such as policy makers, water companies, health departments, agricultural departments, commercial companies, regional authorities, universities, research institutions, etc. The objective of the RA can therefore vary, as can the perceived importance of variables within the RA. Lessons learnt from RA may not be communicated across the board and consequently, they are not directly transformed to risk management practices.

So, who is the most qualified to make a RA or to make a judgment on a RA and get risk management decisions and how can we improve the existing RA approach?

LAC countries are currently developing, or have developed, complicated pesticide registration and RA processes similar to those followed in Europe or the USA. Heterogeneity of pesticide registration process among neighboring LAC countries, trade barriers, different lists of pesticides registered in transboundary areas, including banned or unauthorized pesticides and contrasting climate and agricultural zones makes the RA process more complicated. LAC countries follow national registration requirements rather than regional or continental. LACs should take into consideration their own conditions and limitations of the systems they are trying to adapt to their situation; environmental conditions, farmers' education, establishment of monoculture, local pesticide industry, chain of pesticide market, evaluating authorities, and community living standards must not be underestimated in the establishment of registration and RA processes. Moreover, the importance of increasing the competitiveness of the agricultural sector and keeping the attractiveness to companies producing pesticides should not be overlooked in LACs. The competitiveness of the European agricultural sector is threatened, among others, by the limitation of pesticides registered due to the expensive registration process, although environmental costs are not generally considered. Industry will be discouraged to register new pesticides in LAC if the pre-registration RA process is more complex and/or registration costs increase. Complex evaluation procedures also prevent small regional companies introducing pesticides in their local market. Also, the administrative costs for registering pesticides in the EU are amplified by the complex system in place, i.e. the 'double registration system' of the active ingredient with EFSA and the formulated product with member states, which often is not the most appropriate for LAC countries.

2. The importance of chemical prioritization

Limitations in the pre-registration RA process is evidenced by the detection of previously-approved pesticides in water above agreed water quality standards. Such detections prompted the re-evaluation of pesticides over the past 20 years within the EU, using contemporary RA methodology, which resulted in many older pesticides being withdrawn from the market. Similarly, the post-registration detection of compounds, from a wide-range in chemical classes, resulted in a requirement within the Water Framework Directive to identify those chemicals (not only pesticides) that pose the greatest risk to the environment and/or human health, and to monitor their presence accordingly in order to demonstrate the effectiveness of subsequent mitigation measures. Moreover, implementation of the national action plans for the sustainable use of pesticides has resulted in differing focus among European countries; e.g. Germany aims to reduce the total *risk* of pesticides used whereas France aims to reduce the *quantities* of pesticides used (EU-Directive, 2009/128/EC). Given the vast number of chemicals released into the environment and the cost of monitoring programs, it is necessary to determine which chemicals are most likely to occur in the environment and/or pose a risk, i.e. to prioritize the risk. At the European scale, a list of Priority Substances has been established requiring Member States to monitor for these compounds and to introduce reduction strategies to ensure compliance with water quality standards (EU-Directive 2013/39/EC). However, the limitation remains that the RA methodologies generally used are designed for the national-scale and these can be inadequate to describe processes at the river-basin scale where differences such as microclimate, soil properties, agricultural practices, water balance, flora and fauna, etc can be observed, in addition to having different contamination pressures within the catchment. Also, the origin of the compounds considered as priority substances (point-source, diffuse, urban, industrial and agricultural) is better determined at river-basin scale. Adopting a river-basin approach is effectively a refinement of larger-scale RA process and is likely to provide a more accurate prediction of risk. Consequently, river-basin scale assessments can assist with targeting relevant water bodies for national monitoring programs, and prioritization approaches are therefore a useful tool to complement pre-registration RA approaches.

Pesticide prioritization methodologies have been developed to rank pesticides according to their environmental relevance and to facilitate monitoring programs and ecotoxicological tests focussing on highly ranked priority molecules. The data required for prioritization are somewhat similar to those required for a RA. But which factors should be considered during a prioritization exercise? It depends on the major objectives of each exercise, for example, if the aim is to rank priority substances to a river basin scale according to their environmental risk,

[1] Data source: http://www.fao.org/faostat/en/#data/RP/metadata.

then relevant effect endpoints and receptors to be protected are chosen, and a monitoring strategy can subsequently be redesigned. As mentioned previously, the area of expertise of the assessor influences the outcome of the RA and this is reflected in the research to date. For example, Gotz et al. (2010) proposed a prioritization methodology to rank microcontaminants based on their environmental fate and their potential occurrence in surface waters, without considering toxicity aspects. On the other hand, a systematic prioritization exercise for 500 microcontaminants in four European river basins was conducted by von der Ohe et al. (2011) where the extent and frequency of exceedance of toxicological endpoints were used in combination with other factors (exposure data, evidence of exposure, evidence of risk, analytical method performance) to prioritize contaminants and create 6 risk categories. Similarly, a comprehensive pesticide hierarchy was conducted on a large monitoring dataset by Tsaboula et al. (2016) at river basin scale to rank pesticides into 7 risk categories based on type of toxic effect (short-, long-term), analytical method performance, toxicological endpoints, frequency of exceedance, magnitude of exceedance, spatial distribution of monitoring data, persistence, bioaccumulation, endocrine disruption potential. In all cases, prioritization approaches take into consideration factors included in traditional RAs, but include additional factors, depending on the objective of the exercise which in turn depends on the interest of the assessor.

Consequently, pesticide ranking, prioritization or hierarchy approaches are not uniform, nor use standardized techniques. Why could pesticide prioritization be a complementary tool to the conventional pre-registration RA for managing risks identified? According to Vryzas (2016) almost all pesticides' target sites and respective inhibited biochemical processes are located in, or at least include, biological membranes and these main target sites have been extensively studied. In contrast, the side- or collateral effects of pesticides on biochemical processes, organism populations, communities and the ecosystem, are relatively unknown. These side-effects are more obvious if we consider the hormone-like action of many pesticides, and, that membrane functions, apart from pesticides, are usually regulated by effectors, elicitors, and hormones (Gerbeau-Pissot et al. 2014). Thus, risk determinations are knowingly uncertain, and hypotheses, experience and weighting factors should be included in future RA or prioritization approaches. Governments are responsible for establishing protection strategies and management policies to safeguard the environment and human health. Whilst pre-registration RA approaches provide some indication of pesticide risk, it is known that they have limitations. Leaders and experts have a societal responsibility to combine their knowledge to provide this protection. Prioritization approaches can produce difficulties for regulators as they are not standardized and are based on the experience and expertise of the researcher setting the weighting factors, which could be refuted by others with a different bent. Prioritization approaches could even be used by competitors to unfairly discriminate against certain compounds. However, such difficulties should not detract from the positive contribution that prioritization exercises can make to RA and risk management. To this end, we reviewed prioritization approaches, described below, and critically-assessed them (section 3) in terms of pesticide risk management and the implications of using prioritization approaches in Latin American and Caribbean countries.

3. Application of chemical prioritization

Most chemical prioritization exercises published from 2004 to 2012 were focused on pharmaceuticals (Sanderson et al. 2004; Besse and Garric, 2008; Solomon et al. 2009; Gotz et al. 2010; von der Ohe et al. 2011; Daginnus et al. 2011; Slobodnik et al. 2012). Due to the high number of pharmaceutical drugs used in human medicine and their environmental release, prioritization exercises were applied prior to, and in order to provide focus for, more detailed environmental RAs. Moreover, the lack of ecotoxicological endpoints and environmental fate data for most of the pharmaceuticals negated the use of conventional environmental RA approaches, and other techniques have been proposed such as the quantitative prioritization tool for environmental RA of pharmaceuticals based on (Q)SAR modeling developed by Sanderson et al. (2004).

During 2013–2015 several prioritization studies that included pesticides were published (Smital et al. 2013; Sugeng et al. 2013; Ginebreda et al., 2014; Kuzmanović et al. 2015; Homem et al. 2015; Di Nica et al. 2015), giving different emphasis and weighting factors to input data. Smital et al. (2013) combined chemical and bioanalytical data to prioritize region-specific pollutants. They emphasized the importance of identification of key pollutants at basin scale, rather than focusing on a priori national or European priority compounds. Moreover, in their study the most polar organic contaminants, which are not included in the European and national monitoring strategies have been ranked high in their priority exercise. Sugeng et al. (2013), in their prioritization exercise, rank the 74 most frequently used pesticides in Yuma country (Arizona, USA) according to hazard on human health. They consider the pesticide use, toxicity and exposure potential to rank the pesticides according to cancer, endocrine disruption and reproductive/developmental toxicity. Apart from ranking pesticides for each health effect, an overall chronic health effect ranking was conducted. The highest ranked pesticides were maneb, metam-sodium, trifluralin, pronamide, and bifenthrin. According to Ginebreda et al. (2014) toxic units of the compounds found in a sample can provide information for pollutant prioritization and sampling sites classification which is important from a management point of view. A detailed prioritization exercise based on a ranking index was conducted by Kuzmanović et al. (2015) revealing that among the ten most important compounds, eight were pesticides (chlorpyriphos, chlorfenvinphos, diazinon, dichlofenthion, ethion, carbofuran, prochloraz and diuron). Their results highlighted the importance of conducting prioritization exercises by taking into consideration regional and local (i.e. climate, geo-physical, agricultural and socioeconomic) characteristics. Another interesting result of their study was the dominant role of the intense precipitation on the risk for aquatic ecosystem. An extensive prioritization exercise based on bioaccumulation, environmental fate and ecotoxicity data was conducted to rank personal care products in water, soil, air and sediment compartments (Homem et al., 2015). The RANKVET scoring system was developed by Di Nica et al. (2015) to rank veterinary pharmaceuticals according to their environmental risk (aquatic and terrestrial ecosystems).

During 2016–2017, prioritization studies on both pharmaceuticals and pesticides have been published (Donnachie et al. 2016; Al-Khazrajy and Boxall, 2016; Guo et al. 2016; Skinner et al. 2016; Casado-Martinez et al., 2018; Gros et al. 2017; Tousova et al. 2017; Munthe et al. 2017). Donnachie et al. (2016) group the pharmaceutical prioritization approaches used by environmental scientists into those based on: a) *sales and usage*, b) *occurrence in the environment*, c) *risk ratio*, and d) *multiple variables schemes* (persistency; bioaccumulation; ecotoxicity; chemical properties; weather conditions). The case-by-case expert views is an important component of all proposed prioritization methods and no ranking system will ever be perfect.

Al-Khazrajy and Boxall (2016) have applied a prioritization approach involving the use of predicted environmental concentrations and various effect endpoints in aquatic and terrestrial systems to rank 99 of the top used medicines in Iraqi cities. Guo et al. (2016) have applied a holistic methodology and prioritize pharmaceuticals according to their risk to aquatic and terrestrial environment. In their exercise 16 substances were highly ranked. Sediment-relevant microcontaminants were classified into 5 categories according to exposure and effect data and ranked according to exposure, hazard and risk scores within each category (Casado-Martinez et al., 2018). Gros et al. (2017) applied a prioritization strategy in wastewater and 20 top-ranked chemicals (including priority substances of the EU WFD) were identified based on the compound concentrations, removal efficiency, frequency of detection and on *in silico*-based data for toxicity, persistence and bioaccumulation. Recently, multi-scientific discipline knowledge was combined with opinions of several stakeholders from authorities and organizations related to environmental quality of water bodies to create a conceptual framework for predicting and prioritizing chemical risks (Munthe et al. 2017). In this study a systematic approach for identification, quantification and reduction in the risk of chemicals was designed for use in current and future chemical pollution assessments for the aquatic environment, including the specific challenges encountered in prioritizing individual chemicals and mixtures. The four key topics representing the main scientific challenges were addressed i.e.: identifying and prioritizing hazardous chemicals at different scales; selecting relevant and efficient abatement options; providing regulatory support for chemicals management; predicting and prioritizing future chemical risks (Munthe et al. 2017).

Twenty-one compounds were prioritized and 15 identified as novel candidates for future surface monitoring campaigns during a novel simplified protocol applied in 4 European river basins (Tousova et al. 2017). The protocol was based on *onsite* pretreatment, then extracts were subjected to effect-based analysis (toxicity to algae, fish embryo toxicity, neurotoxicity, (anti-)estrogenicity, (anti-)androgenicity, glucocorticoid activity and thyroid activity), to target analysis (151 organic micropollutants) and to nontarget screening of other pollutants.

During the last 2 years, several pesticide prioritization and RA studies including those conducting in Latin American countries have been published (Carazo-Rojas et al., 2018; Grifferro et al., 2019; Iturburu et al., 2019).

Tsaboula et al., 2019a developed two indices in order to assess the combined pesticide ecotoxicity to aquatic non-target organisms, the Aquatic Quality Index of Short-term Toxicity of Pesticides (AQI ShToxP) and the Aquatic Quality Index of Long-term Toxicity of Pesticides (AQI LToxP). These indices were applied to the environmental results obtained from an intensive monitoring study of 302 pesticides in 102 stationary sampling stations (2382 water samples resulting in 7088 data sets) located on the surface aquatic network of Greek River Basin. The developed indices as well as the proposed quality classification system could be a tool to establish and implement River Basin Management Plans that can contribute to the restoration of environmental health. Even in cases where long-lasting and wide-spread environmental monitoring studies have been established, it is very difficult to handle the complex water quality data generated from them. The development and validation of ecotoxicological indices based on the data generated from an extensive water quality monitoring program could be an interesting approach for the classification of surface water quality as affected by the presence of pesticide residues exerting short (acute) and long-term risks to aquatic non-target organisms. These indices would aid the protection of aquatic life since they provide convenient means of summarizing and evaluating complex water quality data.

The high cost of conducting extensive pesticide monitoring studies is a much more limiting factor in Latin America and the Caribbean. Moreover, the necessity of early identification of environmental threats from pesticides, under complicated and unknown conditions of LAC, highlighted the need for prioritization of pesticides and sampling sites to be monitored. Identification and categorization of sampling stations vulnerable to pesticide contamination could help in the establishment of a cost-effective monitoring scheme without losing valuable information. Tsaboula et al., 2019b, developed an optimum surface water monitoring network at the catchment-scale including only those catchments vulnerable to pesticide pollution. With their methodology Tsaboula et al., 2019b include left-censored data of the analytical results that are commonly excluded from monitoring reports, RA exercises and management plans. With this approach Tsaboula et al., achieved 46% reduction in the number of the monitoring stations without losing valuable data. This approach could be applied in establishing more cost-effective monitoring schemes for LACs big river basins and in developing targeted measures to eliminate or limit the effect of critical pollution sources in surface aquatic systems.

Analytical capabilities and scale of monitoring studies have been considerably improved over the last years in many Latin American and Caribbean countries (Argentina, Etchegoyen et al., 2017, Iturburu et al., 2019; Brazil, Arsand et al., 2018; Costa Rica, Carazo-Rojas et al., 2018; Ecuador, Deknock, et al., 2019; Uruguay, Grifferro et al., 2019; Soliven et al., 2020). Thus, it is now the appropriate time to consider and develop prioritization actions. The establishment of local ecotoxicological indices and the development of methodologies to identify sampling sites vulnerable to pesticide pollution in the context mentioned above is a challenge for LAC.

4. Factors affecting prioritization exercises

Most ecotoxicological RA methodologies mainly focus on sampling a single, or a limited number of pollutants, and do not take into consideration the various stressors contributing to the risk of the same territory. With the current shift away from laboratory animal toxicological studies and the lack of information on quality (quality assurance) of published monitoring and ecotoxicological data there will likely be an increased emphasis on prioritization exercises.

Pre-registration RA is based on strict rules and needs detailed data focused on specific crops, soil properties, pesticide properties, dissipation rates, application strategies, landscape, timing/amount of rainfall and irrigation in relation to pesticide application and other environmental conditions. Although, these data can be available at the field scale, their variability and uncertainty increase at the larger scale (territory, river basin, national) and reduce the reliability of the results. Prioritization exercises are more flexible to include different sources of pollution (point source, agricultural runoff, spray drift, industrial pollution, diffuse source, urban sources) under various scenarios. Prioritization exercises take into consideration combined approaches to describe the overall situation. Monitoring data are an essential component of any prioritization exercise, providing the pattern of contamination which, combined with knowledge on toxicity, allows the development of risk management plans, pollution mitigation action or at least reassessment of monitoring strategies (sampling points, sampling frequency, sampling strategy, priority compounds, analytical method evaluation criteria, etc.). Table 2 summaries the most important components for the implementation of a prioritization exercise.

The main objective of each prioritization exercise determines the factors that should be considered, the weighting factor of each one and the hierarchy that should be followed. Risk communication is also sometimes a compartment of a prioritization exercise. Thus, multidisciplinary scientists and/or knowledge are needed to perform an integrated prioritization exercise. Agronomists, health professionals, toxicologists, environmental scientists, geologists, meteorologists, hydrogeologists, chemists, chemical engineers, modelers and mathematicians, policy makers, commercial companies/chemical manufacturers, or public (authorities) sectors are among those conducting prioritization exercises. Advanced knowledge on the pesticide registration process, the whole pesticide market chain (retail, whole sale market, distributors, advisors, farmer's consultants, farmer), crop distribution and agricultural practices, remediation strategies, chemometrics, analytical methods, toxicological issues, physicochemical characteristics, biological processes, hydrogeology, sampling strategies, ecology are needed from anyone involved in a prioritization exercise. Special care is needed to distinguish exceptional conditions prevailed in each case.

5. Prioritization under LAC's exceptional conditions

The exceptional ecological (biotic and abiotic) conditions that were observed during our 1-month secondments in each country (Costa Rica, Argentina and Bolivia) and our participation in Latin American Pesticide Residue Workshops (LAPRWs) compared to the European reality convinced us that prioritization should be done on a case-by-

Table 2
Important factors considered in a pesticide prioritization exercise in surface water bodies.

Sampling strategy	Toxicology	Pesticide properties	Agricultural practices
Historical data; Grab, automatic sampler, passive, on-line sampling and analysis, sample transport and storage conditions, analyte stability, matrix (water, sediment, biological), targeted or untargeted compounds, metabolites, $	Acute and chronic toxicity, upstream or downstream of protected areas, endangered species, main species, population dynamics, community ecology, other stressors	Sorption, degradation, volatilization, solubility, biomagnification, bioconcentration, stability in sample, plant uptake	Pesticide application amount/frequency, spraying equipment, sprayer mixing/loading/cleaning, container management, crop distribution, irrigation strategy, soil properties, cultivation practices, $
Analytical capability	**Landscape**	**Waterbody characteristics**	**Management**
Instrument; number of analytes and matrices, analyte known, or screening approach; LOD, recovery, accuracy, precision, $	Crop distribution; precipitation, topography, soil type, hydrological pathways	Depth, shape, flow, residence time, sediment type/depth, vegetation,	Priorities, chemometrics, statistics, assessment/weighting factors, risk communication, interaction with various sectors

case basis and that standardized tests and the uniformity in pesticide RA should not be an end in itself. Specific factors affecting the different fate of pesticides in the exceptional tropical environment of Costa Rica were identified and characterized during the workshop and field excursions. The mild, humid climate of Costa Rica provides excellent conditions for the proliferation of fungi, weeds and insects. These pests are abated by applications of pesticides with a frequency that is starkly different to that in Europe and more temperate climates. It is not unusual for pesticides to be applied several times a week (e.g. two applications of fungicide per week in banana crops). One reason for the frequency of application as mentioned above is the unique, favorable climatic conditions for fungus diseases, weeds and insect pests to proliferate and the fact that foliar pesticides are washed off during periods of heavy rainfall, as well as high drift during application. The potential for pesticide contamination of surface and groundwaters is therefore high for some of the products used. Although aerial application of pesticides has been considerably improved, its extensive use could still represent a risk for the extraordinary biodiversity of Costa Rica which accounts for 6% of the world's biodiversity but with a land area of $< 0.0005\%$. Moreover, specific crops (onion, potatoes, carrots, ornamentals, strawberries) are mainly cultivated in mountainous areas where the steep sides and high rainfall have resulted in severe soil erosion, exacerbating pesticide loss via runoff, including lipophilic compounds bound to sediment. Particulate transport via wind erosion can also contribute to surface water contamination. During the 2nd KNOWPEC workshop and field excursions and our participation in 3rd, 6th and 7th LAPRW we had the opportunity to follow the Soyisation of Argentina's and Uruguay's huge plain areas. RA processes developed in EU and USA could not take into consideration the importance of using such high quantities of only a handful of compounds in huge Soyisation areas and the impact to LAC's environment. Also, during the 3rd KNOWPEC workshop and field excursions in Bolivia we had the opportunity to explore the 3 completely different environmental conditions, agricultural areas, and cropping systems followed from small (< 40 ha) and medium (40 to 100 ha) farms of highland and Antiplano areas to very large commercial farms (up to 10.000 ha) of Santa Cruz's area. Practices, heterogeneity and conditions related to the use, fate and effects of pesticides that are apparent in LAC, are not faced in EU and USA where RA guidelines were developed and validated.

Environmental RA and pesticide prioritization approaches in Costa Rica, Argentina, Bolivia and Uruguay is in a primitive stage and the exceptional ecological conditions, the Soyisation of Argentina and Uruguay and the varied cropping systems in Bolivia could require a different approach compared to those followed in Europe or North America. Factors affecting prioritization exercises in Costa Rica, Argentina, Uruguay and Bolivia are the most characteristic example for conducting prioritization exercises on a river basin scale. Latin American and Caribbean countries have developed very good pesticide residue analytical capabilities during the last decade. The LAPRWs are mainly focused on pesticide residue on food matrices, although monitoring studies in environmental matrices are increasingly presented. The first pesticide RA attempts conducted in LAC, mainly for pesticide registration purposes, are copies of European or North American approaches. It would be a mistake to continue in such a way without taking into consideration the exceptional ecological and agricultural conditions faced in LA, and LAC's pesticide policy needs to be adapted to the regional conditions to minimize environmental risks and to protect human health.

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Appendix A. Supplementary data

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