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Discussion

Commentary: Perspectives on aquaculture, urbanization and water quality☆

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ABSTRACT

Aquaculture presents essential opportunities to meet global food security needs, but adverse effects of aquaculture practices on ecological integrity and influences of existing waste management infrastructure on product safety must be understood in rapidly expanding urban and peri-urban regions. Concentration of, access to and use of chemical products is increasing in many urban areas faster than interventions are being implemented. Aquaculture farming is employing "non-traditional" (e.g., treated or untreated sewage) waters in some regions, but the spatial extent of these intentional or de facto water reuse practices with associated water quality and food safety systems are poorly understood around the world. Integrative water reuse, aquaculture product safety, ecological and public health research and advanced surveillance systems are needed. Such efforts appear particularly important because noncommunicable diseases are increasing and pollution is now recognized as one of the major global health threats, particularly in lower and middle income countries. Here we provide some modest perspectives and identify several research needs to support more sustainable aquaculture practices while protecting public health and the environment.

Aquaculture is the fastest growing sector of global food production. This "Blue Revolution" produced more fish for human consumption than global fisheries for the first time in 2014 (FAO, 2016). Continuing this growth in aquaculture, a relatively energy efficient form of food production, is necessary to meet global food demand, for which a 50% increase will be needed globally by 2050 with higher increases required in lower and middle income countries (FAO, 2017). This trajectory presents a important global trend but demand for increased aquaculture appears most pronounced in the Asia-Pacific region, where 22 megacities will exist by 2030 (population.un.org/wup/). The continued growth and long-term sustainability of aquaculture, much like traditional agriculture, requires abundant water of sufficient quality. With aquaculture occurring in ponds, reservoirs and lakes of urban and peri-urban environments (e.g., Lake Taihu, China), many operations are already knowingly or unknowingly using "non-traditional" (or raw sewage or treated sewage effluent) waters. The extent to which such intentional or de facto water reuse practices now occurring for global aquaculture is not known, though this practice will likely increase in water stressed regions where 66% of the global population will live by 2025 (www.state.gov/e/oes/ecw/water/index.htm). This represents a growing concern because 80% of global sewage production is currently released to the environment as untreated waste (WWAP, 2017), at a time when the majority of humans now live in urban areas. Such global megatrends present a number of timely research questions to achieve more sustainable environmental quality in developing (Furley et al., 2018) and developed (Van den Brink et al., 2018) countries. A number of these priority research needs are directly relevant to aquaculture, urbanization and water quality.

An unprecedented concentration of human population and resource (food, energy, water) consumption, including chemical access and use, is occurring in urban areas of developing and even developed regions faster than environment and public health interventions are implemented (Brooks, 2018). With food safety programs (e.g., hazard analysis and critical control points), the primary focus has correctly microbiological threats, but health risks associated with consumption of chemical contaminants from aquaculture products has also been recognized as an important research need (Sapkota et al., 2008). In fact, major producers and exporters of aquaculture products (e.g., China, Norway, India, Vietnam) include countries with differentially developed waste treatment infrastructure, environmental management capacities, and environmental public health delivery systems. It thus appears clear that an integrated understanding of the influences of

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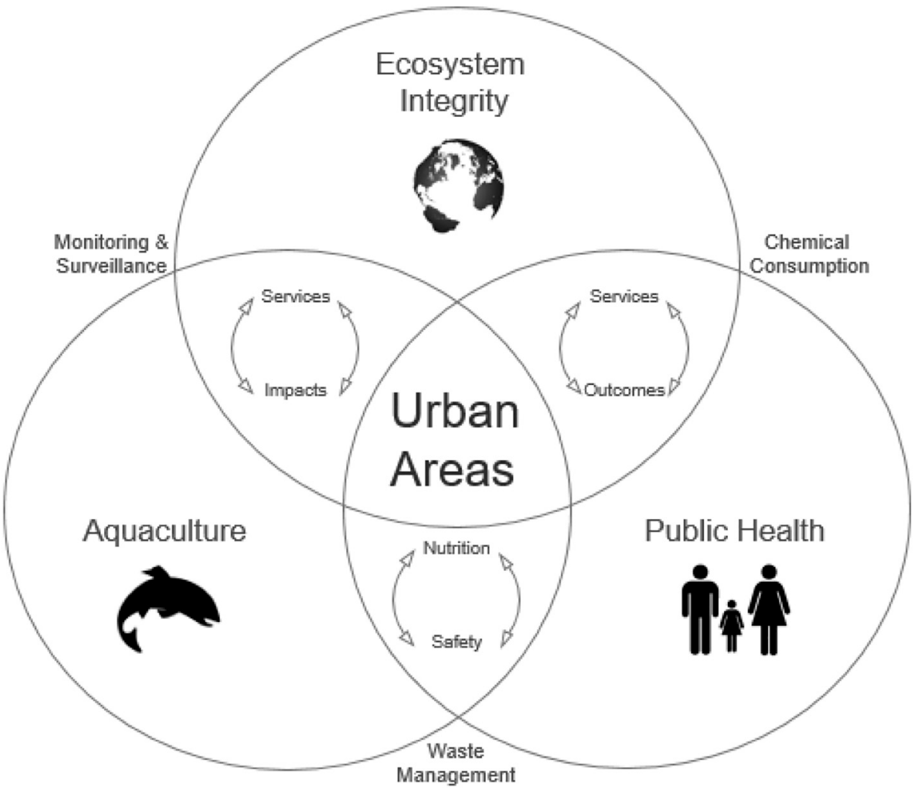

Fig. 1. Integrative studies of urbanization are necessary to understand connections among ecosystem integrity, aquaculture practices, and environmental public health. Coordinated global monitoring and surveillance systems with environment and human specimens banking are needed given differentially developed global waste management programs and an unprecedented concentration of chemical use in urban areas.

urbanization on sustainable aquaculture, ecological integrity and environmental public health is necessary (Fig. 1) to achieve several of the United Nations' Global Goals for Sustainable Development (SDGs; www.globalgoals.org). For example, SDG 11, which focuses on sustainable cities and communities, states: "By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management." Because this represents a noble and laudable goal, here we provide perspectives and aquaculture research needs associated with diverse intersections among urbanization and water quality.

Rapid expansion of aquaculture, particularly associated with in situ production (e.g., net pens) operations in freshwater, coastal and marine systems, presents diverse risks to biodiversity and ecosystem services (Rico et al., 2012). In addition to habitat modification, nutrient contributions from urbanization and agriculture can influence development of harmful algal blooms (HABs), which represent a transformational water quality threat to public health and the environment (Brooks et al., 2016, 2017). HABs also present decided threats to coastal aquaculture production and associated food safety; for example, *Prymnesium parvum*, an emerging threat to inland waters (Brooks et al., 2011), killed 135 metric tons of caged fish in Norway during a bloom in 2007 (Johnsen et al., 2010). HABs are influenced by a number of factors, including climate change and nutrient inputs from anthropogenic activities (Watson et al., 2015; Brooks et al., 2016). The extent to which specific HAB events are stimulated by intensive aquaculture has received less attention, particularly for mixotrophic HAB species (Burkholder et al., 2008), which appear to be increasing in coastal ecosystems (Flynn et al., 2018) often used for aquaculture operations.

For cyanobacterial HABs occurring along the freshwater to marine continuum, environmentally relevant gradients can influence algal growth, toxins production and comparative toxicity, but commonly used water quality models lack inputs for toxins production, which inherently limits predictive capacity of HAB events. Even for anatoxin-a, a relatively well studied cyanotoxin, existing bioaccumulation and toxicity data for fish are limited in quality and quantity and preclude derivation of environmental quality criteria (Lovin and Brooks, in review). Developing predictive growth, toxins production and comparative toxicity models for cyanobacteria that commonly dominate toxic HAB events across relevant environmental gradients is imperative for forecasting, diagnosing and preventing human health risks presented by algal toxins in aquaculture products. Advanced analytical methods are also needed for determination of cyanotoxins in fish, shellfish and plant tissues. For example, Haddad et al. (in review) recently identified significant matrix effects of fish tissues on quantitation of cyanotoxins, but this important observation was only possible due to recent availability of isotopically labeled standards. Clearly, increased availability of high quality, affordable standards will advance environmental toxicology and chemistry efforts with HABs and aquaculture, particularly for shellfish, which we further discuss below.

Influences of veterinary medicines on ecological integrity of freshwater, coastal and marine systems have also received attention for aquaculture operations. For example, Rico et al. (2018) recently reviewed ecological risks associated with European finfish aquaculture and veterinary medicines, which include antiparaciticides, antifungals and antibiotics. Herein, future research is needed to understand the extent to which excessive antibiotic use in aquaculture present risks for antibiotic resistance (ABR) development, particularly in regions with increasing aquaculture production and limited environment and health management systems. Minimal selective concentrations and predicted no effect concentrations (PNECs) for ABR development in surface waters were recently proposed for antibiotics (Bengtsson-Palme and Larsson, 2016). These PNECs of ABR appear useful during probabilistic environmental hazard assessments to identify locations and systems that require additional study and potential interventions, though environmental monitoring data is often limited in rapidly developing regions with extensive aquaculture production (Schafhauser et al., 2018; Kelly and Brooks, 2018). Further, research is necessary to understand ABR risks from urbanization on the quality of aquaculture products in various regions. For example, Chung et al. (2018) recently reported multiple exceedances of these ABR PNECs for several common antibiotics released in leachate from the largest active landfill in Asia, which discharges to a coastal area of Hong Kong with intensive oyster aquaculture (Burket et al., 2018). Because Hong Kong includes more developed waste management infrastructure than many rapidly growing urban areas in developing countries, such contaminant observations in filter-feeding bivalves (Burket et al., 2018) and ABR exceedances (Chung et al., 2018) concretely highlight the need for an integrative understanding of urban water quality, food from aquaculture and ecological and health risks (Fig. 1).

Defining and managing impacts of aquaculture on ecosystem integrity and influences of urbanization on aquaculture product safety can benefit from comparative physiology, pharmacology and toxicology. When molecular initiation events occur through receptors or enzymes, which commonly occurs for pesticides, pharmaceuticals and algal toxins, sublethal responses of wildlife can be markedly more sensitive than adverse outcome thresholds observed for contaminants with nonspecific modes of action (Ankley et al., 2007). Brooks et al. (2008) initially identified the value of leveraging existing pharmacology and toxicology information during environmental assessments of veterinary medicines. A “biological read-across” approach was then proposed, again using veterinary medicines as an example, in which reciprocal basic and applied benefits can result from comparative studies across animal and plant models (Brooks et al., 2009). For example, hundreds of mammalian drug targets are evolutionarily conserved across vertebrates (Gunnarsson et al., 2008; Verbruggen et al., 2018), which can support efforts to prioritize chemicals for future study (Huggett et al., 2003; Berninger and Brooks, 2010; Fick et al., 2010; LaLone et al., 2014; Brooks, 2014; Berninger et al., 2016).

Compared to the high conservation of pharmacological targets across vertebrates, biotransformation pathways differ among species. Common substrate-enzyme relationships for metabolism of pharmaceuticals in humans (e.g., CYP 2D6) may not exist or be functionally conserved in wildlife (Gunnarsson et al., 2012), which can result in decreased biotransformation of some compounds by fish (Connors et al., 2013). However, we submit that comparative biotransformation information for fish, shellfish and aquatic plants can support aquaculture practices if sufficient holding times are identified for organisms to depurate contaminants of concern prior to shipment from production to market. Advancing green chemistry (Coish et al., 2016) and a comparative understanding of physiology, pharmacology and toxicology thus promises to identify, select and design chemical alternatives (Brooks, 2018) that are less bioaccumulative in aquaculture and hazardous to aquatic life, while reducing cumulative exposure to contaminated aquaculture products from urban areas.

Chemical contaminant analyses of food products rely on an indicator approach, much like water quality and other public health monitoring and surveillance systems, in which analyses of targeted microorganisms and chemicals are performed at some frequency. However, targeted analyses of specific chemical contaminants represent the tip of an environmental monitoring “iceberg” (Daughton, 2014), for which the full extent of chemical contamination in environmental matrices is routinely unknown. For example, LC-MSMS analyses of pharmaceutical residues in fish tissues have evolved from employing standard addition (Brooks et al., 2005) and matrix matching (Ramirez et al., 2007) to isotope dilution (Du et al., 2012) approaches as deuterated standards became increasingly available. Despite this progress, deuterated standard availability is still limiting methodological advances, and the development of such standards have not necessarily been developed following rigorous analyses of ecological and health risks. The next wave of analytical advancement for environment and food monitoring is high resolution mass spectrometry, which provides unique opportunities to characterize understudied and previously unknown chemical contaminants, including metabolites and degradates (Hollender et al., 2017) through suspect screening and non-targeted analysis. These broader approaches, in addition to molecular approaches, are specifically needed to ensure quality of aquaculture products from production to consumption. Herein, advancing non-target fingerprinting promises to ensure product safety from historical and emerging natural (e.g., algal toxins) and anthropogenic chemical threats and to identify fraudulent products in international aquaculture supply chains. In fact, products from fisheries and aquaculture are susceptible to food fraud, though information from countries in transition are lacking (FAO, 2018). Such paucity of information on product integrity parallels observations in recent global scanning exercises that identified a limited understanding of aquatic exposure to chemicals of emerging concern (Corrales et al., 2015; Kristofco and Brooks, 2017; Saari et al., 2017; Schafhauser et al., 2018; Kelly and Brooks, 2018). Future research appears particularly needed, timely and important for rapidly developing regions with increased chemical consumption, limited waste management infrastructure, under-developed environmental management systems, and increasing aquaculture production.

Understanding temporal patterns in chemical contaminant threats to food safety of aquaculture products could be markedly advanced by specimens banks. These banks typically include archiving samples collected from representative or targeted environmental matrices (water, soil, fish) and human populations through time. For example, the National Health and Nutrition Examination Survey (NHANES; www.cdc.gov/nchs/nhanes) in the USA and the German Environmental Specimens Bank has afforded unique opportunities to examine chemicals of historical (Rudel et al., 2010) and emerging concern (Subedi et al., 2012) in human populations and fish from different regions of each country. Environment and human observations from these repositories can be evaluated prior to or following chemical introductions to commerce, or following the banning of specific chemical products to ensure exposure modeling predictions are reasonable and policy goals are achieved. Such observations are also invaluable during human health exposure and risk assessments when coupled with population health and disease information. Unfortunately, specimens banks do not exist in most regions around the world, but samples collected from these regions can be shipped to other repositories for future targeted or non-targeted analyses. In the absence of global specimens banking, networks for passive sampling of some chemical contaminants in surface waters have been formed (Lohmann et al., 2017), which are quite useful and provide information on chemical occurrence. However, research is needed for these sampling approaches to improve an understanding of exposure magnitude, frequency and duration and thus more closely provide surrogate measures of bioaccumulation in aquatic life, particularly for polar compounds. Developing a coordinated network of environment, human and agriculture specimens banks further represents a unique opportunity for surveillance of global aquaculture product quality. Ideally, this network would include archiving fish, shellfish and plants from various regions, which could then be coupled with human biobanking and environmental health tracking efforts (ephtracking.cdc.gov) to advance an understanding of these environment and health connections.

Aquaculture presents essential and advantaged opportunities to meet food security needs, but adverse effects of aquaculture practices on ecological integrity and influences of existing waste management infrastructure on product safety must be understood in rapidly expanding urban and peri-urban regions. Such efforts appear particularly important because noncommunicable diseases are increasing around the world and pollution is now recognized as a public health threat, particularly in lower and middle income countries (Landrigan et al., 2018). We hope perspectives presented here will support future efforts to advance more sustainable aquaculture practices while protecting public health and the environment.

Conflict of interest statement

No COI.

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