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A review of ecological effects and environmental fate of illicit drugs in aquatic ecosystems

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HIGHLIGHTS

- Illicit drugs are detected in surface waters throughout the world.
- Evidence suggests that illicit drugs may be "pseudo-persistent".
- A wide array of aquatic organisms may be sensitive to illicit drugs.
- Research that focuses on fate and ecological effects of these compounds is needed.

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ABSTRACT

Although illicit drugs are detected in surface waters throughout the world, their environmental fate and ecological effects are not well understood. Many illicit drugs and their breakdown products have been detected in surface waters and temporal and spatial variability in use translates into "hot spots and hot moments" of occurrence. Illicit drug occurrence in regions of production and use and areas with insufficient wastewater treatment are not well studied and should be targeted for further study. Evidence suggests that illicit drugs may not be persistent, as their half-lives are relatively short, but may exhibit "pseudo-persistence" wherein continual use results in persistent occurrence. We reviewed the literature on the ecological effects of these compounds on aquatic organisms and although research is limited, a wide array of aquatic organisms, including bacteria, algae, invertebrates, and fishes, have receptors that make them potentially sensitive to these compounds. In summary, illicit drugs occur in surface waters and aquatic organisms may be affected by these compounds; research is needed that focuses on concentrations of illicit drugs in areas of production and high use, environmental fate of these compounds, and effects of these compounds on aquatic ecosystems at the concentrations that typically occur in the environment.

1. Introduction

Throughout the world, humans are conducting an unintended ecological experiment by discharging increasing amounts of an ever-changing mixture of biologically active compounds into aquatic ecosystems. Increasing urbanization and continued human population growth are steadily intensifying this experiment, as wastewater makes up an ever-growing fraction of the flow of lotic ecosystems, especially in urban areas [1]. Pharmaceuticals and personal care products (PPCPs) are biologically-active compounds that are routinely detected in surface waters. The environmental fate and ecosystem consequences of PPCPs represent a cross-cutting frontier in aquatic ecology [2] and environmental chemistry [3]. Recent research demonstrates that pharmaceuticals can influence and alter the structure of aquatic communities [4–6] as well as the behavior of aquatic organisms [7,8]. In addition, PPCPs have the potential to influence ecosystem functions such as primary production and microbial respiration [5] and invertebrate secondary production [9].

Illicit drugs and/or illegal use of prescription drugs (e.g., recreational use of opiate painkillers like codeine) are a particularly noteworthy but understudied group of PPCPs. Illicit drugs are designated as those drugs for which non-medical use has been prohibited by international drug control treaties because they are believed to present unacceptable risks of addiction to users [10]. There is a growing global human health risk from the increasing manufacture and use of these chemicals, and there is very likely a global increase in the environmental burden from the continued release of parent compounds, metabolites, and pre-cursor compounds. Hereafter we refer to this group as licit/illicit drugs (LIDs) and they include classes of compounds such as opiates, cocaine, cannabis, amphetamines and other new "designer" drugs [11]. A wide variety of these biologically-active and neurologically-addictive substances have been detected in surface waters [11–13]; LIDs likely enter surface waters in similar ways that other PPCPs have been shown to enter surface waters [14–17]. Locations of LID release or 'hot spots' include sites downstream

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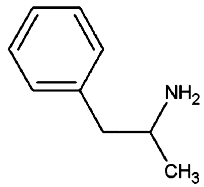
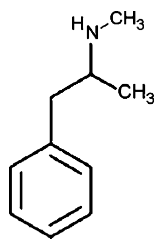
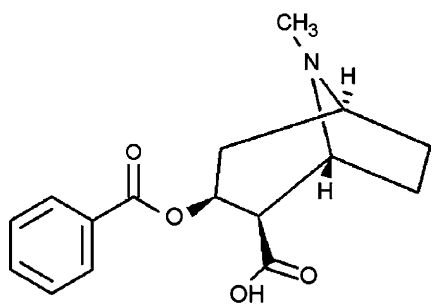
Table 1
Compound properties.

Primary compound(s) excreted	Structure of primary metabolite	Molecular weight (g/mol)	Aqueous solubility at 25 °C (mg/L)	Log K_{ow}	pK_a	Log K_{oc}	Elimination half-life
Amphetamine ($C_9H_{13}N$)		135.21	2800[a]	1.76[c]	10.1[b]	NA	9–14 h 25–35% unchanged Metabolites: 4-hydroxyamphetamine, norephedrine
Methamphetamine ($C_{10}H_{15}N$)		149.23	5×10^{5}[b]	2.07[c]	9.9[b]	NA	24 h 40–50% unchanged Metabolites: amphetamine, 4-hydroxyamphetmine, norephedrine
Benzoylecgonine ($C_{16}H_{19}NO_4$)		289.33	1605[a]	−1.32[a]	2.15	NA	1 h, 6 h (BE) 1–9% unchanged 26–54% as benzoylecgonine Other metabolites: ecgononine methyester