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Improving the dialogue between public health and ecosystem science on antimicrobial resistance

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The concept of health has evolved markedly from a bio-medical, mechanistic model to include an interdisciplinary perspective where human, animal and ecosystem health are integrated. One Health, EcoHealth and Planetary Health are examples of approaches to health advocating collaboration and interdisciplinarity at multiple levels. In practice, successful integration has been challenging and in particular, understanding of the ecosystem component of health lags behind the human and animal components. Antimicrobial resistance is an important threat to human health, which develops, is maintained and transmitted at the human–animal–environment interface. While the human and livestock components of resistance are well understood, this is not the case for the ecosystem component. This gap in knowledge leads to a poor representation of the environmental dimension of antimicrobial resistance in key policy documents and in interdisciplinary work around this issue. We interviewed a group of leading researchers in public health and ecology to explore their perceptions on the integration of ecosystem and public health research in the context of antimicrobial resistance. Experts from both fields considered that research on antimicrobial resistance is only beginning to consider ecosystems. They highlighted various barriers that have contributed to limited integration, such as conceptual barriers, and a lack of knowledge translators as facilitators. Better interdisciplinary integration is needed to address the challenge of antimicrobial resistance. Improving the dialogues between the disciplines is a necessary first step in this process. Greater engagement of ecologists is needed to build a more complete understanding of the role of ecosystems in human health, and identify how human interactions with ecosystems can both contribute to, and restrict, the development of antimicrobial resistance.

Keywords: AMR, ecosystems, interdisciplinarity, One Health, public health, policy

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Introduction

The challenge of antimicrobial resistance

Increasing awareness of the interdependence of human health with that of the ecosystems in which we live (Reid et al. 2005, Lerner and Berg 2017) has underpinned the growth of interdisciplinary, holistic and multi-actor models of health, such as One Health, EcoHealth and Planetary Health (Zinsstag et al. 2011, Gibbs 2014, Whitmee et al. 2015, Lerner and Berg 2017, Prescott et al. 2018). All of these approaches involve the collaboration of multiple disciplines from the natural and social sciences as well as policy makers, although their practical success at integrating various actors has been varied (Zinsstag et al. 2011, 2012).

The threat of antimicrobial resistance (AMR) to public health has been likened to climate change in terms of its scale, urgency and need for collaborative action (Shallcross and Davies 2014, Woolhouse and Farrar 2014, Woolhouse et al. 2015). If current trends persist, AMR is predicted to overtake cancer as the leading cause of death worldwide, with an estimate of 10 million deaths worldwide by 2050 (O'Neill 2014). Pathogenic microorganisms such as bacteria, viruses and fungi evolve resistance to antimicrobials, and resistance is then harboured and transmitted in humans, animals and the environment and at the interface of these various components (Martínez 2008, Woolhouse et al. 2015). While the human and livestock components of resistance mechanisms are relatively well understood, the ecosystem component, both in terms of drivers and transmission pathways (chiefly municipal and industrial wastewater, land spreading of animal manure and sewage sludge, and aquaculture, Singer et al. 2016), remains largely unclear (Berendonk et al. 2015, Woolhouse et al. 2015, Singer et al. 2016) and is considered one of the greatest environmental threats (UNEP 2017). This gap in knowledge is evidenced by missing or minimal representation of the environmental dimension in key policy documents on AMR (Singer et al. 2016, Iossa and White 2018) and a limited activity to mitigate environmental risks at a global level (Anon 2018).

Tackling AMR requires an interdisciplinary approach in which the value of nature – and ecosystems – is intrinsically linked to human health (Hertzen et al. 2011, Angeli et al. 2015). However, research activities, as well as research institutions themselves, are frequently still organised along disciplinary lines, meaning that effective interdisciplinary research can be difficult (Raffaelli and Frid 2010, Zinsstag et al. 2011, Rook 2013, Allen-Scott et al. 2015, Butler et al. 2015, Manlove et al. 2016). This stifles innovation in areas such as AMR and ecosystems, where interdisciplinary working is critical for progress. Here we used semi-structured interviews to gauge the current state of dialogue between the fields of public health and ecology, based on perspectives of experts from both fields (Bryman 2016). Our aim was to gather ideas for improving the dialogue between these disciplines and lead to greater collaboration.

Methods and results

State of interdisciplinary research on antimicrobial resistance

We interviewed 16 leading researchers (nine from ecology and seven from public health; Supporting information for details on methods and analysis, along with selected quotes referred to below) to explore the challenge of interdisciplinary research on AMR. Five main themes emerged from our interviews: 1) the approach used to study AMR; 2) the state of knowledge in the field; 3) the scale and terminology used when discussing AMR; 4) integration of ecosystems research within public health research relating to AMR; and 5) parallels between ecosystem and other sciences (Fig. 1).

Theme 1. Approach. Public health experts discussed how conceptual approaches in their discipline focus on primary care and do not encompass ecology (S1, quote 2 Public Health researcher 3, PH3). Several public health experts commented that, historically, large epidemiological studies and clinical trials have been the foundation of public health. Despite socio-ecological models of health being prevalent (Berkes et al. 2000, Lang and Rayner 2012), they felt that ecosystems and/or the environment were not being considered within wider public health research, and not just AMR-related public health research. In these models of public health, the health of humans is seen as interdependent with the natural environment (Colding and Barthel 2019); however, in practice, much public health research stops short of including the ecological component (S1 quote 3, PH2).

Theme 2. State of knowledge. Ecology experts felt that AMR-focused research within their field of research was still at an early, descriptive phase, rather than investigating effects at ecosystem level. For example, they referred to current research studies as just '*taking snapshots*' (E1), measuring the prevalence of antibiotic resistance genes and pathogens, and missing a broader level of understanding of AMR research, one that links microorganisms to microbial communities, as well as macro-organisms, their communities and entire ecosystems (E2, E3, E7). Therefore, in their view, ecological research on AMR is still investigating basic, mechanistic processes of resistance rather than tackling ecosystem-level perspectives. Two public health experts felt that research in AMR is now at a stage where it needs to progress from describing the problem to finding and testing the solutions (PH4, PH7).

Theme 3. Scale and terminology. Experts from both fields focused on the terminology used and the scale at which AMR is studied (e.g. at the micro versus the macro scale, or at the individual versus the community scale) as central to current research (S1, quote 4, E1). They also noted the way in which public health research and policy (in the UK) are framed around individual exposure rather than at population level (S1, quote 5, PH2, PH1).

Theme 4. Integration of ecosystem research. At first mention in the interviews, public health researchers felt that ecosystem research is being considered within AMR research. In particular, they quoted work in different types of environment,

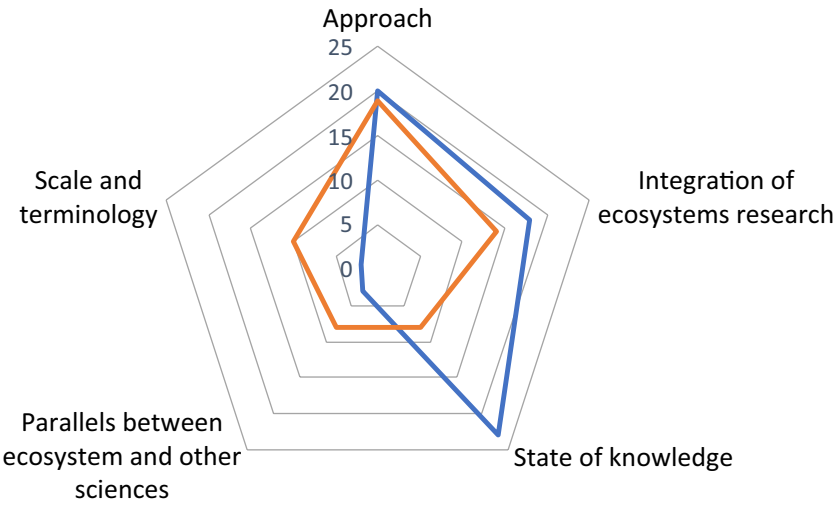

Figure 1. Key themes emerging from interviews with seven public health (orange) and nine ecology (blue) experts. Each spoke in the diagram represents a theme. The numbering represents the total number of times each theme occurred in the interview responses.

from soil to water, and the increasing acceptance of the One Health approach (S1, quote 6, PH6). They also referred to recent publications on AMR in which the environment is explicitly the focus (Anon 2018). However, when asked to explain the integration of ecosystem research, and specifically asked whether the word 'ecosystem' as opposed to 'environment' featured in AMR research, public health researchers stated that One Health did not equate to ecosystems understanding (S1, quote 7, PH6).

Theme 5. Parallels between ecosystems and other sciences. When discussing the potential integration of ecosystem and public health research, several experts from both fields drew parallels with microbiome research and systems sciences. They referred to how DNA sequencing is revolutionising the number of microbial species that can be identified without the need for laboratory cultures (S1, quote 8, E7). In particular, public health researchers drew parallels between ecosystem research and ideas about the microbiome, and human–non-human and interspecies relationships (PH6, PH7). They referred to the growing interest in medical anthropology in how human health is intimately linked to that of other life forms in a kind of 'entanglement' (Nading 2013). Several experts also drew parallels between ecosystem and systems sciences, suggesting an overlap between the two (S1, quote 9, PH3, PH4).

Barriers and facilitators to the integration of ecosystem research into research on antimicrobial resistance

Experts from both fields (i.e. health and ecology experts) identified the importance of conceptual barriers in preventing greater integration of ecosystem research within AMR research. Public health experts also noted terminology and a lack of opportunities to engage as key barriers, whereas ecology experts emphasised contrasting methodologies, a lack of funding and interdisciplinary barriers (Fig. 2). Difficulties in identifying the right partners (E8, E9) and physical separation in different buildings and institutes (E2, E5) contribute to interdisciplinary barriers. Experts from both fields recognised a lack of opportunities to engage, such as focused workshops or meetings, as a fundamental barrier. Conversely, training, opportunities to meet and knowledge transfer intermediaries were identified as potential facilitating mechanisms. In fact, some of the experts from both fields mentioned that their success in the field of AMR was due to their ability of being translators between different disciplines (E9, PH6) and taking a less specialised approach to their discipline (E6, E9, PH3, PH7). On the other hand, one public health expert noted how, while at the research level, moving towards interdisciplinary partnerships would help, at a policy level it would be much harder, especially in low- and middle-income countries, where environmental governance mechanisms are often weaker than in high-income ones (PH4).

Some of the experts viewed a systems approach as a possible way of linking public health and ecology research (PH2, PH3, PH4, PH7, S1 quote 11, E2). Two public health experts mentioned that the socio-ecological model of health incorporates the concept of ecosystems (PH2, PH3). AMR has been framed as a One Health issue (Robinson et al. 2016), and One Health been accepted as the guiding principle in national action plans on AMR (WHO et al. 2016). One ecologist (E4) and two public health experts (PH4, S1 quote 12, PH7) considered One Health to be the most promising framework, although there was also a suggestion that One Health, despite being the accepted 'compass' of the field (PH7), impaired creative solutions and actions beyond it (S1, quote 10). One possible explanation is that One Health has been criticised for perpetuating silos among human, animal and environmental research (Manlove et al. 2016); this limitation has prompted calls to expand the environmental component of One Health to embrace a broader context, such as that of Planetary Health (Zinsstag et al. 2011, Rabinowitz et al. 2018).

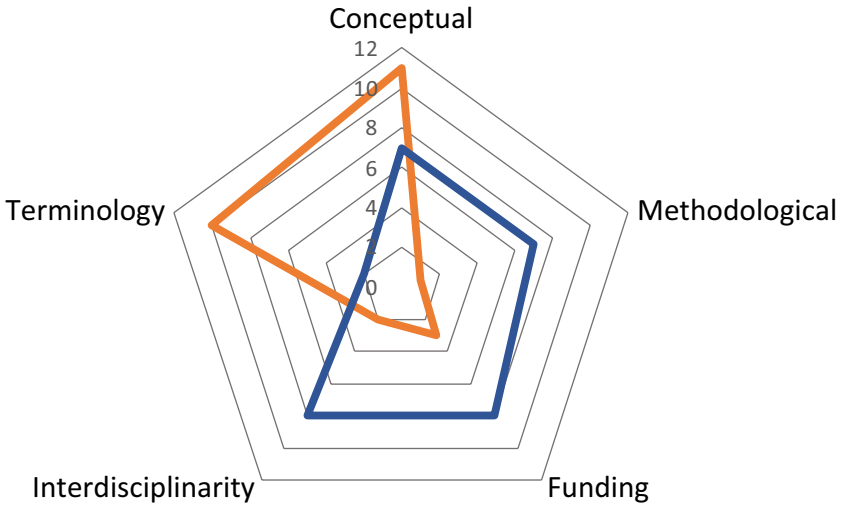

Figure 2. Barriers to integration of ecosystem research identified by seven public health (orange) and nine ecology (blue) experts. Each spoke in the diagram represents a barrier. The numbering represents the total number of times each barrier was mentioned in the interview responses.

Discussion

Moving towards greater ecosystem integration within studies of antimicrobial resistance

Whilst both the fields of ecology and public health are engaging actively with AMR, the role of ecosystems in promoting and regulating AMR is only beginning to gain attention. Some of the obstacles to greater interdisciplinary integration that we identified have also been highlighted by other studies, such as communication difficulties, differing disciplinary approaches and institutional barriers (e.g. lack of credit in promotion and tenure; Roy et al. 2013).

Despite the high-level policy profile that AMR has received in recent years through international agencies such as the World Health Organization (WHO), the Organization for Animal Health (OIE) and the Food and Agriculture Organization of the United Nations (FAO), progress in tackling rising resistance has been slow (Gelband and Laxminarayan 2015, Anon 2019). The ecological component of AMR is one of the key untapped research areas so far (Anon 2019), as most of the attention has focused on drug innovation based on a human-health framework (Wernli et al. 2017).

From our semi-structured interviews with expert ecologists and public health researchers, it appeared that the two fields have limited interaction. Improving the dialogue between public health and ecosystem science requires change at multiple levels. Firstly, from an academic perspective, interdisciplinarity must be part of the education curriculum as early as undergraduate level (Roy et al. 2013, Shomaker et al. 2013, Xie et al. 2017). In this context, it is promising that evolutionary biology is increasingly seen as foundational to medicine students (Trevathan et al. 2008, Stearns et al. 2010, Antolin et al. 2012) and One Health postgraduate education is expanding (Shomaker et al. 2013). Secondly, interdisciplinary opportunities to come together – such as networks, workshops and multi-discipline institutes – are needed to ensure that ecosystems are integrated within AMR research. Thirdly, engagement at the policy level is crucial to ensure effective translation of this new integrative research and enhance the likelihood of science-informed policy actions (Lucey et al 2017). Fourthly, changing the discussion framework around AMR requires promoting the stewardship of microorganisms (the global microbiome) as a shared, non-renewable resource (Carroll et al. 2014, Jørgensen et al. 2017, MacLean and San Millan 2019), and a wider appreciation of the evolutionary dimension of AMR. Not only the word evolution, but also key eco-evolutionary concepts, such as eco-evolutionary feedback loops (recognising the interaction between ecological and evolutionary dynamics), have received very little attention in AMR research (Antonovics et al. 2007, Nesse and Stearns 2008, Hiltunen et al. 2017).

From our analysis, it appears that the field of public health, from research to policy, is increasingly open to integrating the ecological dimensions of health. Several researchers from both fields indicated that One Health should be the framework to link ecosystem and public health research. However, the facts that ecosystems are missing from the definition of One Health, and that there is no agreed definition of One Health (Gibbs 2014), hinder its use for this purpose. Moving towards greater ecosystem integration within One Health and other AMR-related public health research, needs a multi-pronged approach where key learned societies (e.g. the Ecological Society of America, the Nordic Society Oikos, the British Ecological Society) lead alongside funders to increase the visibility of interdisciplinary research in the area. We recommend a number of practical steps to enhance this: 1) learned societies and key academic journals sponsor special issues to highlight good practice and stand-out examples of interdisciplinary research, specifically where ecosystems are the focus of AMR research; 2) learned societies organise workshops to bring ecologists and public health researchers

together to tackle AMR, and outreach to their respective research communities to amplify this work; and 3) research funders build on recent examples of interdisciplinary funding in the field, such as the UKRI Cross Council Initiative to Tackling AMR or the NSF Dynamics of Coupled Natural and Human Systems, to fund interdisciplinary fellowships, which involve discipline-hopping internships and expand current knowledge transfer roles. Alongside the top–down approaches, we also recommend that individual researchers are given more incentives to collaborate with colleagues in other disciplines to develop innovative interdisciplinary research in this field.

None of the public health researchers we spoke to, was familiar with the concept of ecosystems – but none of them appeared to be reluctant to see its importance. This suggests that ecologists are either failing to communicate its importance (unlikely given the recent prominence of IPBES reports on catastrophic biodiversity losses) or showing limited engagement with AMR as a 'human health problem'. We urge more ecologists to take on the roles of collaborators and translators, so that the ecosystem dimension of AMR can be championed, and more sustainable responses to the challenge of AMR can be formulated and realised.

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Author contributions

Graziella Iossa: Conceptualization (equal); Data curation (lead); Formal analysis (lead); Funding acquisition (equal); Investigation (equal); Resources (equal); Supervision (supporting); Visualization (lead); Writing – original draft (lead); Writing – review and editing (equal). **Piran White**: Conceptualization (equal); Formal analysis (supporting); Funding acquisition (equal); Methodology (equal); Resources (equal); Supervision (lead); Writing – review and editing (equal).

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