

Roadmap to a One Health Agenda 2030

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Abstract

The current fragmented framework of health governance for humans, animals and environment, together with the conventional linear approach to solving current health problems, is failing to meet today's health challenges and is proving unsustainable. Advances in healthcare depend increasingly on intensive interventions, technological developments and expensive pharmaceuticals. The disconnect grows between human health, animal health and environmental and ecosystems health. Human development gains have come with often unrecognized negative externalities affecting ecosystems. Deterioration in biodiversity and ecosystem services threatens to reverse the health gains of the last century. A paradigm shift is urgently required to de-sectoralize human, animal, plant and ecosystem health and to take a more integrated approach to health, One Health (OH). The Sustainable Development Goals (SDGs) offer a framework and unique opportunity for this. Through analysing individual SDGs, we argue the feasibility of an OH approach towards achieving them. Feasibility assessments and outcome evaluations are often constrained by sectoral politics within a national framework, historic possession of expertise, as well as tried and tested metrics. OH calls for a better understanding, acceptance and use of a broader and transdisciplinary set of assessment metrics. Key objectives of OH are presented: that humans reconnect with our natural past and accept our place in, and dependence on our planet's ecosystems; and that we recognize our dependence on ecosystem services, the impact of our development thereon and accept our responsibility towards future generations to address this. Several action points are proposed to meet these objectives.

Keywords: One Health, Health governance, Health policy, Sustainable development goals, Ecosystems health, Global health, Planetary Health

Review Methodology: We reviewed academic papers and on line resources for definitions of health for each sector (human, animal, wildlife, plant and ecosystem health). The 17 Sustainable Development Goals (SDGs) and the official lists of diseases published by WHO and the OIE were collated and analysed for their suitability for an integrated approach to management. Selected SDGs were chosen as examples to demonstrate the feasibility of an integrated or one Health approach, which was supported by reviewing the relevant literature for each.

Introduction

Despite decades of academic appeals for an integrative, interdisciplinary and transdisciplinary approach to the many guises of health and disease, the development of human,

animal and environmental or ecosystems health continues within a highly sectoralized and structural governance and policy framework [1–4]. Neglect of environmental or ecosystems health and associated loss of biodiversity is now at a critical point, threatening 'Planetary Health' and the

fundamental processes on which life depends [5]. In addition, the intensification of and the technological innovation in conventional health systems is proving too expensive to maintain and is further complicated by dependency on expensive pharmaceuticals. Earlier gains in health are now looking vulnerable, resulting in global health inequities and a rise in emerging and re-emerging diseases [6]. Indeed, many gains in human development, including health, have been made at a cost to ecosystems, whilst the consequences thereof (climate change, air and water pollution, chemical exposure, biodiversity loss and ecosystem degradation) are now increasingly the causes for deterioration in human health [7, 8]. Emphasis to date has been on narrow perceptions of health and disease, e.g. longevity, human health burden of disease measures and single species host pathogen interactions. The influencing drivers and the need for more preventive health interventions have largely been neglected in favour of technical fixes including antibiotic misuse. A recent contribution from the World Health Organization (WHO) suggests that on average national investment in primary preventive health strategies may be as low as 3% of the countries' total health expenditure [9]. This reactive approach with its rising costs and smaller gains is proving unsustainable. Furthermore, underinvestment in the health and productivity of livestock [10] and plants [11], particularly within the context of vulnerability due to climate change [12], will result in poorer control of diseases and reduced productivity, affecting food security and livelihoods and ultimately impacting on human health.

Houle ([13] p. 401), questioned whether the concepts upon which we base our understanding of health (within the disciplines of epidemiology, pathology, etc.) are themselves 'unhealthy and maladaptive'. Houle also argues that the concept of health should acknowledge our dependency, passivity, weakness and vulnerability as features of our human existence. Rook [14] argues that microbial symbionts and commensals should be seen as a neglected ecosystem service, essential for the development of our immune systems and our well-being. Maintaining individual and public health in the ever changing, complex adaptive socio-ecological system we form part of, requires us to think foresightedly and creatively, while remaining flexible and contributive. The same could be said of maintaining the health or survival of an individual animal or single species population. A paradigm shift is needed towards a fully integrated approach to health; a system(s) approach with a focus on restoring resilience of biological systems at all scales, including humans, animals and plants [6, 15, 16], an approach known as One Health (OH), derived from the One World One Health concept, which emerged in the first decade of the twenty-first century [17, 18].

Zinsstag *et al.* [15] take a narrower view and define OH as 'any added value in terms of health of humans and animals, financial savings or environmental services achievable by the cooperation of human and veterinary medicine when compared with the concepts of approaches of the two medicines working separately.' Beyond attempting a

closer cooperation of human and animal health, 'ecosystem approaches to health' or 'eco-health' considers inextricable linkages between sustainable ecosystems, society and health of animals and humans [19, 20]. The in-depth understanding of ecological processes allowed, for example, to show that mercury poisoning of fish and impeding health risks for humans in the Amazon basin were not due to upstream gold mining but to soil erosion following deforestation [21]. This example and a large body of literature demonstrate that contemporary complex health problems cannot be solved by reductionist but rather systems thinking approaches, such as those promoted by the International Association of Ecology and Health (www.ecohealth.net) [22, 23]. One Health and EcoHealth thinking converge strongly, especially through OH recognizing health as an outcome of social-ecological systems (SES) and its implication for sustainability [23–25]. The term OH is used in this paper because of its high acceptance, whilst clearly recognizing that ecosystems approaches to health [22] and health in social-ecological systems (HSES) [23] are imbedded in the OH approach to complex systems.

The added value resulting from the integration of relevant sciences in a system(s) approach to health is the focus of the Network for Evaluation of One Health (NEOH), a European Union (EU) Cooperation in Science and Technology (COST) funded initiative (COST TD 1404) that has developed a framework and protocols for the evaluation of OH initiatives [26].

This paper stems from work conducted in NEOH. It describes the current sectoralized health systems, highlighting the need for integration and presents the Sustainable Development Agenda 2030 as an opportunity for a paradigm shift. We outline the interlinkages between the sustainable development goals (SDGs) and discuss, with examples, the feasibility and opportunities for achieving synergies through OH. The challenges in assessing interventions in complex adaptive systems are discussed together with the need to adjust our metrics and appraisal principles. To conclude, key OH objectives and action points are proposed for an OH agenda towards a more integrated and accessible health system for all.

Names, Definitions and Their Unintended Consequences

Human development with all its promise in the twentieth century is confronted by several uncomfortable truths. The environment and biodiversity are rapidly declining and ecosystems are becoming dysfunctional. Ecosystem services, those benefits that humans derive from dynamic system of plants, animals and microorganisms, such as clean air and water, fertile soils and timber as well as recreational and spiritual benefits [27], are in themselves, metaphorically speaking unhealthy [28]. At the same time, earlier gains in the health of human communities through modern medicines and technologies, reflected in increasing human

longevity, are threatened by several emerging multi-directional health and disease threats including novel pathogens, growing mental health issues, obesity and hunger, micronutrient deficiencies and ecotoxicological risks [29]. We recognize that despite considerable progress in public health, human health equities across communities and countries seem more distant than ever. The same inequalities and disparities are noted in animal health service capacity and accessibility and in the health of local ecosystems and their potential impact on human health is generally ignored. How did these problems and these global disparities emerge despite the growing understanding of and investment in health across all sectors? To answer this, we review the definitions of health around which the sectoralized health systems have developed.

Human Health

When we think of health, we think firstly of the health of individual humans and communities. The WHO defined (human) health as ‘a complete state of physical, mental and social well-being, and not merely the absence of disease or infirmity’ [30]. This understanding of human health has subsequently evolved to take account of the changing health needs of an individual in relation to age, culture and personal responsibility [31] and an individual’s rights [32]. In addition, it is recognized that human health has socio-ecological determinants and that health underpins development [33]. Frankish *et al.* [34] presented the idea of population health as ‘*the capacity of people to adapt to, respond to, or control life’s challenges and changes.*’ The term Global Health, defined as ‘*an area for study, research and practice that places a priority on improving health and achieving equity in health for all people worldwide*’ [35] remains focussed on human health but is frequently confused with OH. However, results from the latest assessment of the burden of diseases from environmental risks clearly show the need for this wider view, since 23% of global human premature deaths (and unknown numbers of animal deaths with consequential financial losses and loss of biodiversity) can now be attributed to modifiable environmental factors, representing 12.6 million deaths every year [7]. Even this assessment is rather narrow in its interpretation of what ‘environment’ is, and the figure that could be attributed to environmental conditions, particularly in relation to social determinants and behavioural components of health, is likely to be much higher. There are also other concepts related to this, such as Universal Health Coverage, which is more focused on ensuring all members of a particular society receive equal care throughout life.

Animal Health

Our perception of animal health and its definition in the sector is much more disintegrated. This is demonstrated by

the fact that notifiable diseases, welfare, terrestrial and aquatic wild animal health are addressed in separate laws. For example, recent legislation (Animal Health Act 2014) in British Columbia, Canada [36] defines it as ‘the health of a population or subpopulation of animals and includes the preservation of a population or subpopulation of animals that is at risk of being exposed to or affected by a notifiable or reportable disease’. The importance given to infectious diseases of consequence to domestic animals and to humans (either directly as zoonotic diseases or indirectly through economic losses) in relation to the other aspects of animal health, e.g. in international treaties (WTO-OIE), reflects the persistence of the somewhat ancient idea that animals exist solely to satisfy human needs. Only recently, the World Animal Health Organization (OIE) added wildlife diseases to its Listed Diseases and now also includes health as an aspect of its definition of animal welfare. Diseases (zoonoses), which do not cause any disease in animals, have been added to the List, accounting for the OIE change of approach towards animal health and animal disease reporting. In addition, these aspects since March 2016 are addressed in EU Animal Health law [37].

Wildlife Health

Wildlife health as a concept is fairly recent without any formal sectoral responsibility other than generally through environmental and biodiversity legislation, and in the context of diseases considered under legislation for zoonoses in public health and as carriers of diseases of concern for domestic animal health. A working definition of wildlife health is needed that recognizes the major threats to wildlife are not diseases but rather anthropogenic impacts through the so-called development. Stephen [38] states that a modern definition of wildlife health should emphasize that (1) health is the result of interacting biologic, social and environmental determinants that interact to affect capacity to cope with change; (2) health cannot be measured solely by what is absent but rather by characteristics of the animals and their ecosystem that affect their vulnerability and resilience; and (3) wildlife health is not a biologic state but rather a dynamic social construct based on human expectations and knowledge. Conservationists have recognized and promoted what are known as the ‘Manhattan Principles’ (www.oneworldonehealth.org), that the health and sustainable maintenance of wildlife in natural reserves are mutually interdependent with the health of communities and the livestock surrounding them [39].

Plant Health

Plant health, much like animal health, is primarily understood in the context of plants’ contribution to the food sector for humans and to livestock feeds, rather than in the context of their contribution to biodiversity and overall

health of the ecosystem. More recently, however, climate change has drawn attention to global plant population health as part of the solution to global warming [40]. Recent work combines the provision of plant and human health services in Uganda [41].

Ecosystems Health to HSES

Ecosystem approaches to health concerns (including Planetary Health, which is a derivation) is to some extent embedded in the United Nations Environment Programme (UNEP). Recently this organization has diverged from static reports on chemicals, waste, air, water, biodiversity and soils (with a subset of reporting on ecosystems) to a more holistic view using the health paradigm (in fact OH) in reporting the European section of its global environment outlook titled 'Healthy Planet Healthy People' [8]. The theory and practice of understanding and managing human activities in the context of SES has been well-developed by members of The Resilience Alliance (www.resalliance.org) and was used extensively in the Millennium Ecosystem Assessment, including its work on human well-being outcomes (www.millenniumassessment.org). It is hence not difficult to relate human health to SES or so-called human–environment systems (and similarly the health of animals too) as HSES [23]. These systems relate outcomes (which can also be outcomes of health and wellbeing) to systemic interactions, which are primarily influenced by resources, governance and users in a given social, economic and political setting and related ecosystems as part of 'New institutional economics' [42].

The recent global changes in the SES (urbanization, globalization, human population growth, increasing consumption, climate change and loss of habitat and biodiversity) have created an environment, which favours the rapid and often global transmission of emerging and re-emerging pathogens [43]. The complexity of some of these recent global infectious disease threats (SARS, H5N1, ZIKA and Ebola) encouraged a lowering of sectoral walls and a more integrated approach to finding health solutions at an international level in principle (e.g. tripartite agreement between WHO, OIE and Food and Agriculture Organization of the United Nations (FAO)). However, at a national level in almost all countries, ministries remain separate and sectoralized, with their own budgets and agendas without integration of health programmes [44]. There are but a few exceptions e.g. the Veterinary Services in Italy are fully integrated within the Ministry of Health, and at local level (Local Health Units) public health doctors and veterinary officials work together. In Denmark, the Food and Environment are now fused in the Ministry for the Environment and Food of Denmark [45]. The Canadian Science Centre in Winnipeg is fully integrated and saves 26% of its running costs compared with separated human and animal laboratories [46]. The Kenyan Government has, as one of the first in Africa, an integrated Zoonotic Disease

Unit. Efforts and progress towards OH are still restricted by the inertia of long established divisions, institutional and logistical barriers to sharing data and information across institutions [47], power and leadership struggles with failure to agree on task and resource allocation issues [48]. Besides a few studies on joint health service delivery [49], brucellosis [50], rabies control [51] and laboratory infrastructure [46], there is a lack of economic evidence and metrics to measure OH gains [52].

Beyond the paradigm shift called for by OH, namely the reuniting of human, animal, plant and ecosystem health to deal with the current and future health challenges of a complex nature, Wallace *et al.* [53] reinvigorate the notion of specifically focusing on the wider context, which lies behind emerging health problems, including the geo-political, economic and societal global crises and the unsustainability of natural resource use and current global economic systems. Structural OH is said to 'empirically formalize the connections among capital-led changes in the landscape and shifts in wildlife, agricultural and human health' [51]. It requires a shift from linear thinking and simplistic medicalization of health, to systemic transdisciplinary approaches with contributions from a wide range of professionals such as ecologists, agriculturalists, engineers, architects and also social scientists, including economists, anthropologists and behavioural scientists, as well as from the stakeholder community and its representatives [15].

The United Nations (UN) community continues to develop policy and political instruments to drive change. In 2015, the 2030 Agenda for Sustainable Development set new goals (SDGs) to guide global development over the 15 years to 2030. Seen as the daughter of the Millennium Development Goals (MDGs), the SDGs explore health concepts further, in terms of universal human health coverage, the continuum of care, the life-course approach to health services provision integration and the convergence towards minimum global standards in absolute terms, everywhere. They cover the social, economic and environmental pillars of sustainable development, with a strong focus on equity, and are described as being '*integrated and indivisible, global in nature and universally applicable*' [54]. The new 2030 Agenda calls for a new cooperative paradigm based on the concept of 'full global partnership'. The need to 'think differently' to address the deep systemic changes required by this new Agenda has also been recognized at intergovernmental level [55]. We see this as a unique opportunity to propose a roadmap for an OH Agenda for 2030.

The SDGs: Opportunities for Change

The latest WHO assessment of health in the SDGs acknowledges 'that the SDGs, by contrast to the MDGs, reflect a far wider range of environmental, economic and societal concerns. All SDGs are designed to be cross-cutting and the inter-linkages and networks within the



Figure 1 A framework grouping the SDGs based on their intended outcomes, highlighting goals (in yellow) with antagonistic relationships with other goals. Adapted from Waage *et al.* [58].

SDGs are as important as the individual goals themselves' [56]. Health, instead of being based as in the MDGs on three narrow targets in isolation from the other goals, is now recognized as a precondition, an outcome and an indicator of sustainable development [8], and is now one target embedded in the others. There is at least a current acceptance that health depends on many factors outside of human control and that only by attending to the health of other biological and physical elements of the planet, will this be sustained [5, 57].

The Interactive Web of SDGs

Waage *et al.* [58] noted that total sustainable development is more than the sum of its parts and 'is an outcome of positive synergies between multiple elements and may be undermined by negative trade-offs between them'. They go on to criticize the SDGs for being developed within different sectors and presented by the UN without recognizing the interactions, both positive and negative, between them. To demonstrate, they positioned the SDGs in a framework of three concentric levels depending on their intended outcomes but argued that 'governance within silos is no longer tenable'. The inner level of *Well-Being*, which includes 'people-centred' goals such as health, education and nutrition (SDGs 1, 3, 4, 5, 10 & 16),

were noted as providing opportunities for synergies. The middle level, *Infrastructure* relate to those goals perceived as essential for a modern society to function (SDGs 2, 6, 7, 8, 9, 11 & 12) and are closely linked with those in the inner level. The outer level, *Environment* contains goals which relate to the management of natural resources and the provision of ecosystem services and life-supporting systems (SDGs 13, 14 & 15) were noted as having been largely ignored and seriously compromised. Achieving the goals in the infrastructure level must be done so without compromising those in the outer and inner levels. We have adapted this framework further (Figure 1) to highlight three of the infrastructure goals relating to economic growth, industrialization and production and consumption (SDGs 8, 9 & 12). These goals have an antagonistic relationship with other goals, especially under current political economies (see structural OH above). A comprehensive effort to apply principles of New Institutional Economics, postulated among others by Elinor Ostrom [42] could provide a global shift from the current political economy to link economic performance with sustainable practices sometimes described as decoupling [8] in recognition that the only resource available into the future is a renewable one to build greener economies. We have added a further all-inclusive level of OH, which extends to include the SDG 17 for global partnerships, a cornerstone of the SDGs and of OH.

The SDGs provide a key entry point for the OH approach to drive a paradigm shift in policy and practice towards a fully integrated approach to HSES [23]. Due to the political consensus and momentum behind the SDGs as well as the recent frequent global reports on health concerns this is a historic opportunity.

With this in mind, we explored the feasibility of an OH approach to play a strong role in successfully attaining a selection of individual and interlinked SDGs, and provide examples here as evidence of the success of such an approach, theoretical arguments in support thereof or arguments against a narrow targeted and segregated approach.

SDG 1 – To end poverty in all its forms

Poverty, entailing poor housing, lack of food and animal feed, unsafe water supplies and lack of human, animal and plant healthcare lead to an unequal burden of disease. In this context, diarrhoeal diseases, tuberculosis, HIV and malaria are among the top causes of poverty-linked human deaths. In addition, the most marginalized populations are characteristically dependent on livestock and also carry the heaviest burden from diseases that infect both humans and animals [59].

Diarrhoeal disease caused by viral, bacterial and parasitic microorganisms cause around 30 million cases a year [56]. Diarrhoeal diseases are listed among the top ten causes of deaths globally; 1.5 million deaths a year, more than half (842 000) attributable to unsafe water supplies and a lack of sanitation and hygiene [56]. Together with inadequate provision of health care, poverty is the root cause beneath these poor living conditions of humans and their livestock. There are also environmental and agricultural contributing factors, notably poor and contaminated water supplies, and food borne infections, many of which are derived from the livestock and food processing systems and passed on to consumers [60].

Campylobacteriosis ironically although not strictly a disease of poverty is a product of industrialization of food to provide cheap meat, and therefore is likely to affect the less well-off disproportionately. This disease presents an opportunity for a broader, yet integrated OH approach. As an important zoonotic human disease (commonly associated with contamination of poultry meat during processing), public health authorities often instigate high levels of biosecurity in the poultry processing industry. However, being normal gut commensal bacteria of poultry, little attention is paid to it at source by the poultry farmers and veterinarians. An additional concern is the rising trend of antimicrobial resistant campylobacteriosis cases, likely to be driven by use of antibiotics in poultry production both prophylactically and as growth promoters [61, 62]. Concerted action by veterinary and human health authorities and the agricultural sector could potentially alleviate this problem and mobilize the necessary economic support for sustainable solutions [63, 64].

SDG 2: To attain food security and improved nutrition through sustainable agriculture

Whilst the focus (and rightly so) of agricultural development has been on improving food security and providing sufficient caloric intake for the starving, there is growing awareness that the food systems created to address this, are not only unsustainable but are malfunctioning [65–67]. More intensive, modernized agriculture has improved food security in developing countries, but it has ignored the significance of dietary diversity and the micronutrient deficiencies, which result from a reliance on starch heavy diets [66]. In addition, industrialized agriculture has focused on producing three main crops (rice, wheat and maize) and has come at the cost of soil fertility loss and reduced biodiversity, whilst losing the dietary diversity (including related micronutrients) needed for children's physical and cognitive growth and well-being [8, 68, 69].

At the other extreme, worldwide obesity prevalence has more than doubled since 1980 and its prevalence in European countries ranges from 45 to 67% [70]. This seems ironic, that the need to address undernutrition in developing countries is used to promote clearance of land for intensive agriculture (dependant as it is on fossil fuels, fertilizer and pesticides), whilst the unintended consequence is low-cost food on supermarket shelves in high-income countries. This trend along with the consolidation of agriculture and intensification of agricultural systems has had profound consequences on diet. Although there is no single food system that can solve all the problems of both food security and nutrition security without damaging the environment [71], the current dominance of industrial agriculture in the development paradigm is concerning [65]. The unintended consequences are best illustrated by the penetration of corn products into the diet in North America with all its negative health impacts. The situation in Europe is hardly any better with up to 40% of Europe's food being imported [72], requiring four times the land area per head of population in Europe to achieve sufficiency [73]. To make matters worse, 30–50% of food produced globally is wasted, much of it in the food miles involved [74] which in itself is responsible for 3.3 billion tonnes of greenhouse gas emissions, equivalent to the third highest emitting country [75].

There is also a mismatch between current modern, high-income country lifestyles and diets and the evolution of our physiological and metabolic processes [76]. Increasingly sedentary lifestyles mixed with easy access to highly processed diets that are fat, sugar and calorie dense, result in an increase in obesity, cardiovascular disease and other non-communicable diseases (NCDs) such as diabetes, which are the cause of four out of every five deaths in the European Region [70]. Companion animals share many of the same risk factors for obesity and related diseases as their human owners [77] whilst a strong correlation has been shown between overweight dogs and the Body Mass Index of their owners [78]. An integrated OH approach can

reconnect communities with small scale and diverse, low-intensity agricultural systems with low-carbon footprints in high-income countries, whilst in low-income regions, small-scale farming continues to provide the majority of the nutritious food and employment and has contributed massively to food security [79]. Food culture, which promotes dietary diversity, seasonality, nutritional quality rather than quantity, local and moderate consumption, with a higher ratio of fruit and vegetable to meats (the latter derived from rangeland use) and a system, which shuns processing and food profiting, puts the proper value on food and encourages slow, communal eating. These principles are promoted in conservation agriculture, the organic and slow food movements, pastoral systems and wildlife harvesting, and are exemplified in the traditional Mediterranean diet, where populations suffer the lowest levels of NCDs in Europe [80]. Sustaining these traditional agriculture and organic food systems in both low- and high-income countries is a challenge and even in the Mediterranean region, the traditional diet is deteriorating. These countries remain under pressure from consolidation and food industry with cash crops increasingly forced on communities by economic circumstances (poverty). Some supporting efforts continue, for example through the integrated approach towards organic/sustainable agriculture in the Mediterranean carried out by CIHEAM – International Center for Advanced Mediterranean Agronomic Studies. A further consideration is that whilst poor quality, cheap processed fast foods remain available, NCDs will continue to be socially determined as poorer communities, which are separated from the land through urbanization or consolidation of agriculture, find healthier diets unaffordable [81]. Although intensification and agriculture technology are now embedded in agricultural practice, they need not always be applied at an industrial scale and much of the philosophy of sustainable intensification looks to fill yield gaps without fundamentally changing more conserving agricultural practices [82, 83].

The sustainable agriculture SDG is also linked to SDG 5 on gender equality and SDG 3 on health for all. Although comprising 43% of developing country agricultural labour force, women do not have equal access to productive resources, yet they are responsible for 60–80% of the food production [75]. Closing the gender gap in access to land, extension services and other inputs could lift 100–150 million people out of hunger [84] and would also impact on SDG 1 on ending poverty.

SDG 3: Ensure healthy lives and promote well-being for all at all ages:

Urban development (SDG 11) not only creates job opportunities (SDG 8) and wealth (SDG 1) for its citizens, but also presents multifaceted and interactive environment and health interactions and often increases their disease risk and health inequalities [8]. Equally, similar health risks

increase for urban populations of companion animals and for wildlife, which adapt to urban living.

Nearly 50% of premature deaths in Europe are attributable to cardiovascular and heart disease [70] and the concentration of one species, the human, inevitably has consequences on infectious diseases such as tuberculosis which is both a disease of poverty and urbanization in the modern age. This figure is expected to rise given the increases in obesity, increasing urbanization, sedentarization and longevity of human population.

Air pollution results in a significant burden of disease in Europe, with an estimated 600 000 premature deaths from both indoor and outdoor pollution in 2012 [85]. There are also chronic effects, including lung cancer [86], cardiovascular disease [87, 88], decreased lung function in children [89, 90], respiratory infections during childhood [91] and low birth weight [92]. Furthermore, evidence is emerging for a role of air pollution also in other diseases of multifactorial aetiology, for example diabetes [93]. Again this tends to be a problem of poverty and relative poverty in the old and young. Thus, there is a clear link between health of urban populations with SDGs 9 and 11. Urban development without the provision of natural green space, exacerbates air pollution, reduces opportunities to exercise and produces subtle negative effects on physical and mental health [94–97].

Current health systems appear to lack an integrated approach to health issues related to environment and activity. The lack of ecological understanding in public health has led to the adoption of ‘Green Space’ policies without a true ecological restoration of the domestic environment [98]. The benefits of urban green space are multiple, in stress and noise reduction, social cohesion, physical activity, heat stress mitigation and cleaner air but are dependent on access [99–107]. These policies can also result in artificially sustained green spaces with little ecosystem function or biodiversity [108]. If these natural elements were additional to the spatial element, this could significantly enhance the opportunity for the effects of improved well-being and reduced air pollution, and contribute to improved mental health. A current EU project (RESPIRIT) is looking into the links between plant diversity in cities and respiratory health. Therefore, an integrated approach to the health of urban populations (humans, animals and ecosystems) would foresee professionals from public health, veterinary and ecological sciences collaborating with town planners, architects and landscape designers, in the allocation and design of green spaces, ensuring that self-sustaining and resilient ecosystems remain at their core [109].

SDG 6: Ensure availability and sustainable management of water and sanitation for all

Globally, approximately 663 million people lack access to safe drinking water and 2.4 billion have no access to

improved sanitation facilities; 80 and 70% of people who lack access to safe water and sanitation respectively live in rural areas, the majority in Sub-Saharan Africa [110]. Providing sustainable water management is closely linked to SDGs 2, 9 & 12. Recycling of nutrients from human and animal waste saves the use of chemical fertilizers but requires the understanding of material flows and health risks [111]. Agricultural development of natural landscapes can result in deforestation of mountain catchment areas and drainage of marshes and wetlands (for cropping and livestock grazing), interruption or redirection of natural water flow through dams, reservoirs and canals (for power and irrigation purposes) and lagoon and delta dredging for navigational access. Freshwater quantity and quality are dependent on healthy water ecosystems, including catchment areas, river systems, natural water bodies, wetlands and deltas. Restoring and maintaining healthy freshwater ecosystems is a cost-effective way to improve water quality, biodiversity and human health [8, 112]. At a local level, the integration of education (SDG 4) and a gender perspective (SDG 5) are also important to consider in water programmes, as the increased scarcity of water affects mainly poor women and children in rural communities who have then less time and energy for tending crops, cooking meals or attending schools [112].

Human schistosomiasis is a related public health threat, listed as a WHO neglected tropical disease (NTD). It is typically targeted with mass drug administration programmes, provision of safe water and sanitation, molluscicide use and education programmes to highlight risks [113]. However, recent changes in the species evolution and changing transmission ecology, including zoonotic spill overs and multi-host pathogenicity and hybridization have been demonstrated [114–117]. Thus, in the ever changing world of human and animal population growth, anthropogenic environmental changes, globalized movements of livestock and humans, the previous narrow, anthropocentric or disjointed sectoral approach to the control of schistosomiasis in humans will now require a paradigm shift, taking a wider view through an OH approach.

SDG 13: Take urgent action to combat climate change and its impacts

Climate change affects human and animal health directly and indirectly through its impact on biodiversity [8, 112]. Whilst hosts and pathogens have evolved together in a relatively stable climate for tens of thousands of years, that equilibrium is now changing [118] and having an effect on vector distribution and behaviour as well as the rate of evolution of pathogens, which is much slower in the larger host species. This mismatch in rate of adaptive change between pathogen and host is creating opportunities for emergence and re-emergence of disease, e.g. current Zika virus outbreaks in humans associated with establishment and proliferation of *Aedes aegypti* mosquitos in the

Americas; the close to 100% fatality rate from *Pasteurella multocida* infections in the Saiga antelope in recent die-off events in Kazakhstan with possible climate associations [119] and anthrax outbreaks in Siberian arctic reindeer on the Yamal Peninsula, the latter epidemic associated with the hottest summer on record in the peninsula in 2016. Linkages between climate change and the Infrastructure SDGs (2, 7, 8, 11 & 12) are clear. However, with respect to the recent Ebola outbreak in West Africa, investment in intensive agriculture, urbanization and infrastructure such as roads and vehicles with the resultant forest destruction, disturbance of reservoirs and creation of pathways of infection, were not considered important factors despite growing evidence [120–122]. The Emerging Pandemic Threats programme (EPT) of USAID, despite half a billion dollars of investment, failed to predict the Ebola epidemic and the extent of the outbreak represents a massive failure of modern health systems [120]. The EPT had three main investment targets; improved prediction, response and identification of pathogens (laboratory capacity), but it failed to consider the socio-ecological systems in which pathogens emerge. Clearly, a more integrated, OH understanding of the health impacts of climate and other change arising from development is needed, with input from multiple sectors and disciplines.

SDG 14: Conserve and sustainably use oceans, seas and marine environments and SDG 15: protect, restore and promote sustainable use of terrestrial ecosystems

The links between these two SDGs and freshwater management and sanitation (SDG 6) and sustainable agriculture (SDG 2), together with the links to climate change (SDG 13) are clear.

Biodiversity loss occurs due to intensification of crop agriculture and industrial livestock production, urbanization, over exploitation of natural resources (overfishing, unsustainable harvesting and poaching), pollution, invasive species and climate change. Biodiversity loss can impact health through a variety of mechanisms such as increased likelihood of communicable diseases (wider vector distribution across fewer species) and NCDs (reduced crop yields and food diversity, contributing to increasing reliance on fewer unhealthy foods) [8].

The biodiversity within the world's oceans and seas has been changed by human activities both in and on them and indirectly through activities on land and river systems. The link between oceanic ecosystem health and human health is complex [123]. 'Sustainable use' requires an integrated, ecosystems based management strategy, which permits the use of the ecosystem services, whilst fostering the natural capital of the oceans. It should also recognize the link between biodiversity and the health of ecosystems through resilience [124]. Oceanic ecosystem services include natural biological resources, food, carbon dioxide absorption, detoxification of waste water, energy provision

(oil and gas, but also wave energy and providing a location for wind turbines), raw materials of sand and gravel for construction and opportunities for recreation. An integrated approach is required to protect terrestrial natural ecosystems and freshwater ecosystems through sustainable agricultural practices (such as conservation agriculture and with broader consideration of food demand, supply, waste and lifestyle) and to indirectly minimize the impact of estuary and river outputs on the associated coastal ecosystems.

Europe's increasing urbanization and intensive agricultural development (Green Revolution) since 1945 has impacted on the Danube River, which drains water from approximately 817 000 km² of land across 19 countries, and consequently caused eutrophication and dead-zoning of approximately 40 000 km² of the Black Sea in the 1990s [125]. Globally, eutrophication has contributed to approximately 245 000 km² of oceanic dead zones [75]. It is an example of how interconnected terrestrial and aquatic ecosystems are and how disjointed governance and however well-meant, narrow environmental policies in one area can negatively impact on other. An integrated, collective response from multiple countries, agencies and stakeholders is necessary to ensure a sustained management approach, with a focus on maintaining the health of ecosystems including humans. Sustaining terrestrial ecosystems also connects back to the discussion of sustainable agriculture (SDG 2). The sustainability and productivity of agroecosystems is dependent on the conservation, enhancement and utilization of biodiversity especially at the level of the soil but also in terms of pollinators, pest control, water and nutrient cycles and overall resilience [8, 40]. Agriculture now covers half of the EU's land area and the current pattern of use is leading to the deterioration of soil and surface water, food conservation and diversity. The main concern in food conservation is the loss of quality of the food during the long transport and storage times in the modern globalized system and associated waste, which is well above the global average in Europe [126]. Despite the importance of agriculture for food and natural land for health and well-being and ecosystems services, soils are being lost in Europe at an alarming rate of 275 hectares/day to soil sealing or land take [8]. Agriculture is estimated to be responsible for 70% of the projected terrestrial biodiversity loss, whilst 52% of land used for agriculture worldwide today is moderately or severely affected by land degradation and desertification [75]. The need for a transition towards 'ecological intensification', a process involving management strategies that integrate and enhance ecosystems functions associated with crop production, for instance increasing the diversity of plants and animals to increase the resilience of producing systems, has been suggested [127]. In addition, the different movements of conservation agriculture (CA) [128], organic farming [129], fermented food, etc. are all relevant. Europe is lagging behind many other regions of the world in CA and this is a perverse outcome of the Common Agriculture

Policy of the EU to date, with considerable benefits from subsidies to consolidated agriculture. However, CA is now taking a bigger role in the reform process [130].

Forested areas cover 30% of the earth's land surface yet contain 80% of terrestrial biomass and are home to more than 50% of known terrestrial plants and animal species [131]. Despite efforts to increase the protected forest areas, the total global forest area and primary forest areas are still declining, with associated loss of diversity in vegetation and wildlife [132]. In some regions re-forestation is going ahead but largely in the form of commercial plantations, as seen in Europe, with little contribution to biodiversity recovery (UNEP/UNECE 2016). Corporate agriculture within a neoliberal trade system is the main driver for deforestation [133] and until the drivers of our current unsustainable food system are addressed, the benefits humanity draws from ecosystems will be ignored and potentially lost completely.

Conservation and protection of natural ecosystems has since colonial times often relied on the establishment of national parks, fully fenced and patrolled to exclude (sometimes after forcibly expelling) human and domestic animal populations. This fortunately has been recognized as unsustainable, having to rely on unpopular measures such as culling for population control and the expensive relocation of animals to diversify gene pools. In southern Africa, the recent establishment of Transfrontier Conservation Areas (TFCAs), aimed at restoring the ecological connectivity of contiguous conservation areas between different countries, is attempting to redress this issue. However, it will also require an integrated and multiple-use landscape management approach to deliver the goal of sustainable socio-economic development [134]. Management of zoonotic diseases at the human-wildlife-environment interface in such areas clearly requires an OH approach in its broadest sense. In the semi-arid rangelands of East Africa, reconciling the interests of pastoralist communities and wildlife conservation and empowering communities to manage their wildlife has shown some local success through the development of an integrated approach [135].

The burden of diseases associated with biodiversity and ecosystem changes is difficult to quantify since we are considering the loss of a protective service as opposed to the presence of a specific disease risk, and furthermore the burden of ecosystem alteration may be disproportionately experienced by future generations [136]. There is great disparity in the way people experience health impacts from the degradation of ecosystems and it is often the remote and poorest populations, still reliant on their dwindling local terrestrial and marine resources, who will suffer the most. The recognition by Steffen *et al.* [137] that climate change and biodiversity integrity are two core planetary boundaries through which other natural systems operate, (and ultimately our health and existence depends) emphasizes the fundamental need to integrate natural ecosystems in our understanding of health.

What Have Health Assessments Taught us?

Current health governance remains segregated in local, national and international institutions, which lack the authority and tools to prevent emerging health threats at various scales. Recent global threats like Ebola in West Africa and Zika in South America provided valuable lessons, whilst the implementation of International Health Regulations has improved coordination and internationalization of interventions [138–140]. In addition, governance is no longer dominated by health organizations but influenced by many actors, including UN agencies (WHO, UNICEF) and multinational agencies (World Bank), national governments, civil society organizations, multinational corporations and academic institutions, etc. [29]. Animal health and environmental health governance are in a similar state. With a better acceptance of the interconnectedness of health and the multiple determinants and different sectors and actors involved, Frenk and Moon [29] suggest using ‘global governance for health’ as a more inclusive term, rather than restricting health governance to health professionals.

As part of governance, priority setting and budget allocation are based on priority disease lists regularly provided by the WHO and OIE. These are sometimes elaborated at regional or national levels such as at the European Centre for Disease Prevention and Control (ECDC), which is quite active in early detection of communicable disease/zoonoses threats/rapid risk assessment, i.e. recent report of Rift Valley fever in Niger – Risk for the EU [141].

These lack an OH assessment, despite the obvious linkages with the zoonotic diseases and less obvious environmental, socio-economic or structural drivers. For example, the WHO’s ‘Top emerging diseases likely to cause major epidemics’ includes diseases described as serious and requiring immediate action [142]. Despite all six diseases being zoonoses, with arguably strong environmental and socio-economic drivers, the list of experts responsible for prioritizing these does not include veterinarians, ecologists, social scientists or other stakeholders. Although WHO and OIE are advocating a transdisciplinary approach, there is little evidence yet of this in practice.

Our analysis of the drivers and risk factors for prioritized diseases listed by the WHO (NTDs, Neglected Zoonotic Diseases (NZD), Pandemic and Epidemic Diseases (PED) and the top ten causes of death globally), showed 98% of them could be classified as benefitting from an OH, systems thinking approach. A similar analysis of the OIEs listed diseases was performed. Global governance of animal health, the remit of the OIE, has a focus on economically significant livestock diseases. More recently their disease list includes wildlife diseases, including those of insects and amphibians. The diseases were assessed as to whether they had either a significant impact on producers’ livelihoods (mass losses, culls or trade restrictions), on farmed and

wild species populations, had a vector distribution affected by climate change, was zoonotic or caused biodiversity loss within natural ecosystems. On this basis, we advocate an OH approach for all 118 listed diseases.

Feasibility studies for policy making in society are frequently based on five elements; technical, economic, legal, operational and scheduling, with the economic element (cost–benefit analysis) often having the most leverage. This is often not the case in human or animal health where political and technical considerations are primary. However, complex problems, such as new emerging diseases, climate change and antimicrobial resistance create new challenges when assessing their feasibility for control. Current commonly used economic models, metrics and analyses often fail to capture the full extent of costs and benefits produced by health interventions. A sound assessment must be based on scientific evaluation and must combine economic, social and ecological aspects [52, 143]. Predictions in complex problems are heavily dependent on modelling, whilst benefits may take many years to accrue, which increases confounding and makes a traditional cost–benefit analysis difficult. Predicting human behaviour and how it may change over time is an additional challenge. An OH approach, based on complex or wicked problem solving methods [144] with transdisciplinary collaboration, warrants a better understanding, acceptance, integration and use of a broader set of assessment metrics, as promoted by NEOH [26].

But is There Proof of Concept for an OH Approach and its Added Value?

Policy decisions under challenging economic conditions rely not only on sound scientific evidence but on economic evidence too. Several authors have presented evidence of the feasibility and argued for the added value of an OH approach compared to isolated and linear approaches to disease prediction and control [3, 6, 21, 46, 48, 49, 51, 145–149]. The World Bank [46] estimated the annual funding required to build capacity of human and animal health systems in developing countries (with high risk of zoonotic disease prevalence) to WHO and OIE standards was approximately US\$3.4 billion. They estimate that such annual investment would expect global benefits of US\$30 billion each year. However, many examples lack the consideration of environment, ecosystems and structural elements of health in the interventions and benefit assessments.

Parallels between OH and sustainability (built on the pillars of Society, Environment and Economy) have been identified and can be used to broaden the assessment of the added value of OH [150]. In particular, the economic dimensions require a wide assessment beyond the obvious cost benefit analysis to include the less tangible benefits to human and animal health and welfare [148, 150, 151].



Figure 2 Key One Health (OH) objectives and action points to achieve them.

The objective of NEOH has been to provide guidance on metrics and assessment of OH for use into the future. Once established they will help to build confidence in the approach with a scientific method to assess the benefits to individuals up to planetary systems.

Pathway to an OH Agenda 2030

This paper has described the current definitions of health and the segregation of health systems. We propose that considering animal, human and environmental or ecosystems health separately within narrow perspectives is no longer valid. This is based on the increasing evidence of deterioration in biodiversity, ecosystem services and function, and trends towards a reversal in human and animal health gains of the past century. ‘Business as usual’ will continue to achieve some apparent gains in human and domestic animal health through high-cost technological advancements, whilst failing to adopt integrated approaches to address the broader socioeconomic and capital driven structural issues will prove to be unsustainable. The continuously rising health costs are already on the political agenda in many developed countries. For example, the UK is financially burdened with a National Health Service, which is the fifth largest global employer accounting for approximately 8% of GDP [152]. Although there is much to commend this valuable asset (for example, it is relatively more efficient than nearly half OECD countries), is it not also an indication of the parlous state of human health and the focus of health systems on reaction rather than prevention? Whatever the theoretical foundations to implement this change, there is a need to demonstrate the added value of an integrated approach, something which NEOH aims to help achieve through developing better tools for evaluation. Clearly, we need to shift our current focus to a more balanced health investment with

more global benefits to all species. This is encapsulated in the movements for OH, Ecohealth, Planetary Health and Ecological public health, which are essentially converging towards a paradigm shift for a more integrated approach to health.

The two key OH objectives, which must pave the pathway forward to achieving the 2030 Agenda are as follows:

- We, as humans must accept we are not the ultimate and superior product of the complex and adaptive ecosystem we find ourselves in; we are a component thereof and our health is directly related to the health of the system. Therefore, we must respect and reconnect with our natural past and work within the limitations of our ecological niche.
- We must recognize our dependence on ecosystem services, recognize the consequences and negative impacts and externalities of our previous development on the ecosystem and accept responsibility to address, mitigate and where necessary reverse these impacts to restore ecological processes and function. This is not a return to some past historical points but to work with evolutionary and ecological processes to enhance life not degrade it.

Key areas for action to achieve these objectives are laid out in Figure 2 above.

Within the 2030 Agenda for Sustainable Development and associated goals, there are a number of objectives relating to OH. The recognition that most SDGs are interconnected and that deep systemic changes are needed in order to develop new paradigms (based on the integration of environmental, economic and societal drivers and on inter-sectoral collaborations), provides a unique opportunity to shift into the OH paradigm. However, the reality of claimed OH initiatives will have to be critically evaluated.

This assessment proposes the following as a pathway (timeframe in brackets):

- (1) *Exchange and sharing* of the current movements, which share common principles (EcoHealth, One Health, Ecosystems Health, Planetary Health, Conservation Medicine, Ecological Public Health) under one umbrella (3 years).
- (2) *Consolidate the position of an OH approach* outside of the academic environment where it is currently languishing. Political support is vital for this and although considerable political momentum was given to the One World One Health principles a decade ago this needs to be sustained and across a broader constituency (5 years).
- (3) *Build evidence for the added value of an OH approach* through developing the necessary methodological framework and metrics for evaluation of OH interventions; the objective of NEOH (5 years).
- (4) *Establish capacity and protocols for operationalizing OH* within the main agencies (International and National) addressing health policies at the nexus of humans, animals and environment. Promote systemic thinking in health professionals (10 years).
- (5) *Initiate educational processes* at an academic level, government level and ultimately at all levels of society to help the process of change and acceptance of necessary changes in the health paradigm and how society addresses modern health challenges (e.g. established curriculum across medical, veterinary, public health, engineering, architecture, agriculture, land management, economic, social and political science, conservation/wildlife science, etc. faculties). A common OH curriculum could be a goal across all key disciplines and be extended to continuing professional development and government training programmes (ongoing with a common curriculum in 10 years).
- (6) *Foster transdisciplinary research* activities to understand better the drivers of emerging and prioritized diseases and level and degree of change in human (development) activities and behaviour, which will prevent or reduce risk and restore systems resilience (ongoing).
- (7) *Continue to mitigate effects of emerging diseases* at the interface through conventional but environmentally neutral approaches (surveillance, early warning, medical technologies and pharma), reduce transmission risks through appropriate biosecurity and use integrated approaches to disease management. Devise public awareness actions on health protection measures and risk mitigation in the face of crises (ongoing).
- (8) *Science policy interface* to incorporate research outcomes on OH disease drivers including development activities (in land use, agriculture, settlement, transport systems etc.) likely to precipitate disease emergence and models for prevention of risks (ongoing).
- (9) *Participatory political approach* to reach consensus on adoption of proposed OH interventions – a fundamental shift from reactive sectoralized medicine to preventive actions at social, ecological, economic and biological levels of society. OH provides a framework for the application of principles and in itself need not necessarily be institutionalized (10 years).
- (10) *Create communication and exchange platforms* for the OH stakeholders at national, regional and international scale (ongoing).

Conclusion

The SDGs are intertwined and have health embedded within them. We argue that attempting to achieve the SDGs, whilst working within the currently defined and segregated health systems (and their often linear approach to solving health challenges), whilst ignoring the linkages of health to ecosystems services and biodiversity, will increase antagonistic tensions between SDGs thereby undermining overall progress. The SDGs provide a unique opportunity for a move towards a more integrated approach to the future health of all. Our suggested pathway to achieving the 2030 Agenda is built upon the recognition that humans are but a component of an ecosystem upon, which we depend and within which we are called to support rather than undermine the services upon which we and other components depend. In addition, by taking a broader and more inclusive view in evaluating the benefits of OH, we believe enough evidence can be found to demonstrate the added value of an OH approach. We call for an integration of the current movements who share these principles to strengthen and deliver a OH approach with agreed protocols and capacity building within international and national agencies. In addition, we advocate the initiation of an educational programme to mobilize the process of change throughout the education system, creating buy-in from the whole of society through the school curriculum and creating a common OH curriculum for all the tertiary education disciplines with a key role in OH. This will provide a foundation for increased transdisciplinary research activities and mutual understanding in the future and a framework for a shift towards integrated and preventive health measures rather than sectoralized reactive medicine. Furthermore, this integrated approach requires open communication and exchange platforms for all OH stakeholders to encourage participation and to maintain momentum and trust.

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