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RESEARCH ARTICLE

Integrative concepts and practices of health in transdisciplinary social ecology

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Abstract
Increasing recognition of interdependencies of the health of humans, other organisms and ecosystems, and of their importance to socio-ecological systems, necessitates application of integrative concepts such as One Health and EcoHealth. These concepts open new perspectives for research and practice but also generate confusion and divergent opinion, prompting new theories, and call for empirical clarification and evaluation. Through a semi-systematic evaluation of knowledge generation in scientific publications (comprised of literature reviews, conceptual models and analyses of communities of practice), we show how integrative concepts and approaches to health evolve and are adopted. Our findings indicate that while their contexts, goals and rationales vary, integrative concepts of health essentially arise from shared interests in living systems. Despite recent increased attention to ecological and societal aspects of health including broader sustainability issues, the focus remains anthropocentric and oriented towards biomedicine. Practices reflect and in turn transform these concepts, which together with practices also influence ways of integration. Overarching narratives vary between optimism and pessimism towards integrated health and knowledge. We conclude that there is an urgent need for better, coherent and more deeply integrative health concepts, approaches and practices to foster the well-being of humans, other animals and ecosystems. Consideration of these concepts and practices has methodological and political importance, as it will transform thinking and action on both society and nature and specifically can enrich science and practice, expanding their scope and linking them better. Transdisciplinary efforts are crucial to developing such concepts and practices to properly address the multiple facets of health and to achieve their appropriate integration for the socio-ecological systems at stake. We propose the term "transdisciplinary health" to denote the new approaches needed.

Keywords One Health · EcoHealth · Knowledge generation · Communities of practice · Narratives

1 Introduction

Integrative concepts of health arise to contend with linkages between the subjects, attributes, determinants and fields of health in humans and other species and their shared ecological systems. These concepts notably include: "One Health", mentioned by Zinsstag et al. (2005, 2124) and strongly pursued since (Gibbs 2014; Zinsstag et al. 2015; Woods et al. 2018); "comparative medicine" (Lerner and Berg 2015, 1–3); "one medicine" (Jones 2019); "ecosystem health" (Schaeffer and Novak 1988); "EcoHealth", pioneered by Wilcox (2004); and "global health" and "planetary health", introduced by Cannon (2002, 480) and visibly articulated by Johnston et al. (2005). The concept of "Health in Socio-Ecological Systems" has also been proposed (Zinsstag et al. 2011, 148). While some concepts have a long history (for reviews see, for example, Battelli and Mantovani 2011; Lerner and Berg 2015), new frameworks encompassing human, animal and ecosystem health have been developed (e.g. Coker et al. 2011; Rock and Degeling 2016, 68) which transform the human-centred definition of health by WHO (2006, 1).

These integrative concepts of health are diverse and ambiguous—overlapping yet operationally detached (Lerner and Berg 2017, 5). The concepts are also in flux, reflecting

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ongoing changes in knowledge and practices. A lack of consensus around definitions and outright contradictions between them are to be expected, especially in new, broad and heterogeneous areas of research and practice. Yet consensus can be improved and contradictions resolved through better appreciation of both the uniting and distinguishing factors across the concepts. Seeking points of conceptual correspondence and interdisciplinary agreement can help to remedy the disadvantages of narrow views. Importantly, in many integrative concepts of health, the understandings and values of health are largely anthropocentric in orientation, even when measures and evaluations of health are extended to integrate other organisms (Lerner and Berg 2017, op.cit.). Such biases can have profound consequences on how responses to our dependency on other organisms and living systems are conceptualized and implemented. Negative environmental trends or collapses of ecosystems indicate that regarding nature as merely a provider for human needs is insufficient; humans impact other life, which in turn impacts humans (Kumar 2010; Pascual et al. 2017).

We posit that the links between the health of humans and that of other organisms and living systems, especially wildlife and ecosystems, are not yet widely appreciated and well researched. We further postulate that sustainable development is only possible if the dynamic processes affecting, and affected by, the health of ecosystems and of human societies are treated together more fully. In a globalizing world with extensive socio-ecological systems (Zinsstag et al. 2011, 152), with multiple drivers of the health of humans, animals and plants (Richardson et al. 2016; Haahtela et al. 2019, 3) and with interacting processes at many organizational levels (Fig. 1) and time scales, our era involves new threats and challenges yet also opportunities. In these systems and processes of health, socio-ecological structures must be recognized during both acute and foundational crises (Wallace et al. 2015, 70–11), but also in promoting sustainability in the longer term (Rock and Degeling 2016). There are thus important new challenges and opportunities for integrative concepts and practices of health.

The evolution of integrative health concepts has been studied primarily with regard to One Health, as in the entire papers of Gibbs (2014), Degeling et al. (2017), Falzon et al. (2018) and Lerner and Berg (2017), and to environmental public health (e.g. Lovell et al. 2014; Chen et al. 2019). Evaluations of One Health as a field of activity have also been undertaken (Baum et al. 2016; Hitziger et al. 2018). However, extensive and systematic surveys of knowledge in the boundary field of human, non-human and ecosystem health have not been published except for some areas such as zoonoses (Anholt et al. 2012) and infectious disease control (Manlove et al. 2016). In their meta-analysis of sources on One Health, Manlove et al. (2016, 1) stressed that the benefits of the concept "remain unclear because its effects have not been quantitatively described". Among extant

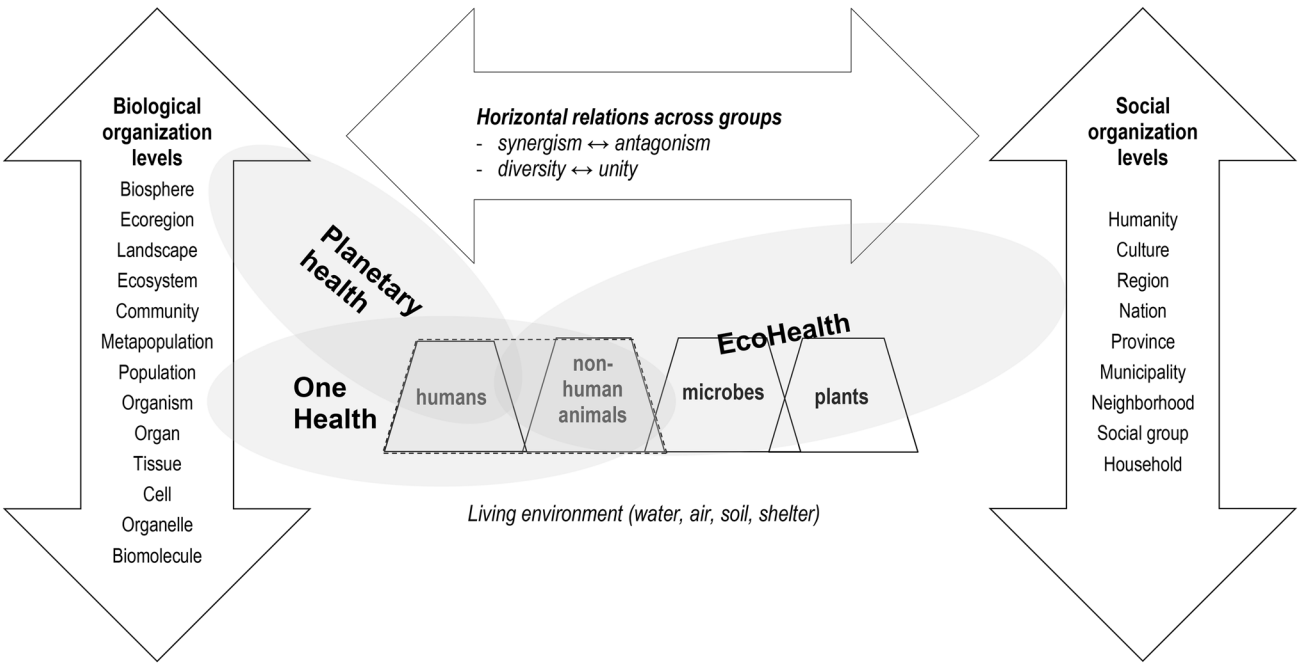

Fig. 1 Dimensions and types of integrative concepts of health. The typical central areas of a few common concepts have been indicated by hatched ovals. Note that: humans and animals overlap (denoted by dashed line), as do plants and animals with microbes which is not a taxonomic but a pragmatic concept (denoted by overlapping shapes), and that distinctions between synergism and antagonism are fuzzy as they coexist and coevolve and those between diversity and unity are value-laden

descriptions, the environmental component in One Health has been found to be underrepresented (Barrett and Bouley 2015, 4). The societal dimensions in the relationships between humans and nature with regard to health have been gauged even more coarsely (Lapinski et al. 2015). Manlove et al. (2016, 5, 10) addressed this dimension mainly by specifying studies on management of health systems, whereas Falzon et al. (2018, 217) focused on economic studies. The frameworks used to assess the impact of One Health have focused on change and evaluation (Hitziger et al. 2018, 216), rather than networks, agency, paradigms and narratives. The criticisms by Hinchliffe (2015, 28, 34) which note a lack of consideration for contexts and processes in knowledge integration, and the proposals of Wallace et al. (2015) for structural One Health, have revealed the need for fuller analyses of—and comparisons between—the paradigms, modes of application and political economy of different integrative concepts of health.

The purpose of this paper is to analyse integrative concepts of health by systematically examining what has been integrated and how, and what are the implications for the co-generation and co-use of knowledge. For the purposes of our analysis, we defined integrative concepts of health as follows: concepts that address, or are applicable in a holistic manner to, the health of multiple living systems. These concepts include, but are not limited to, One Health, EcoHealth, ecosystem health and planetary health. Based on this, and on the above initial evaluations of gaps of knowledge, we address the following research questions: (1) How have these integrative concepts of health appeared in scientific literature, and what methodologies have been employed to study them; (2) How have such concepts been adopted and shaped in practice, and how has conceptual integration of health been perceived by communities practicing it; (3) What underlying narratives of health, knowledge and agency can be discerned in relevant literatures and practices; and (4) What is needed to further develop transdisciplinary co-creation of knowledge? We thus focus on knowledge production, but include initial analysis of its transfer, uptake and impacts, to be followed by in-depth studies of knowledge evaluation, application, implementation and co-creation.

2 Methods

2.1 General approach

We studied the evolution of integrative concepts of and practices on the health of humans, other animals, plants, microbiota and ecosystems, with particular reference to social ecology and the relationship between people, their shared environments, and mediating institutions and organizational systems. We therefore analysed semi-systematically, semi-quantitatively and comparatively the framing and use of such concepts within research and practice, with an emphasis on their ontology and meaning (Buttigieg et al. 2016), and on the extent of their transdisciplinarity, which is defined in multiple dimensions, involving science–society interactions (Stokols et al. 2013, 3–5; Allen-Scott et al. 2015, 867).

To characterize the development of concepts and their uses, we employed conceptual models, drew on the previous literature, and evaluated the development of knowledge empirically by coupled bibliometric and bibliographical analyses (task corresponding to research question 1; see Fig. 2 on the general layout of the methodological components in relation to all research questions). We further studied the framing of such concepts by professional networks—including those of authors within the literature (cf. Manlove et al. 2016, 3–4)—and by communities of practice (see Electronic Supplementary Material [ESM] Section 1, Wenger 1998) where knowledge is generated, shared, processed, translated, negotiated and used, and how these communities of practice have conceived the challenges and opportunities of integration (question 2). Based on these analyses, we explored the overarching narratives deployed by experts working with these concepts (on definitions see ESM and Degeling et al. 2017, 783) (question 3). These tasks jointly allowed us to identify further needs and opportunities for transdisciplinary co-creation and co-use of knowledge with integrative concepts of health (question 4).

2.2 Data collection and analyses

The information search and evaluation procedures are described in detail in the electronic supplementary material (ESM—especially Fig. S1). We primarily performed searches in Web of Science (WoS) of papers published during its period of full coverage 1977-2016. Searches combined key descriptors for integrative concepts of health with (1) generic terms denoting Social Sciences and Humanities (SSH) studies (e.g. soci*, econ*, poli*, behave*, ethic*, phil*); and (2) specific SSH or interdisciplinary terms (e.g. sustainab*, altruis*, strateg*, actor*, "ecosystem service*, paradigm*). Search strategy decisions included: keywords or phrases (in English); data sources (primarily WoS, also for analytics); publication types (journal articles); time spans (1977–2016, 2014–2017, for historical searches longer); research orientations (categories of integrated concepts of health, SSH and other disciplinary fields); actors (authors, funders, organizers); scientific impacts (citations); and scopes of practice related to integrative concepts of health (e.g. clinical, policy-making, planning, advisory).

Excluding articles on global health (a field almost entirely concerned with human health) halved the number of articles retrieved (to 14,000, of which 6000 were in SSH); focusing

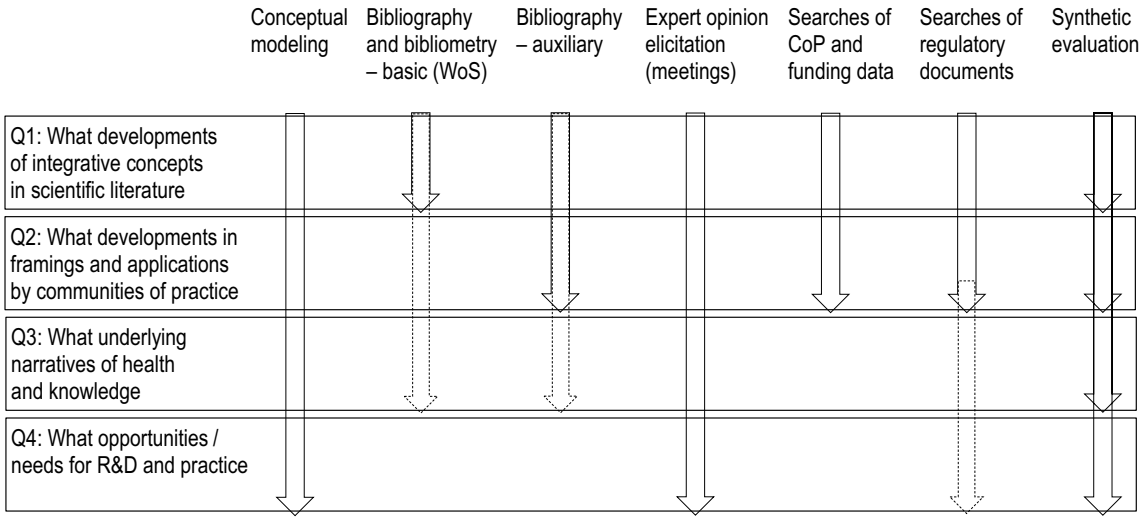

Fig. 2 Simplified diagram of the research and evaluation methodologies in relation to the research questions (Q1–4). The dotted arrows signify weaker or more sporadic involvement of the methodology in addressing the corresponding research questions. *R&D* research and development, *WoS* Web of Science database, *CoP* communities of practice

among the 6000 on "One Health", "EcoHealth" and "planetary health" gave ca. 1500 hits. Papers in all languages were included though English keywords or search phrases were used; English papers were dominant. We evaluated the relevance of sources using titles and abstracts, impacts (of citations and journals) supplemented by author, publication year, paper type and full-text availability. Based on this assessment, we derived a final subset from WoS of 697 recent SSH papers on integrative health concepts (see details in ESM, esp. Tables S2a–c).

We then analysed closely ca. 300 highly cited and otherwise seminal papers of the 697 papers. These papers were identified by the objective criterion of total number of citations (focusing on those cited > 3 times) and by our own judgments of their foundational and broad theoretical, methodological and applied importance from the point of view of social ecology (i.e. combining natural and social aspects), and from the point of view of transdisciplinarity (i.e. involving in addition to broad interdisciplinarity also science–practice interactions). It is acknowledged that such generic criteria of seminal impact are narrow and potentially biased, in part since publications with fewer citations (especially during early years of reception) may be influential, and vice versa: those often cited may not have lasting influence in science, let alone in policy and practice.

We then made "upstream" and "downstream" searches (of sources cited in and of sources citing the retrieved papers, respectively), to improve representativeness and to retrieve important complementary sources. We also retrieved sources by PubMed and Google Scholar searches (using the same search criteria as appropriate) and by non-systematic searches by the authors. These complementary searches included monographs, compilation publications, books (including textbooks), grey literature and databases, constituting important additional publication categories and routes through which to identify the relevant historical literature.

The analyses of communities of practice were based partly on the retrieved literature (including data on organizations and countries hosting and funding research as well as published evaluations that have been made of One Health, EcoHealth and other relevant communities) and partly on searches in information systems of key actors, specifically in the European Union's (EU's) CORDIS (Community Research & Development Information System) and EUR-LEX (EU Law) databases and, to a lesser degree, in documents of FAO and WHO (cf. ESM. Professional opinions and information about activities in communities of practice were elicited specifically in a series of 10 meetings on One Health, EcoHealth and other integrative aspects of health (see ESM Table S1, and Keune et al. 2017). We also used informal expert judgement by the authors in workshops and write shops and in the identification and collective evaluation of publications and of other information sources and activities.

The communities of practice were characterized by qualitative and semi-quantitative methods by: key areas of research and development (R&D) input (funding), conduct (projects and networks) and output (publications), and with respect to linkages to policy and practice. The scientific and professional narratives were characterized on the basis of emergent typologies in seminal publications, with particular reference to framings and beliefs regarding health and knowledge (ESM Table S2d).

3 Results

3.1 Development of integrative concepts of health and their application in research and practice

Integrative concepts of and approaches to health have become more common in scientific literature relative to the overall increase in publications, and also to literature on health or ecosystems in general (Fig. 3a1–2; Table 1; cf. ESM Tables S2a–d). The period of strongest increase in integrative health literature varies within and between topic areas. Environmental health was commonly addressed already in the 1970s and experienced its steepest increase around 1990, especially regarding SSH papers, which has then levelled out in comparison with some other topics such as global health. Studies on ecosystem health boomed in the late 1990s (Fig. 3, Table 1) and then levelled out, but still constitute a greater body of research than that on EcoHealth (Table 1). Studies on forest and plant health exhibit relatively stable trends (Table 1), but also their focus shifted to global change (e.g. Ramsfield et al. 2016). Studies on One Health underwent a rapid increase first in 1992–1996 with "one medicine" and again in 2012–2016 encompassing human–animal interactions; both phases included traditional and emerging diseases. However, there was a notable dominance of infectious diseases within One Health. Partly therefore, the steepest increase in all papers explicitly addressing the key integrative concepts of health (Columns 1–11 in Table 1) was during 1992–1996.

Many retrieved papers were of low relevance, as the integrative concepts were used narrowly, typically in single focused human health or ecological research, or as

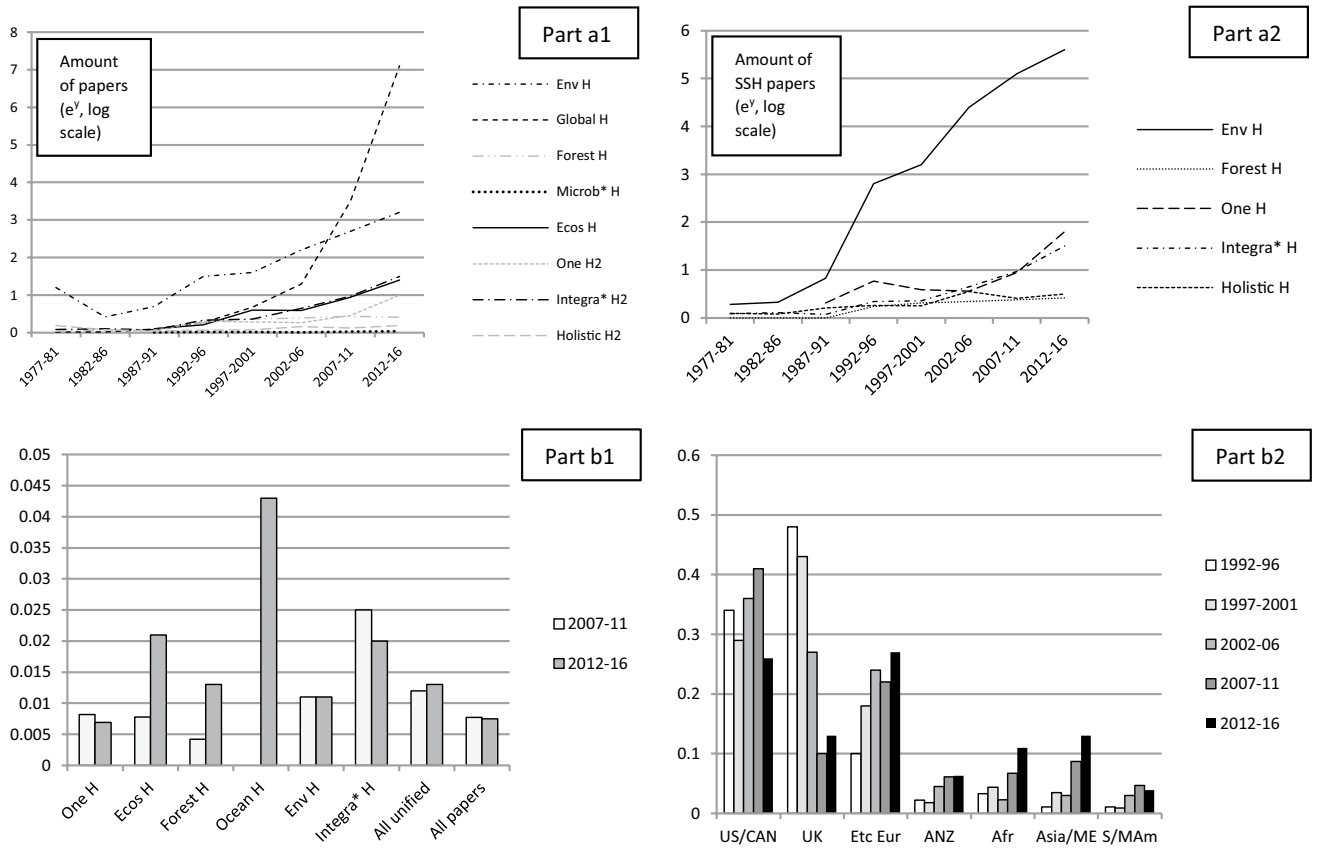

Fig. 3 Trends in the position of integrative concepts of health in the scientific papers identified in the searches, as measured by four key criteria. Long-term trends are shown for all Web of Science papers (**a1**) and for social sciences/humanities (SSH) papers (**a2**) as proportions of total amounts of papers (log scale *y* e−4) for some categories but excluding the dominant human health focused "global health". The data for "EcoHealth or Eco-health" as a more recent and uncommonly mentioned category have not been shown (cf. Table 1). More recent trends are shown for some categories and their combinations for highly cited papers (**b1**, as proportions of all papers) and in author affiliations for papers on "One Health", "EcoHealth" or "planetary health" (**b2**, as proportions of all authors). H or H2 = health (depending on dataset or stage of bibliometrical analysis); Env = environmental; Ecos = ecosystem; US/CAN = USA and Canada; UK = United Kingdom; Etc Eur = Europe except UK; ANZ = Australia and New Zealand; Afr = Africa; ME = Middle East; S/M Am = South and Central America

Table 1 Development of scientific literature on integrative approaches to health (=H) encompassing nature and humans, as reflected in the number of articles on respective key topical areas (numbered 1–11 in running order) retrieved from Web of Science (in 5-year intervals through 2016 in baseline analysis)

Years (abs., relat., SSH)	Environmental H (=1)	Global H (=2)	Planet* H (=3)	Plant H (=4)	Forest H (=5)	Microb* H (=6)	Ecosystem H (=7)	One H (=8)	Eco-H/EcoH (=9)	Integra*H (=10)	Unified H (=11)	Holistic H (=12)	Combined (1–12)	All papers on H	All papers on ecosyst*	All papers
2012–2016																
abs.	2327	5124	15	475	297	29	1007	729^^	59	1108	467	141	11,328	616,692	79,584	7,348,491
relat.	3.2e−4	7.1e−4	1.2e−6	6.6e−5	4.1e−5	4.0e−6	1.4e−4	1.0e−4	8.1e−6	1.5e−4	6.4e−5	1.9e−5	1.6e−3	8.5e−2	1.1e−2	
SSH	1120	2630	12	91	84	2	298	353	39	542	302	100	5277	252,411	14,489	
2007–2011																
abs.	1481	1900	11	232	237	15	510	246	25^^	522	180^^	73	5209	367,962	44,366	5,389,678
relat.	2.7e−4	3.5e−4	3.7e−7	4.3e−5	4.4e−5	2.8e−6	9.5e−5	4.6e−5	4.6e−6	9.7e−5	3.3e−5	1.3e−5	9.7e−4	6.8e−2	8.2e−3	
SSH	686	1006	8	48	51	–	157	129	12	244	111	56	2410	145,163	6466	
2002–2006																
abs.	911	534	8^^	137	160	6	241	110	3	266	23	65^^	2377	198,796	24,336	4,081,897
relat.	2.2e−4	1.3e−4	9.8e−7	3.4e−5	3.9e−5	1.5e−6	5.9e−5	2.7e−5	7.3e−7	6.5e−5	5.6e−6	1.6e−5	5.8e−4	4.9e−2	6.0e−3	
SSH	407	272	6	24	31	–	75	52	3	123	14	51	995	75,281	3035	
1997–2001																
abs.	556	233	3	71	124	8	207^^	99	–	124	9	26	1423	128,521	14,836	3,425,571
relat.	1.6e−4	6.8e−5	2.9e−7	2.1e−5	3.6e−5	2.3e−6	6.0e−5	2.9e−5		3.6e−5	2.6e−6	7.6e−6	4.2e−4	3.8e−2	4.3e−3	
SSH	236	127	2	6	23	–	97	44		68	4	19	617	49,766	1739	
1992–1996																
abs.	411^^	74^^	2	59^^	75^^	5^^	58	85^^	–	94^^	2	18	849^^	81,342^	8748^	2,764,461
relat.	1.5e−4	2.7e−5	–	2.1e−5	2.7e−5	1.8e−6	2.1e−5	3.1e−5		3.4e−5	7.2e−7	6.5e−6	3.1e−4	2.9e−2	3.2e−3	
SSH	153	45		7	13	–	17	42		50	2	14	313	28,832	935	
1987–1991																
abs.	95	14^	–	10	8	1	15	8	–	10	–	7	167	27,560	2230	1,359,596
relat.	7.0e−5	1.0e−5		7.4e−6	5.9e−6	7.4e−7	1.1e−5	5.9e−6		7.4e−6		5.2e−6	1.2e−4	2.0e−2	1.6e−3	
SSH	16	3		2	–	–	2	6		2		4	34	4388	150	
1982–1986																
abs.	39	2	–	7	7	–	–	–	–	10	–	7	64	18,491	1021	935,870
relat.	4.2e−5	2.1e−6		7.5e−6	7.5e−6					1.1e−5		7.5e−6	6.8e−5	2.0e−2	1.1e−3	
SSH	4	–		–	–					1		1	5	1291	10	
1977–1981																
abs.	89	2	–	3	3	–	–	–	–	7	–	15	117	15,968	897	772,438
relat.	1.2e−4	2.6e−6		3.9e−6	3.9e−6					9.1e−6		1.9e−5	1.5e−4	2.1e−2	1.2e−3	
SSH	3	–		–	–					–		1	4	1089	17	

Table 1 (continued)

Years (abs., relat., SSH)	Environmental H (= 1)	Global H (= 2)	Planet* H (= 3)	Plant H (= 4)	Forest H (= 5)	Microb* H (= 6)	Ecosystem H (= 7)	One H (= 8)	Eco-H/EcoH (= 9)	Integra*H (= 10)	Unified H (= 11)	Holistic H (= 12)	Combined (1–12)	All papers on H	All papers on ecosyst*	All papers
Total 1977–2016																
abs.	5933	7900	39	1003	906	64	2034	1285	108	2149	684	352	22,147	1,137,270	176,018	26,077,922
SSH	2622	4107	28	261	210	13	647	627	64	1059	434	246	10,146	573,668	41,007	

The total number of papers in these areas (uppermost numbers in the cells), their relative shares of the total number of English papers in the database (middle numbers in the cells) and the number of papers on Social Scientific and Humanities (SSH) topics (lowermost numbers in the cells) are provided for each 5-year interval. For the column "All papers" and for the lowermost row "1977–2016", only absolute numbers are given. The 5-year periods of steepest increase relative to all papers (given in x e−y) have been indicated (^^), along with high (> 50%) shares of SSH papers

buzzwords. Among highly cited papers (Fig. 3b1), the relative share of the papers in all 11 categories of integrative health concepts—ranging from 0.5–4% depending on the category (Table 1)—was higher than when comparing all papers in these categories (also the papers less cited) to the total number of papers (0.16% during 2012–2016, see column "Combined (1–11)". This suggests the high impact and importance of broadly integrative studies as compared to more specific research. The relative shares of also the highly cited papers and their trends varied between areas, from high levels within human-focused (more narrowly framed) integrated health to lower levels within environmental health and One Health. All these categories indicated stable levels of relative impact (or researcher activity) over time, whereas the share of highly cited papers on ecosystem, forest and especially ocean health increased strongly from ca. 2010 (Fig. 3b1).

As to qualitative traits of research, anthropocentric, economic and pragmatic topics have dominated even in the expanded framing of health which has increasingly addressed global, environmental and societal aspects. The relative share of SSH papers was higher in topic areas such as global health, EcoHealth and holistic health. Regarding the methodological approaches used in literature, "integrative health" commonly encompassed both traditional and modern Western (mainly human) medicines. An English-centred perspective is present in published research notwithstanding inclusion of publications in other languages and from other regions and increasing research efforts and funding in non-English-speaking regions.

3.2 Communities of practice and their knowledge uptake and co-creation: from anthropocentric to socio-ecological

By evaluating the data on professional activities, we identified key strengths, gaps and trends in communities of practice including researchers, other experts and stakeholders. The content and scope of these professional activities directly reflect the uptake and use of integrated concepts and scientific and professional discourses (Table 2). The knowledge co-creation by the disciplinary communities and between researchers and practitioners was more difficult to establish and was traced more indirectly. The variations and trends within knowledge uptake and co-creation activities are for instance affected by the educational backgrounds, and affiliations of the practitioners (communities of human and veterinary medicine, plant health and ecology are thus identifiable, cf. ESM Fig. S4).

We found shifts in the levels of activities of research teams and networks in different geographical contexts, as investigated by author affiliations (Fig. 3b2; cf. ESM Fig. S2 and Table S3). USA and Canada have sustained high

Table 2 Indicative status of integrative concepts of health in communities of practice, arranged roughly from traditional to novel areas of integration (vertical direction) and from broad to narrow consideration of linkages (horizontal direction), emphasizing the broad ecosystem–society and human–nature linkages

Community of practice and area of integration	Consideration of links between ecosystem and society	Consideration of links between human health and nature	Consideration of links between humans and non-human animals	Consideration of links between microbiome and macrobiome in health
Environmental health	++; increasing[b]	++ (risks)[b] + (benefits)[c]	+ (exposure—effects; animal models[d])	+++ (pathogens), </+ salutogens[e]
Ecosystem health	+, yet not focally	+ (ecological focus; human analogues)[f]	+ (ecological focus; e.g. Ocean Health[g])	++ (microbial ecology)
Plant health	+ (food plants and food chains)[h,i]	+; indirect (through food)	− (not relevant except through food chains)	+++ (root/plant microbes and fungi)[j]
Forest health	+ (mainly forest economy)	+ (focus on trees)[k]	< (focus on trees)	++ (root microbes and fungi)
EcoHealth	++, increasing[l]	++, growing (green care)	+ (wildlife welfare; critical animal study)	+ (through global orientation)
One Health	++/+ initially, then declined, now rising[m]	++ initially broad, then limited	+++; focally	+++, focally (pathogens)
Global health	++ (emphasis on governance)[n]	+/< (human health focus)	+ (domestic animals in human health)	+ (pathogens)
Planetary health	++, emerging[o]	++ (increasing, varied)	+ (also wildlife)	+ (micro–macro biodiversity)

Example areas are given in parentheses. The development status is based on an evaluation by the authors of bibliometric and bibliographical information and expressed in a semi-quantitative four-point scale from peripheral or weak to focal or strong (</+/++/+++)

[a]Dahlgren and Whitehead (2007)

[b]Bowen and Ebi (2015)

[c]Keesing et al. (2010)

[d]Shreve et al. (2016)

[e]Kau et al. (2011)

[f]James et al. (2015a)

[g]Halpern et al. (2012)

[h]Fletcher et al. (2009)

[i]White and Brown (2010)

[j]Richardson et al. (2016)

[k]Pautasso et al. (2015)

[l]Zinsstag (2012)

[m]Degeling et al. (2015)

[n]Dora et al. (2013)

[o]Haines (2016)

levels of activity. The relative level of research in the UK has declined, but in the rest of the EU it has increased to match that of North America. Research activity is increasing also in Australia, Africa and Asia, reflecting knowledge needs and efforts in these regions. The shifts were in part linked with diversified funding (ESM Fig. S2). Funding for studies involving integrative concepts, notably One Health, has increased especially in China, and practical applications are likely to follow. Their level of transdisciplinary knowledge co-creation is yet unclear.

Holistic initiatives and practices of health are dynamically developing, despite the inertia also observed. These have emerged along with interdisciplinary collaboration and new partnerships through shared challenges, some of which existed prior to the emergence of integrative concepts of health terms (e.g. King et al. 2004; Parkes et al. 2005). Examination of relevant EU Research and Innovation (R&I) projects (ESM Table S3) revealed that activities on One Health have increased more rapidly than those on ecosystem health when proceeding from the EU's Framework Program 6–7 funding mechanism. Moreover, those on ecosystem health often addressed health as a topic peripheral to ecological studies, or defined ecosystem health unclearly. In both categories, we noted duplication of activities and deficits of broader approaches including social sciences. These suggest weak transdisciplinarity in R&I policy. Specifically, this involves a lack of studies of science–society interactions, e.g. instead including stakeholder communication and

knowledge brokering in R&D projects only as an add-on and not as a topic of analysis in its own right.

Using the literature on integrative concepts of health (cf. Sect. 3.1) and the information on topics of activity, we synthesized their contents along the dimensions of "traditional" or "novel" scope and of their objects of concern (Fig. 4). The scope has broadened to include topics such as benefits along with risks, societal factors and interventions, nature-based health and planetary health. The concerns also increasingly include non-human organisms. In all these respects, there are overlaps between approaches to integration, and convergence and divergence between them. The consideration of interdependencies differs both between the communities of practice and between the respective areas of conceptual and functional integration. In terms of the systems addressed, the approach to health varies from close-range integration (microbiome–macrobiome interactions) over intermediate range (human–non-human interactions) to far range (ecosystem–society interactions). Furthermore, we found temporal developments in the consideration of interactions and interdependencies: while interest in integrative concepts and approaches has increased overall, in some cases it has subsided or lagged behind, such as in the socio-economic dimension (Table 2).

We further examined communities of practice based on their structure and organization, on topics of interest (Fig. 5a) and on activities according to the types of actors and the cycles in knowledge generation and intervention (Fig. 5b; ESM Table S4). We find important application areas of integrative concepts of health (see grey boxes). Many of these areas can be seen as "boundary objects" (on this concept in relation to ecosystems, see Abson et al. 2014) that promote the interaction and, potentially, integration between communities of practice that have been isolated in established disciplines and sectors. Influences of broader social networks (Manlove et al. 2016, 1) are identifiable, and also "Latourian" actor networks can be postulated, as with avian influenza (cf. Tirado et al. 2015, 116, 120). However, it is evident that the uptake and co-creation of holistic knowledge of health are hampered by many organizational and cultural factors.

Among policy instruments and actors in the EU, the use of integrative concepts of health has increased and expanded from traditional environmental health studies and practices, but is still dominated by certain high-profile topics such as antibiotic resistance and food safety (ESM Table S4). A broader and more fundamental socio-ecological perspective seems to be less developed, as was found in knowledge co-creation and R&I policy (see the 3rd paragraph in this sub-section). This also mirrors the status of integrative concepts of health by global communities of practice, e.g. in FAO (One Health is usually placed under animal health activities), and WHO ("integrative medicine" is often linked with traditional and complementary medicine, i.e. integrative with regard to approach, not to organisms, see WHO 2013). Sustainability challenges have facilitated deeper integration of health that includes social dimensions, but this remains to be achieved for non-human and ecosystem health.

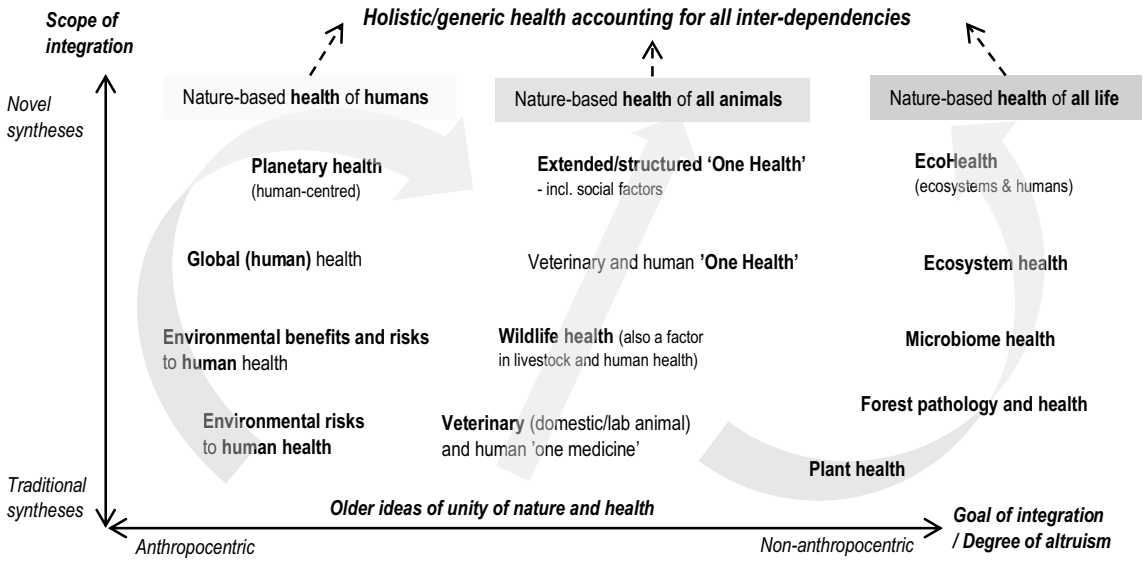

Fig. 4 Development of important discernible fields of integrative concepts of health with regard to overall scope and goals, with examples in medical, veterinary and ecological research as identified through our review. The relationships and successions of fields (suggested by thick arrows) are indicative as they overlap, recur, converge and diverge. Note the emergence of nature-based interests, and potentially of holistic health

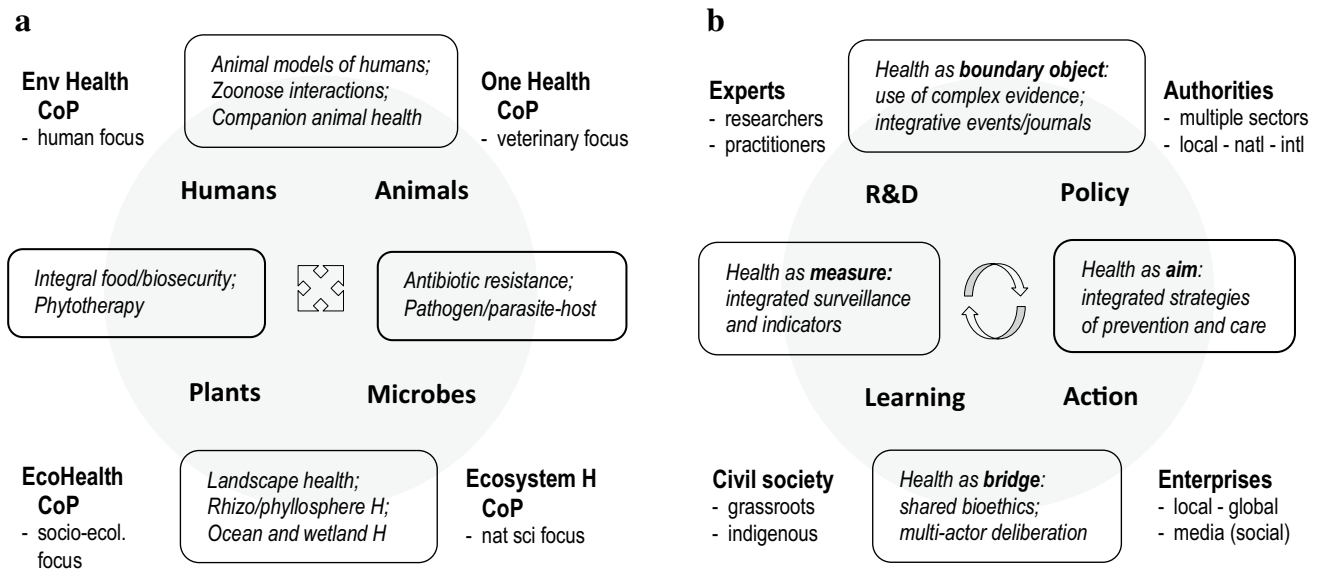

Fig. 5 Integrated approaches to health in key areas. The structure of key relations of communities of practice (CoP), defined by topics (**a**) and actors and activities (**b**). Important topical (**a**) and functional (**b**) areas of integration are highlighted in the rectangular boxes with rounded corners, and the overall significance of health (explained in boldface) is encapsulated in the part (**b**)

3.3 Discourses and narratives of integrative concepts of health: optimistic and pessimistic views

Various overarching narratives of health were discerned in scientific and professional discourse. The narratives are embedded in interpretations of scientific information and thus in cultural conceptions and traditions, both disciplinary and general, reflecting fundamental assumptions and valuations regarding health and health promotion (Table 3). We identify multiple roles for these narratives: (1) conveying ideas, or ideals, about the unity of health and of knowledge; (2) helping to formulate linkages between aspects of health and sectors or fields of activity (a direct role in R&I processes); (3) functioning in communication about health and in interaction between communities of practice; and (4) acting in scientific, professional and social learning. Some of these overlapping functions involve contested framings, value conflicts and even tactical uses of integrative concepts, e.g. to defend or expand positions of established fields (cf. Hinchliffe 2015, 29–30).

Notwithstanding the limits of broadly integrative narratives and corresponding actions, we note a broadening scope of and increasing impetus towards the unification of narratives within human, veterinary and ecosystem health (Figs. 4, 5). We also find shifts towards consideration for the values of nature in itself, i.e. de-centring humans in a more altruistic and communitarian meta-narrative. In veterinary medicine, the wildlife perspective is often still subsumed under domestic interests, but more ecological orientation is emerging. Environmental health has moved from anthropocentric risk to broader themes, notably nature's benefits to health and ecosystem health (Table 2).

In some regards, the narratives that underpin integrative concepts of health retain traditional tropes and features, or have even evolved towards less holism, e.g. when an allegedly interdisciplinary community of practice is dominated by narrow technical concepts (cf. Sect. 3.2). Notably, we find that scientific and applied narratives often do not fully account for economic, political and structural aspects of integrative health and may become reactive instead of proactive. There are drivers or enablers as well as obstacles and limits for unified narratives (Table 3), additionally; therefore, such narratives vary. The outcomes depend on the area of research or practice and on the circumstances, e.g. balance between specificity and generality and between new and traditional knowledge.

We further distilled meta-narratives of health (including that of non-human entities) and of knowledge, reflecting varying expectations (Fig. 6). These narratives are strongly related to world views, notably regarding the value of integrative health and knowledge, and their underlying capacity to be integrated. Narratives range from the extremes of ideologically conditioned optimism to fearmongering, and from the exaggerated certainty of experts, for example as demonstrated by Tversky and Kahneman (1974), to "manufactured uncertainty" (cf. Michaels and Monforton 2005, 43–44). Defence narratives using metaphors of immunity or natural enemies are encountered with zoonosis outbreaks (e.g. Mutsaers 2015, highlights) and can be coupled with

Table 3 Drivers and directions of unification and diversification of concepts and narratives of health, arranged as corresponding and competing factors in striking a balance between the two, of which examples are given in footnotes

Domain	Drivers/enablers of unification	Drivers/enablers of diversification	Balancing opportunities
Science	Historical parallels of unification	Historical uniqueness	Cultivation of traditions
	Holistic knowledge, also indigenous	Science and tech specialization	Interdisciplinary work[a]
	Systems biology	Specialized/targeted biology	Flexible syntheses; "zoom" for breadth and close-ups[b]
	(Gen)omics building common basis	(Gen)omics revealing diversity	
	Animal and in vitro models	Limits of model generality	Systems biology
	Ecological inter-linkages	Ecological context dependency	Contextual social ecology
	Interdisciplinarity	Specialization of disciplines	Demonstrating fruitful integration
	"Theories of everything"	Humbleness for generalization	Comparative studies
	Global notions of health	Particularistic notions of health	Critical animal studies
	Dynamic notions of health	Definite notions of health	Mixed methods
	Citizen/actor engagement in R&D	Health authority and normativity	Linking up specific R&D[c]
	Pleas for generic knowledge	Promotion rules in academia	Articulating cooperative value[d]
	Added value of closer cooperation	(Apparent) value of sector focus	
Policy	Globalization pressures	Local contextualization needs	Policy coordination
	Connectedness	Administrative/juridical borders	Utilizing shared needs
	Sustainability challenges	Anchored sustainability	Structured One H[e]
	Wicked compound problems	Diverse approaches to problems	Deliberation (also risks and benefits of holism)
	Collective, universal decisions	Evidence-based sector decisions	Science-in-society view
	Right to define goals and means	Obligation to define best practice	Sustainability policy of H
	Integrated assessment	Case-sensitive assessment	
Practice	Consensual diagnosis/therapy	Diversity of health advice	Collective decisions on H
	Linked multi-sector care systems	Sectors and jurisdictions	Communicating holism
	Coordinative institutions	Dedicated institutions	Utilizing synergies
	Information sharing	Information tailoring	Integrative training
	Interdisciplinary education	Specialized education	"nature step" for H gains[f]; "H step" in resource use
	Funding of unified approaches	Funding of specialities	
Politics/culture	Knowledge brokering	Silos and particular interests	Transdisciplinarity[g]
	Consensuality in social interaction	Sensitivity to individuality	Balancing cultural shifts
	Ideals of unity	Ideals of diversity (social)	Mainstreaming of holism[h]
	Shared and generative intelligence	(Inter)subjectivity	Respect for connectedness of all life, biophilia[i]
	Universalism	Pluralism	

H health, *R&D* research and development

[a]Phoenix et al. (2013)

[b]Assmuth and Hildén (2008)

[c]Hitziger et al. (2018)

[d]Zinsstag et al. (2015)

[e]Wallace et al. (2015)

[f]Haahtela et al. (2013)

[g]Assmuth and Lyytimäki (2015)

[h]Stengers (2010)

[i]Wilson (1984)

abatement strategies that omit socio-ecological root causes and interventions (Fig. 6 lower right). Counter-narratives emphasize the benign in nature, with either pessimism (Fig. 6 upper left) or optimism (Fig. 6 upper right) towards the limits of knowledge and then towards control of the processes involved. There are intermediate discourses between these types of narratives. Importantly, narratives of adaptive nature, health, care and governance emerge (Fig. 6 central area). For example, nature as a negative influence on health can also be coupled with positive views of resilience and of human control.

4 Discussion

4.1 The importance of integrated concepts of health as reflected in the development of the associated literatures

Integrative concepts of health are important for the development of science and for other forms of knowledge generation such as monitoring and surveillance. They elucidate the interdependencies between humans, other organisms and ecosystems; can provide shared methods of diagnosis,

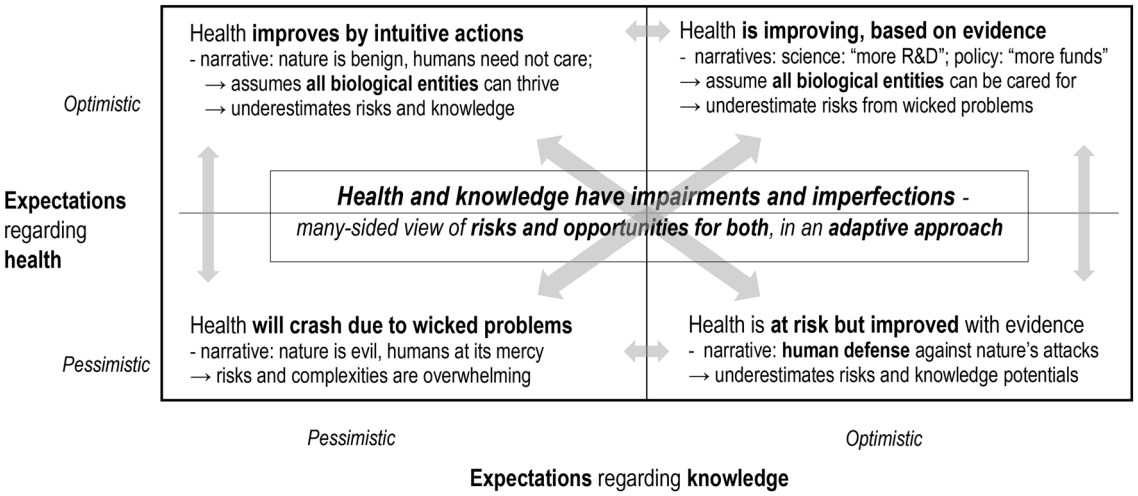

Fig. 6 A typology of narratives of health and knowledge with regard to integration under complexity. The typology is based on expectations regarding the potential or factual improvements in health and the improvement in knowledge, indicating prevailing and alternate narratives discerned in the literature and expert opinion. Note intermediates and interactions between categories. *R&D* research and development

prognosis and therapy; and promote improved and more nuanced understanding of aspects of health. The very emergence of integrative concepts of health, varied as they are, underlines their importance in bridging gaps between fields of knowledge (scientific and applied, also and experiential) and practices. One of the key common attributes of such concepts is the perceived need for sustaining health through a more comprehensive understanding of the relative importance and impacts of interacting mechanisms and systems, including interventions (Zinsstag et al. 2011, 154–155; Borriani et al. 2017, 2). The scope of inquiry includes biological and social systems and potentially biogeochemical systems too, as organisms not only adapt to but also construct their environment (Lewontin 1992; cf. Fig. 1). However, we observed the rapid increases in research on integrative concepts of health (Fig. 3) to be accompanied by continued compartmentalization in silos, a central finding also by Manlove et al. (2016, 1). We also found uneven development in the various dimensions of integration, with particular gaps in integration across humans and other organisms; across biomedical and SSH studies, as did Friese and Nuyts (2017); across soft and hard methods; across different geographical regions; and across research and practice (Table 1). These variations reflect continued ambiguity in the meaning of the integrative concepts and highlight key development needs.

As our analysis suggests, integrative concepts of health can transform thought and practice on multiple levels and in many directions, thus enriching transdisciplinarity (Allen-Scott et al. 2015, 869; Schelling and Zinsstag 2015). This can in principle be developed to new overarching concepts such as holistic health accounting for interdependencies among beneficiaries or agents (Fig. 4), and within practice to more responsive relationships between knowledge, motivation and action. Accounting for linkages between nature and humans is crucial for improvements in health of all living systems, and vice versa: health provides a potent way to explicate and develop those linkages. Therefore, the potential importance of integrative concepts is great. However, improved understanding and promotion of such holistic knowledge generation and uptake on more pragmatic level, across spatial and time scales, will require further study, experimentation, evaluation and implementation. The demonstrated deficits in transdisciplinary health concepts and applications point to considerable challenges before their full potential can be realized.

4.2 Scientific and professional discourses on integrated health: diagnosis, aetiology and emerging cures for myopia

The low relevance of many scientific papers to progressing the development, application or both of integrated concepts of health was often due to limited consideration of biological or socio-ecological entities, mainly in the following respects: (1) studies with outcome measures limited to human health dominated; (2) within environmental health, studies commonly treat the environment as an external influence; (3) in studies of ecosystem health and One Health, natural scientific research dominated; (4) veterinary studies focused on the health or transmission role of domestic animals; (5) many sources allegedly on novel integrative aspects of health were in fact derivative. Among top-cited papers, health was addressed in a narrow manner; few of the papers on broadly

integrative concepts of health including societal aspects were rarely among the most cited.

On the other hand, many sources that did not explicitly address integrative concepts of health were relevant for their development and application of interdisciplinary and transdisciplinary knowledge and practice. For instance, evolutionary studies can unite the health of various host and pathogen organisms (James et al. 2015b, 4083–4087). Such interactions between otherwise distinct areas of research may first be conceptual and weak but can develop to strong functional ties simultaneously transforming fields, as seen with "omics" (Marco-Ramell et al. 2016). Likewise, many areas in human health research have broader relevance, for instance through insights in the shared foundations of health such as the role of microbiome (Ruokolainen et al. 2017, 43; Haahtela et al. 2019, 4), in integrated surveillance (Whitmee et al. 2015, 2018), and in bioethics (Lee 2017, 5). New ways to account for linkages in health are also observable in the exposome concept (Wild 2012), and in allostasis, the process of achieving stability after load (Logan et al. 2018) or, equally, through beneficial stimuli (Lovell et al. 2014; James et al. 2015a).

Most integrative accounts of health were concerned with the dependence of humans on other organisms and ecosystems (e.g. Lovell et al. 2014, 13–14; Whitmee et al. 2015, 1987), but alternative ontologies are emerging which include reciprocal and multi-directional linkages, e.g. of humans as stressors and beneficiaries of ecosystems (Haahtela et al. 2019, 2) and as parts of ecological economy (Whitmee et al. 2015, 2011), of humans as guardians and stewards of socio-ecological systems or as sentinels of sustainability (Loring et al. 2016), of animal-assisted health interventions (Hediger et al. 2019), of a "meshwork" encompassing humans and others (Rock and Degeling 2016, 71), and of extended solidarity between these entities and agents (Rock and Degeling 2015). While there is a dominance of attention to infectious diseases from the point of view of humans and domestic animals (e.g. Jones et al. 2008, 990–992; Wiethoelter et al. 2015), due largely to pandemic threats (Desjardins et al. 2018), there is considerable scope for this area to address the health of ecosystems and socio-ecological systems as a whole. More balanced consideration of 'good', 'bad' and intermediate nature (Antoine-Moussiaux et al. 2019, 3–5) and of risks and rewards are steps in this direction.

The discourse on ecosystem health has been transformed by broad themes of sustainability and resilience (McAlpine et al. 2015, 56–57) and interspecies justice (Lysaght et al. 2017, 5–9). As lay perspectives on zoonotic risks become more prominent, new types of less anthropocentric narratives also emerge (Rabinowitz et al. 2008). This development parallels that in public health where links with sustainable development, salutogenic notions of health, planetary health and human agency are increasingly emphasized (Tilman and Clark 2014, 518; Kurth 2017). Past narratives also recur: the "Earth ethics" underlying much of the interest in such concepts in part involves a re-emergence of "land ethics" (Callicott 2013), and the idea of eradication of health risks resurfaces in epidemics which promoted One Health. A narrative focused on threats, e.g. from vector-borne diseases and zoonoses (Wald 2008; Karesh et al. 2012, 1941–1943), remains strong. This is problematic as the important risks and costs of non-communicable diseases and long-term factors of health can be easily overlooked. Interestingly, global organizations such as FAO, WHO and OiE adopted a One Health concept, despite its vagueness, in response to the avian flu in part to reduce conflicts and defend their legitimacy (Chien 2012, 222–224). It is important to scrutinize such motives behind narratives and their implications for policies and practices. For instance, rallying for One Health without consideration of political realities in its integration with trade and development misses key social and political contexts, which is both naïve and misguided (Mwakalimba and Green 2015).

4.3 Challenges to integration from complexity and specialization, and potential responses

The clarification, further development and better application of integrated concepts of health require sensitivity to the dimensions of integration (Fig. 1), to its contexts (Assmuth and Hildén 2008) and to the resultant complexity (Keune 2008; Keune and Assmuth 2018). The interrelationships of environmental and social aspects of health need to be specifically appreciated (Barrett and Bouley 2015; Zinsstag 2012), extending beyond narrow biomedical paradigms to more general views of knowledge. This will be particularly important when applications and impacts are considered, e.g. through medical or environmental practice and through science and innovation policy (Sect. 3.2, Fig. 4). While ways to incorporate the societal dimension in One Health have been outlined (Lapinski et al. 2015), these are dominated by positivist paradigms (Phoenix et al. 2013, 219–223). These methodological obstacles are compounded by the confirmed dominance of anthropocentric studies and practices (Figs. 5, 6). Similarly, Europe-centric and English language dominance could shape the concepts and approaches used, the narratives upheld, and the policies and practices adopted on integrated health. A more global—and more culturally inclusive—outlook is needed and offers great potential for concepts and practices of health.

The content and scope of integrated concepts of health are in flux, as illustrated by the literature evaluated in our study (Table 1, Figs. 3 and 4). Concepts of ecosystem health range from metaphors to operational models which can accommodate *ex ante* and *ex post* assessment along with participatory governance (Fock and Kraus 2016, 7–8), and those of ecosystem services can (despite a utilitarian lens) renew thinking around the relationship between human health and

the intrinsic value of nature (Ford et al. 2015). Definitions of the integrative concepts of health also vary in scope, and this instability is reflected in their content and underlying values (Lerner and Berg 2017, 5). The shift towards unification can also represent a renewal of the fundamental relationship between science and culture, as found in sustainability science (Lang et al. 2012) also in relation to health (White and Brown 2010), and it can reinforce the return of eco-centric concerns to the forefront of the discipline of bioethics (Lee 2017, 5, 9).

The complexity inherent in broadening the scope of health presents multiple and considerable challenges across scientific disciplines and communities of practice. These challenges are conceptual as well as organizational, cultural, pragmatic and even political. Yet this complexity needs to be tackled in order to address present and future problems and to give a "voice" to those impacted, including non-human organisms in a socio-ecological entity. It is precisely because of these that a transdisciplinary, collaborative and participatory approach sensitive to the perspectives and values of the actors is worth exploration and experimentation (Schelling and Zinsstag 2015). Reconfigurations of integrative concepts of health are thus called for. Such reconfigurations should be developed and applied through additional studies and collaborative action, in order to allow efficient evaluation of concepts such as One Health (Rüegg et al. 2017, 4) and to achieve (tentative) "proof" of concepts (Rabinowitz et al. 2013).

Specialization poses a second key challenge to integration and holism. Persistent "silos" were noted between communities of practice, as found by Manlove et al. (2016, 3–7) between ecological, veterinary and "third" (mainly human medical) communities. Silos are due especially to path dependencies in conduct and funding of practices and to the multiplicity of goals and processes embedded within related institutions. This involves continued dominance of communities of practice whose disciplinary background is located within human and domestic animal health, i.e. anthropocentric, and through which often also narrow technical paradigms and understandings are sustained and defended. External factors such as disasters or greater awareness of ecological crises and interdependencies may be needed to change these paradigms.

4.4 Social and political dimensions of integrative health in the context of sustainability

The impoverishment of the living environment, increasingly through anthropogenic factors, undermines both human health and ecosystem resilience, as found with abrupt climate change (McMichael 2017). The health of other animals and plants also depends on ecosystem quality. Integrative concepts and practices of health emerge to respond to this multifaceted challenge. Yet, the dependency of human, animal and plant well-being on ecosystems is widely ignored in political and economic spheres. The impoverishment of health through repression and other political and societal factors is additionally too often ignored. The complexity, uncertainty, ambiguity and dynamics of actor involvement in tackling these multiple dimensions of health (Table 3) pose "wicked problems" that have increasingly been addressed in policy studies, based on the work of Rittel and Webber (1973), also with regard to health (Walls 2018). New concepts, approaches, narratives and activities are needed also for maintaining the health of multiple systems as adaptive capacity emerging from and sustaining ecological and social functions (Charron 2012). The observed developments in communities of practice adopting integrative concepts of health (Fig. 6) reflect these pressing needs.

Even the increased use of concepts such as One Health may have limited penetration due to weak or unclear political commitments (Chatham House 2017). Problems also include the conception—notably in the human health sector—that One Health is a veterinary initiative of lower priority to the health of humans (Stärk et al. 2015, 124). Therefore, as well as deciding what kind of integrative health knowledge is needed and how to co-create it, communities of practice must also convince policy and decision makers, funders and others of its relevance and guide its use, demonstrating how it can be more valuable than narrow views and practices. This co-creation of actionable holistic knowledge has been studied, e.g. in synergistic Ebola biobanking (Capps and Lederman 2015, 1024–1027), and has been outlined in surveillance in terms of economic assessment (Babo Martins et al. 2016; 386), but less often used regarding the underlying societal goals and processes. For instance, the "proof of concept" of One Health surveillance by Kelly et al. (2017, 114–115) focused on technical and organizational aspects. The recent work on outbreak response sensitive to public preferences by Johnson et al. (2019, 164) is an important step, demonstrating there is no single generalizable best way to implement One Health (or other integrative concepts of health) and emphasizing the need for adaptive governance depending on the case and on collective priorities.

Better accounts of the social and political dimensions in integrative concepts of health, including value judgments, will thus be crucial to further development (Degeling et al. 2015, 2016; Johnson et al. 2019). The definition of human health (WHO 2006) (1) already accounts for societal factors, e.g. the distribution of burdens and benefits and the links between health and economic development (Beaglehole et al. 2011, 449; Lange and Vollmer 2017, 53–57). These accounts are natural also within extensions of health, e.g. nutrition (Cannon 2002). The challenge is to extend such societal considerations to the health of other organisms and living systems and to the corresponding fields of practice.

The notion of health as dynamic adaptation rather than a state, stressed in salutogenetic models of health promotion (Antonovsky 1996; see also Huber et al. 2011), is applicable to other systems and can potentially enrich integrative concepts and practices of health, but will require consideration of political agency.

Integrative concepts and practices of health provide additional depth to notions and policies of sustainability, by combining ecological and social meanings and values, and thus promoting sustainable communities (Ostrom 2009). The conclusion holds regardless of anthropocentrism: humans will be concerned with non-human organisms and ecosystems when they sufficiently understand the interdependencies of their health and that of other biological entities, and, as biophilic creatures, value them (Wilson 1984). From such understanding and ethical valuation, balanced policies and actions can develop, as proposed, for instance for Ebola vaccination (Capps and Lederman 2015, 1014–1016, 1028).

5 Summary and conclusions

We summarize our key findings and discussion points with regard to the research questions posed at the outset:

1. Integrative concepts of health have emerged in the scientific literature in various forms and during different periods, ranging from narrow to broad perspectives and from traditional to novel research. The concepts have expanded to address broader questions and ontological entities, some of them approaching genuinely holistic views of health in social ecology, but are yet dominated by narrowly anthropocentric and biomedical concerns, and by research paradigms that are predicated on positivist views.
2. Communities and conducts of practice have evolved in response to these expanding and transforming scientific interests, to practical concerns and to societal structures and cultures which surround science and practice. Communities of practice have in turn influenced research, in interactive relationships of knowledge co-creation. Specifically, communities in One Health and EcoHealth have grown in response to the connectedness of health, ecological and social problems and have converged although there still is considerable separation and rigidity.
3. Corresponding to the various integrative concepts of health among researchers and practitioners, different narratives and mixtures of narratives of health and of knowledge can be discerned, ranging from optimistic to pessimistic and from definite to inclusive notions. The narratives underlying integrative concepts and practices of health are linked to motivations and goals of research and applications as well as to world views, and thus to concrete political contents and contexts in these integrative fields of thought and activity.
4. By open and innovative participatory transdisciplinary processes, fruitful and even surprising new ways can be found to navigate the dilemmas and tensions between increased breadth and complexity and between different views and values, as shown by developments in science and practice. Agreement can focus on achieving integration, instead of prescribing a certain kind and degree of integration, thus more fully realizing the potential of integrative concepts. This potential in responding to challenges in human and ecosystem health is great, especially when the multidimensionality and context dependency of the challenges and solutions are better appreciated.

We conclude that there are movements towards broader integration of different disciplinary conceptualizations of health, but the associated complexity—biological, geophysical and social—remains a challenge. Progress seems possible, especially by: more fully considering the contingencies and dynamics in the health of living systems; better utilizing the understanding of societal factors in these systems as a means to focus action; using the concept of health as a deliberative device to clarify its meanings within and across disciplines; identifying related values, goals and means. To reach the potential of integrative concepts of health, we thus generally advocate investing in a transdisciplinary approach that connects disciplines and communities engaged in co-production, co-interpretation and co-utilization of knowledge. Continuous reflection on the interplay between the concept of health, with its applications, will help resolve what might be meaningful and useful modes of integration of related concepts and practices. The means of engagement for the actors and communities involved, the appropriate scales, and the acceptable approaches should be subject to further studies. We tentatively propose the term "transdisciplinary health" to signify both the needed broad integration across fields and the dynamic interaction across research, practice and society as a whole, on all scales from local to global.

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