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Enhancing water security for the benefits of humans and nature — the role of governance

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The past two decades have witnessed increasing global concern with the need for sustainable water and land management. Human water security is often achieved in the short term at the expense of the environment with harmful implications in the long run.This review identifies the major governance challenges for (sustainable) water security, and how their nature, and the perception and framing of the societal discourse, have changed. It departs from the definition of Grey and Sadoff [1] '*Water security refers to the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies*' to highlight the need for inclusive and integrative institutional arrangements supporting negotiations and transparent and evidence-based decisions about trade-offs. The review reflects critically on successes and failures of governance approaches, and addresses how far emerging challenges to water security reflect the expanding complexity of problems, greater connectivity of issues, multiple spatial scales, and increasing uncertainty, as well as a lack of adequate governance capacity. The review will identify some promising avenues to explore in scientific, policy and management communities.

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Introduction: water security definition and scope of the review

The past two decades have witnessed increasing global concern with the need for sustainable water and land management in an era of rapid change and persistent water and food insecurity. Population increase, economic development, climate change, and other drivers alter water availability and use, resulting in increased risk of extreme low and high flows, altered flow regimes and water quality, and water demands surpassing renewable supply. Human water security, when narrowly framed [2], is often achieved in the short term at the expense of the environment [3–5] with harmful implications in the long run for socio-ecological systems as a whole.

Such trade-offs contradict political statements and calls for action made more than a decade ago. The Global Water Partnership argued in their framework for action to achieve water security: '*Water security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced*' [6] (p. 12).

The increasing concern about sustainable pathways towards increased water security led Grey and Sadoff [1] to define water security as '*.the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies*' (p. 545). This more encompassing definition embraces a risk based perspective and addresses the role of water as both source of services and source of threat. It also makes evident that trying to enhance water security entails trade-offs and a perception based assessment of risks. What is acceptable is subject to different interpretations by different groups. To make this definition operational a number of key challenges need to be tackled:

- What does acceptable mean for health, livelihoods, environment and production? How can this be determined?
- How should one determine an 'acceptable quantity' in different contexts? How does it depend on both the scarcity of the resource to be allocated and the dominant paradigm guiding allocation?
- How should one determine an 'acceptable quality' for different users and different uses?
- How should one assess 'water-related risks' acceptable 'to people, environments, and economies' in the face of multi-decadal changes in water extremes (floods and droughts) and uncertainties in future climates?

All of these issues make it evident that enhancing water security is first of all a governance challenge. The latest definition of UNDP states that '*Water governance is defined by the political, social, economic and administrative systems that are in place, and which directly or indirectly affect the use, development and management of water resources and the delivery of water service delivery at different levels of society*'.[1] Political, social, economic and administrative systems in place determine societal negotiation processes about what is acceptable, about trade-offs, and about how conflicts can be managed and reduced. We argue that a major governance failure lies in the lack of inclusive and integrative institutional arrangements supporting negotiations, and transparent and evidence-based decisions, about trade-offs.

This review will identify the major challenges for sustainable pathways to enhance water security, and how their nature, and the perception and framing of the societal discourse, have changed over recent decades. The question will be addressed of how persistent, emerging challenges to achieving water security derive on the one hand from the ever-changing nature of the problems that arise from the expanding complexity of the interaction of biophysical and social processes across multiple spatial scales (including the global), and the increasing uncertainty related to climate change. On the other hand, these challenges also emerge because of a lack of adequate governance and management responses (e.g. a restrictive focus on technical solutions, narrow problem framing that neglects complexity, gaps in policy implementation, and lack of vertical and horizontal integration). The review will identify promising avenues that should be explored in scientific, policy and management communities to address these weaknesses in governance.

Challenges for water governance in the light of the trade-off between human and environmental water needs

Accordingly, in this section we review major governance challenges related to water-security by addressing the four questions which we derived from the definition by Grey and Sadoff [1]. We focus on the trade-off between human and environmental water needs, noting that perception and framing have changed attitudes to this trade-off over time.

What is an 'acceptable' trade-off for 'health, livelihoods, ecosystems and production'?

It is a matter of governance to determine whether, and why, to include ecosystems and the environment in the assessment of demand for water, and to identify mechanisms and procedures that can give ecosystems and the environment a voice (as a 'stakeholder'). Equally, it is for the governance regime to determine if this requires a form of financialisation of ecosystems (and their 'services'), to what extent such valuation is a function of social and ecological context, or if this corrupts attitudes to ecosystems [7,8].

An operationalisation of the water security concept requires defining procedures and setting targets for what 'acceptable' means for different domains. We distinguish four approaches to defining what is acceptable which differ in the kind of knowledge used, in the institutional setting of and in the actors involved in the process:

- Scientific analysis and expert judgement;
- Invoking widely shared societal norms;
- Economic cost–benefit types of analysis;
- Place-based assessment of perceptions of concerned stakeholders.

We argue that different approaches dominate the four domains identified in the water security definition, and that this renders an integrative approach to negotiating trade-offs problematic.

What is acceptable from a health perspective is most often defined by scientific analysis and expert judgement. Health-related water security thresholds, e.g. for drinking water, are set by regulations. What is identified as a severe threat to human health is not negotiable in terms of cost–benefit analysis. Regulation by thresholds often follows a precautionary approach, at least in industrialised countries such as the EU 'Registration, Evaluation and Authorization of Chemicals' (REACH) policy [9] with their typically high (conservative) security thresholds. This non-negotiability derives from a strong ethical perspective; the challenge is rather the implementation and enforcement problem, especially when governance systems divide power between a central authority and smaller political units the latter of which may adopt very different threshold standards and/or enforce regulations differentially. For example, in the U.S. implementation of the Clean Water Act gives states the authority to set water quality criteria subject to approval by the U.S. EPA. Despite failure of the law to achieve its water quality goals and continued stress on aquatic ecosystems, only rarely has the EPA exerted its right to disapprove of these standards and impose its own more strict ones [10].

Water security for livelihoods implies guaranteeing basic water-related services for a self-determined life. This goes beyond survival to include the material base for sustaining a life of dignity. Water security targets in this domain are defined by societal norms and place-based assessment of the perceptions of stakeholders, although higher levels of governance may set the tone of debate

[1] http://www.watergovernance.org/whatiswatergovernance, retrieved 12th October 2013.

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(for example, UN Resolution 64/292 recognising the human right to water and sanitation [11]). Trade-offs between water security for livelihoods and for the environment are common, in particular when traditional structures and practices are disrupted or lost, and when production needs are in conflict with environmental water requirements. At the same time, the livelihoods of many are vulnerable to the loss of water related ecosystem services [12].

Water security targets for the environment are often determined by scientific analysis and expert judgement (e.g. the natural reference states and quality indicators defined by the European Water Framework Directive [13]). Increasingly, the concept of ecosystem services is used to represent the benefits of water security for the environment both through the effect of the concept on policy discourse, and its introduction of a financial metric [14].

Water security for different production activities in different economic sectors depends on supply, re-use, and treatment, all of which introduce costs to the production process. What is affordable may be determined by cost–benefit analyses, but strategic considerations and national interests (e.g. food security, survival of traditional industries) also intervene. Water may be treated as an economic good for production activities, implying that market forces determine the level of water security affordable for certain sectors. However, consumption also leads to pollution, and is frequently spatially separated from production, and therefore influences water security elsewhere. Analysis of trade in virtual water may provide a framework for understanding these connections (e.g. [15]).

It is evident that each domain follows a different logic and framing of what is 'acceptable' and of how it can be assessed (illustrated, for example, in an empirical case of negotiation processes over the sustainable management of urban river corridors in Sheffield, UK [16]). This poses a considerable governance challenge about how to analyse and negotiate trade-offs among the different domains.

'An acceptable quantity'

Much scientific and engineering effort has been devoted to developing algorithms, models, and geospatial tools for use in water allocation decisions [17]. However, allocating water is a social decision, not a scientific one. Scientific knowledge on how much water there is to allocate, how it varies over time, where it is, and how it can be supplied to specific geographic regions is merely the starting point for the socio-political process of allocation decisions. In North America and Britain, decisions have historically been made based on access to water sources, and on prior appropriation or riparian rights doctrines. These were codified in laws and regulations in many countries which led to complex, fragmented mechanisms for making allocation decisions, especially where water is scarce [18,19]. In some regions, decisions shifted to a framework of water as a public resource but, as in the landowner-rights 'paradigm', decisions occur within an economic framework, with allocation sometimes depending on 'reasonable use' for agriculture, drinking water, and, rarely, for environmental benefits. Recognition of the many legal, equity, and socio-political problems arising from these approaches, and growing concerns over water scarcity, provide a rationale for changes in water allocation decision-making [10].

Reallocation of water is a sensitive and complicated issue that requires clear criteria for allocation decisions as well as the institutional resources to monitor the enforcement of the decisions. Re-allocations may be permanent or temporary and may be year round, seasonal, or changing with temporal changes in water availability. Depending on the legal framework, governments or basin authorities may make the re-allocation decisions with or without input from those that are affected [20]. Ideally decisions to transfer water rights are made through a negotiated or structured process [21] in which some type of fairness criteria will be included in the re-allocation process that includes environmental 'rights' as well as methods to allocate water among sectors and to take into account custom (current water rights). There are also examples of trading and market-based re-allocation in which water or access to it is sold or traded by the owners in exchange for some compensation. Market-based approaches require mechanisms for settling conflicts especially those arising from real or perceived mis-use of rights [22]. Further, they may require decoupling water rights from land ownership and can be quite controversial [23].

Regardless of the mechanism — market-based or other — there has been a paradigm shift, at least in thought if not in practice, from fragmented, small scale, ownership-rights frameworks to more democratic frameworks in which allocation decisions are made with input from diverse constituencies and within a broader watershed-scale context, and ideally a broader temporal framework that allows for adaptation in the face of uncertainty [24]. In theory, this involves efforts to engage a broad group of stakeholders in a facilitated adaptive management process. The goal is to allocate water to meet as many interests as possible [25]. Stakeholders may need technical input from scientific advisors but are free to make decisions that may or may not be aligned with the 'best science' on, for example, limiting water extraction from sources in order to ensure their sustainability. Unfortunately, recent experience has shown that the extensive experimentation in stakeholder-driven adaptive management groups for water quantity allocations has been less

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successful than hoped [26]. The stakeholder with the loudest voice, the longest 'staying' power, or the greatest political currency often dominates decisions so that some sectors lose, most often the environment [27,28]. Even if decisions are consensual, higher level regulatory hurdles or political decisions may prevent implementation. Inflexible policies, organisational inertia, long response times, and uncoordinated management and regulatory bodies can all constrain implementation of previously agreed water allocation processes [29].

A second trend that has emerged is a watershed framework for management where watersheds may serve as both a scientific unit that can inform water allocation decisions and a social unit that can facilitate stakeholder engagement. However, shifting from political jurisdictional boundaries for water management to watershed boundaries has not often solved the problems highlighted above [30]. This is stimulating consideration of new types of governance structures that may overcome some of these problems. The emphasis is increasingly on combining two concepts; those of shared decision-making, and of more flexible polycentric water governance structures. In the former, the stakeholder engagement process is highly structured, and the decision-making process involves learning as well as facilitated negotiations [25]. It is structured in the sense of being an organised process in which typically there is an independent facilitator or negotiator who manages the process of stakeholder input, so that all interested parties can provide input into decisions. The facilitator has no vested interest in the outcome of the re-allocation process, and works to ensure that the decision-making process is transparent with a high level of information sharing, and opportunities for input that are well-publicised. While this structured process for water allocation decisions can be decentralised, for it to be effective there must be mechanisms for coordinating decisions across all levels of governance — from stakeholder groups to local and higher-level authorities [31]. Furthermore this process is rarely effective unless there is strong societal and governmental leadership [25]. The creation of bridging organisations that facilitate between-actor and between-scale linkages has been recognised as potentially valuable in such coordination [32].

Research is needed to help identify ways to improve water allocation decision-making processes so that there is equitable access to water, and that trade-offs between water security for livelihoods, production and the environment are all balanced. A key requirement is to understand how social transaction costs of polycentric and adaptive water allocation processes can be reduced.

'An acceptable quality'

Compared with its quantity, water quality is a more difficult concept to operationalise. The consequences of human use and degradation of water quality are highly varied, and the degree to which polluted water is re-usable by humans and still capable of supporting ecosystem functions depends on levels of investment in treatment. At present, only a small fraction of the world's water is recycled [33] for a variety of reasons, including that it is a governance challenge to gain public acceptance of recycling for some uses, notably drinking water [34]. The governance of water quality must also be place-based and context-sensitive, as illustrated in the 1980s by Swedish attempts to counter the effects of acid rainfall due to industrial emissions of SO_2. The policy of liming lake catchments in southern Sweden was inappropriately transferred to other lakes in the north, where the streams and lakes in catchments with boreal peaty soils were naturally acidic [35].

Water quality governance focused on meeting human needs is often assumed to be at odds with meeting environmental needs, but this mind-set must be challenged. For example, policies to reduce diffuse nitrate pollution in agricultural runoff in response to health concerns also reduce eutrophication; and appropriate land management practices such as leaving riparian buffer strips can bring multiple ecosystem service benefits, including biodiversity gains, pollution control and flood risk management [36]. Conversely, some decisions that prioritise human water needs can have unforeseen outcomes. The crisis of chronic arsenic poisoning in the Ganges-Brahmaputra-Meghna delta is an extreme case [37]. Here, use of shallow groundwater was encouraged to reduce reliance on surface water polluted with faecal contamination, but this groundwater substitute is widely contaminated with arsenic which is now being brought to the surface, ingested and dispersed.

Water quality governance seems to require a strong regulatory approach based on expert knowledge, although public pressure can influence authorities to act when pollution becomes visible. Where the 'polluter pays' for degrading quality, those whose discharges impact on water quality must have formal consents, with limits on their effluent discharge volume and concentrations, or appropriate mitigation requirements. Investment in the monitoring of surface water quality is necessary to ensure compliance, but the data also need to be shared and publicised to be effective in influencing quality improvement. Charges for consents and fines for non-compliance need to be high enough to encourage internalisation of treatment costs before discharge. However, conflicts of interest, corruption or 'regulatory capture' (when the polluting body has more resources at its disposal than the regulatory agency and can monitor independently, challenge decisions and enter prolonged and delaying negotiations) can lead to outcomes that are not adequately protective [38].

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Different models have developed to facilitate management of water quality, broadly distinguished by their emphasis on chemical and ecological indicators of quality. For example, China currently defines the carrying capacity of chemical pollutants in its rivers, and environmental protection departments give consents to discharge effluent. Water quality monitoring is undertaken by two ministries, which can lead to inconsistencies that weaken regulation and lead to declining water quality [39]. Rapid economic growth can also use the assessed capacity, so that in theory further discharges cannot be permitted; tradable permits between sectors then need to be introduced to prevent overcapacity effluent discharge [40]. A transition finally becomes necessary to a regime in which stricter standards for effluent discharge quality are enforced, and polluters internalise the costs of treatment.

This transition has also characterised the evolution of water quality management in Europe, and following a series of Directives from 1991 (the Urban Waste Water, Nitrates, Habitats, Groundwater, Priority Substances, and Environmental Quality Standards Directives, and the overarching Water Framework Directive), the EU shifted to a concept of water quality that includes hydromorphological, chemical and ecological indicators [41], measures the multi-criteria quality status of a surface water body on a five-point scale, and requires member states to report on quality improvement towards at least the 'Good' state through a programme of monitoring and restorative measures. However, quality targets are negotiable, as exemptions can be sought for 'heavily modified water bodies' if costs for improvement would be excessive. There are philosophical and practical problems with this reference-based regulatory approach [42], but it has been the basis for improving water quality in Europe, notably in trans-boundary rivers. China is now developing its own version of a multi-criteria river health assessment with a strong emphasis on ecological quality indicators [43].

The maintenance of sustainable high-quality surface and groundwater essential for the quality of human life and ecosystem integrity seems heavily dependent on government intervention and a strongly regulatory stance, a position inimical to the current dominance of a neoliberal, small-state political economy, which is therefore a significant challenge for future water quality. Equally, the balancing of human and environmental water needs challenges political and policy cycles to manage both short-term demand and longer-term, inter-generational sustainability.

'Water-related risks' — what is 'acceptable for people, environment, economies'

Traditional approaches for dealing with water related hazards, i.e. floods and droughts, have largely relied on large-scale infrastructure construction. However, increasing human water security by technical infrastructure development has led to increasingly unsustainable trade-offs between human and environmental water needs [5,31]. Flood protection has typically sought to keep water out of the landscape and to control river flows. In order to reduce flood hazards, rivers have been regulated and dikes built. This leads to reduction of both the floodplain biodiversity and water retention benefits provided by floodplain services, and results in increased peak flows downstream [44]. At the same time more material assets (e.g. private homes, business) are placed in the flood plain, leading to increased risk of severe flood damage when embankments fail (the so-called 'levée effect'), or overtop with increased frequency, reducing water security and resulting in calls for more flood protection and yet higher embankments. Areas protected by levées have become more vulnerable to climate extremes, which may increase due to climate change [45]. The risk of damage and fatalities increases as climate extremes cross protection thresholds and intensive land use expands into areas exposed to frequent disturbance; and at the same time the ability to quantify risk is undermined by uncertainty in the probabilities of extreme events in non-stationary time series [46].

As a response to these challenges, a reconsideration of management paradigms towards integrated, adaptive, and collaborative approaches has occurred over the past decade [4,47,48]. A reframing of the trade-off between human and environmental water security has been promoted by taking ecosystem services into account [49]. A pronounced shift in emphasis in the conceptual framing of institutional response to flooding is also notable over the last two decades, from structural flood defence to a more wide-ranging concept of flood risk management. This accommodates diverse strategies including flood warning, retro-fitting of individual properties, and restoring the natural floodwater retention functions of floodplains. The last of these connects flood risk management with the realisation of an environmental (ecosystem) service, and thus requires holistic management of water extremes (floods *and* droughts, both of whose impacts on the service must be understood so that high and low flows can be managed). It also necessitates forms of multi-criteria assessment.

Where previously cost–benefit analyses have dominated appraisal of structural solutions to flooding, linking flood risk management with environmental services opens up new possibilities and tools for governance. There are attempts to financialise environmental services in order to force them into the constraints of cost–benefit analysis, but these can be challenged both philosophically and practically. Robertson [50], for example, provides a trenchant critique of attempts to categorise; to devise approximations to scientific measurement of, for example, wetland functions; to

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'unbundle' these component services; and then to 'stack' their values in order to effect overall valuation. All of this does violence to scientific understanding of the phenomenon (in this example, a wetland).

At the same time, however, it has also become apparent that payment for environmental services (PES) is only efficient and equitable when there are direct transfers from a service buyer to a service provider (a 'steward' of the service), and although such 'user-financed' schemes can occur [51,52], it is rarely the case that a single provider acts alone. This implies that sustainable realisation of environmental services needs to be approved as a societal goal, and government initiatives are often required to incentivise or regulate behaviour that will orient activity towards this goal [53].

There is accordingly both a need and an opportunity for innovation in water management to accommodate its increasingly multi-dimensional nature; and also an urgency, given that the current absence of successful practices increases water-related risk. A critical difficulty is that the diverse criteria to be met in multi-dimensional water management all require different metrics to measure both their baseline character, and the consequences of intervention. This is one justification for financialisation, since it offers a common metric. However, alternatives are emerging, for example, involving multi-criteria analysis and multi-level governance. The 'Outcome Measures' approach developed by the UK Department of Food and Rural Affairs (DEFRA) to underpin investment in flood risk management by the Environment Agency [54] is an example.

In this approach, DEFRA sets a *national* annual budget for grants for flood risk management projects, defines outcome measures (OM) against which such projects proposed by *regional* EA institutions will be judged, and sets national OM targets for delivery by the set of proposals eventually approved and funded. The OMs provide multiple criteria for assessing the projects including economic benefits, numbers of households at risk protected from flooding or coastal erosion, numbers of households in deprived communities protected, areas of riparian or inter-tidal habitat created or improved to meet the objectives of the *international* EU Water Framework, Habitats or Birds Directives. In the U.S., the federal 'Flood Control Act' of 1936 clarified that an important role of the U.S. Army Corps of Engineers (Corps) was to invest in flood-protection and all projects provide should net benefits to the nation. As with DEFRA's OM approach, there is recognition that the Corps needs to move to an Integrated Water Resources Management (IWRM) approach in which multiple decision criteria have different metrics [55].

Both the U.K. Outcome Measures approach and the proposed U.S. IWRM approach involve multi-level governance, and a multi-criteria method to support prioritisation; they are flexible and adaptive so they can be tailored to the context, and strive to be simple and transparent in implementation, with low transaction costs. They do however require deliberation to define national and regional priorities, indicators, and their relative weights.

Integrative flood risk management may also, however, provide a new context for structural approaches, in that the operating rules for reservoirs can be adapted for controlled releases of artificial hydrograph peaks of the kind occasionally required for some ecological functions, such as the provision of bare surfaces for regeneration of riparian vegetation [56,57]. The new multi-criteria world of water management thus also suggests a new role for structural intervention, in an alliance between flood risk managers, engineers, and ecologists. It also suggests a combination of governance modes, regulation, markets, deliberation and participation to overcome the limitations of a narrow expert, technocratic approach.

Compared to the change in thinking in flood management one cannot detect a global rethinking in drought management. It is mainly framed as a (re)allocation problem (cf. 'An acceptable quantity' section). Hardly ever do current water use and land use and development patterns come under scrutiny. However, prospects of climate change strongly suggest that fundamental changes may be required [58,59]

Governance as both a cause of trade-offs and a source for solutions

Governance problems may cause or aggravate trade-offs between human water security and environmental well-being. In some countries, the whole governance system is weak and principles of good governance[2] are not respected. Weakness of the whole governance system (i.e. no respect for the rule of law, lack of accountability and transparency, neglect of interests of less powerful groups) may even lead to a degradation of the environment without achieving water security for all societal groups [31,60]. In other countries governance structures are neither integrative nor adaptive, and provide inadequate regulatory frameworks that fail to take negative environmental externalities into account. Traditional emphasis on structural defence in managing flood protection is an example. Some regulatory regimes may be especially weak at resolving conflict between users. The Water Framework Directive, for example, prescribes a good state for European waters [13], but allows exemptions for heavily modified water

[2] Good governance is participatory, accountable, transparent, responsive, consensus oriented, effective and efficient, equitable and inclusive, follows rules of law (UN Economic and Social Commission for Asia and the Pacific 2003).

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bodies, as noted in 'An acceptable quality' section; exemptions therefore abound. A mechanism to base such decisions on an explicit analysis of trade-offs is lacking.

Regulatory frameworks may not be implemented because of lack of capacity in terms of financial and human resources, skills and appropriate tools. For example, in the U.S. inadequate tools for assessing impacts to streams and associated mitigation requirements are leading to net loss of ecological functions [61,62]. Lack of political will, in combination with ineffective jurisdictions, weak formal institutions, asymmetric power structures, and a strong lobbying capacity of special interest groups may all serve to impede implementation. A common weakness is that issues are framed to represent conflicts as technical problems that arise from inadequate knowledge about complex interdependencies between social and ecological systems, lack of monitoring data, or inefficient technologies. The required solution is then reduced to a technical one, and the need to evaluate broader deficiencies of governance — which may be more challenging to address politically — is then avoided.

At the same time there is evidence that some governance attributes do contribute to reducing or even eliminating trade-offs between human water security and environmental well-being. Most notably, polycentric governance architectures seem to be particularly beneficial; polycentric structures balance bottom-up and top-down (multi-level) and lateral (inter-sectoral) pathways of influence [31,63]. Their modular structure supports learning processes and the diffusion of innovation (although this should not imply that innovation and learning will always lead towards more sustainable water management).

One other potentially beneficial attribute is a combination of governance modes [64,65]. Increasingly, different governance modes — namely, markets, regulatory mechanisms, bureaucratic hierarchies and learning networks — are combined in public policy by more-or-less purposeful design processes [65]. Such diversity is needed to deal with the challenges addressed in the second section above and to be able to integrate different framings, and the logics of argument followed in different domains. Such approaches introduce new tools and techniques, of which the ecosystem services concept is one important example. Ecosystem services describe the benefits derived for human well-being from terrestrial and aquatic ecosystems. They can thus translate the logic of ecosystem well-being into what is important for economic production and human well-being (livelihoods and quality of life). Valuation must and should not be limited to monetary approaches [53]. Combinations of governance modes and approaches that integrate different dimensions of valuation can also overcome the frequently prevailing emphasis on monetary arguments, to include nature in the accounting scheme (although not necessarily using a financial metric).The ecosystem services approach can be an important communication tool to raise the awareness for the need to adopt a systemic and holistic approach. Increasing attention to water as a paradigmatic social-ecological system shifts the focus on the resilience of such systems and the necessity for adaptive management; this in turn increases awareness of complexity, emergence, and uncertainty. Such a reframing towards a systemic perspective is essential to comprehend and communicate the importance of ecosystem integrity for human well-being.

Conclusions and recommendations

Trends in the decline of aquatic biodiversity are alarming. Increasing pressures on human water security give little reason to expect that such trends will be reversed without major transformations in water governance systems and management paradigms. However, one can also observe promising developments with regard to scholarly productivity in fields which are considered relevant for understanding and enhancing water security in a sustainable way.On the basis of our analyses we argue that

- governance arrangements need to support evidence-based decision making, and the application of good governance principles to assess trade-offs between different water security dimensions;
- more attention needs to be devoted to incompatible framings between different governance domains and how a lack of communication and integration can be overcome;
- more experimentation with, and comparative analyses of, combinations of governance modes are needed; and of methods and tools associated with those modes that may be transferred to other water security contexts;
- development is needed of indicators of the trade-offs between different water security dimensions to enable assessment of multi-criteria policy goals, to provide guidance for adaptive management approaches in their implementation in practice.

Scholarly advances alone are of course no guarantee that insights will be translated into changes in politics, policy, and implementation in management practice. Hence, we conclude by suggesting the need for a global network of national platforms linking scientists, policy makers and practitioners in their quest for sustainable pathways towards water security.

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