EcoWISE
Innovative Approaches to Socio-Ecological Sustainability

Bo Yang
Robert Fredrick Young *Editors*

Ecological Wisdom

Theory and Practice

Springer

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Editor-in-Chief

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EcoWISE (Ecological wisdom inspired science and engineering) series aims to publish authored or edited volumes that (1) offer novel perspectives and insightful reviews, through the lens of ecological wisdom, on emerging or enduring topics pertaining to urban socio-ecological sustainability research, planning, design, and management; (2) showcase exemplary scientific and engineering projects, and policy instruments that, as manifestations of ecological wisdom, provide lasting benefits to urban socio-ecological systems across all temporal and spatial scales; or (3), ideally, coalesce (1) and (2) under a cohesive overarching framework. The series provides a forum, the first of its kind, for the broad international community of scholars and practitioners in urban socio-ecological systems research, planning, design, and management.
Books in the EcoWISE series will cover, but not be limited to, the following topical areas:

- Transdisciplinary studies of ecological wisdom, *ecophronetic* practice research, complex adaptive systems, traditional ecological knowledge (TEK), urban resilience, global climate change, urbanization, phronetic social science, and sustainability science;
- Ecological sciences for and practices in ecosystem rehabilitation, habitat reconstruction, landscape restoration, sustainable agroecology, permaculture, architecture, landscape and urban planning and design, resource conservation and management, disaster management, urban flood control and management, and low impact development;
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To Dr. Robert Fredrick Young (1959–2018) whose love for Mother Nature and passion for ecological wisdom inspired the making of this book

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Prologue

Ecological Wisdom: Genesis, Conceptualization, and Defining Characteristics

EcoWISE

Ecological practice is the action and process that humans involuntarily engage themselves in with the aim to bring about a secure and harmonious socio-ecological condition that serves human beings' basic need for survival and flourishing. It is the most fundamental and arguably primordial practice *Homo sapiens* has been engaging in over thousands of years of coevolution with nature and falls into one or any combination of the following categories—ecological planning, design, construction, restoration, and management.

From ecological practice, humans acquired a distinctive master skill par excellence, *ecological wisdom*, that enables them to address and act well on intractable socio-ecological issues that are crucial to their survival and flourishing. While manifesting itself in a myriad of ecological and landscape projects and public policy instruments that has been beneficent to both humans and other residents on the earth, this invaluable intellectual asset of ecological wisdom continues to evolve in the contemporary society of unprecedented socio-ecological transformations, inspiring advancement in modern science and stimulating technological and engineering innovations for the greater good. Ecological wisdom-inspired science and engineering (EcoWISE, for brevity) is therefore the emerging transdisciplinary field of scholarly inquiry that seeks novel insights, deliberately through the lens of ecological wisdom, into contemporary socio-ecological issues, and aims to develop innovative, prudent, and efficacious scientific and engineering solutions. The Springer Nature EcoWISE book series provides a forum, the first of its kind, for the international community of scholars and practitioners to collectively advance this worthy enterprise.

The book series aims to publish authored or edited volumes that (1) offer novel perspectives and insightful reviews, through the lens of ecological wisdom, on emerging or enduring topics pertaining to ecological practice and research; (2) showcase exemplary scientific and engineering projects, and policy instruments that, as manifestations of ecological wisdom, provide lasting benefits to socio-ecological systems across all temporal and spatial scales; or (3) ideally coalesce (1) and (2) under a cohesive overarching framework. The series is intended to serve the broad international community of scholars and practitioners in socio-ecological practice and research.

Integral to EcoWISE are the questions pertaining to the genesis, conceptualization, and defining characteristics of ecological wisdom: What is it? Where does it come from? What defining characteristics does it have? In the following sections, I shall explore these three questions.[1]

Ecological Wisdom

There are three ways in which the scholarly construct of ecological wisdom is defined (for recent and succinct reviews of various definitions, see Liao and Chan 2016, pp. 111–112; Wang, et al. 2016). As described chronologically below, they derive from different etymologies and reflect varied intellectual traditions.

Ecological Wisdom as an Ethical Belief: *Ecosophy*

In a 1973 essay on the main characteristics of the deep ecology movement, Norwegian ecological philosopher Arne Naess coined the term *ecosophy*, by combining the ancient Greek words *ecos* (household place) and *sophia* (theoretical wisdom), to represent an individual's own personal "philosophy of ecological harmony or equilibrium (between human and nature—the author)" (Naess 1973, p. 99). Despite his intention to use this term "to mean ecological wisdom or wisdom of place" (Drengson and Devall 2010, p. 55), no formal articulation was made until 16 years later. In a 1989 essay entitled *From ecology to ecosophy, from science to wisdom*, he inaugurated the fused nexus of ecological wisdom and *ecosophy* with a strong proclamation that for humans "to live on Earth enjoying and respecting the full richness and diversity of life-forms of the ecosphere, … [e]co-wisdom (ecosophy) is needed" (Naess 1989, p. 185).

Along this *ecosophical* line of reasoning, there was a strikingly parallel development in a noncognate context and with no direct intellectual contact. In a 1996 seminal Chinese book *On ecological wisdom* (《生态智慧论》, *sheng tai zhi hui lun*), Chinese philosopher Zhengrong She (佘正荣) coined the term 生态智慧 (*sheng tai zhi hui*), in a way similar, yet unrelated, to Naess', by combining the Chinese words 生态 (ecological) and 智慧 (wisdom). He defined ecological

[1] Drawing primarily on Chinese and English literature owing to my linguistic capabilities, this synthesis is inevitably limited in its scope and thus subject to expansion.

wisdom as *ecohumanism* with the following proclamation (She 1996, pp. 3–4)[2]: "At the transitional juncture from the industrial to ecological civilization, human beings must supplant the anthropocentric humanism with ecohumanism. A tripartite worldview that blends seamlessly ecological sciences, ecological ethics, and ecological aesthetics, ecohumanism is the ecological wisdom human beings need, and can guide the contemporary human beings through the jungle of industrial civilization toward the bright future of ecological civilization."

Acknowledging that "ecological wisdom is the wisdom for living and survival that is rooted in and developed through the primordial process of human adaptation to the environment" (She 1996, p. 2),[3] he posited that the ecological philosophies (i.e., *ecosophies*, as defined by Naess) of some of the greatest thinkers in human history, including those of Laozi, Aldo Leopold, Aurelio Peccei, Holmes Roston III, Arnold Joseph Toynbee, and Zhuangzi, are but archived individual convictions drawing on collective *ecosophical* beliefs (Ibid. p. 3).[4]

This collective perspective of *ecosophy* deviates from the "whole personal view" (Drengson and Devall 2010, p. 56) of Naess'. According to Canadian philosopher Alan Drengson and American sociologist Bill Devall, Naess believes that "[s]ince there is an abundance of individuals, languages, cultures, and religions, there will be an abundance of *ecosophies*" (Ibid.). To differentiate, "[e]ach person's *ecosophy* can be given a unique name, possibly for the place they live, or for something to which they feel strongly connected." Exemplifying this individual's personal view are Naess' "*Ecosophy* T" (Drengson and Devall 2010, pp. 56–57) and Chinese ecological aesthetician Xiangzhan Cheng's "*Ecosophy* C" (2013).

Ecological Wisdom as a Dual Ability: *Ecophronesis*

In a 2017 article entitled *Ecological philosophy and ecological wisdom*, Chinese ecological philosopher Feng Lu (卢风) defined ecological wisdom as the dual human ability to make ethically and politically sound judgment and to take ensuing prudent actions in particular circumstances of ecological practice (Lu 2017, p. 278; p. 285).[5] This human ability approach to wisdom definition has its intellectual root in Aristotelian conception of *phronesis* (i.e., practical wisdom; for a recent and succinct review of Aristotelian *phronesis*, see Xiang 2016, pp. 54–55). It is in fact the philosophical underpinning of a 2016 essay on ecological practical wisdom by American geographer and planning scholar Wei-Ning Xiang (Xiang 2016). In a

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2 "人类在从工业文明向生态文明转变的历史关头,必须超越人类中心主义的价值观,形成一种使生态规律、生态伦理和生态美感有机统一的新的价值观。这就是生态人文主义的价值观。生态人文主义是当代人类所需要的生态智慧,它将引导人类安全地走向未来的生态文明。"

3 "生存智慧来源于生物对环境的适应,因而生存智慧实质上就是生态智慧。对环境的适应是一切智慧最原始和最深刻的根源。"

4 "生态哲学给人类提供了一些深刻的生存智慧。但是这并不是说，在现今的生态哲学中已经达到了尽善尽美的生存智慧， 也不是说在生态哲学出现之前就没有产生过相当深刻的生态智慧。事实上， 在东方古代的文化传统中就产生过非常深刻的生态直觉(智慧—作者),这些生态直觉(智慧)对于当代人类生态观的发展和完善具有十分重要的价值。"

5 "生态智慧是在生态学和生态哲学指引下养成的判断能力、直觉能力和生命境界(涵盖德行)。生态智慧与人的生命和实践'不可须臾离'"(卢风, 2017, p. 285)。

way similar to that employed by Naess and She, Xiang coined the term *ecophronesis*, by combining two ancient Greek words *ecos* and *phronesis*, to represent ecological practical wisdom which he defined as “the master skill par excellence of moral improvisation to make, and act well upon, right choices in any given circumstance of ecological practice” (Xiang 2016, p. 55). Here, Xiang noted the term *skill* is used as an uncountable mass noun synonymous with the term *ability* (as in “the skill”) [Ibid.].

Despite the nascent coinage of *ecophronesis*, both the term and the *ecophronetic* line of reasoning it represents are indeed, according to Xiang, an *ex post* recognition of and a revered tribute to an outstanding group of human beings throughout history (Xiang 2016, p. 59). *Ecophronimoi* are the people of ecological practical wisdom whose master skill par excellence of *ecophronesis* enabled them to be successful in challenging circumstances of ecological practice (Ibid.). Among the prominent *ecophronimoi* are the Chinese ecological planner and engineer Li Bing (480–221 BC) and his colleagues of many generations who collectively designed, built, and sustained the Dujiangyan irrigation system (256 BC to present) in Sichuan, China (Needham et al. 1971, p. 288; Xiang 2014, pp. 65–66), and the American ecological planner and educator Ian McHarg (1920–2001) and his colleagues who planned and developed the town of the Woodlands in Texas, the USA, in the 1970s (McHarg 1996, pp. 256–264; Xiang 2017a; Yang and Li 2016). Their *ecophronetic* practices of stellar quality have brought lasting benefits to the people and other living communities in the areas the projects serve, and clearly achieved the paramount level of “doing real and permanent good in this world” (Xiang 2014, p. 65).

Ecological Wisdom as a Cohesive Whole of *Ecophronesis* and *Ecosophy*

In his 2016 essay on *ecophronesis*, Xiang made the observation that not only are *ecophronesis* and *ecosophy* so profoundly linked, but the connection between them is indeed integral to *ecophronesis*. He noted that in the instances of prudent and successful ecological practice throughout human history, like those of aforementioned Dujiangyan irrigation system and the Woodlands, *ecophronimoi*’s mastery and execution of improvisational skill were mindfully bound by a moral covenant with nature and inspired and informed by the human beings’ enlightened self-interest (Xiang 2016, pp. 57–58).[6] This union of improvisational ability and moral commitment is what American planning scholar John Forester calls “moral

[6]Human beings’ enlightened self-interest is a term used in environmental virtue ethics that serves the same *ecosophical* function as Naess’ *ecosophy* does—it is an ethical belief of the ecological harmony between human and nature (Cafaro 2001, pp. 3–5). According to Xiang (2017, p. 56), under the premise that there exists a relationship of human–nature reciprocity, “it states plainly that it is in human beings’ self-interest—ethical, moral as well as material—to respect and appreciate the intrinsic value of all living and non-living beings on the earth; and that human beings’ own flourishing, at individual and collective levels, should be conceived and pursued in ways that both sustain and depend on the flourishing of the entire ‘more-than-human whole’ of which humans are part.” As “such nonanthropocentrism is a part of wisdom” (Cafaro 2001, p. 15) that is widely shared by people from around the world and across generations, including Naess (see his 1986 essay, p. 72), I use it here as a collective *ecosophy*.

improvisation" (Forester 1999, pp. 224–241). It is with this very master skill par excellence of moral improvisation that *ecophronimoi* became capable of being "doubly responsible" (Nussbaum 1990, p. 94) in any particular instance of ecological practice—honoring commitments and upholding principles on the one hand and attending specific circumstantial particulars, on the other (Xiang 2016, p. 58).

This observation corroborates Xiang's argument that as an *ex post* and long overdue recognition of a reverable human virtue in ecological practice, the scholarly construct of ecological wisdom is incomplete and unbalanced in the absence of either *ecosophy* or *ecophronesis* (Xiang 2016, p. 58). It provides support for his proposal, as depicted symbolically in Eq. (1)[7] (Xiang 2017b), that both *ecosophy* and *ecophronesis* should be juxtaposed at the core of ecological wisdom (Xiang 2016, p. 53).

$$\text{Ecological wisdom} = \textit{ecosophy} + \textit{ecophronesis} \tag{1}$$

This *ecophronetic* line of reasoning for "the *ecophronesis*-*ecosophy* nexus of ecological wisdom" (Xiang 2016, p. 58) finds supporting arguments in Naess' work on *ecosophy*. In the 1989 essay aforementioned, Naess argued that the ethical belief of *ecosophy* is a source of inspiration and guidance for both action and research. "[N]ot a philosophy in the academic sense" (Naess 1989, p. 187); he wrote, "[a]n articulated *ecosophy* includes an attempt to outline *how to inhabit the Earth* conserving her long range, full richness and diversity of life as a value in itself" (Ibid., p. 186). As such, "[w]ithin the framework of Ecosophy research enters primarily as 'action research'" that is "subordinated to practical policies," (Ibid., p. 188), and aimed at "the derivation of particular prescriptions (that are) adapted to particular situation" (Ibid., p. 187). The practical orientation of *ecosophy* and contextual characterization of *ecosophical* research Naess articulated here manifest in his own work on Ecosophy T and the Apron Diagram, and are readily evident throughout his later writings (for a succinct review, see Drengson and Devall 2010).

An Embracing Definition of Ecological Wisdom

Where the *ecosophical* and *ecophronetic* lines of reasoning converges, Xiang posited in a 2017 speech (2017b), emerges a definition of ecological wisdom that embraces *ecophronesis* and *ecosophy* into a cohesive whole. One such definition he initially presented (Ibid.) is further elaborated below.

> Ecological wisdom is the master skill par excellence of moral improvisation for and from ecological practice; it enables a person, a community or an organization to make ethical judgement and take circumspect actions in particular circumstances of ecological practice; it is a cohesive whole of the *ecosophical* belief in the relationship of human-nature reciprocity and the *ecophronetic* ability to make, and act well upon, contextually and ethically right choices.

[7]In delivering this keynote speech in Chinese, Xiang presented the equation as 生态智慧=生态哲思+生态实践智慧. A copy of the PowerPoint presentation is available from the author upon request.

This definition highlights two defining characteristics of ecological wisdom—the ability in ecological practice to achieve the ideal of the unity of moral knowledge and virtuous action, and the ability to conduct preeminent ecological practice research.

Ecological Wisdom as the Ability to Achieve the Unity of Moral Knowledge and Virtuous Action

Five hundred years ago, Chinese neo-Confucian philosopher Wang Yangming (王阳明, 1472–1529) coined the term *the unity of knowledge and action* (知行合一, *zhī xíng hé yī*) to designate a state of moral ideal that he believes "exists for all (humans)" (Ching 1976, p. 68) and can be achieved through and in practice (Ibid., p. 72). In this state of moral ideal, ethical knowledge (*i.e.*, knowledge of the good) and virtuous action (*i.e.*, action to do the good) are only two words describing the same one effort; and as such, one acts spontaneously yet virtuously upon deep moral convictions (Ibid. pp. 68–69).[8] Similar ideas are also found in Aristotle's thinking over two millennia ago. "For Aristotle," wrote Canadian political scientist David Tabachnick, "to be 'ethical' was more than simply knowing right from wrong, but also meant the capacity to act upon that (moral—author) knowledge." (Tabachnick 2013, p. 32).

Ecological wisdom as defined above enables a person, a community, or an organization to achieve Wang's ideal state of the unity of moral knowledge and virtuous action (for brevity, thereafter, *the unity of knowledge and action*) and to meet the Aristotelian ethical standard. As a master skill par excellence of moral improvisation, it activates and amplifies the action-guiding function of *ecosophical* belief such that the ethical knowledge of the good serves as a moral benchmark for one's sound judgment and virtuous action in particular circumstances of ecological practice (Xiang 2016, p. 56). The ensuing outcomes, in the forms of ecological plans, designs, construction and restoration projects, and management policies, are thus simply tangible manifestations of the knowledge of the good, and exemplified by, among others, the aforementioned Dujiangyan irrigation system and the Woodlands. This process of activating and realizing one's *ecosophical* belief is analogous to, if not the same as, *zhì liáng zhī* (致良知)—extending and realizing one's innate conscience (i.e., knowledge of the good) through virtuous actions in

[8] It should be noted that, according to Julia Ching, a Canadian philosopher and a word leading Wang Yangming scholar, for Wang Yangming, "…just as true knowledge is always knowledge of virtue, true action should always be virtuous action. 'The unity of knowledge and action' is primarily a moral ideal rather than a principle of epistemology" (Ching 1976, p. 66). Unfortunately, by many with good intentions it has been mistaken as a principle of epistemology (Dong 2013).

practice—a process that, according to Wang Yangming, leads to *the unity of knowledge and action*.[9]

In a 2003 essay, Chinese philosopher Mingying Deng reinvigorated Aldo Leopold's 1947 concept of ecological conscience (Leopold, 1968, pp. 207–210), and stated it as a coalesced nexus of "the consciousness of being part of a more-than-human whole; the sense of moral goodness of one's own conduct, intentions, or character; and a feeling of ethical obligation to do right or be good in the best interest of the more-than-human whole" (Deng 2003, p. 86).[10] *Eco-conscience* such defined is comparable to the *ecosophy* component of ecological wisdom (section "Ecophronesis: The Ecological Practical Wisdom for and from Ecological Practice") with a shared belief in the relationship of human–nature reciprocity. A subtle difference is that *eco-conscience*, or conscience by and large, is often regarded as an innate quality of every human being [i.*e.*, "the innate knowledge of the good" (Zhang 2017, p. 341)], while *ecosophy* is not reportedly so.[11] The difference can nevertheless be omitted here and now since even Wang Yangming himself makes no distinction between conscience and moral knowledge in his conception of *zhì liáng zhī* (Ching 1976, p. 67). As such, it suffices to say that ecological wisdom, through activating, extending, and realizing *eco-conscience* (*zhì* shēng tài *liáng zhī*, 致生态良知) or *ecosophical* belief grounded in eco-conscience, is capable of empowering a person, a community, or an organization to achieve Wang's state of moral ideal of *the unity of knowledge and action* in ecological practice and thus to become ethical by the Aristotelian standard.

Ecological Wisdom as the Ability to Do Preeminent Ecological Practice Research

In addition to activating the action-guiding function of *ecosophical* belief or *eco-conscience*, e*cophronesis* in the scholarly construct of ecological wisdom is capable of empowering scholar–practitioners and practitioners to do outstanding research for ecological practice.

[9] "致吾心良知之天理于事事物物,则事事物物皆得其理矣。致吾心致良知者,致知也。事事物物皆得其理者，格物也。是合心与理为一者也。" (王阳明《王阳明全集》卷二《传习录中.答顾东桥书》, 上海古籍出版社, 1992).

[10] "(生态良知)是指人类自觉地把自己作为生物共同体的一员,把自身的活动纳入生物共同体的整体活动,并在此基础上形成的一种维持生物共同体和谐发展的深刻的责任感以及对自身行为的生态意义的自我评价能力。" (邓名瑛, Deng 2003, p. 86).

[11] More investigation is requested into the relationships between eco-conscience and *ecosophy*. In the writings on *ecosophy*, authors (Naess, Drengson, Deval, and Cheng, among others) predominantly treated *ecosophy* as a belief of environmental ethics with no articulation to eco-conscience. In a 2017 essay, on the other hand, Chinese ecological philosopher Xuezhi Zhang posited that one's achievement of the ideal moral state of *the unity of human and nature* is grounded in eco-conscience and speculated whether eco-conscience could integrate environmental ethics (2017, p. 342). However, no rigorous investigation into the relationships has been found in the literature.

Scholar–practitioners are scholars who are engaged in use-inspired basic research for practice (i.e., *practice research*) in Pasteur's quadrant and dedicated to generating *new* knowledge that is *useful* to practitioners (Xiang 2017, pp. 2243–2244). Common to all scholar-practitioners who have done outstanding ecological practice research, like McHarg, is their *ecophronetic* way of conducting practice research (Ibid., p. 2245). Wrote Xiang (Ibid., unless essential, citations in the original text are omitted for brevity), with *ecophronesis*,

> scholar-practitioners like McHarg became much capable of generating *new* knowledge that is *useful to the real*: not only did they advance scholarly rigorous—thorough and valid—knowledge that was also *immediately relevant*, *actionable*, and *potentially efficacious* to the real-world practitioners who were in specific knowledge needs under particular circumstances of ecological practice; but they also produced high caliber scholarship that is enlightening to scholars and practitioners from around the world and across generations who have interest in ecological practice research. Furthermore, because *ecophronesis* embraces inherently a transdisciplinary research capability in socio-ecological systems, *ecophronetic* scholar-practitioners like McHarg were immune from the pathogenic influence of 'ivory tower syndrome' (Toffel 2016, p. 1494). They became readily capable of bridging the arguably unbridgeable gap between scientific rigor and practical relevance, and taming the seemingly intractable problems of 'knowledge production' and 'knowledge transfer' (Sandberg and Tsoukas 2011, p. 338), all of which have been and remain to be persistent concerns in both circles of ecological practice and science in the modern-day world. As such, their *ecophronetic* way of conducting practice research manifested itself in a myriad of ecological projects and public policy instrument that has been providing lasting ecosystem services benefits to the human beings across generations.

It is noteworthy that the empowerment of *ecophronesis* equally benefits many practitioners who are engaged in pure applied ecological research that is motivated solely by the applied goals of problem-solving in practice (Xiang 2017, pp. 2242–2243). Exemplifying these *ecophronetic* practitioners are aforementioned Li Bing and his colleagues of many generations. Without seeking a scholarly understanding of the encountered phenomena through the scientific lens, they were enabled to conduct in an *ecophronetic* way preeminent research that contributed to the very success of their ecological practice of stellar quality.

Role Models and the Community of Scholar–Practitioners

One premise underlying *ecological wisdom-inspired science and engineering* (EcoWISE), the overarching concept of this book series, is that science and engineering need to and should be inspired by ecological wisdom. I hope that the preceding sections on the genesis, conceptualization, and defining characteristics of ecological wisdom have corroborated the premise to be just and appropriate. With regard to the subsequent question of *how* science and engineering should be inspired by ecological wisdom to serve the community of more-than-human whole on the earth, one way forward would be for us to emulate the role models of *ecophronetic* scholar–practitioners, whom the last two sections were dedicated to.

Ecological wisdom is not an abstract concept in the scholarly papers, and it is on clear display in the well-lived and fully realized lives of many practitioners and scholar–practitioners who have done preeminent ecological practice and research, and achieved the ideal moral state of *the unity of knowledge and action*. "A good example is the best sermon," to follow the example of these outstanding human beings, *ecophronimoi*, is both fitting and indeed rewarding. As a student of McHarg's in the 1980s, for example, not only did I witness that the unity of moral knowledge and virtuous action was like second nature to him, but I can also testify that like many of his students, my academic aspiration has been ever since inspired and professional path illuminated by his role model as an *ecophronetic* scholar–practitioner. With a gentle caveat that this way of inquiry for EcoWISE aims to examine and advocate *ecophronetic* practice research as a distinctive mode of practice research drawing upon the experience and examples of *ecophronetic* scholar–practitioners, rather than promoting the individuals themselves, I trust that the EcoWISE book series will become a celebrated venue for the building of a strong community of *ecophronetic* scholar–practitioners around the world and am confident that it will serve the community well in their pursuit of exemplary ecological wisdom-inspired ecological practice research and outstanding *ecophronetic* scholarship.

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Introduction: Ecological Wisdom as Discourse

Robert Young

Abstract In this chapter, I argue that ecological wisdom (EW) is becoming an important social and ecological discourse. Discourses are language and frames that establish first principles which in turn guide action. The role of discourse in framing ecological debate, policies, and design is tremendously potent, especially in light of today's significant intellectual, social, and ecological shifts. EW has been described by academics and scholar–practitioners as an "emerging field of scholarly inquiry," a " benchmark" in planning and design, a "domain of knowledge," and a "new framework for landscape and urban planning" (Fu et al. 2016; Liao and Chan 2016; Wang et al. 2016; Xaing 2014; Young 2016a). While most prominent in the fields of urban and regional landscape architecture and planning, I posit EW's potential as a discourse encompassing the realms of material science, civil engineering, architecture, anthropology, philosophy, psychology, political and urban ecology, and a wide range of other disciplines. Responding to the epochal challenges facing our society and life itself, EW draws upon history, science, spirit, culture, and place in its development. Accordingly, it offers a compelling discourse to guide society toward a more meaningful and successful role within the ecosphere and in realizing its own possibilities.

1 Introduction

Ecological wisdom, (EW), has variously been described by academics and scholar-practitioners as an "emerging field of scholarly inquiry," a "benchmark" in planning and design, a "domain of knowledge," and a "new framework for landscape and urban planning" (Fu et al. 2016; Liao and Chan 2016; Wang et al. 2016; Xaing 2014; Young 2016a). In addition to an important area of study, EW has also been labeled a vital imperative for action: "an urgent response" to "long-lasting and even irreversible ecological harms" (Liao and Chan 2016, 133).

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Given the rapid expansion of EW scholarship over recent years, including two international symposiums (Chongquing, China—2014 and Austin, Texas, USA—2016), two peer-reviewed special issues in the journals *Landscape and Urban Planning* (2016) and *Urban Management* (2017), articles on EW published in a variety of other peer-reviewed journals (Young 2016b; Zhao and Xu 2010), its influence in planning documents (Young et al. 2017), and this book series published by Springer Nature Press, I argue that EW is becoming an important social and ecological discourse. While most prominent in the fields of urban and regional landscape architecture and planning, I posit—and I believe this book in part reflects—its potential as a discourse encompassing the realms of material science, civil engineering, architecture, anthropology, philosophy, psychology, political and urban ecology, and a wide range of other disciplines.

2 Defining Terms

2.1 Wisdom

Before exploring the idea of EW as a discourse, it is important to first define terms. Fundamental to EW is the concept of wisdom itself. While the idea of wisdom has a long pedigree crossing many disciplines and cultures for the purposes of this piece I select the definition proposed by Gugerell and Riffert of wisdom as “a capability to act well based on experience, understanding, knowledge, insight and common sense” (Gugerell and Riffert 2011; Wang et al. 2016, 105). Inherent in this definition is the combination of learning and action. Fundamentally, wisdom is coordinating “knowledge and an ability to act” (Wang et al. 2016, 102).

2.2 Ecological Wisdom

The definition of ecological wisdom reflects this emphasis on praxis. Accentuating broad experience and learning, scholars note, EW “consists of evidence-based knowledge, tacit, and/or explicit that originates and evolves from diverse philosophical, cultural, and disciplinary backgrounds and across generations.” It draws, ideally, on sources which are “transgenerational, transcultural, transphilosophical, and transdisciplinary” and is defined by active outcomes which achieve the symmetrical enhancement of social and ecological health (Xaing 2014, 67; Young 2016a). Thus, similar to *wisdom* writ large, EW is delineated by its mandate to combine knowledge and action: to be “a means of knowing, understanding, and applying ecological information” as a guide to good planning and design (Wang et al. 2016, 100). In this light, Fan (2008) defined EW simply as a “’wisdom of civilization’ that is an organic unity of science and ethics” (Fu et al. 2016).

2.3 Discourse

Discourse lies at a critical juncture connecting knowledge with action. In his book, *The politics of the Earth: Environmental discourses*, published by Oxford University Press in 1997, John Dryzek described a discourse as "a shared way of apprehending the world." As such, he argued, a discourse is a means toward creating "coherent stories or accounts" each of which "rests on assumptions, judgments, and contentions that provide the basic terms for analysis, debates, agreements, and disagreements" (Dryzek 1997, 8). In this manner, he offered, discourses play a singularly vital role, establishing first principles which are decisive in guiding action. Thus, these first principles, rooted in language, matter.

3 The Power of Discourses

The role of discourse in framing ecological debate, policies, and design is tremendously potent. It "conditions the way we define, interpret, and address environmental affairs" (Dryzek 1997, 10). Indeed, philosopher Michel Foucault posits it represents the operation of power in its most primary form (Foucault 1980). Discourse is the first tool of authority to be deployed as it sets the subsequent bounds for debate and action. It is the wizard's spell. As a result, the struggle over shaping discourse is intense. It is not an ideal external to power that is then broken or bended by it—rather discourse is the expression of power itself as it begins to take form. It can be resisted or advanced by various influential tendencies but the end product is a synthesis of the relative strength of the forces engaged in this dialectic. While discourses can, through this process of competition evolve over time, they are very powerful in their moment of hegemony, swaying opinion and policies in the public and private sectors as well as among the general citizenry.

Beyond mere external influence, however, discourses can take deeper root. They often "become embodied in institutions" and thus "constitute the informal understandings that provide the context for social interaction, on a par with formal institutional rules" (Dryzek 1990, 19). In this manner, they "help to constitute and reconstitute the world just as surely as do formal institutions or material economic forces" (Dryzek 1990, 201). Consequently, discourses become the foundation, or perhaps better stated, the social physics molding these forces. In this regard, they are very potent and indeed, the only thing that can weaken them is a new discourse of gathering strength.

The basis of this strength is the ability of discourse to shape the stories we accept as accurately describing our world. According to Dryzek, discourses and the stories they enable are based upon four fundamental elements:

1. "Basic entities whose existence is recognized or constructed;
2. Assumptions about natural relationships;
3. Agents and their motives;
4. Key metaphors and other rhetorical devices" (Dryzek 1990, 16–17).

As noted above, I argue that the recent rise of EW in framing research, discussion, and active planning indicates its potential to constitute a new emerging and powerful discourse.

4 Ecological Wisdom as Discourse

4.1 Basic Entities

The first element Dryzek identifies as fundamental to the creation of a discourse is "basic entities whose existence is recognized or constructed" (16). For EW, these entities are broad-based. EW recognizes standard components such as institutions, social movements, and charismatic individuals. It also recognizes ecological forces as active subjects. In each of these categories, EW throws a wide net including for consideration entities both within the present as well as the past. In addition to this breadth, it acknowledges, across a wide cultural range, the material force, validity, and value of scientific rationalism as well as more ephemeral factors such as emotion and the spiritual (Eisenman and Murray 2016; Young 2016b). In this sense, it seeks to achieve Xaing's proposition of being "transgenerational, transcultural, transphilosophical, and transdisciplinary" (Xaing 2014, 67).

4.2 Natural Relationships

The second fundamental component constituting discourses are "assumptions about natural relationships" (16). EW contains a number of such assumptions, the primary being—as stated by landscape architect, Ian McHarg—that "natural processes constitute social values" (McHarg 1969). Like McHarg, EW argues the values embodied in these processes are of considerable significance and which, when understood and adhered to, offer substantial guidance toward proper planning and design.

EW also assumes such templates to "right action" are not easily discerned. As a discourse, EW recognizes the "wicked" nature of many challenges facing society and that the social/ecological interface is particularly rife with such complexities. The nature of their "wickedness" is the challenges they present to the equitable distribution of impacts and in gaining the social learning necessary to realize this equity. To address these challenges, EW emphasizes and draws upon a spectrum of support including historical experience, detailed understanding of short and long-term ecological processes, and sensitivity to culture. To be effective, EW also assumes that although there are scientific, philosophical, and artistic elements that have general validity, this validity is modified by understanding all relationships to be, to a degree, context-dependent. Thus, EW argues, all relationships are engaged in an ongoing dialectic with history, place, and culture.

4.3 Agents

This process is carried out and further mediated by the next fundamental component Dryzek identified in discourse development: "agents and their motives" (16). In keeping with its broad-spectrum approach, EW recognizes a wide scope of agency. Unlike many other discourses, EW acknowledges ecological forces as agents both in their socially deleterious and beneficent forms. As noted, basic ecological processes and "black swans," extreme variations in these processes, are elemental drivers in the call for EW (Taleb 2010; Liao and Chan 2016).

EW recognizes social actors as well. EW researchers have identified certain professional bodies and their technically expert researchers and decision makers as constituent in the articulation of EW (Fu et al. 2016; Wang et al. 2016; Wang and Xaing 2016). Academics have also identified indigenous perspectives and social movements as vital actors in constructing EW's lexicon (Liao and Chan 2016; Patten 2016; Young 2016b).

In addition to institutional and cultural agents, EW researchers have given particular attention to inspired individuals such as the ancient Chinese hydrological engineer Li Bing, prominent landscape architects Fredrick Law Olmsted and Ian McHarg, ecologists Alexander von Humboldt, Ernst Haeckel, Arthur Tansley, and Howard and Eugene Odum, philosophers Laozi, Arnie Naess, and Zhengrong She, designers Sym van der Ryn and Stuart Cowan, and planner Sir Patrick Geddes (Liao and Chan 2016; Steiner 2016; Wang et al. 2016; Xaing 2014, Yang and Li 2016; Young and Clavel 2016). To this could be added a host of additional persons including Ellen Swallow Richards, Janine Benyus, Jane Jacobs, and others who could be viewed as innovators, thinkers, and practitioners of EW.

4.4 Metaphors and Rhetoric

Lastly, Dryzek identified "key metaphors and other rhetorical devices" as a primary factor in the coalescence of a discourse. In this area, EW shows particular strength. Central to presenting EW as a landscape and planning concept were the seemingly unusual rhetorical bedfellows of Andrew Carnegie and Daoist philosophy. Wei-Ning Xaing associated them in his editorial introducing EW to the readers of the journal of *Landscape and Urban Planning* through Carnegie's stated interest in "real and permanent good," and the Daoist principles of *daofazirun*: "following nature's lead" (Carnegie 1889; Xaing 2014).

In combination, several EW researchers argue, the pursuit of these ideals point toward the Daoist concept of "right way" or "right choice." Postmodernism has, properly, created significant skepticism toward such notions without their being much more fully articulated and defined. In an effort to address this concept in greater detail I have posited "right choices" as indicated by actions which enable the symmetrical enhancement of social and ecological systems and their evolutionary potential (Young 2016a). This ideal is not unlike the "land ethic" articulated by Aldo Leopold in his, *A Sand County Almanac*"—"A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise" (Leopold 1949).

A similar rhetorical devise deployed in the EW literature is borrowed from landscape planner Ian McHarg's ideal of "design with nature." From his book of the same title, McHarg describes accomplishing this through acknowledging the "intrinsic suitability" of a particular piece of land or cultural edifice for a particular type of development (McHarg 1969). Wang and Xaing describe this manifestation of EW as "nature inspired design," and Liao and Chan further articulate it as "a systematic land development approach that avoids environmentally sensitive areas and works with natural dynamics" (Liao and Chan 2016, 112; Wang and Xaing 2016).

Such an approach is construed, especially by Asian EW scholars, as "harmonious" or aspiring toward an "harmonious coexistence with nature" (Fu et al. 2016; Wang et al. 2016; Zhang et al. 2016). This "harmony" is elucidated in a deeper sense than mere "balance" of therefore requisitely separated human and environmental realms (Fu et al. 2016; Wang et al. 2016). Rather, what this rhetorical term refers to is closer to a constructive fusing of their inherently interrelated dynamics. This is perhaps best reflected to date in the EW literature by the scientific rationalism of urban ecology and the spiritual Daoist ideal that classifies humans as simply a part of (rather than separate from) nature.

5 Knowledge and Action

As actionable method, EW researchers describe this unity as "practical wisdom" or "ecophoresis" (Xaing 2016). These terms note an approach centered on *engagement in* rather than the *management of* an environment that is described as having intrinsic value beyond its simple existence as a resource for meeting human needs (Wang et al 2016).

In addressing their approach to action most previous environmental discourses Dryzek identified such as survivalism, Prometheanism, administrative rationalism, democratic pragmatism, economic rationalism, sustainable development, green rationalism, and ecological modernization have sought to explain, to varying degrees, how to defeat, control, or conserve a subordinate nature. When not placed in active opposition to nature, other discourses, such as those within green romanticism, largely reject scientific rationalism, labeling it a source of social and ecological domination, or seek to subordinate humans to an idealized Nature.

As a discourse, however, EW goes to none of these extremes. EW asks rather how humanity has and can evolve symmetrically with and within nature. EW views humanity as a fundamental part of the ecological domain, a domain whose characteristic of evolution applies to genetics as much to its social and technological expressions. As such, EW frames this evolution in terms of the development of human consciousness as well as our physical corpus; our scientific reason as much as our technologies. It sees our place in nature not as a problem to be solved but as a relationship to study, understand, elaborate, and refine.

In addressing this evolutionary process, previous discourses have often viewed past action alternately as binding precedent, immaterial antecedent, lost ideal, or a mere social construct; but EW regards the past and historical time in general as part of what might be called "the long present." The long present of EW is more akin to John McPhee's concept of deep time than traditionalism's backward gaze, modern rationalism's contemporary focus, green romanticism's idealization of a past, idyllic age, or postmodernity's refusal to see time as a coherent framework (McPhee 1998; Young 2016a). EW acknowledges the long present as encompassing both the importance of contemporary scientific rationalism as well as natural history and its resultant traditional ecological (and social) knowledge. Further, it recognizes the value of scientific inquiry as well as emotional and spiritual values in ascertaining wisdom in the ongoing development of human society.

Thus, the discourse of EW does not affirm any particular monopoly of knowledge or action in humanity's relationship to nature by declaring them dead, eternal, or non-existent. Rather, EW, by opening up the realms of thought and deed, democratizes them. Accordingly, a vast new array of possibilities in terms of design, policy, technology, and political economy are made available. None of these forms are anointed either permanent or relegated to the "end of history" or "muck of the ages" (Fukuyama 1989; Marx and Engels 1976). Consequently, current and past forms of tools, ideas, and designs are viewed as contingent, evolutionary entities that can move in a multiplicity of directions, appear, reappear, and evolve in our organization of society. As such, they can be labeled as, but not assessed by, being modern (or postmodern), past, futuristic, or contemporary. In this manner, they remain valid, emerging, reemerging, or dissipating as we establish an ecologically sound political economy, evaluated only by their impact on and ability to achieve the symmetrical healthy development of social and ecological systems. Thus, through the discourse of EW, enlightenment gains are retained while their blinders are discarded and shackles broken.

Within EW as discourse, then, there are no directing temporal or polemical gods that determine whether a technology or social form should be exalted or extinguished. Rather, in EW, to paraphrase Nietzsche, such gods are dead (or vulnerable to be killed). EW posits only the actual social and ecological results (immediate *and* long-term) as relevant in deciding what should fill the resulting vacuum. Within this relationship, our own collective constructions of political economy, spiritual understanding, and agency must determine what social forms emerge. Industrial society in its present aspect (or its *post* persona) is not assumed triumphant or to have a monopoly on who and what can be admitted as viable for consideration. By the same token, under EW, traditional knowledge and radical environmentalist propositions are put to the test of scientific rationality to explore their potential value and impact in real time and upon real systems.

6 Conclusion

As Dryzek comments in his review of environmental discourses: "the way we think about basic concepts concerning the environment can change quite dramatically over time and this has consequences for the politics and policies that occur in regard to environmental issues" (Dryzek 1997, 5). In the face of today's significant intellectual, social, and ecological shifts, many existing discourses are limited in their capacity to either deeply reimagine contemporary society or to materially act in reconstructing it. Dryzek himself sees many lacking a "radical" edge that can give them greater potency and ability to transcend their limitations. This judgement is especially true if the original Latin meaning of the term "radical"—"to the root"—is the basis of this comment, for green romanticism for all its radical trappings is, at its core, an idealist approach with a problematic relationship to broad-based, material action.

EW offers a strong, new (and old) response to these limitations. Responding to the epochal challenges facing our society and life itself, EW draws upon history, science, spirit, culture, and place in its development. Accordingly, it offers a compelling discourse to guide society toward a more meaningful and successful role within the ecosphere and in realizing its own possibilities.

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Part I
Ecological Wisdom Theory

Ecophronesis: The Ecological Practical Wisdom for and from Ecological Practice

Wei-Ning Xiang

Abstract This essay addresses three questions pertaining to the assertion that ecological wisdom connotes both Platonian *sophia* (theoretical wisdom) and Aristotelian *phronesis* (practical wisdom): What is Aristotelian *phronesis* in the context of ecological wisdom? Why should it be juxtaposed with *sophia* at the nexus of ecological wisdom? How relevant is it to the contemporary ecological practice (planning, design, construction, and management)? The essay posits the construct of *ecophronesis* (ecological *phronesis*) as the ecological practical wisdom that people acquire from and use for ecological practice, describes the relationship between *ecophronesis* and Naessian *ecosophy* (ecological theoretical wisdom), and explores the relevance of *ecophronesis* to ecological practice and actionable science.

Keywords *Ecophronesis* · *Phronesis* · *Ecosophy* · Ecological practical wisdom
Ecological wisdom · Ecological practice · Moral improvisation
Actionable science

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Highlights

Ecophronesis is the master skill par excellence of moral improvisation in ecological practice.
It is inspired and informed by human beings' enlightened self-interest.
It is developed through reflective ecological practice.

1 Introduction

In a 2014 editorial on ecological wisdom, Xiang asserts (p. 67, original references are omitted for brevity).

> Unlike *ecosophy* which Norwegian philosopher Arne Naess coined in 1973, by combining the ancient Greek words *ecos* (household place) and *sophia* (theoretical wisdom), as a synonym for ecological wisdom or wisdom of place to represent an individual's personal 'philosophy of ecological harmony or equilibrium', the concept of ecological wisdom in the context of ecological research, planning, design, and management connotes both *sophia* and the Aristotelian concept of *phronesis* (practical wisdom), and embraces both individual and collective knowledge. As such, ecological wisdom is by nature ethical, inspirational, and yet still practical.

This assertion, aimed to delineate implicitly the scope of a reinvented concept of ecological wisdom that is distinct but not separate from that of Naessian *ecosophy*, necessarily raises questions as to *what* Aristotelian *phronesis* is in the context of ecological wisdom, *why* it should be juxtaposed with Platonian *sophia* at the nexus of ecological wisdom, and *how relevant* it is to the contemporary ecological practice of planning, design, construction, and management (hereafter ecological practice, for brevity). These questions are fundamental to the scholarship of ecological wisdom and centrally important to the enterprise of ecological wisdom research and practice. However, because of the nascence of ecological wisdom as a scholarly construct in the realm of ecological practice, and the predominant focus on *ecosophy* in the discourse of ecological wisdom (e.g., Cheng 2013; Drengson and Devall 2010; She 1996), they have neither been addressed nor ever raised until just now.

This essay aims to fill this knowledge gap. It is organized in the order by which the above three questions are raised with a preamble section on Aristotelian *phronesis* and its contemporary reinvigorated conceptions.

2 Aristotelian *Phronesis* and Its Contemporary Conceptions

In Book VI of *Nichomachean Ethics*, Aristotle describes *phronesis*, i.e., practical wisdom, as "a reasoned and true state of (human) capacity to act with regard to human goods… (that) is not concerned with universals only; … (but) also take(s) cognizance of particulars…" (Flyvbjerg, 2001, p. 58; Tabachnick 2004, p. 999; Tabachnick 2013, p. 41). For Aristotle, *phronesis* is the intellectual virtue, or "the (human) ability to recognize and actualize whatever is best in the most complex, various, and ambiguous situations" for the good (Rorty 1988b, p. 272); it is distinct from, but no less than, the other forms of wisdom, *sophia* (theoretical wisdom), which pertains to universal truth (Flyvbjerg 2004, p. 289; Schwartz and Sharpe 2010, pp. 5–8; Tabachnick 2013, pp. 38–39).

Two millennia later, after a long period of marginalization in the western intellectual world (Chishtie 2012, p. 101; Flyvbjerg 2001, p. 53, p. 59, p. 70; Flyvbjerg 2004, p. 289), this classical construct of Aristotelian *phronesis* reemerged as a subject matter of scholarly discussion (Ellett 2012, pp. 14–19; Kinsella and Pitman 2012a, p. 1, p. 7; Tabachnick 2004, p. 997). Since the mid twentieth century, it has become an important theme of contemporary scholarship across a wide spectrum of fields outside philosophy and religious studies, the two knowledge domains where "[w]isdom has been a topic … since the dawning of human civilization" (Gugerell and Riffert 2011, p. 226). These include biomedical ethics, communication studies, cultural anthropology, education, professional practice, psychology, geography, management science, planning theory, and political science (e.g., Baltes and Staudinger 2000, p. 122; Flyvbjerg 2001, pp. 3–4; Flyvbjerg 2004; Flyvbjerg et al. 2012, pp. 1–2; Gugerell and Riffert 2011, p. 226; Kinsella and Pitman 2012a; Tabachnick 2004, p. 997). In the realm of ecological practice, however, no specific articulation of Aristotelian *phronesis* has been made.

In the evolving literature of neo-Aristotelian *phronesis* that came with the revival, the classical virtue has been reinvigorated to become more intelligible and operational in the modern context, and yet it remains rooted in the very same foundation Aristotle laid over two thousand years ago. For the discourse of ecological wisdom, and to address the three questions raised at the beginning of the essay, a brief review of some relevant and nonphilosophical conceptions of neo-Aristotelian *phronesis* is necessary and so provided in this section. Readers who are interested in a philosophical review are referred to the section *The importance of phronesis* in Zagzebski (1996, pp. 211–231).

2.1 Phronesis *Is the Master Skill Par Excellence for the Good*

In a 2010 book entitled *Practical wisdom: The right way to do the right thing*, American psychologist and economist Barry Schwartz and his political scientist colleague Kenneth Sharpe describe *phronesis* as the "moral *skill*" (Schwartz and Sharpe 2010, p. 8, p. 19, italic by the author) of "performing a particular social practice well" (Ibid., p. 5). Unlike artistic or technical or other specific skills, they emphasize that *phronesis* is the master skill par excellence (Ibid, p. 6) that enables its possessor to figure out "the right way to do the right thing in a particular circumstance, with a particular person, at a particular time" (Ibid, pp. 5–6). In their influential work on the Berlin wisdom paradigm, German psychologists Paul Baltes and Ursula Staudinger utilize the general term *wisdom* in place of *phronesis* when referring to practical wisdom, and define it as "*an expertise* in the conduct and meaning of life" (Baltes and Staudinger 2000, p. 124, italic by the author), and characterize it as "a cognitive and motivational metaheuristic (pragmatic) that *organizes* and *orchestrates* knowledge toward human excellence in mind and virtue, *both individually and collectively*" (Ibid., p. 122, italic by the author). In developing a conceptual framework for *phronetic* social science, Danish planning scholar Bent Flyvbjerg defines *phronesis* as "a sense or *a tacit skill* for doing the ethically practical" (Flyvbjerg 2004, p. 287, italic by the author). Later, he and political scientist colleagues Todd Landman and Sanford Schram elucidate that *phronesis* is the practical wisdom "on how to address and act on social problems in a particular context" (Flyvbjerg et al. 2012, p. 1).

In these modern and nonphilosophical conceptions, authors all tend to reinterpret the classical notion as a more intelligible construct of human capacity, whether as skill or expertise. Here, the term *skill* is used as an uncountable mass noun that stands for the ability (as in *the skill*), coming from and orchestrating one's knowledge, practice, experience, etc., to do something well in a particular context; semantically, it differs from its own nuanced countable form (as in *a skill* or *skills*) which means a particular ability or type of ability [Oxford English Dictionary (http://www.oxforddictionaries.com/us/definition/learner/skill); Dictionary.com (http://dictionary.reference.com/browse/skill?s=t). Both were accessed February 28, 2016]. The term *expertise* in defining practical wisdom under the Berlin wisdom paradigm is used as a synonym of *skill* in its broader sense (Baltes and Staudinger 2000, pp. 124–125). Interestingly, not only is this inclination to defining *phronesis* as skill coextensive with the "virtue as skill" thesis proposed by some contemporary philosophers (for the thesis, see Stichter 2011, pp. 79–82; for philosophical accounts on the relationship between virtue and skill, see Annas 2011, pp. 16–32; Zagzebski 1996, pp. 106–116), but modern-day research on skill and expertise is also claimed to be a foundation for "the most plausible conception of the virtue as skill model" (Stichter 2011, p. 81).

What are the incentives for people to acquire and exercise *phronesis*? In regarding *phronesis* as skill, authors of neo-Aristotelian *phronesis* literature persistently sustain the premise Aristotle and most virtue ethicists, ancient and contemporary, hold that the motivational states of good intention are integral components of *phronesis* (Baltes and Staudinger 2000, p. 123, p. 127, pp. 131–132; Chia and Holt 2007, p. 510; Kemmis 2012, pp. 156–157; Van der Ryn and Cowan, 2007, p. 14). People acquire and exercise *phronesis* for *the good* within the frame of a well-lived and fully realized life (Rorty 1988a, p. 17; Rorty 1988b, p. 274), with the aim "to bring about a more secure and harmonious human condition" (Chia and Holt 2007, p. 510). The claim Australian education scholar Stephen Kemmis made in 2012 says it all (pp. 157–158), "The longing for *phronesis*, for (practical) *wisdom*, … is really a longing for a world in which people honestly and capably strive to act rightly and to avoid harm… (and to do) the good for each one and the good for humankind."

2.2 Phronesis *Serves the Practical Need for Making and Acting Well on Right Choices*

As skill, what human need does *phronesis* serve? Why is *phronesis* necessary? Aristotle recognized that human activities, whether in everyday life or in any type of social practice, demand choices most of which involve balancing or mediating among distinct and often clashing interests, competing aims, extremes of excess and deficiency in principles, and legitimate yet rigid rules; and that at the time of contemplated action, making the right choices begs for the ability or skill to not only find the balance, i.e., the "mean," that suits the particular circumstance in which a course of action takes place, but also coordinate intermediary interests, aims, principles, and rules into a single line of action. He contended that in the philosophical tradition, the only candidate for such virtuous ability or skill is *phronesis*—practical wisdom. This is not only because *phronesis* is directed toward practices, any kind of practice, in its own right with the whole range of intellectual and character excellences that determine what an action should be taken and how it is performed (Rorty 1988b, pp. 272–275), but also because the other form of wisdom *sophia*, the umbrella concept for theoretical wisdom advocated by both Socrates and Plato, pertaining to universal truth, is too abstract and context independent to meet the practical need for making context-dependent choices (Flyvbjerg 2001, pp. 55–57; Kemmis 2012, p. 157; Schwartz and Sharpe 2010, pp. 5–8, pp. 29–30; Zagzebski 1996, pp. 220–221). Furthermore, in the repository of human knowledge, neither *episteme* (i.e., scientific knowledge related to *sophia*) nor *techne* (i.e., craft-based knowledge) lends itself to serving this human need because the former, according to Socrates, Descartes and Kant, must, or at least aims to, meet the *sine qua non* of context-independence (Berkes 2012, p. 276; Chishtie 2012, p. 101; Flyvbjerg 2001, pp. 38–39); and the latter roots firmly in practical instrumental rationality (Kinsella and Pitman 2012a, p. 2; Tabachinck 2013, pp. 37–52). Only through activities that resemble those associated with *phronesis* (Chishtie 2012, p. 102, p. 113) can these two forms of human knowledge, and *episteme* in particular, be organized and orchestrated to facilitate the development of human excellence in social practice, both individually and collectively (Baltes and Staudinger 2000, p. 122).

In the literature of neo-Aristotelian *phronesis*, the line of reasoning has been widely embraced that advocates *phronesis* as an unsubstituted complement to *sophia*, *episteme,* and *techne*, and cultivates "the nexus that joins knowledge generation and professional practice in scientific and related professional communities" (Chishtie 2012, p. 112). It is in fact the main intellectual ferment for the *phronetic* revival across a wide spectrum of disciplines (Flyvbjerg 2001, 2004; Kinsella 2012, p. 35; Kinsella and Pitman 2012a, p. 1; Schwartz and Sharpe 2010; Tabachnick 2004, pp. 997–998; Zagzebski 1996).

2.3 Phronesis *Is a Gift to Those Who Reflect in and on Practice*

Aristotle believes that wisdom, especially practical wisdom, is not the gift of a few sages; ordinary people can learn to be wise in acting on practical matters through a learning-by-doing process (Annas 2011, pp. 16–17; Schwartz and Sharpe 2010, p. 5, p. 8, pp. 11–12). Modern-day psychological and neuroscience research reveals that people are born to be wise—having the potential to develop the intellectual and moral skill of practical wisdom (Schwartz and Sharpe 2010, p. 10, p. 52, p. 82); and that the development of these potentials requires the experience of learning by doing at either or both individual and collective levels (Baltes and Staudinger 2000, p. 124; Schwartz and Sharpe 2010, pp. 51–68). Here, the "learning-by-doing" experience means literarily that people learn to be practically wise by doing practically wise things (Schwartz and Sharpe 2010, p. 26). In a sense, it is similar to the "study-of-practice" experience described by American planning scholar Judith Innes, in which participants' learning, deciding, and acting all take place in an embedded context so that these otherwise tripartite activities are not, and conceivably cannot be, distinguished from one another (Innes 1995, p. 185).

But what, among possibly many practically wise things, can people do to enrich their "learning-by-doing" experience toward *phronesis*? R*eflection*, as revealed by the contemporary research on professional *phronesis*, is arguably the essential one (Kemmis 2012; Kinsella 2012; Sellman 2012; Weick 2007, p. ix). As Canadian professional practice and education scholars Elizabeth Anne Kinsella and Allan Pitman put it, "[p]ractical wisdom requires discernment and implies reflection" (Kinsella and Pitman 2012b, p. 165). American organizational theorist Karl Weick further corroborates that "a habit of profound reflection upon men and events" is a defining characteristic, along with "an ability to reach conclusions of universal as well as immediate value," of a person of practical wisdom (Weick 2007, p. ix).

According to American leading pragmatist, philosopher, and educator John Dewey (1933), reflection, when contextualized within reflective thinking, is an "*active, persistent and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it and further conclusion to which it tends*" (p. 9). As such, "[*i*]*t converts action that is merely appetitive, blind, and impulsive into intelligent action*" (p. 17). This articulation between reflection and intelligent action is further developed by American philosopher Donald Schön into a bipartite yet cohesively fused process of *reflective practice* (Schön 1983, 1987, 1992), in which reflection occurs not only in the mid of practice (reflection-in-action), but also retrospectively (reflection on action) (Kinsella 2012, p. 38). By embracing a continuum of reflection (Kinsella 2012, p. 36) individually and/or collectively (Forester 1999, p. 249; Kemmis 2012, p. 159), a dialectic process of reflective practice cultivates the development of individual and/or collective *phronesis* (Forester 1999, p. 249; Freeman et al. 2007, pp. 171–173; Kemmis 2012, p. 158; Kinsella and Pitman 2012a, p. 9; Yanow and Tsoukas 2009, pp. 1345–1346).

3 *Ecophronesis*: The Ecological Practical Wisdom for and from Ecological Practice

Drawing upon the neo-Aristotelian conceptions above summarized, this essay posits *ecophronesis*, a brief form of *ecological phronesis*, as the practical wisdom in the context of ecological practice—ecological practical wisdom. More explicitly,

> *ecophronesis* is the master skill par excellence of moral improvisation to make, and act well upon, right choices in any given circumstance of ecological practice; motivated by human beings' enlightened self-interest, it is developed through reflective ecological practice.

As an extension of neo-Aristotelian *phronesis* to the realm of ecological practice, *ecophronesis* inherits and preserves the three defining characteristics discussed in Sect. 2 with regard, respectively, to what *phronesis* is, what it does and in what context, and how it can be developed. Nonetheless, because a number of unique and prominent characteristics ecological practice possesses, *ecophronesis* necessarily differs from its ordinary counterpart in at least two aspects.

3.1 Ecophronesis *Is Inspired and Informed by Human Beings' Enlightened Self-interest*

In ecological practice, like in any kind of social practice, people acquire and exercise *phronesis* for *the good*, with the aim "to bring about a more secure and harmonious human condition" for each one and for humankind (Chia and Holt 2007, p. 510; Kemmis 2012, pp. 157–158. See also discussions in subsection 2.1 of this essay). However, unlike in other kinds of social practice, such as medicine, education, mechanical engineering, and law, where practitioners primarily deal with human affairs in the context of socio-ecological systems, practitioners in ecological practice concern themselves *primarily* and *explicitly* with the relationship between human and nature on top of social relationships (Steiner 2016, pp. 1–4, p. 173). This unique characteristic of ecological practice necessitates the presence of a key idea in the *ecophronesis* definition, that of Human *beings' enlightened self-interest* in "the community of beings" (Berkes 2012, pp. 286–287; Cafaro 2001, p. 4).

The notion of *human beings' enlightened self-interest* is concerned with two fundamental questions in ecological practice—what should a "harmonious human condition" look like on the earth? How should it be pursued? In the belief that there exists a relationship of human–nature reciprocity (Berkes 2012, pp. 286–287), it states plainly that it is in human beings' self-interest—ethical, moral, and material—to respect and appreciate the intrinsic value of all living and nonliving beings on the earth (Berkes 2012, pp. 286–287; Cafaro 2001, p. 4, p. 16) and that human beings' own flourishing, at individual and collective levels, should be conceived and pursued in ways that both sustain and depend on the flourishing of the entire "more than human whole" of which humans are part (Cafaro 2001, pp. 8–9, p. 15).

As such, *human beings' enlightened self-interest* is both an ethical belief or position and a moral incentive in the construct of *ecophronesis*. In particular, as an ethical belief, it serves as what Austrian system scientist Eric Jantsch calls "a regulatory device" (Jantsch 1980, p. 14) of "effectively action-guiding" function (Rorty 1988a, p. 15; Rorty 1988b, p. 273) that provides people who hold the position with the benchmark for judging *what is right* to choose and the guidelines for deciding *how to act on* rightly in any given circumstance of ecological practice; as a moral incentive, it inspires people to acquire and exercise the skill of *phronesis* in ecological practice so that they are able to make, and act well upon, choices right for "the community of beings," and ultimately, through this *phronetic* process, to "become better people" living "more joyful lives" themselves (Cafaro 2001, p. 16; for similar ideas on *phronesis* in relation to well-lived and fully realized lives, see Rorty 1988b, p. 274).

The idea of *human beings' enlightened self-interest* in "the community of beings" is enduring and invigorative; its application to ecological practice has been fruitful throughout human history. As American archaeologist and environmental historian Charles Redman points out, in many ancient indigenous societies, ranging from the Australian aborigines, to the island Polynesians, to the American Indians, and to many small-scale predecessors of Western civilization, "[t]he dominant theme is *mutuality*, that is, existing under a moral order that blends together humans, nature, and sometimes even the gods into one family" (Redman 1999, p. 24). This notion, according to several scholars from diverse disciplinary backgrounds, including Fikret Berkes, a Canadian scholar of traditional ecological knowledge (TEK), Philip Cafaro, an American environmental philosopher, John Lyle, an American landscape planner, and Redman, has profoundly inspired the development of a series of similar ideas in environmental virtue ethics of the modern world. These include, but may not be limited to, ideas of Rachel Carson, Aldo Leopold, James Lovelock, George Marsh, Arne Naess, Albert Schweitzer, and Henry Thoreau (Berkes 2012, p. 287; Cafaro 2001, pp. 14–16; Lyle 1985, p. 139; Redman 1999, p. 22, pp. 25–27). Furthermore, underlying *design with nature*, a paradigm of ecological practice since the dawning of human civilization (Lyle 1985, p. 15, p. 264) that was made prominent through a 1969 seminal book of the same title by American landscape planner and educator Ian McHarg, is a "(moral) covenant between human communities and other living communities" (Van der Ryn and Cowan 1996, p. 104) that aims to "give expression to the potential harmony of man-nature" (McHarg 1969, p. 5). Among many exemplary cases in which the ecological practice of design with nature has benefitted both human and nonhuman beings are the 2300-year-old Dujiangyan irrigation system in Sichuan, China (Needham et al. 1971, p. 288; Xiang 2014, pp. 65–66), and the near half-of-a-century old town of The Woodlands in Texas, the USA (McHarg 1996, pp. 256–264; Yang and Li 2016, this volume).

3.2 Ecophronesis *Is a Master Skill Par Excellence of Moral Improvisation*

How exactly does *ecophronesis* serve human's ambition in any given circumstance of ecological practice to make, and act well upon, right choices that embrace human beings' enlightened self-interest? What exactly does *ecophronesis* comprise that enables it to do so? Inspired by Aristotle's idea that in order to acquire *phronesis*, one must follow the example of preexisting *phronetic* persons, that is, *phronimos* (Tabachnick 2013, p. 43), one approach to searching for insights into these questions is to study instances of exemplary ecological practice, and examine how people of ecological practical wisdom, *ecophronimos*, that is, worked *phronetically* and what master skill par excellence they acquired and employed. Like the study-of-practice approach the communicative action theorists proactively employ (Innes 1995, pp. 183–186), this way of inquiry aims to examine and advocate *ecophronesis* as a distinctive form of skill drawing upon the practice of *ecophronetic* individuals, rather than promoting the individuals themselves. After all, "[o]ur love of *phronesis* is a tribute to and an admiration for those who have it. Those who have *phronesis* gain it through (successful and unsuccessful) experiences in which they have aimed to 'do' … the good for each one and the good for humankind" (Kemmis 2012, p. 158).

One classic case in point is the aforementioned 1973 ecological planning project for the new town of The Woodlands in Texas, the USA, by Ian McHarg and his colleagues from Wallace, McHarg, Roberts and Todd (WMRT)—the Philadelphia-based architecture, landscape architecture, and urban planning firm that was contracted for the project. Apart from detailed accounts on the project and periodic assessment on its lasting benefits reported in scholarly articles and professional publications which are well documented in Yang and Li (2016, this volume), most illuminating is a 1996 reflection by McHarg in his autobiography *A quest for life* (1996, pp. 256–264).

At the beginning of the project, McHarg and his colleagues were stunned by the steep challenges they were facing. The planning site covers a forested area of 72 km^2 in southern Texas, 45 km north of the city of Houston, Texas. Physiographically, it features an extremely flat topography, a widespread coverage of impenetrable soil, and a close hydrological association, both surface and underground, with the city of Houston; conventional engineering approaches to storm water management had proven to be inadequate ecologically and expensive economically, resulting in almost all development projects in the area universally unsuccessful. In the face of these challenges, "[c]ould it (the site) support development, in terms of market and ecology?" (McHarg 1996, p. 256). To answer the question, an entirely novel approach was required. Wrote McHarg, "[w]e had to discover a method of development that would not increase runoff and would not lower the water table and, finally, we must accomplish artificial recharge of all water used so as to eliminate subsidence (in Houston)" (Ibid., p. 260). "To the best of my knowledge each of these was a novel problem for planning. It was downright unfair to have to confront them all on a single site" (Ibid, p. 257).

The subsequent process was exploratory, reflective, and effective. Inspired by the observation that rare but highly permeable soil types correspond to the flora and fauna habitats and biodiversity, McHarg and his colleagues conducted a geohydrological analysis of the soils and concluded that the addition of asphalt, concrete, and housing on the already impermeable soils would have no appreciable ecological effect. A novel yet "profoundly simple concept" (McHarg 1996, p. 260) then emerged—to allocate land uses and determine their density from the geohydrological properties of the soils. Around this idea, an ecological master plan was developed. In the plan, development is allocated primarily on the nonporous soils; detention and retention ponds and swales are all concentrated on the more permeable soils permitting surface water to percolate down into the underground and recharge the aquifer; the ponds and swales are connected to a humanly augmented natural drainage system in which storm water is impounded briefly before entering the ponds and swales; and the richness of flora and fauna communities found primarily on the more penetrable soils is intact. Later in the planning process, a cost-benefit analysis was conducted through which McHarg and his colleagues demonstrated persuasively that implementing the design-with-nature plan would not only cut costs, when compared to plans developed under the traditional engineering approach, but also bring many dividends to the developer and the future residents during and after the development. The *ex ante* analysis, which McHarg eloquently presented with his plan, played a decisive role in convincing George Mitchell, the developer, and project engineers to adopt the plan (McHarg 1996, p. 264; Lyle 1985, p. 237).

It did not take long before the town began to enjoy what American research psychologist Judith Rodin (2014) calls "the resilience dividend" that McHarg and his colleagues had promised. The most tangible among many is the dividend of ecological resilience against urban flooding. Wrote McHarg (1996, p. 260), "[o]n two successive years, after portions of the new town were built, there were events of thirteen inches' precipitation in twenty-four hours (330 mm/24 h, that is). The pools were brimful, as were the streams and swales, but twenty-four hours later only the sediment on leaves showed the extent of inundation. There was no flooding in The Woodlands during those occasions when Houston was closed down by floods." Furthermore, this and other ecological, economical, and social dividends are remarkably steady and lasting—an *ex-post* testimony of an effective ecological practice that satisfies human beings' enlightened self-interest. Two decades later, McHarg offered the following reflection (Ibid., p. 264), "The Woodlands now has a population of 30,000 with 10,000 jobs. The forest is intact, the hydrologic system is in balance … the population is very gratified, as is the developer. Woodlands continues to attract an ever-increasing proportion of the Houston housing market. *But best of all is the demonstration that it is not only possible, but profitable, to design with nature. Nothing beats the combination of righteousness and profit*" (italic by the author).

This is evidently an exemplary case of *phronetic* ecological practice in which the *ecophronimos*, McHarg and his colleagues, *were enabled*, and therefore, able, to figure out extemporaneously the right way to do the right thing for the right reason in a particular place and time. But by *exactly what mechanism* were they enabled to do what they accomplished? It is arguably the skill or capability of moral improvisation.

Improvisation, when contextualized differently from improvisational jazz and theatrical performance where it originates, is an action an organization and/or its members take extemporaneously yet intentionally in practice to manage unforeseen challenges or to embrace emergent opportunities with available knowledge and resources (Cunha et al. 1999, p. 302, pp. 308–309; Hadida et al. 2015, p. 440; Laws and Forester 2015, pp. 358–360). Etymologically, the English word *improvise* derives from the Latin *improvisus*—unforeseen, unexpected—which is based on *provisus*, the past participle of *providere*—make preparation for (Oxford Dictionaries, http://www.oxforddictionaries.com/definition/english/improvise, accessed February 28, 2016). The importance of improvisation to practice has long been recognized (e.g., Forester 1999, pp. 224–241; Nussbaum 1990, p. 94, pp. 96–97). As American planning scholar John Forester puts it, "academics can theorize, but practitioners must improvise" (Forester 1999, p. 236). At an organizational level, improvisation is needed under multiple circumstances. These include, but are not limited to, situations when there is a pressing need to react to novel events or surprises, when novel events or surprises cannot be addressed adequately with existing plans or operational capabilities, or when an intentional decision is purposefully made to forego formal planning (Cunha, Cunha, and Kamoche 1999, p. 308; Pavlou and El Sawy 2010, p. 448). Because of its close association with organizational adaptability, creativity, innovation, and learning (Cunha et al. 1999, pp. 311–312), and because it can be nurtured and cultivated (Vera and Crossan 2005), improvisation as a distinct construct and efficacious action that help bridge the gap between theory and practice (Crossan 1998) has received much attention in recent years from a broad range of scholarly fields (For reviews on the growing area of organizational improvisation, see Cunha, Cunha, and Kamoche 1999; Weick 2002; and Hadida et al. 2015; for a recent account on organizational improvisation within the context of planning, see Laws and Forester 2015).

The ability to improvise effectively is considered a hallmark of practical wisdom (e.g., Frank 2012, pp. 53–54; Macklin and Whiteford 2012, p. 92; Rorty 1988b, p. 274; Schwartz and Sharpe 2010, p. 25). According to American philosopher Martha Nussbaum, for both Aristotle and American pragmatist William James, "the metaphor of theatrical improvisation … is a favorite … image for the activity of practical wisdom" (Nussbaum 1990, p. 94). In fact, Aristotle himself figured this out more than two millennia ago while observing how the masons used rulers on the Isle of Lesbos in Greece. Wrote Schwartz and Sharpe (2010, p. 28–29), "A normal, straight-edged ruler was of little use to the masons who were carving round columns from slabs of stone and needed to measure the circumference of the columns. Unless you bent the ruler. Which is exactly what the masons did. They fashioned a flexible ruler out of lead, a forerunner of today's tape measure. For Aristotle, … the masons of Lesbos didn't bend the rule to cheat or deceive. They bent the rule to do what was right, and to do it well… This, knowing how to bend the rule to fit the circumstance, was exactly what practical wisdom was all about." From this observation, furthermore, he discerned that the way the masons made choices and improvised in acting on the material world illuminates and indeed exemplifies how *phronesis* works in the social world (Ibid., p. 28).

Reflection nurtures improvisation. In the literature on neo-Aristotelian *phronesis*, improvisational capability has recently been articulated with Schön's reflective practice theory aforementioned (see subsection 2.3) and stated as the ability "to invent what is needed at the time" and "on the spot" through reflections both *in* and *on* action (Macklin and Whiteford 2012, p. 92; Yanow and Tsoukas 2009, pp. 1345–1346). Wrote Kemmis (2012, p. 156), "The person who has this virtue (of *phronesis*)… has a capacity to think *critically* about a given situation … and then to think *practically* about what *should be done* under the circumstances that pertain here and now, in the light of what has gone before, and in the knowledge that *one must act* ...".

McHarg and his colleagues unmistakably demonstrated their effective improvisational capability in The Woodlands case. Indeed, it is their audacity to act upon the challenges imposed by novel problems, habit of exercising profound and critical reflection regularly, and ability to be adroit at orchestrating available and discovering new knowledge and resources that made the ecological practice at The Woodlands a success. Moreover, as improvisation is not inherently good or bad, and may lead to either positive or negative results (Cunha et al. 1999, pp. 327–332; Vera and Crossan 2005, p. 204), equally if not more important to and evident in The Woodlands (and in other instances of prudent and successful ecological practice as well) is the *virtuousness* in the improvisational action. That is, the execution of improvisational skill by McHarg and his colleagues was effective—developing the right master plan and persuading its adoption and implementation—because it was mindfully bound by a moral covenant with nature, and inspired and informed by the beings' enlightened self-interest as discussed in the preceding subsection. The union of improvisational ability and moral commitment, that is, "moral improvisation," as Forester calls it in his 1999 book *The deliberative practitioner: Encouraging participatory planning processes* (pp. 224–241), is what enabled McHarg and his colleagues to do what they accomplished in The Woodlands. Acting as "moral improvisers" (Forester 1999, p. 236) who are "doubly responsible" (Nussbaum 1990, p. 94), McHarg and his colleagues were able to find and sustain a fine balance between the dual responsibility of honoring commitments and upholding principles, on the one hand, and attending specific circumstantial particulars, on the other hand; through such a balanced panoramic lens, they were able, like any *ecophronimo* would—to paraphrase American philosopher Amelie Oksenberg Rorty (1988b), to see what should be seen, desire what is worth desiring, find solutions to what appear to be intractable problems, and carry solutions "easily, smoothly, and above all habitually" to well-formed and even elegant actions (pp. 272–273). From this perspective, *ecophronesis* can and should be regarded as the master skill par excellence of moral improvisation incubated in and developed through reflective ecological practice. In ecological practice, many effective moral improvisers, such as McHarg and his colleagues in the Woodlands case, Li Bing and his colleagues of many generations who built and sustained the 2300-year-old Dujiangyan irrigation system in Sichuan, China (Needham et al. 1971, p. 288; Xiang 2014, pp. 65–66), achieved a paramount level of "doing real and permanent good in this world" (Xiang 2014, p. 65), exemplifying the stellar quality of *ecophronetic practice*.

4 *Ecophronesis* and *Ecosophy*: The *Phronesis–Sophia* Nexus of Ecological Wisdom?

As ecological practical wisdom, how would *ecophronesis* relate to *ecosophy*—a term Naess coined in 1973 as a synonym for ecological (theoretical) wisdom or wisdom of place (Drengson and Devall 2010, p. 55)? As underscored in the discussion on *ecophronesis* in Sect. 3, ethical beliefs as a *sine qua non* of *ecophronesis* are critically important to the ecological practice of design with nature. In the absence of either concept, therefore, ecological wisdom itself as an umbrella construct is incomplete and unbalanced. However, as a brief examination indicates below, *ecophronesis* and *ecosophy* are two distinct concepts from the genesis and in substance, presenting a challenge toward the formation of the eco*phronesis*–eco*sophy* nexus of ecological wisdom.

In his 2013 book *The great reversal: How we let technology take control of the planet*, Canadian political scientist David Tabachnick highlights the fundamental differences between Platonian *sophia* and Aristotelian *phronesis* (Tabachnick 2013, pp. 37–40), from which *ecosophy* and *ecophronesis* derive, respectively. S*ophia* is purely theoretical and about what one should believe, whereas *phronesis* is associated with the practical and human affairs and about how one should act; those with *sophia* may seek out the truths of the world, but only treat them as "an end of itself"—personally fulfilling, and have no, or do not have to have, intention to provide anything of use (Ibid., p. 39), whereas those with *phronesis* directly participate in and intent to improve the lives of their neighbors and fellow citizens. Socrates, a champion of *sophia*, spent his days wandering the streets of Athens looking to start an argument (Ibid., p. 38), whereas Aristotle, the advocate of *phronesis*, spent his time on the Isle of Lesbos observing how the masons improvised in measuring the circumference of the columns with rulers (Schwartz and Sharpe 2010, pp. 28–29).

As to the differences in substance, according to Drengson and Devall, two students of Naess', *ecosophy* represent an individual's personal yet "openly normative" "philosophy of ecological harmony or equilibrium" (Naess 1973, quoted by Drengson and Devall 2010, p. 55), and include "ways of life actively engaged on a daily basis (for the individual)" (Drengson and Devall 2010, p. 57), whereas *ecophronesis* is the master skill par excellence of action for and from ecological practice, and can be found in individuals, teams, or organizations. Further, the ethical position underlying the *ecophronesis* definition—human beings' enlightened self-interest—implies a "social norm" which might not necessarily be consistent with individual and often diverse *ecosophies* [e.g., Naess' "Ecosophy T" (Drengson and Devall 2010, pp. 56–57) and Cheng's "Ecosophy C" (2013)].

With these and other more nuanced differences to be identified, how could the two concepts be reconciled in a congenial manner under the umbrella construct of ecological wisdom? A full-scale investigation is requested.

5 *Ecophronesis*, Ecological Practice, and Actionable Science

How relevant is *ecophronesis* to the modern-day ecological practice?

In the contemporary society of unprecedented socio-ecological transformations, ecological practice takes place Wickedness in socio-ecological systems where human values and interests are diverse across different social, economical, and cultural groups, and where human beings' self-interest may not always coincide with the interests of nonhuman beings. Ecological practice must therefore attend simultaneously the vast variety of intertwining social and economical relationships within the human society as well as the relationship between human and nature. And yet, all of these relationships are characterized by high levels of complexity, wickedness, and in particular, context dependency (Xiang 2013, pp. 1–2, 2014, p. 66). This unique characteristic differentiates ecological practice from other social practices and underscores the importance of *ecophronesis* to ecological practice and potential advantages it can bring.

First, *ecophronesis* serves as an instrument that enables people to make prudent judgment and take constructive actions in dealing with socio-ecological issues in a particular circumstance of ecological practice. As demonstrated unmistakably in the exemplary instances of ecological practice, including those in The Woodlands and the Dujiangyan irrigation system (Needham et al. 1971, p. 288; Xiang 2014, pp. 65–66), the underlying commitment to defining and satisfying human beings' enlightened self-interest motivates people and guides them through the process of ecological practice; the moral improvisation capability it comprises enables people to act audaciously upon the challenges associated with novel problems or emergent opportunities, to be skillful at orchestrating available and developing new knowledge and resources to find and choose right solutions, and execute effectively.

Secondly, *ecophronesis* provides a way that helps bridge the gap between scientific theory and ecological practice. In the face of steep challenges toward human sustainability, people become increasingly cognizant of, and even more familiar with, a strikingly odd phenomenon. On the one hand, the world is desperately seeking science for effective ecological practice. For instance, in reflecting on attendees' sentiment at the 2011 Open Science Conference of the World Climate

Research Program held in Denver, Colorado, the USA, American journalist Richard Kerr asked "[t]ime to adapt to a warming world, but where's the science?" "Can science save us?" (Kerr 2011, p. 1053). Yet, on the other hand, scientists (natural, physical, and social) who "have been translating their science for policymakers and the media at an increasingly rapid pace" (Palmer 2012, p. 5) feel profoundly frustrated simply because their voices do not seem to be heard (Murphy 2006, p. 1; Palmer 2012, p. 5). As an alternative to the existent and apparently malfunctioning model of "more science, better science, and *then* effective communication" (Palmer 2012, p. 5), the concept of *actionable science* has been advocated (Kerr 2011; Palmer 2012; Nassauer et al. 2014). According to American ecologist Margaret Palmer, actionable science is "(the) science that is motivated to serve society" and "has the potential to inform decisions (in government, business, and the household), to improve the design or implementation of public policies, or to influence public or private sector strategies, planning and behaviors that affect the environment" (Palmer 2012, p. 6).

However, the prospect of actionable science for ecological practice would be less optimistic should it keep the orthodox tradition of modern science aiming to approach the six ideal criteria American philosopher Hubert Dreyfus articulates for scientific theory (drawing upon those of Socrates, Descartes, Kant, and others)—explicit, universal, abstract, discrete, systematic, complete and predictive (cited in Flyvbjerg 2001, pp. 38–39). This is because despite the fact that the context-independence (criteria 2, 3, 4) and predictive (6) requirements can be pursued and even met to some degree of scholarly rigor in natural or physical sciences whose subject matters are arguably tamable, they need to be carefully assessed in the development of socio-ecological systems research for ecological practice whose subject matters are wicked in general, and context dependent in particular (Rittel and Webber 1973; Xiang 2013). Moreover, the profound divide the actionable science enthusiasts advocate to close or at least reconcile in some congenial fashion between the two cultures of modern science and the humanities remains consistently persistent since the Enlightenment (Wilson 1984, pp. 47–49), constituting a substantial and often even more fierce barrier to the development of actionable science.

Ecophronesis, as both a scholarly construct and a Janus-faced fusion of ethical beliefs and mindful actions, provides a way that helps bridge the gap between scientific theory and ecological practice with its underlying premise of context-dependence and the moral improvisation capability. As demonstrated in The Woodlands example, with the commitment to being "doubly responsible" (Nussbaum 1990, p. 94) and the *ecophronetic* capacity to orchestrate available, and discover new, relevant knowledge and resources to meet the specific needs and local conditions, McHarg and his colleagues were capable of not only "getting the right science," but also "getting the science right" (National Research Council 1996, pp. 6–7). They sorted out the science and techniques suitable for the issues most relevant to planning and decision-making and performed the scientific analysis in a way that contributed substantively to the success of the ecological practice. Following "the principles for emancipatory knowing" (Innes 1995, p. 186), their way of research, *practice research*, is solely motivated by and entirely devoted to practical interest, and leading to "emancipatory knowledge" (Ibid.) that is usable, useful, and efficacious in a particular instance of ecological practice. It is notably in sharp contrast to applied research, in which ecological practice is often regarded as an "applied" version of the knowledge, methods, and principles of a specific branch of natural, physical, or social sciences and is thus treated as a practical demonstration of the scientific principles (Buchanan 1992, p. 19). This seems to suggest a possible conception of an integrated approach to ecological practice, one that blends together knowledge (science) and action (practice) under the overarching framework of *ecophronesis*. Comparable to the knowledge–practice–belief complex Berkes developed in his TEK research (Berkes 2012, pp. 17–19), this *ecophronesis*–knowledge–action approach complements existent approaches (e.g., the six-principle approach by Van der Ryn and Cowan 1996); its moral improvisation capability embedded in *ecophronesis* can be nurtured and cultivated through practice, education, and training (Pavlou and El Sawy 2010; Vera and Crossan 2005); its practice research yields emancipatory and effectively actionable knowledge. With these foreseeable advantages, further research is warranted on the roles *ecophronesis*, in general, and the *ecophronesis*–knowledge–action approach, in particular, play both in bridging the gap between scientific theory and ecological practice and in contributing to the development of actionable science.

6 Conclusions

The term *ecophronesis* coined in this essay and its conceptualization are an *ex-post* recognition of and a revered tribute to those human beings, the *ecophronimos*, who, over thousands of years of human co-evolution with nature, developed the master skill par excellence of ecological practical wisdom that enabled them to make, and act well upon, the right choices in challenging circumstances of ecological practice. While manifesting itself in a myriad of ecological and landscape projects and public policy instruments that has been serving human beings' enlightened self-interest, the invaluable intellectual and character asset of ecological practical wisdom continues to evolve in a contemporary society of unprecedented socio-ecological transformations, stimulating advancement in modern science and inspiring technological and engineering innovations for the greater good. What *ecophronesis* offers then is a reinvented actionable perspective that motivates and enables people to act with a wisdom inspired *ecophronesis*–knowledge–action approach to ecological practice.

The proposed idea of *ecophronesis* opens up opportunities for innovative and transdisciplinary research. In addition to the topics outlined in the essay on its association with *ecosophy*, the conception of the *ecophronesis*–knowledge–action approach and its potential contributions to the development of actionable science, many possibilities exist. These include, but are not limited to, principles of *ecophronesis*, the nurture and cultivation of moral improvisation capability in ecological practice, practice research as a form or paradigm of knowledge inquiry for ecological practice, and parallel *ecophronetic* concepts and ecological practices in different cultures and religions. Research on these and other topics will enrich immensely our understanding about this reinvented intellectual and character asset and inspire us to follow the lead of the *ecophronimos*, acting with wisdom and designing with nature.

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Where Does Ecological Wisdom Come from? Historical and Contemporary Perspectives

Bo Yang, Shujuan Li, Wei-Ning Xiang, Ian Bishop, Kuei-Hsien Liao and Jun Liu

Abstract On October 17–18, 2014, the first international symposium on Ecological Wisdom for Urban Sustainability was held in Chongqing, China. The symposium engaged more than 200 participants from eight different countries and diverse disciplines (e.g., philosophy, ecology, architecture, landscape architecture, planning, engineering, literature) (Healey in Symposium on ecological wisdom for urban sustainability a great success 2014; Young in Landscape Urban Plann 166:27–36, 2016a). Besides having a fruitful and inspiring symposium, participants reached the consensus that answering several important questions is needed to move ecological wisdom research forward. These questions include: What is ecological wisdom? Where does it come from? How is it related to ecological knowledge? What are the general principles of ecological wisdom? Subsequently, a team of participants convened for a post-symposium workshop. This review is a

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result of these activities, which answers important questions raised above. In addition, this chapter speculates on how ecological wisdom can become (more) actionable in contemporary planning, design, and management. The chapter concludes with a proposal for future research.

1 Introduction

On October 17–18, 2014, the first international symposium on Ecological Wisdom for Urban Sustainability was held in Chongqing, China. The symposium engaged more than 200 participants from eight different countries and diverse disciplines (e.g., philosophy, ecology, architecture, landscape architecture, planning, engineering, literature) (Healey 2014; Young 2016a). Besides having a fruitful and inspiring symposium, participants reached the consensus that answering several important questions is needed to move ecological wisdom research forward. These questions include: What is ecological wisdom? Where does it come from? How is it related to ecological knowledge? What are the general principles of ecological wisdom?

Subsequently, a team of participants convened for a post-symposium workshop. This review paper is a result of these activities, which answers important questions raised above. In addition, this paper speculates on how ecological wisdom can become (more) actionable in contemporary planning, design, and management. The paper concludes with a proposal for future research.

2 Background of (Ecological) Wisdom Research

Recent decades have witnessed a renewed reflection on wisdom in the literature of social sciences such as psychology, education, management sciences, rather than in its traditional home disciplines of philosophy and religious studies (Gugerell and Riffert 2011). In order to understand the increasingly complex urban sustainability conundrum, there are calls for an integrated framework for (ecological) wisdom research across social and ecological arenas (Gugerell and Riffert 2011; Xiang 2014a, b).

As a subset of wisdom, ecological wisdom is a term that enjoys less recognition in the literature. However, it manifests itself widely in terminologies such as nature-inspired design, “green” policy and design, biomimicry, sustainable design and planning, biophilic design, and others (e.g., Yeang 1995; Beatley 2000, 2010; Benyus 2002; McDonough and Braungart 2002). Ecological wisdom is regaining broader recognition, and being proposed for use in socio-ecosystem planning and management (Patten and Xiang 2015).

Ecological wisdom is in particular relevant to the human and nature relationship. One of the central problems confronted by design professionals, as well as by those advocating a wise society more broadly, is how to properly tackle the relation of human and nature. Today, urban sustainability faces stiff challenges with the coupled effects of human and biophysical changes (globalization). On one hand, a comprehensive approach is being called for to tackle grand sustainability challenges. On the other hand, sciences and technologies—considered as the solutions—are developing into increasingly compartmentalized sub-disciplines that lack the holism necessary for tackling sustainability challenges. Human civilization is at the crossroad in that deep ecological crisis cannot be alleviated simply through the accumulation and application of scientific knowledge. To effectively tackle global ecological crisis, we need ecological wisdom (She 1996; Yang and Zuo 2006; Lu 2014).

We argue that planning and design professionals should turn to select pre-modern and recent contemporary figures for guidance (Laozi and Aristotle, for instance). We sense in these figures a rich appreciation of (ecological) wisdom and ways that may help deal with thorny sustainability questions today (Ruderman 1997). The concepts of ancient ecological wisdom were developed in the absence of modern scientific methods. *Tao-de-jing*, for instance, written by Laozi (c.a. 571 BC–471 BC) distills the ecological wisdom of ancient Chinese and it remains influential worldwide today in the fields of philosophy, planning and design, management, and others (Feng 1991; She 1996; Cheng and Bunnin 2008). In India, Buddhism, especially the practice of Zen, presents a rich legacy of ecological wisdom and the pursuit of a harmonious relationship between human and nature (She 1996; Redman 1999).

Although our concept of "urban" has changed radically since ancient times, we use "urban" in this paper as a general description of human settlements in ancient and contemporary epochs. Urban areas have become increasingly reliant on resources imported (or captured) from their hinterlands (which have themselves become larger over the centuries). Consequently, urban areas are "hotspots" within which to tackle sustainability challenges. We seek to conjure up the spirit of ecological wisdom of both past and present traditions, and to explore actionable agendas to relate ecological wisdom with contemporary practices.

3 Ecological Wisdom and Principles

3.1 Definitions of Wisdom and Ecological Wisdom

The Oxford Dictionary of English defines "wisdom" as "the quality of having experience, knowledge, and good judgment." It is one's ability to make good ethical and political choices.

Wisdom is considered as a personality trait, which is related to knowledge, whereas the acquisition of knowledge does not guarantee the acquisition of wisdom (Gugerell and Riffert 2011).

There is no unified definition of "ecological wisdom." Norwegian philosopher Arne Naess first put forth the concept of "ecological wisdom" based on his ecocentric personal philosophies, ecosophies, combining the root words from ancient Greek ecos (household place) and sophia (wisdom) (Drengson and Devall 2010). In this chapter, we provide a working definition of *ecological wisdom*—a wise person or society's ethic, knowledge, ability, and grit to do the right thing (or not do certain things), in socio-ecosystem planning, design, and management, as manifested in time-honored projects, efficacious policy instruments, and is informed by lessons learned.

3.2 Brief Review of Ecological Wisdom from Wise Figures (Human–Nature Relationship)

We elaborate on the above working definition through illustrations of the principles, composition, acquisition, and defining characteristics of ecological wisdom based on review of eight prominent philosophers, scholars, and practitioners (Fig. 1). Ecological wisdom strives for a harmonious relation of human and nature, and

Fig. 1 Perspectives in ecological wisdom (EW): Key figures and (first) environmental protection policies in China and Europe–America [*Tian Lu* 《田律》 is an ancient environmental protection policy of Qin Kingdom during the Warring States (480 BC–221 BC). The policy, slated on Qin bamboo slips (秦简), was unearthed in Yunmeng, Wubei Province, China in December 1975. *Tian Lu* specifies six ordinances concerning agricultural land cultivation and preservation, mountain and forest land protection, and others. It also forcefully prohibits certain activities, such as blocking up river ways, deforestation, burning weeds and wood for fertilizer (air quality protection), and it controls pest migration to Qin Kingdom (i.e., customs quarantine practice that burns the yoke and rope on the horse). *Tian Lu* as ancient China's environmental protection policy is perhaps the first of its kind in the world (百度百科, n.d.; 人民政协报 2015)]

therefore invigorating urban sustainability in context of human interventions (Redman 1999; Gunderson and Holling 2002). The ideas of the above eight figures, along with other contributors, are placed in context of three main phases of ecological wisdom development over centuries, including—nature-dominated design, design with nature, and ecological wisdom informed design—which reflects an evolving understanding of human and nature relationship. Industrial Revolution suggests a tipping point after which humans start to deeply rethink the role of science (and technology) in promoting urban sustainability, and how human cooperation with nature can be better operationalized (Agarwal and Narain 1997; Benyus 2002).

Given the widespread and diverse sources of philosophical wisdom, such as Chinese, Indian, and Western cultures that nurtured philosophy (Feng 1995), for the purposes of this review we focus on China and Europe–America.

China has a history of more than 5000 years. Over the course of the nation's civilization, numerous people have contributed to the development of (ecological) wisdom. Ecological wisdom, like most fields, is in debt to a handful of visionary thinkers, four of which deserve special mention: Laozi, Li Bing, Qian Xuesen, and Liang Sicheng. Yet, China was not alone. Seminal ideas also evolved in parallel in western culture through prominent figures such as Socrates, Plato, and Aristotle. Relative recent contributors include Frederick Law Olmsted, Ebenezer Howard, Patrick Geddes, Aldo Leopold, Rachael Carson, Arne Naess, Ian McHarg, and others. Appendix provides a more detailed account on the perspectives in (ecological) wisdom from eight recognized historical figures.

3.3 Principles of Ecological Wisdom

The review of ecological wisdom development in China and Europe–America distills general principles of ecological wisdom, including reverence to nature, sustained relevance, holism, and practicality. These principles are manifested in evidence-based, time-honored ecological projects and effective policy instruments.

3.3.1 Reverence to Nature (Land Ethics)

Ecological wisdom starts with reverence for nature. Vehement love and concern toward nature is the premier principle of obtaining ecological wisdom (Xu and Nangong 2012). The way that humans express worship to nature varies across cultures and religions. Buddhism prescribes that every living organism has the potential to become a Buddha. Only with a respectful attitude to land (nature) can one obtain wisdom and, therefore, a happy life. This land ethic is also shared by Laozi's naturalistic philosophy. Laozi's concept of *wuwei* (no assertive action) is another means of revering nature through active procrastination. Procrastination is humanity's natural defense in a world that they do not and cannot (fully) understand. Reviewing the history of major ecological disasters, many of them could have been avoided were active procrastination involved (Balint et al. 2011; Taleb 2012). Humans are responsible for things they do, as well as things they do not do. Ecological wisdom thus encompasses the courage not to do something (Goede 2011).

3.3.2 Sustained Relevance (Novelty)

Sustained relevance means that the breadth and depth of a particularly wise ecological thought remain novel today. The sustained longevity of ideas, tenets, and strategies of ecological wisdom often predates their time, by decades, if not centuries. Li Bing had conducted a comprehensive analysis of the Dujianyan irrigation project more than 2300 years ago. The success of Dujiangyan is attributed to Li Bing's tireless reconnaissance of the hydrological and ecological conditions, and the flora and fauna of the site (Gu 2005). Geddes' regional, ecological survey approach predated the discipline of ecology, and he directly influenced the birth of urban planning as a profession. Geddes' "folk-work-place" concept proposed in 1915 was remarkably similar to today's concept of sustainability (Steiner et al. 1988; Talen 2005; Steinitz 2008). Qian's Shan-Shui City theory has been widely accepted and employed in China and generated fine contemporary examples such as the Beijing Olympic Forest Park, home of the 2008 summer Olympics. In short, the principle of sustained novelty suggests that the significance of ecological wisdom is (better) appreciated when placed in historical context.

3.3.3 Holism

Holism, as a perspective on human and nature relations, represents another principle of ecological wisdom. The design professions often deal with complex systems (e.g., coupled socio-ecosystems) which are recognized as an organic whole and should be treated holistically. The properties of a complex system are not equal to, but more than the simple sum of its components (Yan et al. 1993). All components of the system are interrelated and interactive. The interplay and connection of the components are recognized by Chinese and Western scholars, such as stated in Laozi's *Tao-te-ching* ("Enumerate the carriage parts, still not a carriage.") and American urbanist Jane Jacobs' assertion that a lively neighborhood is more than a hodgepodge of buildings, street infrastructure, and people (Jacobs 1961). The harmonious relationships among components and processes of social–ecological systems are reflected in the Chinese philosophy of holism, based on the recognition and understanding of the coordination between structure and function of a system between human and nature, and between utilization and protection (Yan et al. 1993).

3.3.4 Practicality (Actionability)

Aristotle's idea of phronesis emphasizes the practicality of wisdom, that social process constantly demands choices, and making the right choices demands wisdom (Schwartz and Sharpe 2010). Likewise, ecological wisdom is distinctly practical; it cannot be purely abstract or ethereal. In urban planning, phronetic planning stands for the practical wisdom to make judgments on values and power in order to inform particular and concrete planning decisions (Flyvbjerg 2004). Ecological wisdom integrates science, technology, management, and culture and, hence, goes beyond the philosophical level. Ecological wisdom is enhanced through trial and error in practice. It includes lessons learned from failures. It is what people need to understand about how they should, and should not, act in a real-world context, in order to achieve socio-ecological sustainability (Xiang 2014a). Wise persons will take actionable steps that are small in nature (presuming that one cannot know the consequences of the interventions) and will prefer reversible interventions (in lieu of ones that have irreversible consequences) (Scott 1998; Hibbard 1999).

4 Acquisition and Manifestation of Ecological Wisdom

4.1 Acquisition of Ecological Wisdom: Existing Frameworks and Conceptual Model

4.1.1 Knowledge-to-Wisdom Transformation: Existing Frameworks

Wisdom can be acquired at different levels (individual and society) and inspired by different sources. In this paper, we refer to three commonly accepted frameworks to study the genesis and development of ecological wisdom at individual level. The first is the DIKW (data–information–knowledge–wisdom) hierarchy (Rowley 2007). In this hierarchy, each element is formulated based on the preceding one. Built upon knowledge, wisdom is the ultimate goal to achieve.

The second framework is put forth by Feng Qi (Feng 2011). Wisdom development is the process of understanding "the World" as well as "the Self" [认识世界并认识自我]. The process of knowledge-to-wisdom transformation [转识成智, (Feng 2011, pp. 236–241)] is the theorization of factual and tacit knowledge—a process goes from abstract to explicit, and from explicit to abstract. "The World" stands for factual knowledge, and "the Self" connotes (re)arrangement of information and (re) interpretation of experiences (tacit knowledge) and personal goals in life.

The third is Ardelt's framework that wisdom accrues through elderly people's self-reflection (Ardelt 1997, 2000). Age is therefore an essential ingredient for wisdom acquisition. Specifically, wisdom-related knowledge is developed only through quality aspirations as part of the elderly's experiences, compared with intellectual-related knowledge which has been accumulated throughout life (i.e., self-reflection is not essential).

These three frameworks show a common linkage between knowledge and wisdom. That is, knowledge is a required component for wisdom development, and wisdom acquisition can be open to everyone. Essentially, wisdom development is a cognitive process of self-reflection, reevaluation, or reaffirming of past experiences, and formulating (new) tacit knowledge. However, the level of wisdom that someone can achieve varies.

4.1.2 Ecological Wisdom Development: A Conceptual Model

There is little discussion in the literature on the development of ecological wisdom. Based on the common characteristics of the three existing frameworks, we propose a conceptual model for the process of ecological wisdom development at individual level (Fig. 2). This new framework provides a plausible, yet speculative, case on how design professionals can become practically wise(r).

Review of eight recognized wise figures reveals several defining characteristics among them, including knowledge, judgment (ethic), and ability to do the right things. These defining characteristics connote both the *principle-based knowledge* (Gugerell and Riffert 2011, p. 239) of what is true and right socio-ecologically and the *ability* to develop this knowledge effectively and apply it efficaciously (Xiang 2014a).

Knowledge Base

Declarative knowledge and procedural knowledge are two *conditio sine qua nons* for (ecological) wisdom development. The former is *knowing that* ("factual knowledge"), and the latter is *knowing how* (Gugerell and Riffert 2011, p. 237).

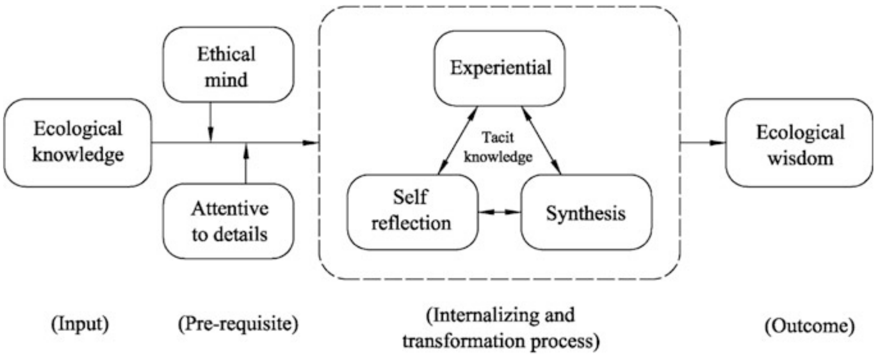

Fig. 2 Conceptual model of ecological knowledge to ecological wisdom transformation process at individual level

(Baltes and Smith 1990) further stated five criteria for wisdom-related knowledge, the first one being rich "factual knowledge." In this sense, factual knowledge, including ecological and other scientific knowledge, would be the knowledge base for ecological wisdom development. Design professionals when facing ecological questions can resort to ecological science for its extensive knowledge of the natural systems (Palmer et al. 2004; Zalewski et al. 2009; Palmer 2012). Yet, the knowledge base for ecological wisdom goes well beyond ecological science. Liang's plan for old Beijing, for instance, was based on his deep factual knowledge in cultural and historical preservation and his appreciation of the city as a complex, yet holistic social–ecological system.

Prerequisites

Two prerequisites follow. Firstly, a wise person must be bequeathed with an ethical mind. Although it is inevitable that humans alter their immediate environments for better livability, sound land ethics remind someone of their rights and duties with respect to human society as well as for the biosphere—factual knowledge needs ethical guidance (Ardelt 2000; Cheng 2005; Jeste et al. 2010). Secondly, a wise person is attentive to details in tackling design problems ("God is in the details"). The success of Dujiangyan is attributed to Li Bing's tireless reconnaissance of the hydrological and ecological conditions, and the flora and fauna of the site (Gu 2005). In 256 BC, in the absence of modern scientific methods and with technologies of little sophistication, Li Bing and his team designed a project that functions strong for centuries. The level of preparedness on these two prerequisites sets the stage for the knowledge-to-wisdom transformation process and the likelihood of success.

Knowledge-to-Wisdom Transformation Process

Transformation toward ecological wisdom involves the steps of self-reflection, experience, and synthesis. These steps do not follow a predetermined order, but rather, are interwoven and need constant internalizing and assimilation of factual knowledge and tacit knowledge. Ecological wisdom presumably accrues slowly, while self-reflection facilitates the process of migrating to a higher wisdom level. Historical figures reviewed in this paper (e.g., McHarg, Geddes, and Naess) constantly reflected on their own theories and practices. McHarg, for example, substantively expanded the scope of his ecological planning approach to "human ecological planning." Similarly, Laozi elaborated on "inner cultivation" and nourishing one's "soul" in developing his naturalistic philosophy (Chan 2014).

Experiential knowledge (or tacit knowledge) is another machinery of ecological wisdom development (Baltes and Staudinger 2000; Yu 2003). McHarg stated that "asphalt people know little of nature and care less." His argument was that the life experiences of individuals are critical to the appreciation of ecological wisdom. It cannot be obtained from a book or a computer (e.g., "artificial wisdom")

(Sevilla 2013). Fazey and colleagues (2006) also suggested that experiential knowledge plays an important role in (wiser) decision-making. From a wisdom development standpoint, Ardelt (2004) proposed that it is necessary and sufficient to have particular cognitive, reflective, and affective (compassionate) personality traits, suggesting that experiential knowledge, in addition to scientific knowledge, is essential.

Last, synthesis is another key step to obtain ecological wisdom (Feng 2011). The amount of accumulated knowledge is reportedly doubling every two or three years, while a wise person has the ability to knit together information from disparate sources into a coherent whole (Gardner 2008). Strong mental synthesis is found in prescient masters such as Laozi and Aristotle, as well as the other historical figures reviewed. For instance, McHarg's ecological wisdom was anchored in his ability to synthesize ecological data and information, and his creative blending of scientific theories with planning and design. Shan-Shui City theory was also blessed through Qian's ability in system thinking, which was built upon his area of specialization in system theories.

4.2 Manifestation of Ecological Wisdom

Ecological wisdom manifests itself in evidence-based, time-honored, and often instantiated ideas, principles, strategies, and approaches that have led to the creation and sustained longevity of exemplary built projects, policy instruments, and product designs (Xiang 2014a). There are myriad examples from around the world, such as in China (e.g., Dujiangyan irrigation project), America (e.g., Staten Island study, Central Park), as well as in other countries, such as Japan (famous traditional gardens such as Kenrokuen in Kanazawa—integration of art, culture, ecology), Great Britain (Beddington zero energy development—mixed use, thermal efficiency, increased density, green construction, etc.), and Brazil (sustainable urban planning in Curitiba, densification, protection of green space, reduced automobile use, etc.).

Effective policy instruments also abound, such as in the US National Environmental Protection Act, the Clean Air Act, and the Ecological Compensation regulations. Similar efforts in the 1970s occurred in other countries such as Canada and Western Europe (Drengson and Devall 2010). In China, *Tian Lu* (田律) as an ancient environmental protection policy of Qin Kingdom (480 BC–221 BC) demonstrates the environmental consciousness of the Chinese and sets perhaps one of the first examples in the world (see Fig. 1) (百度百科, n.d.; 人民政协报 2015).

In product design, nature-inspired design revealing ecological wisdom also pervades, for example, "green design" that emerged in the 1980s. In the green design movement, two concepts are particularly influential. "Cradle to cradle" is a new paradigm shifting away from the conventional design model of "cradle to grave," in order to eliminate all together the concept of waste, which does not exist in natural ecosystems (McDonough and Braungart 2002). Biomimicry is another influential concept inspired by the patterns and strategies of biological systems (Benyus 2002).

Although ecological wisdom is arguably qualitative, the performance and benefits of the corresponding projects (or policies) could be quantified through scientific evaluations. A major benefit of ecological wisdom is its enabling of resilience (Liao 2012, 2014). Ecological wisdom informs adaptation approaches in response to complex environmental dynamics and social changes. Built projects, even those that embody ecological wisdom, may experience unexpected large-scale hazardous events (e.g., 100-year flood, a high-magnitude earthquake) or a despotic and seriously unwise regime. Survival through the unexpected requires active public involvement (societal wisdom) in adaptive designs. Hence, ecologically wise thinking enhances resilience from the social–ecological standpoint. Qian's Shan-Shui City and Geddes' "folk-work-place" theories are essentially building resilience into social–ecological systems. In recent decades, in response to elevated impacts from climate change, ecologically informed strategies have been applied to shoreline protection and sea level rise mitigation. For instance, "soft" solutions or ecosystem-based adaptation (e.g., the mobile sand motor of the Netherlands, dunes, and beaches) are used to assimilate natural dynamic forces to buffer storm surges for vulnerable areas (Aravena et al. 2011; Biľak 2013; Che et al. 2014).

5 Discussions

5.1 Reinvent Ecological Wisdom: Potential Barriers

Despite the enormous benefits that ecological wisdom can bring, efforts to reinvent ecological wisdom encounter two potential barriers. The first is the hegemony of science in today's education system. The Science Revolution has made human's reverence to nature almost obsolete (Benyus 2002; Merchant 1980). Dualism remains the norm through which science examines nature in Western philosophy (Bateson 2002; Wang 2013). Through reductionism, science tends to simplify its study subject and oftentimes fails to recognize the reciprocal relationships between human and nature (Sheppard and McMaster 2004). This approach draws criticisms because ecosystem's resilience is reduced by over simplification (Hibbard 1999). Before the Industrial Revolution, the rate of human's deconstruction of land generally matched nature's rate of recovery, whereas after which human began surpassing nature (Benyus 2002; Carson 2002).

The second potential barrier lies in materialism, which is valued by high modernity (Harvey 1989; Scott 1998). Modernity encourages people to pursue infinite material wealth. Most people believe that "the meaning, value, and happiness of human lives is ultimately in the process of making, possessing, and consuming material wealth" (Lu 2014). To make things worse, modern science and technology support such an understanding of human lives. Parallel to modernity is the mainstream economic paradigm. Maximizing the society's throughput has been the norm, which already exerted tremendous impacts on ecosystems (Benyus 2002; Zalasiewicz et al. 2010; United Nations 2014).

5.2 Scholarly Responses and Alternatives Approaches

Naturalists in Europe and North America openly criticized the primitive excesses of the Industrial Revolution, such as Ebenezer Howard's garden city proposal for London, and Frederick Law Olmsted's design for New York's Central Park (Sprieregan 1969; Steiner 1981). Moreover, while science, especially ecological science, is a powerful tool to understand the biophysical environment, and it provides a solid knowledge base for ecological wisdom acquisition, it cannot, alone, solve urban sustainability problems. Li Bing used indigenous knowledge and primitive technology to construct the Dujiangyan irrigation system. This is a forceful argument that ecological wisdom for the real and permeant good may not necessarily need sophisticated science, but rather, demonstrates the importance of understanding the site (nature) in a holistic way (ecological wisdom principle of holism).

Furthermore, human needs to go beyond modernity and materialism, or sustainability challenges would go deeper given the false premise of life's meanings (Lu 2014). There are certainly alternative approaches to enrich life. Naess' account of ecosophy is "… a philosophy of ecological harmony or equilibrium" (Naess 1973), which essentially speaks on a way of life. It shares common ground with Laozi and Aristotle's ideas that Aristotle considers the ultimate goal of life is—happiness, and Laozi's naturalistic philosophy expresses itself through the concept of *wuwei* ("do-no-harm") (Chan 2014). Both Laozi and Aristotle espouse the notion of cultivating one's virtues. Similar ideas are found in Hinduism and in some forms of Zen Buddhism (Drengson and Devall 2010). High quality of life (happiness) is possible with a low level of material procession and consumption and, therefore, low ecological footprint (Drengson and Devall 2010; Young 2016b).

Economies are similar to ecosystems. Both systems use energy and materials as inputs and generate products. However, the production process is one direction in economy (i.e., transfer to product and waste), whereas cyclical in nature. There is no such thing as waste in nature (Benyus 2002). Ecosystems operate through ambient solar energy, such as found in China's "pond-wisdom" that demands high efficiency, self-regulating, and -sustaining agrarian practices (Mitsch and Jørgensen 2003). Similarly, industrial ecology seeks an alternative development mode that is based on closed-loop, sun-driven biology.

5.3 How Can Ecological Wisdom Be (Better) Encouraged and Manifested

It is an ideal timing to reinvent ecological wisdom and use nature's blueprints to enhance urban resilience, when much of the twentieth century's infrastructure needs to be replaced. At the society level, ecological wisdom can be better encouraged and manifested via the following three aspects.

5.3.1 Institutionalize Policies for Land Ethic and Best Practices

National-level environmental protection policies help instill a culture and social norm of reverence to nature. In China, for instance, this practice emerged in ancient times (e.g., 700 BC–200 BC). In order to cultivate sound land ethic, numerous thinkers facilitated land stewardship policies (see Fig. 1), such as *Records of Ritual* (《礼记》, c.a. 200 BC). Moreover, the three philosophical schools or religions in China (Daoism, Confucianism, and Buddhism) reinforced best practices in land management. For example, according to Buddhism, human is subject to punishment in his/her next life cycle because of misconducts, including unethical land management practices (e.g., massive forest cut and animal kill). Similarly, indigenous knowledge (e.g., Traditional Ecological Knowledge, TEK) demands setting aside sacred lands from development (Martin et al. 2010). Hence, shared ethical norm of this kind elevates the level of appreciation of ecological practice across society. In short, it is all about good governance at personal and public levels (Goede 2011).

5.3.2 Promote Holistic Processes and Regional Planning

In practice, ecological wisdom is manifested through holistic processes that enhance group creativity (collective wisdom), such as in Ian McHarg's multidisciplinary design process (McHarg 1969), and the analytical-deliberative process used to enact environmental polies (e.g., U.S. National Environmental Protection Act, NEPA of 1969) (Renn 2006). These comprehensive processes enhance the competence in collective decision-making, demonstrate holism in policy instruments, and ensure a high likelihood of project success.

Collective wisdom for urban sustainability is also manifested in regional planning. For instance, the Tennessee Valley Authority (TVA) remains "the best model for Eugene Odum's (1971) idea of the use of river basins as the optimum unit for ecological planning" (Steiner et al. 1988). The TVA is also a manifestation of Geddes' "regional ecological survey" approach and ecological wisdom, and it stands for a prototype of holistic regional planning.

5.3.3 Research Needs to Documentation, Communication, and Theorization

Ecological wisdom lasts with effective communication, documentation, and theorization of historical experiential knowledge (ethical and tacit). Being a noteworthy one, TEK (indigenous knowledge) cannot be generalized without a delicate level of synthesis, theorization, and communication (Bohensky and Maru 2011; Huntington 2000). TEK embodies rich "traditional" ecological knowledge and manifests itself in time-honored practices (e.g., Mayan water management). However, some TEK is only accessible through indigenous languages, or particular TEK would be forgotten if the language associated with it discontinues. Thus, documenting and examining TEK and pertinent languages become important for TEK heritage (Martin et al. 2010).

Likewise, at the cooperation level, studies have suggested the development of archives or knowledge banks that can help others who follow to make wiser ecological decisions.

For example, Huang and Shih (2009)'s study shows that China Steel Corporation of Taiwan continually improves its environmental and financial performance through environmental knowledge creation, accumulation, sharing, utilization, and internalization. Knowledge base is part of a large knowledge circulation process. In other words, there needs to be a repository as well as a means by which the stored information can be well communicated. This type of practice simply helps reduce the likelihood that really unwise decisions a person, organization, or community makes, and hence making the society seem wiser.

5.4 *Other Efforts*

Several efforts are moving ecological wisdom research forward. In addition to this current book, two other journals (*Chinese Journal of Ecology* and *Landscape Architecture*) have published special issues on ecological wisdom in 2016. Additionally, the publisher Elsevier planned a multidisciplinary Shanghai conference on *The Future of Cities* (September 2016). The International Society for Ecological Wisdom (国际生态智慧学社, www.isew.org.cn) serves an international forum for explorations into the art and science of ecological wisdom and their contemporary relevance. Last, a group of authors from the first ecological wisdom symposium hosted a special session in the 100th Ecological Society of America's annual meeting in Baltimore, USA (August 2015). This special session provided a forum for ecologists to explore the prospect of building a new strategy for guiding ecosystem management and planning through the integration of ecological wisdom principles with those from ecology (Patten and Xiang 2015).

In summary, we propose a 4-T approach (transdisciplinary, transphilosophical, transcultural, and transgenerational) in research, education, and practice. We suggest that everyone participate in actions, including doing permanently record (write); persistently explore, think, and disseminate; and be a good person of virtues (Xiang 2014b).

6 Conclusions

Through the lens of human and nature relationship, this paper reviews historical roots and pathways in China and Europe–America with respect to ecological wisdom development and their approaches toward and implications on urban sustainability. It is recognized that ecological wisdom is manifested and encouraged in various ways across different cultures, through projects or policy instruments (or religions). These parallel developments in different cultures reveal similar principles of ecological wisdom, in which reverence to nature is of paramount importance.

The acquisition and accumulation of ecological knowledge are potentially open to all individuals. However, an additional process is needed to transform knowledge to wisdom. We present a conceptual model for this transformation process. Integral to this effort is interdisciplinary research, education, and practice. Finally, we argue that an effective approach to working toward a wise society is to institutionalize best practices (e.g., through knowledge bases), environmental protection policies, and social norms. The recognition of urban sustainability root problems and the fundamental role that science should play are imperative to achieve ecological wisdom and a harmonious relationship with nature.

Appendix: Recognized Wise Figures in China and Europe–America

Laozi

Laozi [老子, or 老聃, 571 BC–471 BC] was an "axial" philosopher whose insights helped shape the course of human development (Arendt 1974; Chen 1969). Dao (道), as the core of Laozi's thoughts, has cosmogenetic and ontological meanings ("the Mother of the world") (Chen 1974, p. 51; Chan 2014). Dao articulates that the relation of human and nature (or cosmos) is holism. Laozi's credo of "The unity of human and nature" (天人合一) illuminates the relation being the "One" (Lao 1970; Cheng and Bunnin 2008).

Laozi espouses holism in his naturalistic philosophy, distilled in his seminar book *Dao-de-jing* (道德经). The power of *Dao-de-jing* lies in its insights into way of life. An essential element of Laozi's naturalistic philosophy is the concept of *wuwei* (无为, "nonaction" as the transliterated form). *Wuwei* explains naturalness in practice. It means "non-assertive action," or "non-coercive action," rather than total inaction (Chan 1998, 2014; Lai 2007). This concept differs from any form of action characterized by self-serving desire, in that Laozi's "leaning was devoted to self-effacement and not having fame.” Essentially, *wuwei* could be understood as a “do-no-harm” approach. It is a philosophy of life, which is transformed into a naturalistic philosophy characterized by “simplicity, calmness, and freedom from the tyranny of desire” (Chan 2014, p. 23). Thus, this naturalist thinking at the metaphysical level speaks on ancient Chinese’s (land) ethics and has considerable contemporary relevance (Chen 1969; Cheng and Bunnin 2008).

Li Bing

Li Bing [李冰, c.a. 300 BC–200 BC] lived during the Warring States period (480 BC–221 BC) in China. Li was the governor of the Shu Shire under the Qin Kingdom. In 256 BC, he presided over development of the Dujiangyan (都江堰) project, which is one of the world’s oldest, large-scale irrigation projects. Benefits of the project include serving irrigation water for more than 0.68 million ha of farmland in the Chengdu Plain of Sichuan and domestic water supply for tens of millions of people for the past 23 centuries (Zhang et al. 2012; Cao et al. 2010). It is also important to mention that he was achieved with minimal impact on the ecology, contrary to large dams which can have similar benefits in irrigation and water supply.

Dujiangyan is a self-regulating hydraulic system comprising three uniquely designed components—a fish mouth-shaped water diversion embankment (*yuzui*), a sediment and overflow spillway (*feishayan*), and a bottleneck-shaped irrigation gateway (*baopingkou*) (Xiang 2014a). This hydraulic compound automatically diverges upstream water in a seasonally alternated four-to-six ratio and naturally discharges 90% of the sediments before channelizing the water into distribution systems (Zhang et al. 2012; Xiang 2014a). For yearly maintenance, people summarize their construction experiences in simple slogans: “harnessing shoals deep, building dams low” (Li and Xu 2006; Peng 2008). In short, Dujiangyan project offers an example of harmonious coexistence between human and nature (Li and Xu 2006). With virtually no guidance from science and with limited technology, Li’s comprehensive analysis from project conceptualization, design, construction, and maintenance demonstrates the essential of ecological wisdom in ensuring project vigor and success. Li’s secret is the idea of *daofaziran* (道法自然, following nature’s lead) in Daoism (Peng 2008; Xiang 2014a), as elaborated in Laozi’s *Tao-de-ching*.

Qian Xuesen

Qian Xuesen [钱学森, 1911–2009] was a prominent scientist of aerodynamics. Although Qian was not a designer per se, his ecological wisdom sheds light on urban development and sustainability. Qian’s Shan-Shui City theory is a response to worsening environmental problems in urbanizing China. “Shan [山]” means mountain, and “Shui [水]” means water—two essential components in Chinese garden designs. “Shan” and “Shui” together refer to the natural environment, and “city” stands for the built environment. Qian envisioned that all citizens can live in a garden through the marriage of classical garden arts with contemporary city planning (Hu, n.d.; Bao 2000; Wu 2001).

Qian's Shan-Shui City theory has been widely accepted and applied in cities such as Guilin (1987), Sanya and Wuxi (1990), and Guangzhou (2000) (Hu, n.d.; Su 2011), for the reason that his theory is deeply anchored in traditional Chinese history, culture, and philosophy. Shan-Shui [山水] itself reflects Chinese peoples' reverence for nature. Archeological findings suggest that Chinese agricultural civilizations mostly developed in foothills or hillsides, and as a result, the Chinese are in awe to mountains (nature). Shan-Shui evolves from the primitive idea of awe of nature, environmental aesthetics, and recreation opportunities that Shan-Shui provides (Yang 2005; Wu and Fu 2009). Qian's theory further emphasizes the importance of protecting natural and cultural landscapes, and urban biodiversity during rapid urbanization. The interpretations of Shan-Shui are found in naturalistic philosophies and other ideas from ancient Chinese philosophers such as Laozi, Zhuangzi, and Confucius (Yang 2005). In summary, Qian's theory finds its roots in Chinese traditional human settlements and related wisdom (e.g., *Fengshui* principles in site selection. The theory provides inspirations for today's urban design activities (Wu and Fu 2009; Da 2012).

Liang Sicheng

Liang Sicheng [梁思成, 1901–1972] was internationally recognized as the "Father of Modern Chinese Architecture" (Lin 1996; Li 2002). His major achievements were historical preservation of Chinese architecture (e.g., pagoda) and development of an architecture national style. Liang's ecological wisdom was best revealed in his proposal (with Chen Zhanxiang) to preserve the old Beijing (Lou 2003; Lai et al. 2004). In 1952, the Communist Party's plan was to transform Beijing, an ancient cultural and political center of the recent 800 years, into an industrial city. Contrary to this plan, Liang's proposal was to protect the fabric of the city and the natural environment entirely, through establishing a new urban center west of the old Beijing—protecting the ancient capital as a living laboratory of China's civilization.

Unfortunately, Liang' proposal was baffled. However, history shows that Liang's holistic perspectives on urban development sixty years ago are far-reaching. Current urban problems that Beijing experiences are exactly what Liang predicted (Lin 1996; Hu 2006). High-rise buildings and street realignment replaced the old city fabric (e.g., city walls, gateway entrances, old dwellings) and entirely destroyed the physical appearance of old Beijing. Since 1949, Beijing has increased five times in urban area and four times in population. From 1959 to 1992, Beijing lost nearly one third of its green land. Today, around 25% of the traffic intersections are extremely congested (Wang 2003; Hu 2006). The Great Smog in 2013 is another wake-up call of Beijing's severe air pollution and environmental degradation. Ironically, Beijing is now starting to build new satellite towns that may alleviate functional conflicts and urban syndromes. History attests to Liang's ecological wisdom and his prescient warnings from sixty years ago.

Aristotle

Aristotle (384 BC–322 BC) was known for nearly two millennia as The Philosopher. In the Western secular tradition, the historical roots in philosophy and science are built upon Aristotle and his teacher Plato. Aristotle as the most prominent successor of the pre-Socratic philosophers strove to order the extant knowledge about the world. He laid out episteme, techne, and phronesis for the foundation of science, technology, and wisdom, respectively (Ruderman 1997; Gardner 2008).

Specifically, Aristotle's concept of phronesis speaks on practical wisdom (prudence). Contrary to Plato's view that wisdom, as the "master virtue" is theoretical, abstract, and available to only a few, Aristotle viewed wisdom as a practical, balancing act, and the procurement of wisdom as open to all individuals. These different perspectives on wisdom beholders are important. For Aristotle, wisdom depends on "one's ability to perceive the situation, to have the appropriate feelings or desires about it, to deliberate about what is appropriate in these circumstances, and to act" (Schwartz and Sharpe 2010). Aristotle distilled the idea of practical wisdom in his classic book, *Nicomachean Ethics* (Aristotle 1999). Ethics, for Aristotle, is not mainly about establishing moral rules and following them, but rather, is about performing a particular social practice well (Tessitore 1996; Schwartz and Sharpe 2010). Therefore, Aristotle's ideas of phronesis and ethics are not metaphysical treaties. They harbor deep insights into the practicality of wisdom. Along the same vein, ecological wisdom embraces the characteristic of practicality. It emphasizes wise design (or policy) and decision making on real ground. It is all about how to act rightly. Hence, ecological wisdom is distinctly practical, not theoretical.

Patrick Geddes

Patrick Geddes (1854–1932) was a Scottish botanist and urban planner. Geddes' goal was to bring nature into urban areas (Geddes 1915). Geddes' ecological wisdom lies in his belief that an egalitarian society needs to be in harmony with nature. People need to understand their landscapes ("civic survey"), and the understanding at regional scale is paramount (Meller 2005; Talen 2005). Focusing on this scale, Geddes proposed a method, called "Valley Section," to understand human activities and their relations to nature (Welter 2002; Steinitz 2008).

Geddes' regional survey approach depended on information not only from the natural sciences (e.g., soil, geology, climate, rainfall, winds), but also information grounded in empirical observations of a place in order to illuminate the relations among culture, work, and environment, better known as "folk-work-place" (Steiner et al. 1988). To reveal these relations, Geddes implied an understanding of the ecological connections among the "folk-work-place" attributes, although he did not use the term ecology (Steinitz 2008; Ndubisi 2014).

The ecological wisdom of Geddes was summarized in his seminal book: *Cities in Evolution: An Introduction to the Town Planning Movement and to the Study of Civics* (Geddes 1915). In this book, Geddes elaborated that town planning requires "a synoptic vision of Nature to enable a constrictive conservation of its order and beauty" (Geddes 1915, p. v). In other words, town planning is dependent upon knowledge of the large-scale, regional complexities of the landscape, and the human response to that landscape (Young 2017).

Ian Lennox McHarg

Ian McHarg (1920–2001) was a Scottish American ecological planner and landscape architect. He was best known for the seminal book *Design with Nature* (McHarg 1969). McHarg's ecological wisdom is manifested in his comprehensive design process, demonstrated in more than 90 actual projects—with noteworthy ones such as The Woodlands town development (Texas, USA) (Yang and Li 2011; Yang et al. 2015) and the Staten Island study (New York, USA) (McHarg 1969, 1996). McHarg's extensive involvement in projects allowed him the opportunity to constantly reflect on the success and lessons learned. Through linking his theory ("creative fitting") to practice, McHarg substantially refined and expanded his ideas and methods in ecological planning (McHarg and Steiner 1998; Ndubisi 2014).

Influenced by Geddes, McHarg incorporated nature into the design process and set the premise for contemporary practice, and he was also influential outside of landscape architecture and planning fields. His ecological wisdom also includes his capability to communicate in layman's language which persuaded numerous individuals to accept his ideas (Spirn 2000). His theory and methodology pervaded the National Environmental Protection Agency (NEPA) and then other federal and state environmental management programs (Bass et al. 2001).

Multiple-scale synthetic thinking was critical to McHarg's ecological wisdom. It allowed him to assemble the right colleagues to consult and work with (e.g., interdisciplinary team approach). McHarg was also capable of interpreting complex ecological data and (re)prioritizing design goals to recast simple(r) design problems. McHarg applied his ecological wisdom, through his design process and analytic framework, in suburban and exurban settings primarily. His followers expanded and extended his wisdom and approach to urban settings (Spirn 1984; Steiner et al. 2013; Steiner 2014).

Arne Naess

Arne Naess (1912–2009) was a Norwegian philosopher who first proposed the concept of ecosophy ("ecological wisdom"), and in conjunction with this concept, he launched the deep ecology movement in the early 1970s. To Naess, the status quo economy (i.e., economy placed before the environment) is the shallow ecology movement, with economic growth and increased consumption being the central values of the society. In contrast, he coined the terms deep ecology and ecosophy to call for a paradigm shift in reviewing human and nature relations (Naess 1973, 2005; Drengson and Devall 2010).

Specifically, Naess offered eight Platform Principles for the deep ecology movement (Naess 2008; Drengson and Inoue 1995), such as: "all living beings have intrinsic value; humankind does not have a right to reduce this diversity and richness; and an ideological change would essentially entail seeking a better quality of life rather than a raised standard of living." Further, Naess specified ecosophy's norms, such as "Self-realization for all living beings!", and "Self-realization!" as the ultimate norm (Naess and Rothenberg 1989, p. 197).

Essentially, Naess explained how personal philosophies of life could be consciously articulated to aim for ecological harmony and wisdom, in tackling the relation with the environment (nature). Naess' thoughts originated from ecology, which emphasizes the diversity and complexity of life, and symbiosis, which maximizes self-realization potentials under conditions of limited resources (Naess, and Rothenberg 1989, p. 199). Naess' thoughts were similar to principles for resilient ecosystems, which embraces diversity and richness of species in the ecosystems, as in his ecological philosophy that "Self-realization for all living beings!" is essential for "Self-realization!" He also pointed out that ecological wisdom needs to be practical. The ultimate norm "Self-realization!" implies the imperative to realize oneself and to help others to realize themselves. In this sense, ecosophies ("ecological wisdom") are not just theories. They are ways of life that are actively engaged on a daily basis (Drengson and Devall 2010; Drengson et al. 2011).

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Part II
From Natural Resources to Living Communities: Frameworks for Interventions

Creating with Nature: Ecosophy C as an Ecological Rationality for Healing the Earth Community

Xiangzhan Cheng

Abstract As a theory of philosophical ecology, Ecosophy C is an alternative to Arne Naess' Ecosophy T. It contains nine expressions with the capital C: Chinese culture, Confucianism, Continuity of being, Creating life, Compassion, Cheng Hao, Community, Cultural evils and Communicative reason. Ecosophy C asserts that the philosophical roots for today's global ecological crisis fundamentally lie from the Fact/Value Dichotomy, which declares that values (such as moral obligations) could not be derived from facts and denies the possibility of logically deriving what *ought to* be from what *is*. The paper asserts that the key to healing the Earth Community Project is to reinterpret Hume's Is/Ought Dichotomy from the perspectives of ecology and ecosophy. With critical reflection on the reinterpretation for Hume's Is/Ought Dichotomy in today's environmental ethics (represented by Callicott's work), the paper offers an alternative resolution of Hume's Is/Ought Dichotomy from the perspective of Ecosophy C, which tries to transform the Aristotelian syllogism as a traditional way of justifying Leopold's "seeing as structure" towards a new way of asserting the is-ought statement. The fact-value structure upholds human agency with ecological rationality, which is educated by communicative reason and pursuing great virtue, creating life with Nature.

Keywords Ecosophy C · Earth community · Hume's is/ought dichotomy
Leopold's "seeing as structure" · Ecological rationality · Creating life
Communicative reason

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1 Introduction

Whenever we hear of global environmental (or ecological) issues, we are automatically concerned that our planet Earth is sick. That is why Ian L. McHarg, the author of the outstanding book *Design with Nature*, names his collected writings, produced between the 1950s and 1990s as *To Heal the Earth* (McHarg and Steiner 1998). As a true visionary and passionate believer in the inter-dependence of man and nature, McHarg Ian brings an ecological imperative to landscape and urban planning, and provides an ethical and scientific touchstone for anyone trying to discern humanity's rightful and meaningful place as part of the natural world. Given the fundamental fact that we are living on planet Earth, it is perfectly reasonable to define what we typically call "nature" or "the natural world" as "planet Earth" within the contemporary context of environmental issues.

How we understand Earth is crucial for prescribing the correct methodology to effectively heal the planets wounds. Essentially speaking, in terms of the fact/value dichotomy, our knowledge about earth, including our related discourses is not only a matter of scientific exploration for "fact", but also an endeavour of searching for "value". The noted cultural historian, Thomas Berry defines earth as the "Earth community" and explores humankind's place within it (Berry 2006, 2014).

The difference between the two expressions, "planet Earth" and "earth community" is of great importance for the healing the earth project, based on ecology and ecological awareness. The outstanding ecologist and the founder of today's environmental ethics, Aldo Leopold, stressed in particular the importance of the concept of community in the science of ecology. In his 1947 essay entitled "The Ecological Conscience," Leopold (1991, 340) defined ecology as "the science of communities" and consequently defined ecological conscience as "the ethics of community life". So, the phrase "Earth community" connotes a much stronger ecological significance than "planet earth", which suggests that earth community is an ecosystem with many kinds of species, including human beings and that humankind has some duties towards its affects on that ecosystem.

Based on the preceding ideas, the paper asserts that philosophical ecology (i.e. ecosophy) is no longer a value-free science in its original sense, proposed by Ernst Haeckel in the mid-nineteenth century, who defined "ecology" as the study of relationships from organisms in their natural environments. Ecosophy's core aim is to define philosophically the rightful "relationship" of humankind as an organism, the earth community. In this sense, ecosophy is ultimately human ecology. Leopold and many other ecological philosophers have offered some valuable answers to this subject, such as "love and respect" proposed by Leopold (1989, viii). Thus, this paper will explore the richness of human beings' love and respect for the earth community from the perspective of Ecosophy C. Its basic idea is that the fact/value dichotomy in philosophy upholds a similar expression of Hume's Is/Ought Dichotomy. The keyword "ought" as illustrated in the following proposition: In order to heal the earth (or to save the global ecological crisis), what kind of value *ought* we human beings *to* take?

Based on Ecosophy C, the paper's answer is to take the idea of creating life as a human value based on communicative reason. This paper firstly introduces an ecological echo to Hume's Is/Ought Dichotomy in today's environmental ethics, and then offers a new possible resolution of Hume's Is/Ought Dichotomy from the perspective of Ecosophy C. The paper takes Ecosophy C as ecological rationality based on Leopold's "Seeing as Structure", which can be educated through communicative reason. Finally, the paper advocates that the themes of any ecological studies *ought to* be "creating with Nature", and is the most important premise in Ecosophy C.

2 Hume's Is/Ought Dichotomy in Today's Environmental Ethics

The "is–ought problem" was raised by Scottish philosopher and historian David Hume (1711–76) in his *Treatise of Human Nature*. Hume discovered that there seems to be a significant difference between descriptive statements (about what is) and prescriptive or normative statements (about what ought to be), and it is not obvious how one can get transformation from making descriptive statements to prescriptive ones. Hume discusses the problem in book III, part I, section I of his book, *A Treatise of Human Nature* (1739):

> In every system of morality, which I have hitherto met with, I have always remarked, that the author proceeds for some time in the ordinary ways of reasoning, and establishes the being of a God, or makes observations concerning human affairs; when all of a sudden I am surprised to find, that instead of the usual copulations of propositions, *is*, and *is not*, I meet with no proposition that is not connected with an *ought*, or an *ought not*. This change is imperceptible; but is however, of the last consequence. For as this *ought*, or *ought not*, expresses some new relation or affirmation, it is necessary that it should be observed and explained; and at the same time that a reason should be given, for what seems altogether inconceivable, how this new relation can be a deduction from others, which are entirely different from it. But as authors do not commonly use this precaution, I shall presume to recommend it to the readers; and am persuaded, that this small attention would subvert all the vulgar systems of morality, and let us see, that the distinction of vice and virtue is not founded merely on the relations of objects, nor is perceived by reason. (Hume, 335)

Hume's work has generated some interpretive controversy. According to the dominant twentieth-century interpretation, Hume states that no "ought" judgement may be correctly inferred from a set of premises expressed only in terms of "is", and that vulgar systems of morality commit this logical fallacy (Cohon 2010). This complete severing of "is" from "ought" has been given the graphic designation of Hume's Guillotine (Black 1964).

Today's environmental ethics tries to bridge the gap between "is" and "ought". The most noticeable work is J. Baird Callicott's 1982 paper; *Hume's Is/Ought Dichotomy and the Relation of Ecology to Leopold's Land Ethic*. Callicott asserts that Aldo Leopold's Land Ethic, is the modem classical expression of environmental ethics, which happens to fall short of Hume's prohibition against deriving ought-statements from is-statements. Callicott reviews Hume's is/ought dichotomy in its historical theoretical context and tries to find a general formulation, bridging *is* and *ought*. His goal is to show that Aldo Leopold's Land Ethic is expressible as a special case of this general formulation, through which to articulate, defend and extend the seminal environmental philosophy of Aldo Leopold.

Callicott's core question in this paper is: How can an evolutionary and ecological environmental ethics bridge the gap between *is* and *ought*? By answering this fundamental question, he considers two further questions: How may whole–species, ecosystems and the biosphere itself, be the direct objects of moral concern? How may the intrinsic value of nonhuman entities and nature as a whole be justified?

Without any doubt, Callicott's defence of Leopold's Land Ethic is a leading voice in the new field of environmental philosophy. However, his argument concerning Leopold's direct passage from descriptive scientific premises to prescriptive normative conclusions is not logically sound. Making up for his deficiency in the process of argumentation, this paper tries to offer a new possible resolution to the transformation from *is* to *ought*. Firstly, let's see Callicott's example. Callicott supposes a parent says to their teenage daughter, "You *ought* not to smoke cigarettes"; the teenager replies, "Why not?"; and the parent responds, "Because a cigarette *is* deleterious to ones health". Callicott then formulates the following typical Aristotelian syllogism:

(1) "Cigarette smoking is deleterious to ones health."
(2) "Your health is something toward which as a matter of fact you have a positive attitude (as today we would say; a warm sentiment or passion, as Hume, more colorfully, would put it)."
(3) "Therefore, you ought not to smoke cigarettes". (Callicott 1989, 122)

In either promise (1) or (2) there exists an *is*, and there is an *ought* in the conclusion (3), Callicott asserts that this argument derives an ethical obligation from a factual claim about human health, which is a perfectly legitimate transition from *is*-statements to an *ought*-statement. However, Callicott's argumentation is a problematic one. The key is how to understand the nature of premise (2) "Your health is something towards which as a matter of fact you have a positive attitude." The question, of which should be raised here is: is this an *is*-statement, or an *ought*-statement?

Many would understand this to be an *ought*-statement, not an *is*-statement. Scientifically speaking, anyone's health condition is a kind of *fact*. However, our attitude towards anything including health is always a matter of *value* judgement, i.e. a person prefers to be healthy than suffer from illness. For a person who hopes to extricate from what he/she thought as social or mental sufferings, he/she may take a totally negative attitude towards health, even his/her life. Therefore, attitudes towards health are matters of *value*, not matters of *fact*.

Metaphysically speaking, there are two opposite attitudes towards life, creating life and killing life. Point 4 in Ecosophy C is "Creating life", which is viewed as the great virtue of Heaven and Earth expressed significantly the Chinese classic, *The Book of Changes* (I Ching). What Callicott called "the positive attitude towards health" is just an ecological echo to this classical notion in China, which can be enlarged as "the positive attitude towards the health of the earth community". When we express "to heal the Earth community", we have potentially adopted the positive attitude of creating life in the earth community, not the negative attitude of killing life in it. In a word, only by creating life philosophically as our fundamental value, can we take the positive attitude towards health, including an individual's health and the whole earth community's health. This means that the nature of Callicott's premise (2), "Your health is something towards which as a matter of fact you have a positive attitude", is not a purely is-statement, but an *is-ought*-statement combining both *fact* and *value*.

The above new interpretation can be supported strongly by today's understanding of ecology. Another leading scholar in the field of environmental philosophy, Holmes Rolston III, tries to combine the *is*-statement and *ought*-statement by proposing what he calls "Ecological Is and Ought". In the entry of ecology for *Encyclopedia of Science, Technology, and Ethics*, he argues:

> Scientists and ethicists alike have traditionally divided their disciplines into realms of the *is* and the *ought*, facts and values. No study of nature, it has been argued, will tell humans how they ought to behave. But this neat division is challenged by ecologists and their philosophical and ethical interpreters. There may be goods (values) in nature that humans ought to consider and care for. Animals, plants, and species, integrated into ecosystems, may embody values that, though non-moral, count morally when moral agents encounter them. Ecology invites human beings to open their eyes and to appreciate realities that are valuable in ways humans ought to respect. (Rolston III 2005, 582)

No traditional study of nature can "tell humans how they ought to behave" in Rolston's words. However, today's ecology does "tell humans how they ought to behave", which is "to open their eyes and to appreciate the realities that are valuable in ways humans ought to respect". Rolston's entry of ecology here is a good example. Another sound example is Eugene P. Odum's work. In his classic textbook *Fundamentals of Ecology* (5th edition), he introduces ecology's relevance to Humankind with the focus on the worldwide environmental awareness movement since the 1970s. The textbook asserts that environmental concerns are again coming to the forefront of our minds due to the human abuse of the Earth that continues escalating. "We hope this time, to use a medical analogy; our emphasis will be on prevention rather than on treatment, and ecology as outlined in this book, can contribute a great deal to prevention technology and ecosystem health" (Odum and Barrett 2005, 3–4).

To some extent, today's ecology as a science aims at not only finding *ecological facts* like "ecosystem health", but also *ecological value* is added to its concerns. Ecosophy C introduced in this paper is the philosophical expression of the same theme of *ecological value* discovered by scientific ecology.

3 A Resolution of Hume's *Is/Ought* Dichotomy from the Perspective of Ecosophy C

Ecosophy as a term is the combination of the prefix "eco-" and the suffix "-sophy". The term can be taken to refer to "ecological wisdom" in a more general sense. Norwegian philosopher Naess Arne first proposed this term in the 1970s. Given that every situation is unique and specific, Naess introduces Ecosophy T to denote his own kind of ecosophy. The "T" referred to Tvergastein, a mountain hut where he wrote many of his books. He encouraged his audience to develop his or her own systems of guides, say, Ecosophies X, Y or Z.

Inspired and encouraged by Naess, I proposed Ecosophy C in 2013 and 2016. C here denotes eight expressions with the capital C: 1. Chinese culture, which is my cultural background; 2. Confucianism, which is generally viewed as the symbol of China in our cultural ecosystem; 3. Continuity of being, the metaphysical and ontological promise of Chinese philosophy and aesthetics; 4. Creating life, which is viewed as the great virtue of Heaven and Earth expressed significantly in the Chinese classic, *The Book of Changes* (I Ching); 5. Compassion, which is mainly embodied in Zhuangzi's philosophical story of appreciating the fish's joy and means having the faculty to share empathy with all life; 6. Cheng Hao, a philosopher in the Song Dynasty, whose aesthetic thought represents the most systematic expression of ecological appreciation in Chinese aesthetics; 7. Community, a key term in ecology, based on Aldo Leopold's developed idea on ecological conscience; and 8. Cultural evils, a key idea proposed in my own aesthetic theory, "An Aesthetics of Creating Life" (Cheng 2013a, b, 2016). A new, ninth point should be added to the list to make Ecosophy C more comprehensive, which is Communicative reason.

Ecosophy C asserts that everything including the human species in the universe is created by a mysterious power, which might be called the Dao (or Tao) in Chinese philosophy. Compared with myriad things in the universe, humankind is the only species which enjoys the unique power to take *value*-directed activities beyond the animal instinct. Based on this power given by a long evolutionary process, human beings' moral mission is to act as the assistant of Heaven and Earth, which is to help the earth community create and nourish all life forms. In a word, creating life, nor killing life, *ought to* be taken as the first value principle.

The preceding statement is aiming at healing the ecological crisis and its most crucial embodiment, species extinction. Scientifically speaking, species extinction is a *fact* which can be briefly introduced here: it is widely believed that our planet *is* now in the midst of its sixth mass extinction of plants and animals. We're currently experiencing the worst spate of species die-offs since the loss of the dinosaurs 65 million years ago. Faced with this scientific *fact* of species extinction, how *ought* we *to* explain it and respond to it? The *ought* question here is no longer a matter of *fact*, but a matter of *value*. We must face the well-known philosophical "Fact/Value Dichotomy".

From the perspective of the universal evolutionary process, extinction *is* a natural phenomenon brought about by various kinds of natural causes. However, since the rise of industrialization and its accompanying social trends, such as urbanization and mass population, scientists estimate that we are now losing species at 1000–10,000 times the background rate, with literally dozens going extinct every day. The hard truth is that the current extinction crisis is caused by our human activities, which means that extinction *is* no longer a natural phenomenon, but a cultural one. Faced with this pungent *fact*, should or should not we human beings take responsibility for our behaviours? This question is related philosophically to Hume's Is/Ought Dichotomy.

Odum's effort "to use a medical analogy to concern ecosystem health" is widely adopted by environmental philosophy, which can be called "ecological rationality". Generally, ecological rationality studies humans in real-world domains and explores which heuristics are promising in certain environments (Todd et al. 2012). However, ecological rationality in this paper is redefined as a human's ecological value judgement, whose core is to make sound *is-ought*-statements combining *ecological fact* and *ecological value*. Briefly, judgements made by ecological rationality is no longer a traditional Aristotelian syllogism, but as Leopold's "seeing as" structure. In another words, the basic structure of this special statement "seeing as" is inspired by Leopold's following statement:

> Conservation is getting nowhere because it is incompatible with our Abrahamic concept of land. We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect. There is no other way for land to survive the impact of mechanized man, nor for us to reap from it the esthetic harvest it is capable, under science, of contributing to culture. That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics. That land yields a cultural harvest is a fact long known, but latterly often forgotten. (Leopold 1989, viii)

Our concept of land hides our *value* and attitude towards it: commodity, or community. We may compare the following two statements raised by Leopold:

(1) The land *is* a commodity.
(2) The land *is* a community.

The real meaning of both "*is*" statements can be replaced by the structure of "is seen as", which can clearly showcase our *value* and attitude. When the land "is seen as" a commodity, we are only concerned with its instrumental value and regard it as a natural resource. In a contract, when the land "is seen as" a community ecologically, we realize that humankind is just a member of a big home and that we have been produced and nourished by it. So, to some extent, neither of the statements are *value*-free, they are both *is-ought*-statements.

What is more important here is the transformation from the concept of commodity to the concept of community. How is it possible? Leopold did not explain this point fully. My argument is that only through human ecological rationality can this transformation be possible. Callicott has used this human power to reconstruct the core of Leopold's Land Ethic focusing on the biotic community, which can be viewed as an exemplary case of ecological rationality:

(1) "We all generally have a positive attitude toward the community or society to which we belong;"
(2) "Science has now discovered that the natural environment is a community or society to which we belong, no less than to the human global village;"
(3) Therefore, "we ought to 'preserve the integrity, stability, and beauty of the biotic community'". (Callicott 1989 127)

Callicott's reconstruction of the core of Leopold's Land Ethic here appears very reasonable. However, he did not explain clearly the reason for the premise (1): why *ought* we to generally have a positive attitude towards the community or society to which we belong? Without sound explanation for it, the expression of *ought* in conclusion (3) would be baseless. It is convincing that point 4 in Ecosophy C, Creating life, can act as a philosophical base, which can be shared as a universal value through Communicative reason.

Communicative reason or Communicative rationality (German: kommunikative Rationalität) is a theory mainly proposed by Jürgen Habermas in his work *Theory of Communicative Action*, in which it is defined as "the processes by which different validity claims are brought to a satisfactory resolution" (Habermas 1984 75). Habermas offers his own distinctive definition of rationality, which is epistemic, practical and inter-subjective. For Habermas, rationality consists not so much in the possession of particular knowledge, but rather in "how speaking and acting subjects acquire and use knowledge" (Bohman and Rehg 2014).

Faced with the ecological crisis represented by species extinction, communicative reason is necessary for ecological rationality. Ecological rationality is epistemic, practical and inter-subjective: it is epistemic because it is informed by scientific facts discovered by ecology; it is practical because it is aimed at healing the earth community including human existence; it is inter-subjective because it is reached by communications among subjects from various cultural traditions. In her new book *The Sixth Extinction: An Unnatural History*, Elizabeth Kolbert describes the mass extinction of species that seems to be unfolding before our eyes. "There have been five comparable crises in the history of life on Earth", she writes, but this one is different: It is being caused by us. By burning fossil fuels, we are rapidly changing the atmosphere, the oceans and the climate, forcing potentially millions of species into extinction. Five watershed events in the deep past decimated life on earth, hence the designation "Sixth Extinction" is especially for today's human-propelled crisis (Kolber 2014).

Causing species extinction, or increasing species diversity? This is a crucial question similar to Hamlet's question of "to be or not to be". From the perspective of ecological rationality, species diversity ensures ecosystem resilience, giving ecological communities the scope they need to withstand stress. This scientific explanation means that species-rich ecosystems are healthier for a species' long-term survival, including human society's sustainability. I believe that all of us (i.e. all psychologically sane people) in the earth community hope to keep up the earth's sustainability. With this goal-oriented agreement and understanding, the ultimate aim is to win a satisfactory resolution for the global community, which is a healthy Earth community for all its members, including humankind. It is because this final goal that all ecological research will reach human ecology, which touches upon the core question of how humankind *ought to* interact with the earth community.

Rolston points out:

> One needs human ecology, humane ecology, and this requires insight more into human nature than into wild nature. True, humans cannot know the right way to act if they are ignorant of the causal outcomes in the ecosystems they modify.
>
> And they cannot act successfully without technology. But there must be more, and here ethics is required to keep science, technology, and life human and humane on this, humanity's home planet. (Rolston III 2005, 583)

Ecosophy C is both a human and humane ecology, because it advocates creating life and against killing life. In a word, creating life with nature *ought to be seen as* the first principle by all people with sound ecological rationality.

4 Conclusion

What is called "The Sixth Extinction" is the most obvious indicator of the global environmental crisis, which is not a natural phenomenon but a disaster caused by human activities. Based on the belief of creating life, Ecosophy C asserts that human agents (what is traditionally called the human subject) *ought to* take responsibility for the increasing series of disasters and *ought to* take effective actions to save the earth community. Within today's ecological crisis, any discourse about a species extinction is not only a *fact* description and judgement, but also a *value* on care and judgement, which means that the modern fact-value dichotomy and its another expression, is/ought dichotomy, should be overcome philosophically, so as to ground the project of healing the earth community.

The effective way of demonstrating this point is the transformation from the Aristotelian syllogism to Leopold's "seeing as structure". The agent of making the is-ought statement is not the modern human subject, but the human agent with ecological rationality educated through communicative reason, pursuing the great virtue of creating life. As a keyword in ecology and ecological ethics, the term "community" indicates clearly that all problems *ought to* be resolved by its members' Communicative reason.

Ecosophy C proposes that every human agent living in the Earth's community *ought to* act locally to heal the whole community's crisis represented by species extinction, which is to create life with Nature. In this sense, Ecosophy C is a kind of ecological rationality. How to educate and develop ecological rationality in various cultural traditions and societies should be put on the top of today's humanitarian agenda.

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Classifying Human Interventions in Nature as a Framework for Ecological Wisdom Development

Ian Bishop

1 Introduction

In a 2014 editorial on ecological wisdom, Xiang appealed for an overarching framework for ecological wisdom acquisition and application:

> As ecological wisdom consists of evidence-based knowledge, tacit and/or explicit, that originates and evolves from diverse philosophical, cultural, and disciplinary backgrounds and across generations, ideally both the process of, and approach to, its acquisition and application should be designed and implemented in a way that is transgenerational, transcultural, transphilosophical, and transdisciplinary. But under what overarching framework, through what mechanism, and exactly how can such a theoretical ideal be materialized…? (Xiang 2014, p. 67).

In this paper, we suggest that one step toward the development of such an overarching framework is to understand the diverse nature of human interventions in relation to the variety of knowledge and skills involved and that the contemporary path to ecological wisdom will be aided by an extensive knowledge base of human interventions. Ecological wisdom is developed through and expressed in human actions—that is, human interventions in the natural environment—and is facilitated not only by scientific knowledge but also by an ability to seek out, and learn from, past human intervention experience. An essential precursor to its acquisition and application is therefore the pertaining human experience—evidence-based knowledge and skill that originate in and evolve with the process of human intervention (Ackoff 1989; Feng 2011; Rowley 2007; Xiang 2014). The human intervention experience, once systematically documented, recorded, and stored in a knowledge base, and made readily accessible, will be of great value to contemporary landscape and urban planning, design, and management. The development of such a knowledge base of human intervention necessarily requires a

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classification system under which instances of intervention and the associated human experience can be codified and made readily usable. However, neither such a knowledge base, nor the classification system it requires, even exists.

Within these premises, in this paper, we propose a scheme of *classification* for human intervention in the natural environment that has the potential to support the reinvention and communication of ecological wisdom developed through intervention processes. It is also almost certainly incomplete and open to future extension and modification with further theoretical development and input from many disciplines. Further, other species also alter their environments, consider the beaver, and there are potentially classification schemes applicable to animal interventions—whether individual, symbiotically with other species (including humans) or even parasitic. Perhaps, we can also derive human wisdom from these, but for this chapter we confine ourselves to human behaviors.

It should also be noted that our proposed classification scheme, the first of its kind, is intended to be independent of value judgment and is not a basis for *assessment* or *evaluation* of the quality of interventions. This is because judging whether interventions are wise is a quite separate consideration that is dependent upon, among many other factors, the diverse and almost ever-changing values of society, evaluation against contemporary concepts such as sustainability and resilience, and further theoretical development and input from many disciplines. The proposed classification scheme should therefore not be interpreted or used as a basis for judging whether interventions are wise or not. The paper includes examples of interventions of various kinds some of which are currently judged to be wise and others deemed—often in hindsight—unwise. However, we are not seeking comment on their wisdom merely using them to illustrate our proposed dimensions of human intervention.

The remainder of the paper is organized as follows. In Sect. 2, we discuss the changing character of human–environment relations and the significance of human interventions as central to this relationship. We then briefly consider the literature on the relationship between knowledge and wisdom. These two discussions buttress our contention that the path to ecological wisdom, however defined, will be aided by an extensive knowledge base of human intervention. To support organization of such a knowledge base, we propose (Sect. 3) a set of six dimensions on which ecological interventions can be classified. This is followed (Sect. 4) by brief discussion of the potential structure of such a knowledge base. Section 5 offers some conclusions.

2 Background

2.1 Human Intervention in Natural Processes

While human beings are unquestionably part of the environment, they have special status because of their ability to assess the likely consequences of their actions.

We therefore refer to human actions that result in changes to the remainder of the natural world as interventions. Even the earliest hunters and gatherers changed their environments, but their numbers and technologies were usually insufficient to make dramatic changes. Then, we began to use fire, to redirect water, and to manage vegetation. The scale of interventions in nature, in terms of both physical and temporal dimensions, began to grow. These changes were often based on limited knowledge of the underlying science but sufficient awareness of the outcomes to apply such interventions for human benefit (Fig. 1). Since then our science has improved, our technologies have further developed and our population has grown. For many, this has led to increased life expectancy, increased leisure time, more material goods, and other contributions to quality of life. However, while our ability to exploit nature has had many positive outcomes, our collective actions can now also have serious local impacts on human health and welfare and long-term global impacts. Many authors have studied, documented, made forecasts, and recommended policy on the human–nature relationship. The contemporary western view of this relationship perhaps has its genesis in the 1960s (Hardin 1968; McHarg 1969), but the articles in this issue reveal a longer history and broader cultural perspectives. It was in the 1960s also that environmental impact assessment (EIA) was first enshrined in law through the US National Environmental Policy Act of 1969.

Many people see adverse consequences as necessary collateral damage from development, and EIA is meant to provide awareness of the consequences and ensure that developments are not excessively damaging to the environment. In reviewing the history and achievements of EIA, Jay et al. (2007) concluded that:

> Even its most immediate aims of ensuring that the likely environmental consequences of developments are properly taken into account and ameliorated where necessary are only being met to a limited degree. The achievement of its substantive aim, contributing to more sustainable patterns of activity, although difficult to assess, appears to be even more elusive. (p. 298)

It is apparent that EIA is not itself sufficient to bring wisdom to environmental decision-making. Less project specific are the processes of strategic environmental assessment (SEA), which emerged, after EIA, as an independent process with a view to ‘the integration of environmental considerations into the preparation and adoption of plans and programs with a view to promoting sustainable development’ (European Commission 2001). White and Noble (2013) after reviewing the SEA literature ask why ‘there is not more widespread evidence of it achieving sustainability outcomes’ (p. 65). To remedy this failure, they make four recommendations, including ‘placing much more attention on how to facilitate institutional learning regarding sustainability through SEA application’ (p. 65). This institutional learning is closely linked to the tacit knowledge that we see as central to the application of wisdom.

While techniques such as EIA and SEA may, at times, have succeeded in promoting local sustainability, sometimes the effects of human interventions are so pronounced and/or sudden that they constitute threats to both humans and nature and are called environmental crises or environmental disasters. Table 1 includes

Fig. 1 Interventions in the environment. **a** Domestication of crops (adapted from User: Kingtut/ Wikimedia Commons /CC-BY-SA-2.5). **b** Water management for irrigation (from http://wiki.mapbar.com/wiki/都江堰). **c** Pest control (from http://chineseposters.net/posters/pc-1958-025.php). **d** Ship sunk to make artificial reef (from iStock.com/WhitcombeRD)

some examples and categorizes them according to their sources and consequences. Vallero and Letcher (2013) argue that 'all environmental disasters … have a cause-effect component' (p. 1). They list five types of cause: miscalculation, extraordinary natural circumstances, critical path, negligence, and inaccurate prediction of contingencies. Humans are involved, to a greater or lesser degree, in all of these. Biggs et al. (2011) suggest that as the drivers of change become increasingly global, rather than local, and as increasing connectivity means that an

Table 1 Examples of environmental crisis or disasters classified according to the source (columns) and the victims (rows)

	Human	Nature (with prior human folly)
Human	• The great smog of London, 1952 • Minamata disease from mercury poisoning in Japan (the 1950s and 1960s) • Dispersion of high-level radioactivity: from Windscale and Chelyabinsk (1957), to Chernobyl (1986) • The great smog of Beijing, 2013	• Fukushima, Japan (2011), in which a major earthquake and tsunami triggered the release of radiation • Hungary (2010), days of heavy rain caused the release from storage of 1 million m^3 of red toxic sludge • New Orleans (2005), where the flooding induced by Hurricane Katrina was made worse by failure of protective levees
Nature	• The devastation of the Aral Sea (since the 1960s) • Draining of the Everglades, Florida (early twentieth century) • Deforestation of Easter Island (seventeenth century onward) • Introduction of Nile Perch into Lake Victoria (1950s) • Exxon Valdez(1989) and Deepwater Horizon (2010) oil spills • Effect on the world coral reefs of the warming and acidification of the oceans (since the industrial revolution but accelerating recently)	Not applicable unless we think about asteroid collisions with earth and the periods of major species extinction

intervention in one place may provoke a crisis in another place, we are likely to experience increasing concatenation of crises. In other words, the scale of the issues is growing.

Another unprecedented element in understanding human interventions lies in the creation of new landscapes that cannot be returned to their original ecological status. These are being referred to as novel ecosystems (Collier 2015; Morse et al. 2014) and constitute a whole additional field of study.

2.2 *Knowledge and Wisdom*

Wisdom is sometimes seen as the apex of a pyramid with data, information, and knowledge forming the supporting layers. This continuum is variously referred to as the information hierarchy, knowledge hierarchy, or wisdom hierarchy (Rowley 2007). Rowley argues (p. 168) that 'the implicit challenge is to understand and explain how data is transformed into information, information is transformed into knowledge, and knowledge is transformed into wisdom.'

Rowley (2006, p. 257) summarizes earlier debates and goes on to define wisdom as: 'The capacity to put into action the most appropriate behavior, taking into account what is known (knowledge) and what does the most good (ethical and social considerations).' This definition is easily extended to encompass ecological wisdom as it applies equally well to human influences on the environment as to other decision-making. Of course, if individuals, or nations, do not share ethical principles or have dissimilar views on societal objectives, they will have different views on what is wise.

According to Ackoff (1989, p. 3), 'there can be no wisdom without understanding and no understanding without knowledge.' Rowley (2007) also reviews many definitions of knowledge. These commonly include a distinction between tacit knowledge, which is held by an individual based on his/her practical experience, and explicit knowledge, which is codified, recorded, and made available for others. She adds: 'knowledge might be viewed as a mix of information, understanding, capability, experience, skills and values' (p. 174). Rowley concludes that explicit knowledge is indistinguishable from information and that it is tacit or practical knowledge that is the additional human component developed through experience. Other knowledge classifications have been suggested (e.g., personal, procedural, and propositional), but the spectrum from tacit to explicit is also generally adopted in the knowledge management domain following the arguments of Nonaka (1994). Other types that are sometimes proposed, such as operational knowledge (ways of doing), can be either explicit or tacit.

Jessup and Valacich (2003) see wisdom as an accumulation of knowledge supporting decision-making, through familiar concepts, in new situations or those with complex problems. Jashapara (2005, pp. 17–18) agrees that knowledge transfer is an essential part, but also insists that ethics are part of wisdom: 'Wisdom is the ability to act critically or practically in any given situation. It is based on ethical judgment related to an individual's belief system.' Wisdom, therefore, is an internal state dependent on good ethical instincts, good background knowledge, and ability to make judgments in accord with the acquired knowledge and ethical principles.

Ecological wisdom, then, is wisdom applied to nature and the environment. Xiang (2014) states 'ecological wisdom is by nature ethical, inspirational, and yet still practical. Not only is it about the virtue of doing real and permanent good in this world through the socio-ecological practice of landscape and urban planning, ecological design and engineering, but it is also capable of inspiring and empowering people to figure out the right way to do the right thing in a particular circumstance' (p. 67). There is also frequently a need for courage and leadership to implement changes that may not be universally popular (Gordon and Berry 2006). Dealing with the ethics of environmental intervention is not our focus, nor is the role of courage except to the extent that courageous and ethical decision-making are easier when supported by scientific knowledge that is widely communicated and enhanced by the tacit knowledge that comes from experience.

3 Dimensions of Intervention

As argued above, a starting point for sharing of tacit knowledge is effective communication of experience and this can be supported by an extensive knowledge base organized through a meaningful system of classification. To our knowledge, no systematic study of such a knowledge base has ever been done, nor has a classification system been suggested. We propose a set of dimensions, essential for classification, that distinguish ecological interventions by their rationale, type (engineering, treaty-based, etc.), physical scale (local, regional, continental, global), temporal scale (short, medium, long), levels and sources of uncertainty (linked to levels of knowledge), and impact level. It could be argued that the agent of the intervention should be part of the classification scheme: where the agent might be civil government, military, corporate, NGO, individual, or some other community grouping. However, despite their differences in ability to intervene, the same actions could come from different agents, from within different societies, and so this does not seem to be an essential distinction. The study of power relationships within the natural environment and their effects on the landscape has been considered elsewhere (e.g., papers within Mitchell 2002; Wescoat and Johnston 2008). The following subsections explore our proposed dimensions more fully.

3.1 Rationale

Humans may intervene in the environment (a) to forestall forces and changes in nature which threaten a community, (b) to remedy prior unwise interventions, or (c) because there are irresistible human benefits from engineering the environment. These require some unpacking.

A. Threats arise from natural events such as earthquakes, floods, and fires. Wise interventions may include moving people out of danger areas, using resistant building technologies and creating barriers between the threat and the people. As cities are not easily moved, humans commonly look for solutions involving management of the natural forces, such as the North Sea dykes protecting the Netherlands. When this is not possible (earthquakes), we wisely create infrastructure and buildings that can withstand seismic forces.
B. There are many prior, or ongoing, human mistakes to be remedied. There are clear examples at all different physical scales: local—river and riparian restoration; regional—revegetation to halt desertification; oceanic—halting Canadian cod fishing; and global—the worldwide ban on the use of chlorofluorocarbon (CFC) compounds to save the ozone layer.
C. The third rationale for intervention is different from cases A and B and both easier and harder to argue for—depending on the scale/impact of the intervention. In situations where there is no direct threat from natural forces and no human-induced crisis to be averted, when is it justified to intervene in the

environment? Humans have been doing this throughout history to meet basic human needs for food, shelter, and so forth: e.g., building reservoirs and channels to support irrigation for agriculture, extracting resources to build houses or make pots. When demand is not too high, agriculture and forestry can be sustainable activities; the externalities of mining may affect only small areas. The so-called green revolution increased agricultural output without having to consume more land. Genetic modification may provide similar benefits, although the risks still need deep consideration. Plantation forestry has reduced the need to log some of our forests. Aquaculture can potentially reduce the stress on ocean fisheries—so long as sea catch is not the food source. A well-designed irrigation scheme can enhance habitat as well as supporting food production. On the other hand, meeting human needs by killing endangered species in order to supply body parts to the wealthy is widely seen as unjustified.

In this context, and especially in relation to environmental hazards, the terms mitigation, adaptation, and resilience are frequently used. Mitigation involves changes in human behavior to reduce the risk of bad outcomes (e.g., reduction in greenhouse gas emissions or the CFC ban mentioned above). This is most commonly in response to real or perceived threats to the environment and is closely associated with our type B. Adaptation involves recognition that environmental changes are unstoppable and it is necessary to find ways to live within the new constraints imposed by that change (e.g., more climate extremes). Interventions of our type A are often adaptations. Resilience, or the ability to withstand environmental pressures and changes because of wise prior decisions, is a very important consideration in this context. Interventions of type C may provide resilience if wise.

3.2 Type of Intervention

Once a decision is made to intervene in the environment, there are various approaches to realization of the objectives. The intervention may be based on:

- *Engineering*, such as the barrage across the River Thames designed to stop flooding in London at times of storm surge.
- *Persuasion* to change individual human behavior, such as anti-litter campaigns ('Clean Up Australia') or the Four Pests Campaign in China (1958–62). This is easier if the initial impetus comes from the people ('bottom-up') rather than from the government ('top-down').
- *Biological control*. In Northern Australia, the moth *Cactoblastis cactorum* successfully controlled the runaway of the introduced prickly pear cactus, whereas the use of the South American cane toad (*Bufo marinus*) to control beetles affecting the sugar cane industry has resulted in the decimation of many native species.

- *Regulation*, which may be implemented to control industrial pollution or other forms of environmentally inappropriate behavior. Regulation may be city, state, or nationally based, with sometimes the implementation of international agreements (e.g., the bans on use of CFCs and trade in ivory).
- *Market forces*, the recent use of cap-and-trade approaches to management of carbon emissions has been widely supported by economists, but there have been some implementation issues in pioneering Europe (Aldy and Stavins 2012).
- *Military,* Eckersley (2007) restricted the term ecological intervention to specifically military intervention into another country, to prevent major environmental catastrophe. She used the examples of intervention in a Chernobyl-like nuclear meltdown or in the genocide of mountain gorillas, when the host countries are unwilling or unable to take actions necessary to prevent such outcomes.

These different approaches, which may not be exhaustive, also tend to have different actors involved. Once a political decision has been made, the main actors may be the general public (persuasion and market forces), scientists, engineers, or, in our extreme case, the military. Implementation of an intervention may also be dependent on the social context. At some scales, and for some types of intervention, planners and designers are key actors. We see planning and design as processes leading to decisions on intervention and not as, themselves, types of intervention.

Not all options are open in all societies. A detailed study by Esty and Porter (2005) found that national environmental performance is heavily dependent on (a) an appropriate regulatory regime, and (b) the economic and legal context ('administrative, political, scientific, and technical capabilities and institutions'). This suggests that some kinds of intervention—such as effective regulation, and particularly market-based mechanisms, are dependent on social institutions and the rule of law. Success also depends on economic resources sufficient to carry out intervention policies.

3.3 Physical Scale

The physical scale of human interventions can range from treatment of the health of individuals to global bans on damaging industrial chemicals. The examples given below are chosen to illustrate points within this range.

The use of antibiotics by an individual can be seen as ecological intervention of a very local kind. The benefit to the infected individual is widely recognized, but overuse can lead to greater issues such as resistant superbugs. From this microscale, we can move progressively to larger scales: to the private garden, to public spaces within a city, to broader landscapes, bioregions that may cross national boundaries, large nations (as decision units rather than ecologies), regional national groupings, and the whole planet.

At the level of the private garden, there has been considerable attention paid recently to the use of indigenous vegetation to provide habitat for native birds and to a lesser extent, animals. In Australia, movement toward native 'bush' gardens and away from more regimented English styles began with Edna Walling in the 1920s. The principle is now well established. Such gardens also tend to need less water and can be seen as positive interventions. In Sri Lanka, the Kandyan gardens are famous for their diversity and their productivity (Jacob and Alles 1987).

At a larger scale, encouragement of native, drought-resistant gardens may also be part of the ecological strategy of a city. In 2014, the City of Sydney released its Urban Ecology Strategic Action Plan (City of Sydney 2014), which recognized the role of both public and private spaces and the importance of a knowledgeable public: 'Increased awareness of biodiversity in the LGA (local government area) is likely to also lead to increased care and concern, not just on private property but on public land as well' (p. 94). In the rapidly expanding cities of China, environmental values can be diminished in the rush of development. In China, and beyond, the many urban interventions of Kongjian Yu and his colleagues are widely recognized (Sanders 2012) and are based on the principle of restoration of ecosystem services including provisioning of food, water, and energy, purification of water, carbon sequestration, climate regulation, water detoxification, cultural and spiritual inspiration, recreational experiences, and scientific discovery (Yu 2010).

As an example of regional intervention, in the Australian Alps, the Alpine Ash (*Eucalyptus delegatensis*) forests are suffering more frequent fires that have occurred historically. While most Eucalyptus species have evolved defenses to fire—to the point of depending upon it—the Alpine Ash has no defenses except to drop its seeds when mature. Frequent fires have prevented large areas of forest, much of it in National Parks, from reaching maturity, and all the trees are dead (Bowman et al. 2014). The question now is should 'nature' be allowed to take its course and hope for a gradual revival of the Ash or should other species better adapted to a regime of more frequent and intense fires be introduced?

At the Continental Scale, any intervention requires agreement of all countries on the continent. This is feasible in Europe where the EU has many continent-wide regulations but harder on other continents with more diverse cultures and institutions. The Antarctic continent on the other hand is home to no nations and is, in effect, governed by international treaties (the Antarctic Treaty System), and from an environmental perspective, by the Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol). Of particular significance, as an ecological intervention, is the prohibition of all activities, other than scientific research, relating to mineral resources. The wilderness and aesthetic values of the continent are a 'fundamental consideration,' and all activities, including tourism, require environmental assessment.

Such internationally based protection (33 countries have ratified the Madrid Protocol) could also be applied to areas of the oceans that are outside national jurisdiction (the high seas). However to date, no agreement has been reached on full protection of any such area. Protection has been limited to large national initiatives, such as British designation of 640,000 km^2 around the Chagos Islands of the

Indian Ocean as the world's largest marine reserve. In an attempt to redress the lack of protection for the high seas, Greenpeace is calling for a network of highly protected reserves covering 40% of international waters. Applying to many international waters are more limited protections such as the bans on certain kinds of fishing and on commercial whaling.

3.4 Temporal Scale

There are no widely agreed time spans for what constitutes a short-, medium-, or long-term intervention. Climate scientists see short term as decades and long term as millennia, but many documents—such as environmental effects statements—use these terms without any specificity. One exception is the Caribbean Large Marine Ecosystem Project (clmeproject.org), which suggests 1–5 years, 6–10 years, and greater than 10 years as appropriate. We are inclined to the view that medium term goes further into the future than 10 years, as 25 years is now a small part of an average life span in the developed world and, in terms of ecological consequences, an 11-year span would not be considered long term.

Some examples of interventions with different time frames include:

- *Short term (1–5 years)*: In Australia, kangaroo numbers can build to levels that are bad for the species and for the wider environment. Consequently, normally protected species, like the eastern gray kangaroo, may be culled by government, or with government approval, to reduce populations to more sustainable levels. The Australian Capital Territory, for example, has an annual (winter) cull designed to protect fragile environmental reserves. The need for repeated application makes this clearly a short-term intervention.
- *Medium Term (6–25 years)*: Many organizations develop 10-year, 20-year and even 25-year (e.g., Great Barrier Reef World Heritage Area) plans for the region under their control. Truly medium term are interventions with gestation periods in the chosen range. The winner of the inaugural (2014) England River Prize for restoration was the River Wensum in Norfolk. The restoration strategy (Anon 2009) included a 10-year plan of works and recognition that some aspects, such as natural narrowing of the channel to its original form, may take longer.
- *Long Term (more than 25 years)*: The Comprehensive Everglades Restoration Plan is identified on its Web site (www.evergladesplan.org) as 'The Journey to Restore America's Everglades.' FAQ14 asks 'How long will it take to restore the Everglades.' Answer: '…it will take a few decades, and the composite impact of many projects to obtain all the benefits…'. This intervention (if funding and momentum are maintained) is certainly long term.

This dimension has added complexity because of the potential for individual small short-term acts, such as plowing a field or driving a car, to be repeated many times by multiple agents and so becoming long-term influences on soil erosion or atmospheric pollution.

3.5 Uncertainty

Knowledge and uncertainty are two sides of the same coin. Researchers talk a lot about uncertainty because, for a scientist, knowledge is the default position. Practitioners/designers talk about their knowledge of relationships—based often on assimilated experience rather than hard science. As Burgman et al. (2012, p. 1956) state: 'Typically, people who manage ecological systems are confronted by imprecise, sporadic, or unavailable data, high stakes, limited understanding, and urgently needed decisions.' The difficulty arises from uncertainty; the ability to do anything at all arises from knowledge.

Just as there are kinds and levels of knowledge, there are kinds and levels of uncertainty. The differences in kind interact such that in ecological modeling, 'uncertainty in model parameters and functions compounded rapidly, even for reasonably well-understood ecological systems, highlighting the possibility that many model predictions may be unusable' (Burgman et al. 2012, p. 1956).

However, these issues are compounded by the absence of model development or calibration data from the more extreme conditions, which are also those that most put ecosystems at risk. In our times, few natural ecosystems are surviving on their own without some level of human support—such as through National Parks and Reserves. These ecosystems, because their boundaries are finite and thus limited in climatic range, are at particular risk from extreme climatic events or other kinds of severe disturbance. However, there is always uncertainty about the level and distribution of such risk. Game et al. (2008) explored the delineation of the Great Barrier Reef National Park off the east coast of Australia. They found that if catastrophic risks are assessed across such a large conservation area then a more robust set of boundaries (i.e., with a high tolerance of uncertainty) might involve little additional cost.

Correct definition of the problem is itself a key issue in this context. Expert judgments are often part of the process but as Burgman et al. (2012, p. 1962) point out 'procedures for eliciting expert judgments usually are not described in methods sections of reports and papers, even when the model outputs and decisions that rest on them are sensitive to these judgments.' It is important that uncertainties are explicit. What distinguishes uncertainty (or knowledge) for the purposes of this paper is not so much its degree, which is especially difficult to quantify ('unknown unknowns'), but the type or source of the uncertainty. We identify three classes of uncertainty that may impact on the wisdom of a proposed ecological intervention:

- Lack of knowledge about the ecological *processes* in the area in question.
- Lack of knowledge about *future pressures* (overall climate change; severe disturbance—fire, flood, monsoon failure; poachers).
- Lack of certainty about the continued availability of management resources or political will—that is the *popularity* of the intervention—which makes the outcome uncertain because it is dependent on ongoing support.

3.6 Impact Level

The impact of ecological interventions may correlate with their spatial or temporal scales, but it is possible to have a widespread, long-lasting influence of comparatively low impact. The growth in greenhouse gas emissions between 1750 and 1950 would be a case in point if emissions had stabilized at that time. Impact could be assessed in a variety of ways. One approach is through *changes* in the goods and services that environments provide to support the lives of people. The difference, before and after intervention, in some metric is a measure of impact. One possible metric is the ecological services (ES) approach (Costanza et al. 1997) that considers 17 different ecosystem goods or services ranging from global functions such as gas regulation in the atmosphere to local functions including aesthetic and artistic values. ES accounting has been criticized as being excessively anthropocentric and failing to consider the intrinsic worth of aspects of the environment. While this is an ethical debate beyond the scope of this paper [see a synopsis of various critiques of ES in Schröter et al. (2014)], on this argument ES estimates may undervalue ecosystems but not so much as the current economic paradigms tend to undervalue them. ES is therefore a step forward and potentially a mechanism for judging the degree of change (positive or negative) following an ecological intervention.

Illustrating how ES analysis might be applied, Costanza et al. (2014), in an update of the analysis in Costanza et al. (1997), suggested total ES values have declined by between 4.3 and 20.2 trillion USD per annum. A review of the figures indicates that most of this decline arises from transformation of coral reefs (54% lost), tidal marshes/mangroves (22% lost), and swamps/floodplains (63% lost) into other biomes concurrent with a very dramatic increase in the estimated value per ha of reefs and marshes (based on taking mean estimates from 94 and 139 independent studies, respectively). Thus, the positive impact of restoring 10 ha of tidal marshes/mangroves is of the order of 2 million USD per annum. Bringing 10 ha of desert back into temperate forest, on the other hand, would only realize around 31,000 USD in ES per annum. In assessing impacts of an intervention, it seems sensible to do this per unit area; otherwise, impacts will simply be closely correlated with physical scale and not a separate measure. This approach has also been used locally to assess changes in ES following changes in land use or land management (Grêt-Regamey et al. 2007; Hu et al. 2008).

There is, however, no way within the ES framework to assess the effect of an intervention on the viability of a particular species. It remains an imperfect instrument, and consequently this is likely to remain the most contentious of our six dimensions to evaluate.

4 Forming a Knowledge Base

The concept of a repository of information and knowledge about ecological interventions is not original. Zalewski et al. (2009) describe the worldwide network for demonstration projects in ecohydrology. They suggest, as we do, that such a repository can help the transition from knowledge to wisdom. They argue that ‘only implementation of knowledge in large scale Demonstration Projects … enables generation of wisdom’ (p. 9). The UNESCO-IHP Ecohydrology Program (EHP) launched the Demonstration Projects in December 2011 (http://www.unesco.org/new/en/natural-sciences/about-us/single-view/news/ihp_ecohydrology_program_launches_demo_projects/#.VFSQDUuLQfw) beginning with 30 projects classified as Global Reference, Operational, Evolving or Emerging. Only the first two categories (eight projects) were, at that time, sufficiently advanced to be either ‘showing best practice’ or ‘implementing EH principles.’ Even within the restricted focus of integrated biological and hydrological processes, 8 projects, or even 30, seem too small a number to support the ‘generation of wisdom’ applicable across a world of diverse hydrological projects. There is no explicit mechanism for searching within this knowledge base, which surely restricts its potential usability if it grows over time.

Our dimensions, which are intended to support a knowledge base which is at once usable, useful, and efficacious, include 3 rationales, 6 implementation types, 5 physical scales, 3 time periods, 3 types of uncertainty, and a sliding scale of impact (called high, medium, and low for temporary convenience), giving up to 2430 combinations each of which can be considered as a distinct phenomenon. Do they all exist? For example, are engineering interventions always long term? Could one foresee a global scale military intervention? It seems hard to imagine finding examples of all 2430 combinations. Looking for these would, however, be a major contribution to a knowledge base of ecological wisdom, which would also serve as a basis for decision support and communications.

While a schema such as the one proposed here provides a way to classify interventions, this does not itself help us to decide what is wise in terms of either historical interventions or proposals for the future. The past is certainly easier than the future because the outcomes are generally visible and measureable. What may still be missing, however, is the knowledge of what would have happened without the intervention. Sometimes aspects are clear: Without the dykes, the Netherlands would be much smaller. Without the Dujiangyan irrigation system (2300 BCE), the Chengdu Plane would not have become ‘the Land of Abundance’ (*Tianfuzhiguo*). Comparing the actual present with the counterfactual present allows us to judge whether the outcome is a good one—on some set of multi-dimensional criteria.

Consequently, an appropriate knowledge base of ecological wisdom should include:

- Original conditions and the rationale for intervention.
- The specifics of the changes made and assessment of these on a set of dimensions such as those proposed in this paper.
- The likely consequences of no intervention.

Both ‘wise’ and ‘unwise’ interventions should be included without necessarily judging into which group they fall—since this depends on contemporary ethics. The knowledge base might include the potential for users to give their own assessment of the recorded interventions. An intervention that has stood the test of time and provides real and permanent good would be recognized through a weight of positive reviews. Application of the ecological services approach provides another mechanism for long-term evaluation, as do techniques arising from the growing literature on eco-efficiency (Zhu et al. 2015) and resilience (Plummer and Armitage 2007; Angeon and Bates 2015).

In addition, the dimensions introduced here, as an approach to classification, may help determine which proposed interventions have the best chance of being eventually seen as wise. The classifications can help provide an argument for continuing support as well as being the basis for a searchable knowledge base. This paper is not proposing a specific mechanism for development of this knowledge base, but suggesting that the principles outlined here can be a basis for further discussion. This will not be a simple process. Expert, or knowledge-based, systems for medical diagnosis were first suggested over 50 years ago (Ledley and Lusted 1959), yet research and development continue, and many ongoing issues are still being identified (Sheikhtaheri et al. 2014). Yet within specific domains, the success rate is frequently above 90% (Sheikhtaheri et al. 2014). Among our 2430 classes of ecological intervention, some will be more amenable to the application of a knowledge base and artificial intelligence than others.

5 Conclusions

The unconsolidated nature of ecological wisdom (Xiang 2014) necessitates the development of a knowledge base of human interventions, wise or otherwise, and their underlying ideas, tenets, strategies, and approaches. Such a knowledge base, once built and implemented, can serve multiple functions in support of wisdom development in contemporary landscape and urban planning, design, and management. These include, but are not limited to, learning, benchmarking, and communicating. The development and application of the knowledge base can also help build synthesis across these instances toward the development of general principles of ecological wisdom.

For the development of such a knowledge base, we have identified six dimensions of ecological intervention: rationale, type, physical scale, temporal scale, uncertainty, and impact level. Some examples of interventions, with suggested dimensions, are summarized in Table 2. All possible combinations in this six-dimensional classification space may not exist, but certainly great diversity remains. Under this overarching framework, a knowledge base, in concert with a knowledge management system, could be constructed gradually, coordinated through a suitable institution, and made available online to others. An example from another field is the Cochrane Library, an online (cochranelibrary.com) repository

Table 2 Examples of different interventions and their classifications

Subject	Example	Rationale	Type	Physical scale	Timescale	Uncertainty	Impact
Forest gardening	Kandyan forest gardens—Sri Lanka	Benefit	Behavioral	Local	Medium	Few	High
Soil conservation	No-till agriculture—Worldwide	Benefit	Behavioral	Local	Medium	Process	Medium
Irrigation system	Dujiangyan irrigation scheme—China (see Fig. 1b)	Benefit	Engineering behavioral	Local	Long	Few	Low
Artificial habitats	Sinking ships—various locations esp. USA (see Fig. 1d)	Benefit	Engineering	Local	Medium	Process	Low
Pollution control	Ban on CFCs—Worldwide	Remedy	Legislative	Global	Medium	Few	High
Restoring wetlands	Comprehensive everglades restoration plan—USA (Florida)	Remedy	Engineering biological	Regional	Long	All three types	High
Toxic waste cleanup with bioremediation	Exxon Valdez oils spill cleanup—USA (Alaska)	Remedy	Engineering	Local to Regional	Long	Process and popularity	High
River/riparian restoration	Shanghai Expo water gardens (China), River Wensum (UK)	Remedy	Engineering biological	Local	Medium	Process	Medium
Biological pest control	*Cactoblastis cactorum* release—Australia	Remedy	Biological	Regional	Long	Process	Medium
Revegetation (also carbon sink)	Holding back desertification—China	Remedy	Biological behavioral	Regional	Long	Popularity	Medium
Technology fix for pollutant	Carbon capture and storage—optimism in coal industry	Remedy	Engineering	Global	Long (maybe)	Process	Medium
Species protection	Whaling ban—most of world	Remedy	Legislative	Global	Medium	Popularity	Low
Erosion control	Many different approaches	Remedy	Engineering biological	Local	Short	Pressure	Low
Coastal protection	Thames barrage	Threat	Engineering	Local	Long	Future pressures	Low
Flood protection	Dykes—The Netherlands	Threat	Engineering	Local	Long	Few	High

for systematic review of healthcare interventions (see Higgins and Green 2008). This paper posits that a similar knowledge base of ecological wisdom can serve as a wisdom development support system to facilitate the knowledge-to-wisdom transformation in contemporary landscape and urban planning, design, and management for individuals, organizations, and society at large. As Goede (2011) wrote: 'Wise individuals are required to create wise organizations, and wise individuals and organizations are needed to create a wise society' (p. 37).

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Part III
From Natural Resources to Living Communities: Vernacular Water Systems

Nature-Inspired Stormwater Management Practice: The Ecological Wisdom Underlying the Tuanchen Drainage System in Beijing, China, and Its Contemporary Relevance

Lixiao Zhang, Zhifeng Yang, Alexey Voinov and Sulan Gao

Abstract Ancient Chinese cities have implemented a number of outstanding projects in unique local landscapes that still currently remain in use, and some of these ideas are similar to recent modern projects. An example of successful ecological engineering is the Tuancheng drainage system in Beijing. The present study presents a technical analysis of this drainage system and describes a hydrological model for a one-time rainstorm event and one-year water balance using the Stella® platform. The results demonstrate that the drainage criteria were reasonable and that the implementation was exceptional. One of the excellent designs is the underground circular C-shaped drainage system in the terrace, where at each turning point, there is a pit to collect rainwater. In addition, the inverted paving of the trapezoidal brick on the surface and soil improvements largely contributed to the rapid infiltration of rainwater. During an intense rainstorm, the system effectively attenuated stormwater and increased the infiltration proportion. In 1965, with only 226 mm of rainfall, this system retained 27 mm more water in the soil. The Tuancheng drainage system is an excellent example combining drainage and storage, ground and underground, and gray and green infrastructure to create a hydrological landscape functionally equivalent to natural conditions. Exploring ancient wisdom and using the ideas of our ancestors could help us contribute to more effective and efficient strategies to address the issues of urban stormwater management.

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Keywords Ecological wisdom · Urban stormwater · Hydrological modeling Stella® · Tuancheng

1 Introduction

The present study focuses on Theme 4 discussed in the editorial by Xiang (2014), exploring ecological wisdom as a hidden pathway toward sustainable development. The focus of both the International Symposium held in Chongqing in October 2014 and the special issue of *Landscape and Urban Planning* was to pursue answers to the questions presented in this editorial. One of the central principles for this symposium and the special issue was to report evidence-based and case-specific research contributing to a better understanding of ecological wisdom. Urban drainage is naturally a serious problem, and potential solutions could benefit from examining relevant ancient ecological wisdom (Xiang 2013). This is especially true for China, where urban drainage development and management are largely lagging compared with other industrialized countries. Therefore, we investigated the ancient urban drainage systems of Beijing, specifically the Tuancheng drainage system, to obtain appropriate ideas, principles, strategies, and approaches for the management of urban stormwater and to determine how this information can inform contemporary stormwater management in China.

With rapid urbanization and precipitation patterns becoming more unpredictable as a result of climate change, urban storm flooding has become an increasingly prevalent problem in urban areas of China. Flooding can lead to extremely serious consequences, causing heavy casualties, and deaths, traffic paralysis, water pollution and economic losses (Li 2012). The most recent and largest flooding event was the 7.21 Beijing Rainstorm in 2012, a catastrophic natural disaster resulting in 37 deaths and at least 10 billion RMB in economic losses. More than 100 of the 661 largest cities in China suffer from flooding problems during monsoon season, and more than 400 cities experience some degree of water shortage (Du 2012; Li 2012). The ongoing climate change has exacerbated this contrast between extreme flooding and drought (Zhou 2014).

In recent decades, there has been increasing interest in ecological engineering and ecological design (Todd et al. 2003), which attempt to apply natural methods in designing engineering solutions. Indeed, the ancient Chinese adopted the principle of learning from and working with nature for hundreds of years and have designed and implemented smart systems, some of which are currently still performing well, and in some instances, these ancient systems are even better than much more recent designs. The concepts underlying these projects are similar to modern popular stormwater management approaches (Che et al. 2013; Fletcher et al. 2014), such as low-impact development (LID) (USEPA 2000), best management practices (BMPs) (Muthukrishnan et al. 2006), and sustainable urban drainage systems (SUDS) (Sharma 2008). There is no better example of successful civil engineering than the Tuancheng (*round castle*) in Beijing. As a miniature replica of the Beijing drainage system, the design, construction, and maintenance of the Tuancheng drainage system reflect the ecological wisdom of the ancestors and have been used to achieve a sustained and adequate ecological operation in urban infrastructure development.

2 The Evolution of Urban Drainage Systems in Beijing and the Design of Tuancheng

2.1 A Brief History of Urban Drainage Systems in Beijing

Beijing itself is surrounded by hills to the northwest and lies on an alluvial plain that slopes to the southeast toward the ocean. As early as the *Western Zhou* Dynasty (*1046–771 B.C.*), Beijing was equipped with ditches and channels for urban drainage, which have been shown in archaeological digs. It was not until the *Yuan* Dynasty (*1271–1368 A.D.*) that an integrated drainage and retention lake system was built, coincident with the planning and construction of the capital city *Yuan Dadu*. Not only was a natural surface water system used to channel stormwater in *Yuan Dadu*, but a complete open-channel-hidden-culvert drainage system was also built to collect surface water flow within the inner city. The river and lake systems outside the imperial city, including the Gaoliang River, Tonghui River, and Jishuitan Lake, were primarily used for water transport and served as important components of the urban drainage system (Fig. 1). Inside the Imperial city, the palace drainage system included the Jinshui River, Taiye Pond, and open channels and blind ditches. For example, some Yuan culverts and channels were discovered next to major avenues in modern Beijing. The main roads and streets in *Dadu* were located next to drainage channels. In light of the geographical conditions of Beijing, both drainage and storage devices were considered in the design. To ensure the smooth flow of runoff and to increase the flow rate, the complex drainage system with open channels and blind drains exploited topography with higher elevations in

Fig. 1 The drainage system of Beijing during the *Ming* and *Qing* dynasties

the northwest and lower depressions in the southeast. In addition to diverting water to natural rivers, many lakes and ponds were excavated and utilized to increase stormwater retention (Du and Zheng 2010; Hou 1985).

Although Beijing continued to serve as the capital of China in the *Ming* and *Qing* dynasties, the overall pattern of *Yuan Dadu*, in the central region, changed. The regions in the north diminished and expanded into the South City, ultimately forming a "convex"-shaped pattern. In addition to the relocation of the city center, Nanhai Pond was excavated, extending the area of Taiye Pond. Most of the drainage system of *Yuan Dadu* was preserved with some minor changes at different times, adding canals in every corner of the city. Some of the *Ming* and *Qing* drainage improvements have been identified in the Forbidden City, where a network of drainage lines, open ditches, and blind ditches intertwined, connecting all of the palaces and courtyards. Generally, water was gathered through east–west sewer lines flowing into the north–south line and subsequently into Jinshui River (the river in front of the Gate of Supreme Harmony). During the *Ming* and *Qing* dynasties, there was a regulation mandating that the ditches in the Forbidden City be cleaned in the spring. These watercourses remain in use today (Fig. 1). It has been estimated that the channel density of the metropolitan area in Beijing during that time was 1.07 km per km^2, with a total capacity of 19.35 million m^3, and every square meter had a capacity of 0.32 m^3 (Wu 1995).

In the middle of the *Qing* Dynasty, with the construction of imperial gardens in the northwestern suburbs of Beijing (e.g., Chaungchunyuan, Yuanmingyuan or the Old Summer Palace, Yiheyuan or the Summer Palace, Jingyiyuan, Jingmingyuan), three wetland systems were formed, i.e., the garden water system in the northwestern suburbs of the city, Jishuitan Lake and Taiye Pond in the inner city, and the lower level bogs (e.g., currently Yuyuantan Lake and Longtan Lake), which definitely served as important retention areas for urban stormwater.

The ancient drainage system of Beijing works well, even to this day. Notably, serious flooding primarily occurs in newly expanded urban areas, particularly under the overpasses and in depressions, but not the inner city of Beijing. In the design of ancient Beijing City, natural hydrological processes were considered and played an essential role in shaping the urban drainage system to control flood and harvest rainwater. The construction of the drainage system was integrated into the natural waterway system and subsequently connected to the man-made wetlands and imperial garden systems.

2.2 The Design of the Tuancheng Drainage System

The Tuancheng is shaped like a cake: a round terrace with several layers and rich vegetation on top. This system was first built in 1417 AD during the *Ming* Dynasty and renovated many times since. The Tuancheng has a perimeter of 276 m and a height of 4.6 m with a total area of 5760 m^2. There are 38 old trees more than 100 years old, including *Pinus tabulaeformis Carr.*, *Pinus bungeana Zucc.*, *Platycladus orientalis (L.) Franco*, and *Sabina chinensis (L.) Ant*. These trees are drought-resistant species. This area is world-famous for three treasures, namely old-growth trees, the jade urn, and the white jade statue of Buddha. However, the hidden drainage system in this area is a real cultural heritage and deserves more attention. Unlike the Forbidden City, which was equipped with stone dragons' mouths for spouting rainwater, there is not a single discharge point around the wall perimeter, neither are there any open drainage ditches on the surface. Notably, water logging would kill the drought-resistant trees described above through the induction of root rot. However, there is no mechanism for the trees to utilize the water from Beihai Lake, which is located 5.64 m below the surface. Certainly, rainwater harvesting was necessary to support the vegetation on the terrace.

Beihai and Jingshan parks launched a two-year research project under the administration of the Beijing Municipal Bureau of Parks. This project was aimed at exploring the antique rainwater technology used in the Tuancheng to reveal the mechanisms underlying the performance and longevity of this system. In particular, this study investigated the underground circular culvert system and the inverted trapezoid gray bricks and soil improvements, which largely contributed to the rapid infiltration of rainwater in the terrace to avoid waterlogging while storing sufficient water for vegetation growth (Lai et al. 2003; Li et al. 2003).

2.2.1 Paving with Inverted Trapezoid Gray Bricks

Apart from the buildings, most of the ground surface was paved with inverted trapezoid gray bricks for rainwater detention and seepage, as shown in Fig. 2. The water absorption capacity of these bricks can reach 18.84% by weight (Lai et al. 2003). Between the paved bricks, there are triangular spaces drawing water into the ground. Due to the spaces and the impermeable brick surface, rainwater cannot remain on the surface of bricks and create runoff until the spaces are saturated with water. The spaces also facilitate air permeability and evaporation from the ground. Thermoluminescence dating showed that the earliest bricks were baked 590 years ago in 1411 during the reign of *Yongle* (永乐) of the *Ming* Dynasty, while other bricks were made only 180 years ago during the reign of *Daoguang* (道光) of the *Qing* Dynasty. Thus, the Tuancheng was constantly repaired during the *Qing* Dynasty with some brick replacement. However, the form and performance of these bricks have remained the same.

2.2.2 Underground Culvert for Drainage and Infiltration

In addition to the gray bricks, another well-conceived element of the design is the underground circular C-shaped culvert system in the terrace, where at each turning point, there is a pit to collect and discharge rainwater (Fig. 3). Altogether, there are 9 rainwater inlets covered with stone strainers connected to the underground culvert. Electromagnetic detection showed that the depths of the inlets decreased from

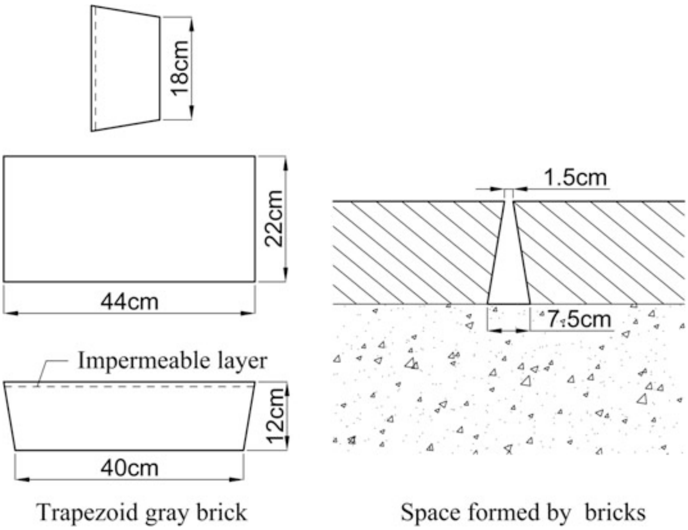

Fig. 2 Design of inverted trapezoid gray bricks

1.90 m (inlet N 1) to 0.81 m (N 9). The rainwater collected during runoff flows through the culvert from inlet No. 9, to inlet No. 8 and consecutively down to inlet No. 1, ultimately flowing out of the terrace through channel No. 11 (Fang et al. 2002). The walls and floor of the culvert are tiled with the same gray bricks (IWHR 2001).

During a heavy rain, the water flows into the culvert through the nine inlets and infiltrates into the soil through the spaces between the bricks. All surplus water is collected in the culverts around the Tuancheng and subsequently flows away. When there is a moderate or light rain, the water is retained on the surface and gradually seeps into the soil (Fig. 4). Thus, as much rainwater as possible is collected and stored to irrigate the trees. Currently, the system still works well, providing for the old trees and protecting the tree roots from waterlogging and drought during the dry season. Additionally, the culvert and rainwater inlet create an underground ventilation system enabling outside air to penetrate deep into the soil, increasing soil aeration and improving vegetation growth.

2.2.3 Improving the Soil Structure

Sampling showed that the soil is composed of three layers: supporting, organic, and yellow sandy loam. The depth of the supporting layer is approximately 10 cm and is filled with chaff and lime with good water permeability. The density of the soils in this layer is 1.23–1.31 g/cm^3, which is best suited for the growth of coniferous trees (Lai et al. 2003). The organic layer (also 10 cm) is made of organic components, such as shells and animal bones, which are also porous and supply

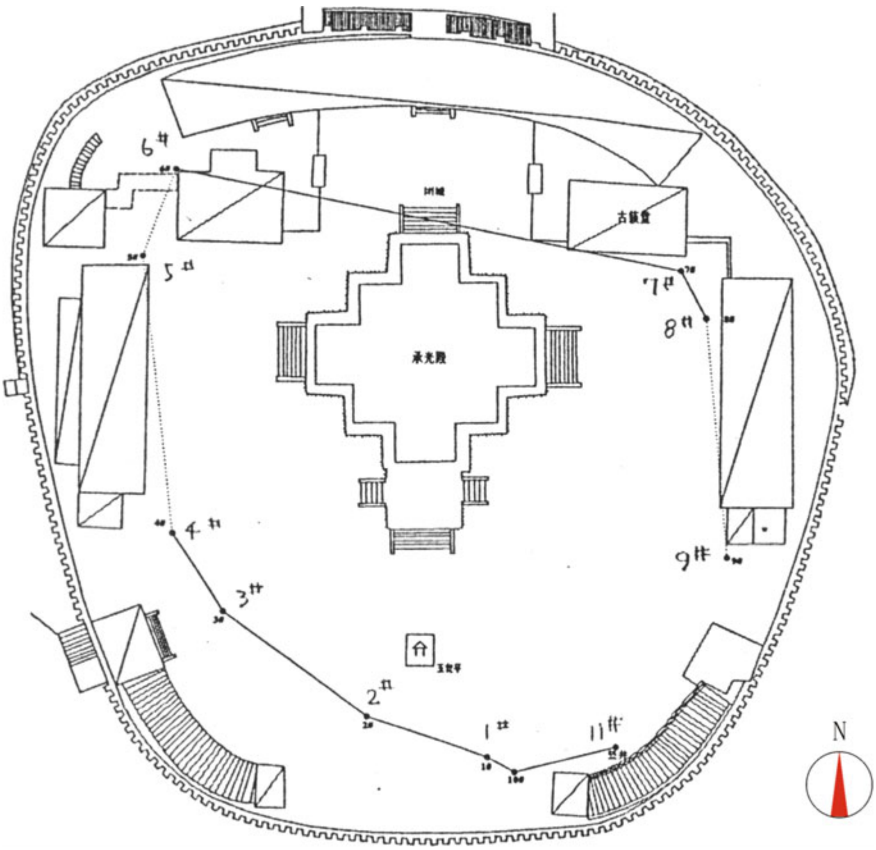

Fig. 3 The distribution of the culvert and the surface inlets (redrawn according to Lai et al. 2003)

nutrients to the old trees, suggesting that the designer of this system provided a sufficient and lasting supply of trace elements for these trees when planning the Tuancheng. Most of the soil in the Tuancheng is yellow sandy loam with a depth of 4–5 m. The experimental infiltration coefficient of the yellow sandy loam in Tuancheng is 1.23×10^{-5} m/s (Li et al. 2003). The design of the culvert and good permeability of the yellow sandy loam play an essential role in reducing moisture near the roots of the trees, thereby preventing root rot.

2.2.4 Drainage Criteria

After measuring the site parameters, analyzing the drainage area, computing the capacity, and documenting the spacing of the drainage outlets, some rough empirical Tuancheng drainage design criteria were deduced and reconstructed in reference to the studies of Wright (Wright et al. 1999). The main drainage outlet

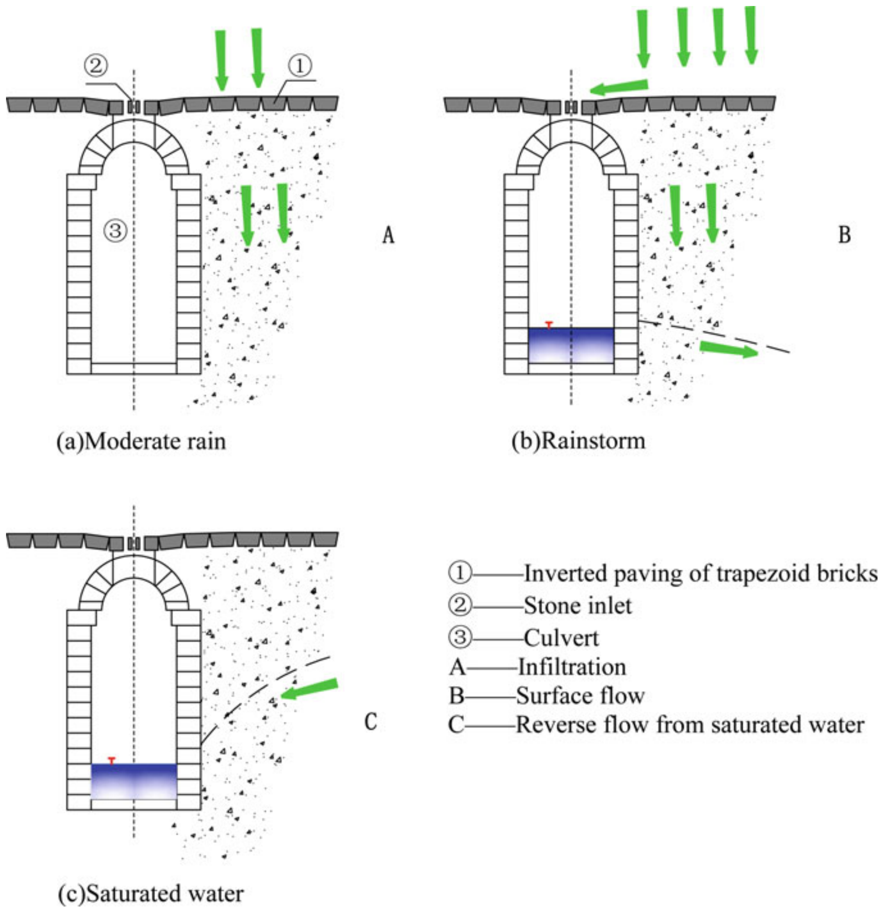

Fig. 4 Design and illustration of the performance of the Tuancheng drainage system under various rainfall regimes

parameters are presented in Table 1. Notably, the designers of the Tuancheng likely did not have any formal criteria or references for these projects and largely relied on experience and trial and error. The parameters shown represent approximate empirical equivalents. The field survey of the Tuancheng drainage system and conditions of the vegetation, buildings, and walls showed that the capacity and performance of this drainage system were generally adequate in terms of flow capacity and temporary detention storage to accommodate the intense storms that occur in this urban system. Nevertheless, model experiments are still useful to determine how this system attenuates, harvests and drains surplus stormwater (Table 1).

Table 1 Surface runoff criteria for the Tuancheng drainage outlets

Primary	Value
Total outlet number	9
Catchment area per drainage outlet	640 m^2
Drainage outlet size	48 cm by diameter
Drainage outlet capacity, maximum	1500 L/min
Design flow per drainage outlet	1200 L/min
Design rainfall intensity	140 mm/hr

3 Model Design

In this study, a simple system dynamic computer simulation model was developed, namely the Tuancheng Hydrological Model (TCHM), to examine how the Tuancheng drainage system performs under various extreme meteorological conditions, to determine how water discharge and detention are balanced, and to estimate the reserve capacity of the system in terms of both water storage (to mitigate drought) and water removal (to mitigate flooding). Simulations were performed using Stella®^{TM} 9.0, a high-level visual-oriented and language simulation software widely used in ecological modeling (Feng et al. 2013; Zhang and Mitsch 2005). An elaborate description of the Stella® package is provided by Isee Systems (2006).

A conceptual diagram for the major mechanisms of stormwater detention and discharge in the Tuancheng system is shown in Fig. 5. The model represents five processes: detention, infiltration, runoff, seepage, and discharge.

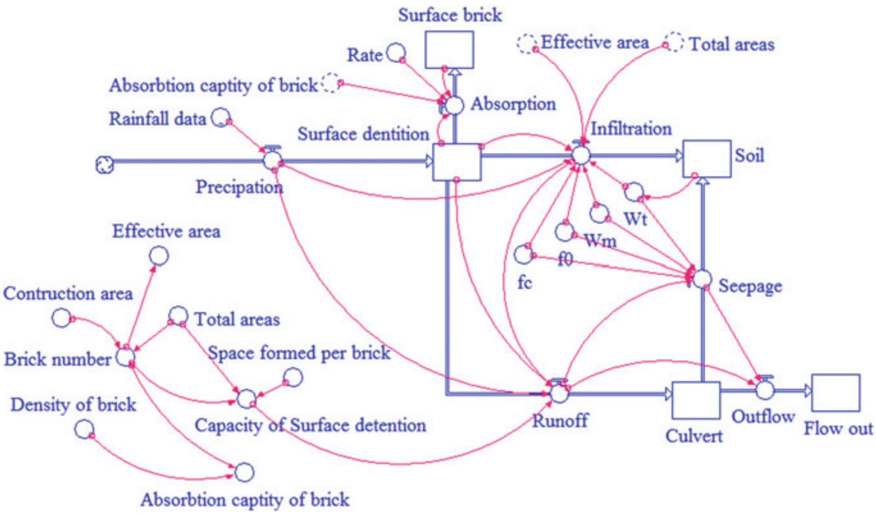

Fig. 5 The Stella® diagram for TCHM

3.1 Water Detention by the Surface Tiles

Rainfall reaching the surface first hits the ancient bricks and flows into the space between the bricks. The water in the space is simultaneously absorbed by the soil and soaked by the bricks. Notably, the bricks themselves have a certain holding capacity and serve as a sponge to soak up some of the water. The impermeable layer on the brick surface sends the water flow into the space between the bricks and subsequently into the soil as rapidly as it is infiltrated, which is highly critical in harvesting more water during a light rain. When all of the spaces between bricks are saturated, the remaining water flows toward the drainage inlets. We defined the open areas not covered by the bricks and buildings as the effective area, i.e., the area with soil left open for water infiltration. Considering the minor space around the effective area, approximately 1.5 times the effective area was used to simulate the soil water infiltration. Importantly, all units of volume were converted into the rainfall unit, i.e., mm; thus, the model is formulated per unit area. It is assumed that the water absorption rate of the bricks remains constant. The volume of the space formed by inverted trapezoid gray bricks can be calculated based on the parameters shown in Fig. 2.

$$\mathrm{SD} = \text{tile number} * \text{volume per tile/total area} \tag{1}$$

where SD is the volume of the space formed by the bricks (mm); tile number is the total number of all bricks used to pave the ground surface; volume per tile is the space formed by one brick; and total area is the entire surface area of the Tuancheng.

3.2 Water Infiltration and Seepage

As shown in Fig. 4a, infiltration is initiated when stormwater reaches the soil around the bricks. The Horton equation was adopted to describe the infiltration process (Horton 1939):

$$f = f_c + (f_0 - f_c)e^{-kt} \tag{2}$$

where f is the infiltration capacity (mm/hr); f_0 is the initial infiltration capacity (mm/hr); f_c is the final infiltration capacity (mm/hr); and k is an empirical constant (hr^{-1}).

The initial infiltration capacity f_0 was related to the initial soil moisture condition using a simple linear relationship (Chahinian et al. 2005). Therefore, Eq. 2 can be rewritten as follows (Xu 1998):

Table 2 The values of the main input parameters for the simulation conditions used in the TCHM

Parameters	Unit	Value	References
f_0	mm/5 min	4.4	Hu (2010)
f_c	mm/5 min	0.9	Hu (2010)
W_m	mm	348.53	Lai et al. (2003)
Absorption rate of tiles	mm	0.1	Liang et al. (2010)
Total area	m^2	5760	Field measurement
Construction area	m^2	1800	Field measurement

$$f(t) = f_0 * (1 - W(t)/W_m) + f_c * W(t)/W_m \tag{3}$$

where $W(t)$ and W_m represent the soil moisture at time t and the maximum soil water content, respectively.

In most cases, the reverse flow from saturated storage (scenario C in Fig. 4) does not occur, particularly during a flash storm, when it rains for a short time. However, there is another chance for the soil to absorb water, i.e., through seepage in the culvert. The same Horton equation was used here. The system parameters used in TCHM in this study are shown in Table 2.

3.3 Runoff and Discharge

Runoff only occurs when the spaces between the bricks are fully saturated and the rain intensity is larger than the saturated infiltration rate. Because the Tuancheng area is rather small and there are three rainwater inlets servicing this region, the surface water travel time is negligible. After runoff enters the culvert, this water is discharged into the urban sewerage system through channel No. 11 (Fig. 3).

3.4 Model Validation

Notably, in 1961, Tuancheng was listed as one of the key protected cultural sites in China. We were not permitted to install water meters in the culvert and underground channels. Therefore, we had to rely on the observations of the surface runoff to indirectly examine the model (Fig. 6).

On July 16, 2014, there was a heavy rain lasting for approximately 5 h (from 19:15 till 0:15). The entire event was recorded by a small meteorological station on the campus of the university (approximately 3 km from Tuancheng), with a time resolution of 5 min. In addition, field observations were conducted at Tuancheng to assess when the surface water flow appeared. At 21:21, when the accumulated rain reached 6.7 mm, the outside street showed evident runoff, but Tuancheng had none.

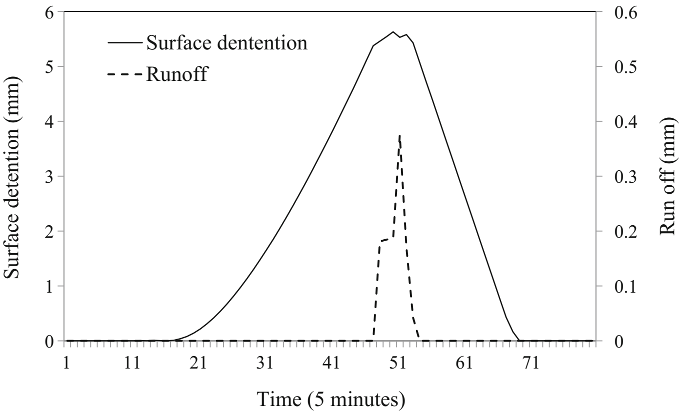

Fig. 6 The simulation result of the TCHM for the rain on July 16, 2014

The runoff appeared at 23:40, when the rainfall was 23 mm. The runoff water flowed into the culvert through the stone inlets. The model showed surface water at 23:25 pm, when the accumulated rainfall reached 21 mm. Although there was some discrepancy between the model results and actual events, generally, the observations were close enough to determine that the model performs reasonably well.

4 Results and Discussion

Two simulation scenarios were adopted to investigate the performance of the system for allocating rainwater: the “7.21” storm event on July 21, 2012 to explore how stormwater was conducted and drained and the extremely dry year of 1965 (actually the driest year in the past 100 years), with a total rainfall of only 226 mm in Beijing.

4.1 Simulation of the 7.21 Storm Event

The total rainfall near the Tuancheng areas was approximately 108 mm on July 21, 2012, which lasted for approximately 6 h and had two peaks. The time step of the simulation was 5 min.

As shown in Fig. 7, even for such extremely heavy storm rain, the drainage system of Tuancheng works well, rapidly draining water while harvesting and storing rainwater in the soil. First, the slotted drain plays an important role in detaining water, creating a space for at least 7 mm of rainwater. More importantly, this drain serves as a buffer, providing extended time for the bricks and soil to

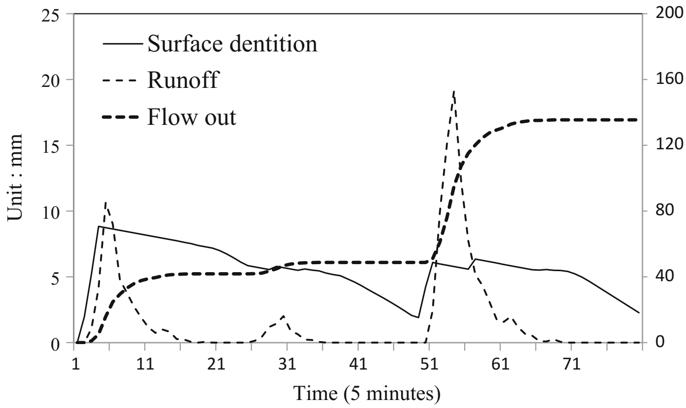

Fig. 7 Simulated draining process by the Tuancheng during the 7.21 storm rain event

absorb more water. Approximately 80% of the rainfall had been taken away, 16% of the rainfall infiltrated into the open soil not covered by tiles and into the tiles themselves, and the remaining 4% of the rainfall was detained within the spaces between the bricks, which also eventually flowed into the soil and evaporated into the air. As mentioned above, the absence of surface water accumulation is essential for pine and cypress trees and protects the roots of these trees from disease.

4.2 The Water Balance of Tuancheng in 1965

According to the available rainfall records of the past 100 years, 1965 was the driest year, with a total rainfall of only 226 mm. During this year, there were two storm events with precipitation higher than the 20 mm that produces surface runoff (Fig. 8). It is impossible for us to obtain information about rainfall at a finer time

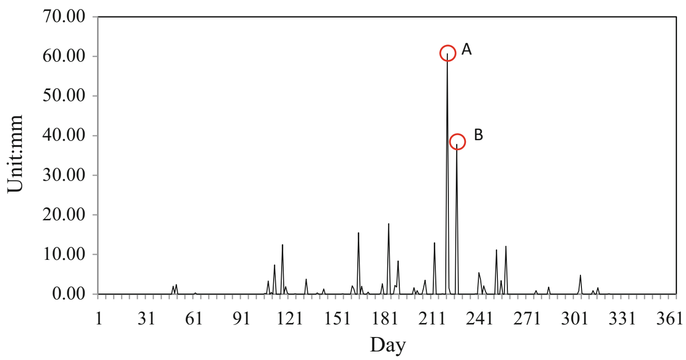

Fig. 8 The rainfall pattern in 1965

resolution. Therefore, we have to rely on the storm pattern design to reproduce these important storm events (Mou 2011; Vaes and Berlamont 2001). In addition, based on the field observations (Sect. 3.4), it is assumed that if there was no drainage system in Tuancheng, then the surface could detain no more than 7 mm of rainwater. In such a case, the total effective rainfall that infiltrated into the soil in 1965 for the Tuancheng ecosystem was approximately 226 − 7 = 219 (mm).

In contrast, only two rain events (a and b shown in Fig. 8) showed surface water flow in the presence of the Tuancheng drainage system. When we input the storms of these two rain events into the model, the simulation scenarios help to determine how the system could maximize rainwater harvest in such an extremely dry year. An annual water budget was used to estimate the amount of effective rainfall for the Tuancheng ecosystem, both surface and subsurface. According to the model results, the total amount of effective rainfall could reach 156 mm in 1965. Thus, Tuancheng was assumed to detain an additional 27 mm of rainwater, which is important for vegetation growth. As described above, in Tuancheng, there are altogether 38 ancient trees, including 26 arborvitaes, 2 lacebark pines, and 10 China Savins. The annual least water requirement for these trees is approximately 55 m^3 (9.5 mm rainfall equivalent) (Che 2008). This amount of water is far less than the additional water harvested through this system. Although we could not conclude that these trees would have been killed by drought without this additional harvested rainwater, the chance of survival during such an extremely dry year would have certainly been lower. The fact that these types of trees are rare in arid areas of China, where rainfall is less than 100 mm, supports this assumption.

4.3 Uncertainty Analysis

The TCHM model was developed to obtain a better understanding of the water harvesting and discharge during rainstorms. One of the central formulas in this model is the Horton equation used to describe the infiltration process and the seepage in the culvert. Notably, Horton's model is empirical by nature; thus, f_0 and f_c should be calibrated. We semi-quantitatively calibrated these two parameters, reflecting limited data, thereby introducing some uncertainty. These parameters could be more accurately calibrated if the runoff on the surface in the culvert and the discharge from the channel could be simultaneously measured; however, we could not obtain these measurements. In addition, a constant was assumed for the absorption coefficient of the tiles based on the reports for baked bricks. In reality, the water absorption dynamics of these ancient bricks, particularly when the initial water content is present, remains uncertain.

Another source of error might exist in the estimation of the water balance in 1965. First, a storm reconstruction was used to reproduce the rain process using 5-min time steps; and second, the water requirements of trees were roughly estimated based on the literature. For a more accurate estimation, the Penman Monteith equation (Allen et al. 1998; Monteith 1981) could be used to model this process when sufficient data are available for parameter input and model calibration. This equation could be used in a future direction for model development.

Nevertheless, the central focus of this study was not to build a sophisticated and accurate model but to show that the smart design of the stormwater system works. As long as we can achieve these goals, even a simplified model is acceptable (Voinov 2008). In this case, this model facilitated the analysis of the trends and extreme events in the system.

5 Ecological Wisdom Underlying the Smart Design of Tuancheng

Smart ancient projects, such as Tuancheng, are puzzling. How could the designers engineer such ingenious solutions and subsequently put these strategies into practice? How did these ancient scientists become ecologically and practically wise? Certainly, we do not know what standards of ecological wisdom existed during ancient time, but we could attempt to interpret the solutions in the contemporary context.

It remains difficult to explicitly define ecological wisdom, particularly because this wisdom was only recently acknowledged as an emerging domain. In the context of Chinese traditional philosophy, ecological wisdom might refer to the comprehensive ability of humans to achieve a harmonious coexistence with nature by making adequate decisions and choices in a resilient, systemic manner using available knowledge. We do not know how to learn to determine “the right way to do the right things” or how to instantly become wise, but we propose that trial and error, followed by reflection, and analysis is one of the essential components of the self-organization of the ancient knowledge system. We also propose that a certain level of precaution and safety margins is essential to ensure that we do not ruin the system through experimentation and examination using a trial and error process. Therefore, ecological wisdom should be defined in a broader dimension, as part of the protocol of doing real and permanently good things (real-spatial dimension, permanent-temporal dimension). Correspondingly, according to Xiang (2014), ecological wisdom should include specific examples of the prior time-honored knowledge of an individual or group in the realm of ecological research and planning practices. In other words, the ideas, principles, strategies, and approaches proposed by such wise individuals should be adhered to, implemented, and materialized to become actionable knowledge.

5.1 Principles and Ideas Reflected in the Design of Tuancheng

It is evident that our ancestors respected and understood the natural and ecological principles observed in ancient times. These individuals have certainly achieved a paramount level of doing real and permanent good in the field of ecological research, planning, design, and management through the implementation of ideas, principles, and strategies of ecological wisdom that have long been in coexistence with nature (Xiang 2014). The nature-inspired experiences and advanced concepts underlying these practices deserve the attention of modern engineers (Che et al. 2013). The wisdom of the ancient Beijing drainage system can be represented in the design of the Tuancheng drainage system, an excellent example that combines drainage and water retention systems on the ground and underground using gray and green infrastructure, to create a hydrological landscape functionally equivalent to the required natural conditions (growing trees in a city environment).

Correspondingly, in the design of the Tuancheng drainage system, the ancient people regarded stormwater management as a hydrological process rather than only part of municipal engineering. The central idea was to build a healthy hydrology, rather than install more pipes and concrete tanks to rapidly discharge the storm water (Todeschini et al. 2012). These basic principles for urban drainage system design are similar to the concept of low-impact development (LID), involving the realization of a natural hydrology using site layout and integrated control measures. The natural hydrology for each site strives to maintain a balance between pre-development runoff, infiltration, and evapotranspiration through a functionally equivalent hydrological landscape and water cycle (Fletcher et al. 2014; USEPA 2000).

Arguably, the drainage systems of the ancient times generally required adequate land areas and space for the application. Rapid urbanization and growing population density in a metropolis, such as Beijing, make land one of the most scarce and precious resources. As described above, the Tuancheng system was carefully planned and constructed to fully exploit the confined space at carrying capacity. A smart design with regard to both surface and subsurface hydrology was implemented on a small area of 5760 m^2, which functioned well in draining stormwater, providing an important visual amenity for the community. The remarkable C-shaped subsurface drainage definitely extended stormwater infiltration and disposal areas. The nine surface inlets and the large culvert provided adequate space for water discharge and fed a subsurface storage reservoir to avoid high water table conditions during high-intensity rainstorms. The potential decay with time, high terrace, and appropriate balance of water demand and supply were overcome by the exceptional ability of the ancient engineers to construct adequate building foundations and install effective drainage systems. This smart design encourages current urban planners and designers to make the best possible use of the land and achieve multiple objectives of performance, esthetic landscape appeal, biodiversity, and even cultural continuity consistent with the location (Li et al. 2012).

5.2 Learning from Ecological Wisdom to Address Urban Flooding in China

With contemporary stormwater management becoming increasingly challenging because of rapid urbanization, increased land modifications and population concentration, all further exacerbated through climate change, exploring ecological wisdom could help to identify more effective and efficient strategies for coping with these challenging issues in the current context of China. The development and management of urban drainage systems have experienced significant changes over the past decades, shifting from largely narrowly focused approaches (with the sole aim of reducing flooding) to an approach with multiple purposes (Fletcher et al. 2014). The evolution of modern stormwater management can be traced back to McHarg's book "Design with Nature" published approximately 47 years ago (McHarg 1969), followed by the ideas and projects of John Todd on "Ecological Design" and "living machines" (Todd and Todd 1994) and other projects at the end of the last century. Indeed, such concepts are identical or at least similar to those of our ancestors, previously designed and planned hundreds of years ago. Unfortunately, in its pursuit of economic growth, modern China has fallen far behind in some sustainability practices, including urban stormwater management, which is clear from frequent reports of flooding, even in the case of moderate rains.

Ideally, we need to combine the enlightenment from our ancestors with advanced ideas and technological solutions in current planning and management. A sound approach to stormwater management should be flexible, considering local characteristics and fully accounting for temporal, spatial, social, and political factors realized in various regulations and laws, among other issues (Barbosa et al. 2012). The geophysical characteristics of different urban areas (e.g., climate, hydrology, land, soil and topography) will influence the choice of best management practices (BMP) for stormwater management and disposal (Barbosa et al. 2012). According to (Jones et al. 2012), the variability of volumetric performance in studies of BMPs indicated that design attributes and site conditions play a key role in BMP performance. The ancestors had previously given high priority to local conditions in engineering design. However, we should not ignore that land use pattern has been largely altered with paved green areas and filled water bodies as a result of urbanization. Nevertheless, the current urban drainage system techniques, including infiltration trenches, permeable surfaces, water storage, swales, water harvesting, detention basins, rain gardens, wetlands, and ponds, should always be considered in the local context when sustainability is desired. When determining stormwater management practices, it is relevant to consider that a good solution might not be operational in all contexts.

Another important idea from the ancestors is to treat urban drainage issues as a system project rather than a single object of civil engineering. Fortunately, the new urban drainage systems developed in China are also shifting from pure infrastructure engineering for pumping and channeling water to multi-functional systems involving water harvesting, pollution control, ecological restoration, and flood control in which natural hydrological processes are considered and play an essential role in shaping the urban drainage landscape. Currently, the central authorities of China have released a pilot list of 16 so-called *sponge cities* and issued construction guidelines (MOHURD 2014), representing a good example of the positive changes in urban drainage system development in China.

In addition, temporal and spatial dimensions are always an intrinsic part of the knowledge system for sustainable urban drainage. The Tuancheng illustrates how our ancestors made the best use of space and accommodated spatial dimensions in a smart design. Moreover, any decision requires testing. The planner and designer should rigorously investigate the cases and proceed with caution rather than readily adopting existing practices. Modeling also plays a crucial role. We should also realize that now, even more rapidly than before, we live in a world that is constantly changing. Climate change, or global change in general, has a strong impact on the best practices of design. The Tuancheng drainage system still performs well because there were no substantial changes in the climate over the past 600 years since this system was built. In the face of current global changes, we should consider design solutions that either have a large margin of additional capacity to manage potential wide fluctuations in environmental conditions or evolve to adapt to changes.

As stated above, urban stormwater management in China is more challenging because of high population densities, fast urbanization, scarce land and water resources, environmental pollution, climate change, and complexity of infrastructure. Certainly, there is a long way to go, but we can make better progress by applying the ecological wisdom of our ancestors and by learning from other regions and cultures around the world. In addition, substantial studies are needed to integrate traditional principles with modern technologies and strengthen the linkage between urban planning, landscape design, municipal engineering, and ecological restoration.

6 Concluding Remarks

With fast population growth and rapid urbanization, Chinese cities are in a conundrum, simultaneously suffering from both severe waterlogging and water scarcity. The success of the Tuancheng drainage system rests on the fact that for 600 years, this system survived all of the intense rainstorms and droughts without suffering from foundation failures or damage, providing livable habitats for trees on a 4.6-m-high terrace with no irrigation. The results of hydrological modeling illustrate and explain how this system works. The Tuancheng drainage planning in this terrace was well conceived and constructed. The surface and subsurface drainage works were built to manage storm rainfall and protect the trees from both waterlogging and desiccation. This small case illustrates the rich ecological wisdom of our ancestors.

The ecological wisdom illustrated by the Tuancheng lies in the nature-inspired design that provides for a healthy hydrological cycle and plays an essential role in shaping the urban drainage system, similar to the concept of LID proposed 560 years later. Moreover, the design of the C-shaped culvert elegantly addresses the space limitations and balancing of water demand and water logging. The ecological wisdom of these design principles remains informative for the modern design and planning of urban drainage systems.

Yet another challenge of the current management is the transition to more democratic societies, likely making it even more difficult to implement the best solution that satisfies large numbers of people. It is one thing when engineering is performed for an Imperial garden with almost no restrictions on costs and building efforts. It can be different when all sorts of preferences, beliefs and biases of the society at large are involved (Voinov et al. 2016). Now we need to ensure that the design solutions are transparent and appealing to stakeholders who understand and are ready to support these practices. A more participatory approach can be of great value here. In this context, appealing to the ecological wisdom of the ancestors can also be a good ‘selling point’ of a project and increase the trust and engagement of stakeholders in its implementation.

Certainly, contemporary stormwater management in China is more challenging than ever compared with many other counties worldwide. To address the complex problems, it is important to synthesize and integrate ecological wisdom from ancient China with that from other cultural systems, i.e., exploring transgenerational, transcultural, transphilosophical and transdisciplinary ecological wisdom and applying those ideas and technologies to deepen the current understanding of modern urban stormwater management and build water-resilient cities in China and other areas worldwide.

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Ecowisdom and Water in Human Settlements

Katherine Lieberknecht

1 Introduction

In the following chapter, I examine human–water relations in cities to demonstrate how water provides a visible, critical connection to nature in urban areas. These interactions allow opportunities for humans to co-create "ecologically wise" solutions for long-term resiliency. Researchers describe ecological wisdom (EW) as contextually relevant and historically grounded "ideas, tenets, strategies and… approaches that have led to the creation and sustained longevity of exemplary ecological projects and effective policy instruments" (Xaing 2014, 67). In particular (Young 2016, 95), framing of EW as an understanding that "human beings are within nature…rather than outside or over nature" bears particular importance to the idea that human–water relations provide a significant example of coevolutionary urban habitat.

Before I begin, I would like to clarify that EW is not solely *environmental* wisdom, i.e., historic and contextual knowledge about environmental aspects such as water, soil, or biodiversity. Rather, EW is *ecological* wisdom, which means it encompasses wisdom about systems and relationships, two key parts of ecology. As such, EW contains information about physical components of the system (such as water, soil, or the built environment) and social relationships (such as governance, management, or future stewardship). Therefore, as discussed above, humans comprise a critical part of EW, as we strive to build knowledge about ecologically appropriate interactions with the rest of nature, the built environment, and within settlements. Thus, EW is co-created by humans and the rest of nature: To add an urban ecological layer to Ian McHarg's work, we are designing with nature, and humans are a part of nature, too.

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Water in human settlements provides a good litmus test for the following proposition: EW offers successful pathways to conserving, repairing, and facilitating socio-ecological systems that may lead to long-term resilience. Water's ubiquity and power mean that water impacts almost all systems within human settlements. Whether in small villages or expanding megacities, water affects public health, food systems, public safety, housing, transportation, recreation, and energy systems, to name just a few examples. In addition, water, because of its often visible feedback loops and variability in flow, provides a useful yardstick of flexible, context-specific EW solutions, designed by humans considering the rest of nature.

In this article, I provide a brief literature review focused on two important characteristics of water in settlements: visibility and variability. I then give an overview of my methodology and then define and discuss two EW strategies communities have developed to work with water. These two strategies provide useful examples of the types of wise systems that humans have designed with the rest of nature. I finish by concluding that although context always matters, transferable EW patterns exist and can be shared, allowing any community to work toward EW. In particular, water's visibility and variability allow a significant opportunity for people to co-create resilient urban habitats with the rest of nature.

2 Water in Human Settlements: Visible and Variable

Two characteristics of water in particular add depth to an examination of water strategies through an EW lens: water's potential for visibility and water's variability over space and time.

2.1 Water, Visibility, and Wisdom

Water's visibility encourages us to recognize nature in cities—whether experienced as a pleasant walk along an urban creek, an opportunity to watch birds bathe in a puddle, or rising floodwaters that warn us to evacuate, at least until the storm subsides. The visibility of water can remind us of the availability, quality, and potential dangers of urban water systems. On the other hand, hidden water can create problems. Creeks partially hidden by retaining walls behind retaining walls can suddenly—and without much notice—flood to dangerous levels; unseen and undervalued water bodies may be treated as informal sewers; urban streams divorced from their historic, permeable watersheds result in ecological systems characterized by poor recharge and low stream flow. When human actions hide water in cities, it becomes difficult to see, experience, and steward the water–human relationship.

But when water remains or again becomes visible, humans become more aware of water's value. Many cities have examples of contextually relevant and historically grounded visible water systems, such as Frieberg's bachles, Rome's ornate public fountains, or Mumbai's stepwells. These examples of the blue built environment serve to supply water but also deliver a visible reminder of the lifeline that water provides to urban areas. In these systems, visible water acts as a critical ecological feedback loop and an important part of resilient systems (Hemenway 2015)—both key aspects of an EW approach to water strategies.

3 Water, Variability, and Wisdom

Water distribution varies over space and time. As such, water's variability requires of humans an adaptive and context-specific process, which is a hallmark of EW. Although the earth is a blue planet, in much of the world humans oscillate between not having enough and having too much water. Water distribution varies across space, which is evident when we think about climate and vegetation; water variation over time can prove to be an even more vexing problem for static human settlements. Water distribution can change seasonally, such as in areas with monsoon weather patterns that receive a year's worth of rain in 1 month, or in places dependent upon snowmelt that see a significant flow increase in early summer. Water also has annual patterns in the form of wet and dry years.

Human social systems also impact water distribution and variability. For instance, unequal political power can result in water being distributed unequally between cities and rural areas, or between two cities and nations, which researchers have identified as a variation of the classic area versus power problem (Page and Susskind 2007).

Besides space, time, and power, climate change now also adds another layer of uncertainty to water variability. With a changing climate, places are experiencing variations in water distribution ranging from more severe flooding to more extreme drought. Historically, engineers have used the concept of "stationarity"—that hydrological processes in a particular watershed or area could be described by probability distributions that do not change over time (Pahl-Wostel 2011). Climate change means that these previously static distributions are now changing; EW may offer a palette of needed approaches to help incorporate this additional uncertainty into water supply, flood, and drought planning.

Because of the variability that characterizes many water systems, humans have sought to make water predictable by controlling or modifying the flow of water for the purpose of obtaining water supplies, mitigating drought, or reducing flooding. However, many of these "one-size-fits-all" solutions, such as megadams and centralized, single-source water supplies, have caused billions of dollars in damage and have contributed to vulnerable human settlements (World Commission on Dams 2000). EW's context-specific, historically sensitive systemic approach to water's variability provides an opportunity to create more resilient methods. EW's "toolkit" includes the gathering of local and regional data about evolving conditions; an adaptive approach to choosing, implementing, and maintaining (or changing, if needed) social and ecological system strategies; and an approach to resiliency based on diversity and distribution, providing an opportunity to prescribe an array of diverse, small strategies related to a bigger whole, rather than a single large solution.

Although much of EW's strength depends upon its sensitivity to local context, there are some common patterns to glean from interactions among water, soil, vegetation, and humans. In the following section, I will define and discuss two general EW strategies for water systems, based on intersecting comprehensions of water, soils, vegetation, and humans, communities have created to mitigate variability or take advantage of visibility. These two strategies provide useful, durable examples of the types of wise systems that humans have designed with the rest of nature.

4 Methodology

In this chapter, I highlight two EW water strategies developed by communities. These strategies were identified by using Yale University's Human Relations Area Files (HRAF) database to identify 1012 records of historic and context-specific water systems from around the world, based on empirical data gathered from across the disciplines (Lieberknecht 2017, in review). HRAF is an internationally recognized cultural anthropology organization; its mission is "to encourage and facilitate the cross-cultural study of human culture, society, and behavior in the past and present" (Yale University 2015). HRAF maintains two online databases; I used the eHRAF World Cultures database for this research. The eHRAF World Cultures database includes ethnographic collections focused on indigenous people and ethnic groups globally and immigrant and indigenous cultures in the USA and Canada. Currently, the database includes 290 cultures and 600,000 pages of text. Records are categorized by region, subregion, and culture (e.g., North America, Plains, and Plateau/Comanche).

I searched for terms related to water strategies, identified text segments with these terms, imported the identified text segments into a spreadsheet, and noted the author, publication, region, subregion, and culture. I then summarized and coded the information in each text segment using keywords, which I developed from an existing list I had created from the literature review and also supplemented with additional keywords as the need arose during the summarization process. After I assigned keywords to the text segments, I again went through the 1012 records to standardize the keywords, ensuring that I used keywords throughout the records consistently. I chose to use a manual approach to text analysis rather than using text analysis software because of methodological concerns about errors of omission (Young and Wolf 2006), given the historic and linguistic diversity of records.

Several caveats exist about this methodological approach. Since the eHRAF database is an existing collection of ethnographic research, these data can be used as a source of ideas about how human settlements have managed water over time. However, given that I did not develop this database and therefore had no control over which records were or were not included, these data cannot be used as a comprehensive list of all water strategies. Nor can the database be used as a source of data for meaningful statistical analysis, since, for instance, the frequency of a specific water supply strategy might be due to a bias in the selection of records to include in the overall database.

This process generated about a dozen general water strategies that appear to provide durable, context-specific approaches to communities working to manage water. For the purpose of this chapter, I highlight two of these strategies: the matching of different water sources with appropriate uses in human settlements and ensuring water quality by protecting the soil and vegetation assemblages that impact a specific water supply. For both strategies, I provide historic information about how communities used these strategies as a means of EW, matched with a current example of a Central Texas community using the same strategy as an EW approach to water. I also focus on the strategy's physical system, social system, and approach over time—what I view as three interesting and important components of EW solutions.

I chose to highlight current examples in Central Texas because this region is my home, so I have more socio-ecological knowledge about this place than most other places. In addition, at least in some quarters, Texas does not have much of a reputation for either being ecological or for being wise—so I would like to demonstrate through these examples that I believe all communities can work toward EW, even under imperfect conditions. In other words, EW is a living, breathing approach that is available to everyone willing and able to pay attention to place.

5 EW Approaches to Water in Settlements: Strategies and Supporting Examples

For each EW strategy, I will provide information about how people have adapted these patterns within particular places and times, as well as a contemporary example from Central Texas. I also will briefly give an overview of each strategy's physical system, social system, and any temporal aspects.

5.1 Matching Sources and Uses: Prioritizing High-Quality Water with High-Quality Uses

The urban water cycle consists of many different water sources, including rainwater, groundwater being pumped or bubbling up as springs, surface water such as creeks and rivers, or wastewater, to name a few. Many communities throughout history have matched these different sources of water with different uses, as a means of prioritizing the highest quality flows for uses that require pathogen-free water. Because of water's variability, communities modified their uses over time, depending on availability and scarcity. For instance, people used springs, wells, or rainwater for drinking, cooking, and sometimes washing, but if a particular water supply became limited, people would switch to lower-quality surface water for uses like washing, reserving the highest quality water for drinking (Lieberknecht 2017 in review). In contrast, many of today's cities approach water sources and uses from a completely different perspective, providing potable, highest quality water to all urban water uses, regardless of need. As a result, research estimates that in some cities, 95% of the potable water supply goes to uses that do not require high water quality (Wong and Brown 2011, 484). Taking expensive, highly treated, energy-intensive potable water and using it to water, a lawn is a poor way to match different water sources and uses. Many municipal uses could safely be matched with lower-quality water sources such as collected rainwater for vegetation watering or reclaimed water (treated wastewater) or gray water (previously used but pathogen-free water) for toilet flushing, resulting in saved water, energy, and money.

From an EW perspective, a physical system that matches different water sources for different water uses requires localized, context-specific data gathering about water sources, water quality, and water uses. Socially, communities have to be willing to use different sources of water. Depending on the place, this may require getting over the "ick" factor of using treated wastewater, which can be a difficult hurdle to overcome (Lemonick 2013). In addition, water managers have to be willing and able to manage and finance more distributed, diverse water systems that are dependent on multiple sources; this adds a layer of complexity for places that had previously depended on one source of water (City of Austin staff member, personal communication 2015). Over time, water source quality and water uses have to be monitored, so that policy makers and managers can make changes as new sources become available, new uses are identified, or water quality shifts.

San Antonio, Texas and its municipal water system (San Antonio Water System, or SAWS) offer an example of a city that was an early adopter of a distributed, diversified water system that uses different sources and qualities of water for different uses. Until recently, San Antonio was the largest city in the world to depend solely on groundwater for a water source (SAWS 2014). San Antonio is located along the chain of artesian springs that occur as groundwater from the Edwards Plateau geographic formation meets the Blackland Prairie ecoregion; the resulting topographic drop forces the groundwater up, creating highly pressured springs. When the Spanish built the missions that became present-day San Antonio, hundreds of springs were clustered in the area, although most no longer produce water today, due to aquifer depletion (Texas State Historical Association, undated). Frederick Olmsted visited the area in 1857 and wrote:

> …The San Antonio Spring may be classed as the first water among the gems of the natural world. The whole river gushes up in one sparkling burst from the earth. It has all the beautiful accompaniments of a smaller spring, moss, pebbles, seclusion, sparkling sunbeams, and dense overhanging luxuriant foliage. The effect is overpowering. It is beyond your possible conceptions of a spring. You cannot believe your eyes, and almost shrink from sudden metamorphosis by invaded nymphdom." (Olmsted 1857, as cited in Brune 1981: 71)

The visibility of these springs not only impressed Olmsted, but also inspired SAWS original distributed municipal water system, built to use multiple springs scattered across the city (San Antonio staff member, personal communication). SAWS continues to maintain a distributed water system that now also draws from diverse flows of water, matching different water sources with appropriate water uses. Groundwater from multiple wells continues to be the predominant source of municipal water, but SAWS also produces reclaimed wastewater, which is used for watering lawns, parks, and golf courses, for industrial purposes, and to fill the San Antonio River that flows past the famous River Walk. SAWS has also developed an aquifer storage and reuse system that allows them to even out the variability of aquifer water production without harming the endangered species that depend on high aquifer levels. San Antonio's aggressive water conservation program can even be considered to be an additional water flow—the millions of gallons of water that has been saved through indoor and outdoor water conservation allow the city to reduce their dependence on groundwater.

Although SAWS' shift to a more diversified water system was accelerated by the 1990s-era federal endangered listing of several species living in the aquifer and its springs (SAWS 2014), SAWS credits in part its ability to quickly adapt to using diversified water sources to its origins as a water system based on multiple, spatially dispersed springs (SAWS 2014). Today, this fast-growing city has managed to decrease its water use to less than it used in 1984, even though its population has grown 67% to 1.3 million (SAWS 2014); water conservation combined with water source flexibility has allowed this city to co-exist with the other species dependent upon the aquifer and has created a city population known for its "water literacy." Most famously, the current aquifer level is given each night on the evening news, alongside the weather forecast for the next day (KENS5 Eyewitness News 2016)

SAWS' water system is not perfect; recently, San Antonio has come under much criticism for its plans for a long-distance pipeline to bring groundwater to San Antonio from another county (Collier 2015). However, many of the characteristics of SAWS' story describe an EW approach to urban water management: Contextually relevant and historically grounded "…strategies…that have led to the creation and sustained longevity of exemplary ecological projects and effective policy instruments" (Xaing 2014, 67).

5.2 Source Protection: Using Soil and Vegetation to Preserve Water Quality

Source protection, or the protection of land over and around drinking water supplies, is one of the oldest strategies used by human settlements for water quality protection (Trust for Public Land 2006). Land protection for drinking water supplies remains the best way to safeguard long-term quality of water supplies (Barten and Caryn 2004), and the public continues to demonstrate strong political and financial support for source protection of water supplies (Barten and Caryn 2004). The US Environmental Protection Agency (EPA) estimates that the cost of treating contaminated groundwater supplies is on average 30–40 times more, and upward of 200 times greater, than preventing their contamination by protecting land above and around water supplies (EPA, undated). Source protection can be accomplished by direct purchase of land or land rights, or through land use regulations that require that sufficient soil and vegetation remain in place to filter water.

Viewed through an EW lens, source protection for water quality purposes sets aside a physical system of protected or regulated land so that a natural assemblage of soils, plants (both above ground vegetation and roots), microbes, and larger soil fauna interacts to filter water, remove pollutants, and recharge water supplies. The basic mechanism of filtration remains consistent across ecoregions and cities, although local context determines soil and vegetation type, climate, precipitation rates, and process speed. Socially, an EW approach might focus on resolving the potential rift between urban residents who benefit from the water protection but do not necessarily see or directly experience the protected source lands outside the city, or who do not appreciate the positive impacts of land use regulations in the city. For instance, since source protection in the modern era is often paid for by municipal bonds (Trust for Public Land 2006), from a social perspective, it is important for taxpayers to understand the relationship between their funding, their clean water, and the source protection land located outside the city limits and the land use regulations within the city itself. Peering into the future, an EW approach might consider the possibility of conflict over long-term protection of the water quality land, given that if the city grows, the protected land will likely experience development pressure and possible encroachment.

Austin, TX's Barton Springs pool and the Edwards Aquifer that contributes to it provide a current example of how a community, over decades, has chosen to value and protect a water system by implementing layers of land protection, both through regulation and through outright land purchase. I have chosen this example because it showcases how one community has practiced an EW approach toward a cherished water system, under imperfect conditions but with a substantial amount of success. Austin's human–water relations show how water can provide a visible, critical connection to nature in cities, while providing a medium for humans to co-create EW solutions for long-term resiliency.

Many Austinites consider Barton Springs pool to be the green heart of Austin: The spring-fed, three-acre pool is surrounded by sloping hillsides and a 350-acre park. Four springs feed the pool, which is a dammed area of Barton Creek; the pool bottom and sides are the natural limestone creek bed, and fish swim beside the human swimmers. At least once a week, the dams are opened, and pool staff and the flowing creek itself remove debris; during the rest of the week, the creek is routed under the pool's sidewalk, where it then joins the downstream creek bed again just after the second dam. The springs keep the pool temperature at a constant 68° Fahrenheit, which means that people can use the pool year round.

Beginning in the 1960s, Austin's nascent environmental movement began to coalesce around protection of this nested water system: the pool, the springs, the larger creek system, and the regional groundwater recharge zone (Swearingen 2010). Although Austin's fast population growth and Texas typical low-density land use development have negatively impacted creek and spring water quality and quantity (Lieberknecht 2000), city residents have successfully organized for a number of development regulations and land protection projects that have retained the filtration capacity of the native soil and vegetative system by reducing impervious surfaces and pollution (Lieberknecht 2000; Swearingen 2010). And, like the San Antonio case, federal protection of endangered species habitat in the 1990s added an additional layer of land and water protection, this time to protect the Barton Springs Salamander (Lieberknecht 2000).

The EW lessons from this example could fill an entire book, but three particular highlights include the physical built environment of the pool itself that makes the spring and water system so visible, a management system built around the cohabitation of humans and the rest of nature, and a soil/vegetation protection process that created a broader regulatory system to improve water quality throughout the Austin area (although unfortunately, not to the degree necessary to return water quality and quantity at pre-urbanization levels).

The groundwater that feeds the creek, spring, and pool is not visible (except during very wet times, when one of the springs bubbles like a fountain), but the built environment of the dammed pool structure and the mown hillside leading down to the pool create a highly visible, recognizable, and beloved Austin icon. Although Austin and the surrounding Central Texas area are well known for its swimming holes, Barton Springs pool maintains an iconic status for many residents; at least, part of its reputation lies in the juxtaposition of a fast-growing city with the pool, the Civilian Conservation Corp-era structures, and the larger park. The contrast between the pool–spring–creek water system and the rest of Austin creates a symbol of both what Austin was (a laid-back, small city whose residents had lots of time to sunbath and swim) and what Austin strives to be (a green, livable metropolis in the heart of Texas).

Although Barton Springs creek and spring water quality and quantity have declined as the watershed and recharge area's hills have experienced large-scale housing, commercial, and road development over the past 30 years, the management of Barton Springs pool and the source protection it has inspired provide a robust example of how a community has worked together to cohabit with the rest of nature, albeit not perfectly. The tiny salamanders that live in the springs and swim in the pool alongside people would have likely done just fine, or perhaps even better, if Austin had not grown around its habitat. However, it is also possible that without the attention and protection paid to the springs, the pool, and the broader water system by concerned Austinites, that the salamander would have disappeared alongside countless other unnamed and undiscovered species endemic to the limestone karst aquifer ecosystem (Swearingen 2010). Austin certainly has negatively impacted this water system, but it has also, although imperfectly, successfully protected some of the function and flow of the spring and creek system and secured habitat for the salamander and other species.

Lastly, Austin's relationship to Barton Springs pool created a rigorous, nationally recognized city-wide water quality protection program—which may not have occurred without the concerted effort to protect the springs and pool. Land use regulations and outright land protection efforts developed to protect the springs and creek by retaining healthy soil and plant assemblages have created a metropolis that is growing in way that at least partially retains ecological function. Perhaps perversely, the success of these land protections and regulations can be seen by comparing the water quality of creeks that flow through the newer parts of the city, versus the creeks that flow through the oldest neighborhoods: The water quality protection that resulted from the process to protect Barton Springs has ensured the newer development in Austin is shaped to protect water quality and quantity, even as the creeks in the older parts of town, which were developed before the Barton Springs-era protection, continue to suffer from significant pollution and inadequate base flows (Swearingen 2010).

6 Conclusion

Water–human–cities interactions provide a useful test case for the idea that EW offers a pathway to conserving, repairing, and facilitating socio-ecological systems that may lead to long-term resilience. In this chapter, I discuss two water strategies that I consider to be ecologically wise: matching different water sources with appropriate uses within human settlements and ensuring water quality by protecting the soil and vegetation assemblages that positively impact a specific water supply. These two strategies were identified by using Yale University's Human Relations Area Files database to identify historic and context-specific water systems from around the world and based on empirical data gathered from multiple disciplines (Lieberknecht 2017 in review). For both strategies, I provide information about how communities used these strategies historically, matched with a contemporary example of a Central Texas community using the same strategy as an EW approach to water. I also highlight the strategy's physical, social, and temporal systems, since each of these components are critical pieces of EW solutions.

These two examples give us some practical, applied advice about how communities practice EW. First, although the context is always critical, there are transferable EW patterns that can be shared between places, just as ecology provides us with general knowledge about relationships and interactions. Two of these transferrable patterns include: (1) the efficient matching of different water sources with appropriate water uses, matched with by a social context consisting of a community willing to make changes and adopt behaviors necessary to diversify water supplies, and (2) the use of soil and plant assemblages, nested within a social system of incentives and regulations, to protect and restore water quality and quantity. Second, any community can work toward EW, in real time, even under less than perfect situations. For instance, although Austin's work to use land protection and regulation to keep the Barton Springs water system healthy has not completely resolved the creek's water quality problems, this process has strengthened water quality and supply recharge policies throughout the city, bringing Austin closer to a EW system of water management. Likewise, although San Antonio still has more work to do to balance its population growth and low-density development with declining groundwater supplies, the city has made significant progress by diversifying its water sources, saving water, energy, and municipal funds in the process.

A final consideration: water's visibility and variability provide a unique opportunity for people to work with the rest of nature to co-create resilient homes. EW offers a useful, flexible pathway for this process. As a parting thought, I offer one last story from San Antonio. San Antonio named their wastewater and recycled water facility Dos Rios Water Recycling Center (Spanish for two rivers), a play on words that refers to the "river" of city wastewater that is piped to the facility and the Medina River, a branch of the San Antonio River that receives the treated wastewater produced at the facility. Wastewater flows are some of the only increasing water sources in places like Texas, where surface and groundwater supplies are declining, but cities are growing. As mentioned earlier, the wastewater that enters the Dos Rios facility is cleaned to such a degree that the city reuses it to water landscapes, sell for industrial production, and to fill the River Walk branch of the San Antonio River.

In December 2013, SAWS voluntarily applied to the State of Texas for permission to donate 50,000-acre-feet of its recycled wastewater for instream flows in the Medina River/San Antonio River system (Brown 2014). The recycled water is discharged from the Dos Rio facility and eventually makes its way to the Gulf of Mexico, where it supports habitat for the world's last wild flock of the endangered Whooping Crane (*Grus americana*). The Whooping Crane flock suffered significant losses during the low flows of the severe 2011 drought (Mosqueda 2013); San Antonio's urban water system now provides a stable, high-quality flow of water for the river and bay ecosystem, which hopefully will provide a buffer during future drought events.

San Antonio still uses substantial amounts of groundwater and has come under criticism for their plans to build a long-distance pipeline to import water from another county. However, San Antonio's contribution of reclaimed wastewater to provide environmental flows to Whooping Cranes and the larger ecosystem shows one visible pathway of how peoples in cities can interact with water to produce ecological value. My hope is that other cities and communities realize their own potential to design and implement EW water strategies, even in incremental ways (Fig. 1).

Fig. 1 Photograph of San Antonio's treated wastewater from the Dos Rios wastewater plant being returned to the Medina River, which eventually provides water to the world's last wild flock of Whooping Cranes (*Gruz americana*); they make their home in the San Antonio Bay along the Texas coast of the Gulf of Mexico. *Photograph credit* William Niendorf

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Traditional Ecological Wisdom in Modern Society: Perspectives from Terraced Fields in Honghe and Chongqing, Southwest China

Zhifang Wang, Qianzi Jiang and Yuanmei Jiao

Abstract In reflecting the shortcomings of modern science, traditional ecological wisdom (TEW) is increasingly believed to have profound capacities in providing inspirations for ecological design to sustain our future. However, the evolution and applicability of TEW in modern society are often overlooked. To better understand this issue, this paper explores and compares two cases of terrace-based agricultural landscapes in southwest China with different ecological wisdom and cultural significance. The goal of this paper is to understand the roles of TEW embedded in traditional agricultural landscapes in the context of landscape changes during modernization. The TEW is explored from two aspects: landscape as the physical representation; and culture covering the ethereal realm and human aspects. Both cases demonstrate significant TEW: the Hani Terraces of Honghe as a practice–belief system and Chongqing pond–paddy fields as a practice–norm system. In modern society, norms shift rapidly and beliefs fade due to new techniques and new lifestyles introduced during modernization. Some physical landscapes embedded with TEW are also destroyed in the development process. There has been some limited modern utilization of TEW, including touristification of the Hani Terraces, commodification of pond–paddy fields and some ecological engineering experiments inspired by agro-terrace structure. In general, the easiest and prevailing way to utilize TEW in modern China is only about physical components. Cultural components of TEW are heavily influenced by modernization and often neglected

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in modernization. Since ecological wisdom is more about knowledge and procedure in doing permanent goods, this paper ends with a suggestion for further highlighting and applying the procedure, functional, and cultural components of TEW beyond forms and economic concerns to better complement modern science for future sustainability.

Keywords Ecological wisdom · Traditional knowledge · Landscape planning Landscape design · Modernization

1 Introduction

Inspired by the Dujiangyan irrigation system in Sichuan, China (constructed in 256 BCE by Li Bing), Prof. Xiang (2013; 2014) raised the question of whether ecological wisdom can overcome some shortcomings of modern science in maintaining and promoting sustainability. The definition of ecological wisdom offered by Xiang (2013) is that it "consists of evidence-based knowledge, tacit and/or explicit, that organizes and evolves from diverse philosophical, cultural, and disciplinary backgrounds across generations." Similar concerns about modern science have been discussed in the realm of traditional ecological knowledge, which is believed to have profound capacities in sustaining our future although it is normally ignored and dismissed in favor of modern science (Menzies 2006; Secretariat 1992). Early in 1987, the World Commission on Environment and Development (1987) stated in Our Common Future that "larger society could learn a great deal from traditional skills of indigenous cultures in sustainably managing very complex ecological systems." The discussions concerning ecological wisdom and traditional ecological knowledge share a parallel perspective toward sustainability that is complementary to modern science.

Despite a shared vision in regard to sustainability and complementary roles to modern science, ecological wisdom is rather different from traditional ecological knowledge, which can be considered a historical counterpart of modern science. Ecological wisdom is inseparable from modern science although it is a general term that appertains to both historical and contemporary depths. Ecological wisdom is a specific form of ecological domain knowledge which includes specialized instances of individual and collective prior knowledge in the field of ecological research, planning, and management. Ecological wisdom is about the virtue of doing real and permanent good through social-ecological practice and is also sufficient to inspire people to think out "the right way to do the right thing in a particular circumstance" (Schwartz and Sharpe 2010). The use of ecological wisdom commences with the permanent goal of developing "management directives" focused toward sustainability of ecosystems, either human-based urban ecosystems or nature-based natural ecosystems (Patten 2016). As a peculiar type of domain knowledge, ecological wisdom comprises declarative and procedural knowledge of an individual or group of individuals that can be context dependent with respect to who, when, and where (Alexander 1992).

On the other hand, ecological wisdom is inextricable from traditional ecological knowledge. Among varied sources and inspirations for ecological wisdom, traditional practices have become of increasing interest (Armstrong et al. 2007; Menzies 2006). This paper uses traditional ecological wisdom (TEW) to generally represent procedure and tactical knowledge embedded in traditional ecological practices, which are pivotal sources of wisdom regarding ecosystem design and sustainable resource uses. In such circumstances, TEW has a similar meaning to traditional ecological knowledge because only successful practices that included wisdom have been sustained over years of consciousness of short-term mistakes and environmental damage in the past (Pierotti and Wildcat 2000). In the interaction between tradition and modernization, how TEW can be integrated into modern wisdom in contemporary society is inherently challenging. The evolution and applicability of TEW in modern society are vital.

Worldwide, there have been some successful practices incorporating TEW into sustainable solutions for today's environmental problems and land management. In most cases, traditional wisdom is agriculture-based knowledge. For instance, contemporary Mayan agro-ecosystem design learns from ancient Mayan practices in dividing an area into collective zones that drain into reservoirs in order to support year-round agriculture by collecting water during the rainy season for use during the four-month dry season. The system also utilizes succession and not agrochemicals to augment natural energy flows by selective plant, weed, and periodic burning (Diemont and Martin 2009). In the Beni region of the Bolivian Amazon, techniques from Pre-Columbian cultures were reintroduced in 2007 to address seasonal flooding and drought for more stable food production (Painter 2009). Additionally, the processes to create and maintain Terra Preta have been utilized to revolutionize tropical soil management for increased food production (Glaser 2007). Similarly in some areas of India, traditional rainwater harvesting structures are still essential components for water harvesting, groundwater recharge and food production (Pandey et al. 2003). As we seek to increase sustainability around the globe, TEW obviously becomes a pivotal source of inspiration (Martin et al. 2010).

Yet there is much more traditional wisdom not applied, underexplored or inapplicable to modern society. Although TEW holds much potential to aid modern society for sustainable designs, it must be researched and applied with great care to avoid past mistakes because TEW is "situated knowledge" (Chambers and Gillespie 2000) with context dependence (Martin et al. 2010). For instance, current applications of Mayan agricultural techniques have shown reduced levels of sustainability as the size of agricultural lots and fallow time decrease in the Lacandon systems (Diemont et al. 2006). Despite the great potential of TEW, integrating traditional human activities and perceptions, including land use, value systems, traditional cultures, religious faith and socioeconomic activities, into contemporary landscape management is one critical challenge in modern landscape ecology (Herrmann and Torri 2009). In exploring the ecological wisdom of Ian McHarg, one of the most influential ecological practitioners, Yang and Li (2016) ask how ecological wisdom residing in early projects could inform modern design. Similar concern is needed for TEW because modernization, urbanization and globalization bring new techniques, new lifestyles and new constraints that may not be complementary to traditions. What has happened to TEW in modern society requires more attention.

The issue of TEW in modern society is even more vital and pressing in China compared to that in the west. On the one hand, China is a country with over 5000 years of agricultural practices that have accumulated vibrant and abundant wisdom in sustaining local ecosystems while producing sufficient food for everyday life. This kind of wisdom was named as the art of survival in Chinese history (Kongjian 2006). On the other hand, China has been and is experiencing unprecedented urbanization (NBSC 2013), which can either destroy the TEW with careless development or draw inspiration from TEW to address current societal and environmental problems. However, the evolution of TEW in modern China is often overlooked.

This paper focuses on terraced agriculture to demonstrate the evolution of TEW in modern China. Traditional practices of terraced agriculture in mountainous areas of southwest China demonstrate phenomenal ecological wisdom through landscapes developed from ecological processes and cultural practices of the sites. Terraces are widely distributed in numerous regions throughout the world, including in North Africa, coastal areas of the Mediterranean Sea, France, Central America, China, Japan, India, the Philippines, Korea, and Southeast Asia (Gao 1983). The most famous terraces among these are the Hani Terraces and Longji Terraces in China, the Banaue Rice Terraces in the Philippines and the Machu Picchu Terraces in Peru (Iiyama et al. 2005). In recent years, with increasing concern for indigenous landscape and ecological issues, scholars have paid more attention to the ecological effects of and protection methods for terraces (Iiyama et al. 2005). Much experience from both social movements and institutionalized deliberative practices has led to the conclusion that local people are much more able to deal with complicated social and technical questions than conventional wisdom generally assumes (Richardson and Doble 1992). Traditional ecological knowledge is manifold and very valuable for resource management (Houde 2007; Pierotti and Wildcat 2000; Thomas 2003).

This article examines two cases: the Hani Terraces in Honghe, Yunnan Province; and pond–paddy fields in Chongqing. These two cases were selected and compared because they are both terrace-based agricultural landscapes in southwest China but representing different ecological wisdom and cultural significance. By looking at the changing relationships linking the local community with their surrounding natural environment, the goal of this article is to understand the roles of ecological wisdom embedded in traditional agricultural landscapes in the context of landscape changes for modernization. This paper aims to reveal whether TEW is compatible or applicable in contemporary society, while provoking further thought into the potential of traditional wisdom in future sustainability. The following two questions are particularly addressed:

What is the TEW embedded in terrace-based agricultural landscapes?

What are the challenges to sustain the TEW embedded in terraces during the process of modernization and urbanization?

2 TEW Embedded in Terraced Fields: Comparing Two Cases

This article compares the Hani Terraces from Honghe and the pond–paddy fields in Liangjiang, both in mountainous environments of southwest China. Figure 1 shows the contextual locations of these two cases and their typical terraced landscapes.

The Hani Terraces are primarily about terraced rice agricultural ecosystems in Honghe Hani and Yi Autonomous Prefecture, Yunnan Province. The most famous Hani Terraces are within the Ailao Mountains on the south bank of Red River that provides typical mountainous context and valley environment for the local people.

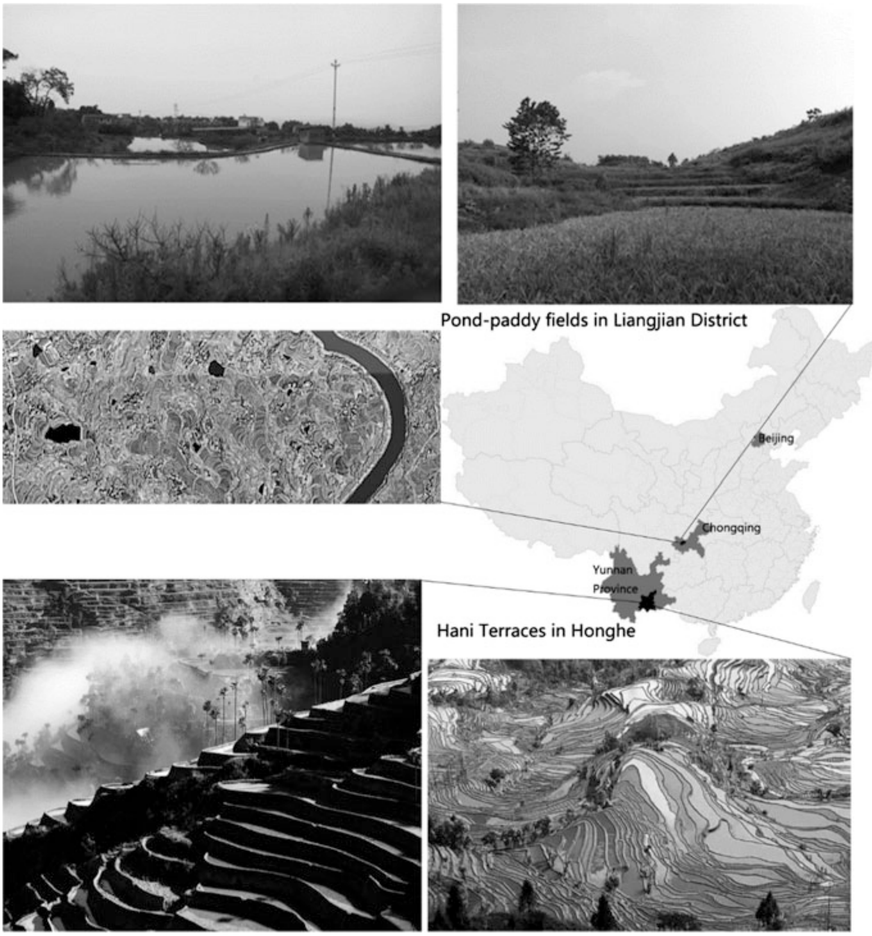


Fig. 1 Two comparative cases, Hani Terraces in Honghe and pond–paddy fields in Liangjiang, and their locations in China

These areas are within the tropical and subtropical climate zone and subjected to strong monsoon humidity. On average, the elevation differences from the mountaintop to the river valley of our study area are 2000 m. Mountainous topography vertically crafts different climates and landscapes, always with a dry-hot environment in the valley and a wet-cold ambiance on the mountaintop. This area has a moderate climate with an annual average temperature of around 16 °C. Rich precipitation and moderate temperature result in flourishing forests and foggy environment due to saturated clouds, which can cover the mountains and the valleys approximately 180 days per year. Terrace agriculture has strongly marked the history and local features of Hani regions during the past 1300 years. The art of terracing mountainsides to farms is Hani's unique solutions to survive in the mountains. From the base of hills to hilltops, hundreds and even thousands of terraces carve the hillside along the contour lines, stretching out to tens of kilometers. The size and shape of each terrace vary conforming to the specific hillside topography. Varied terracing together with changing topography leads to a beauty of diversity and rhythm. Embedded in these agricultural practices, Hani culture can be considered as a terraced-agricultural civilization.

Pond–paddy fields are prevailing agricultural landscapes in Liangjiang District, Chongqing. This area has a northern subtropical climate with strong monsoon humidity. On average, the elevation of this area is 331.88 m (153–888 m). The average annual precipitation is about 1200 mm, with 60–80% concentrated between April and September. This area also has a moderate climate with an average temperature of 18.2 °C and less than 20 frost days per year. Paddy soil and purple soil are prevailing in this area. Despite the similar environmental conditions and climate with the Hani Terraces, the pond–paddy fields in Liangjiang District have much less cultural significance and scenery splendors. As shown in Fig. 1, pond–paddy fields are common terraces for everyday life in mountainous environments.

These two locations represent terrace fields with dramatically different cultural significance in contemporary society. The Hani Terraces are a unique type of traditional agricultural landscape in China. They were constructed and maintained over hundreds of years mainly by the Hani minority group, one of the oldest ethnic groups in Yunnan Province. The Hani Terraces were entered as a Cultural Heritage by UNESCO in 2013. The pond–paddy fields in Chongqing are very common terraces in the daily lives of local communities in mountain areas and worldwide do not have as much cultural significance as the Hani Terraces. Comparing these two sites will reveal how TEW from terrace fields is explored and utilized in modern society, ranging from heritage sites to common terraces.

The research methods of this paper were primarily GIS analyses, open-ended question surveys and cognitive map analyses. GIS is commonly used to extract landscape changes from available satellite images and land cover data. To extract ecological wisdom from local people, we utilized cognitive maps to analyze the conceptual landscape structure that supports everyday life. Originating in psychology, a cognitive map can be viewed as a personal mind map concerning a particular situation or problem of interest (Kaplanet al. 1982). Lynch (1960) applied

Table 1 TEW comparisons between Hani Terraces and pond–paddy fields

	Characteristics	Landscape-based ecological wisdom	Culture-based ecological wisdom	Functions
Hani Terraces in Honghe	A practice–belief system	Spectacular scenery; holistic system	Strong, embedded in everyday life and religious beliefs	A full cycle of water, resource, and energy usage
Pond–paddy field system in Liangjiang District	A practice–norm system	Local need-based landscape pattern	Relatively weak, intrinsic and holistic to daily life	Stormwater management in rainy seasons; drought management in dry seasons

this concept to physical environment analysis and defined it as the individual's "generalized mental picture of the external physical world (p. 4)." Cognitive maps are abstract and selected information from repeated personal experiences. Abstract representations of a cognitive map allow simplification of complex real environmental information. Cognitive maps cannot only distinguish the various physical parts of an environment but also indicate how these parts are organized in a personally meaningful way.

Based on GIS analyses and on-site surveys, critical differences were identified between Hani Terraces and pond–paddy fields. Table 1 summarizes their comparisons, and the details are described in the following sections.

2.1 TEW Embedded in Hani Terraces

The TEW in Hani Terraces can be regarded as a practice–belief system, which is embedded in every aspects of Hani people's life during years of struggle for a peaceful coexistence with the surrounding environment. This paper primarily describes TEW from landscape and cultural perspectives. Landscape is the physical representation of TEW while culture covers the ethereal realm and human aspects of TEW.

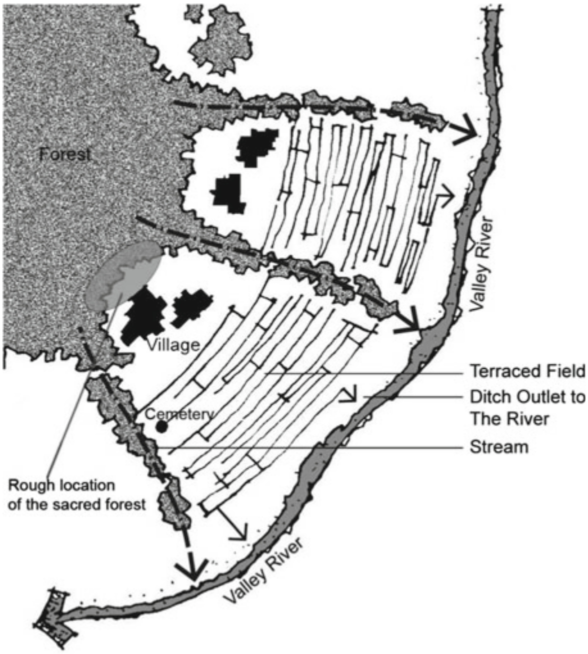
2.1.1 Landscape-Based TEW

A map of the cultural landscape of the Hani Terraces for the upper reaches of first-order branches of the Hong River was created using GIS and QuickBird satellite images. Although shapes and magnitudes vary in different places, Hani settlements always have four basic landscape structural components: forests both natural and sacred, settlements, terraced fields and waterways including rivers and irrigation channels. The ideal and conceptual spatial organization of these components is shown in Fig. 2—it can be described as a clear vertical land use/land cover distribution on steep slopes with "higher forest–middle village–lower terrace–lowest river" (Hu et al. 2008). The natural forest is one of the most spatially dominant features of the Hani landscape and includes both primary and remnant forests. Sacred forest has no physical or visual distinction from other forests but must be located at the top of the village as the residing place of village gods. Only local residents know the exact location of the sacred forest and nobody is allowed to enter the sacred forest except on one special religious day annually. All kinds of forests normally account for 45% of the total Hani landscape (Cao et al. 2013). The terraced fields are visually the most extraordinary component and account for another 40% of the landscape (Cao et al. 2013). The Hani people were famous for their grand terraces along mountainsides used to produce food. Most terraces are located in areas with gradients of 10°–25°, and the steepest slopes exceed 60° (Zhan and Jin 2015). The settlements exhibit a strong understanding of the surrounding natural landscape. Hani villages are usually located in the concavity of sun-facing mountainsides, with a forested mountain behind, surrounded by scenic forests and an open view of terraces in the front (Fig. 3). The size of villages was traditionally determined by factors such as available cultivated land as well as accessible distances between villages and terraces. The cemetery was always located at the foot of the village. Sometimes, several villages shared a cemetery due to their limited population (Fig. 2).

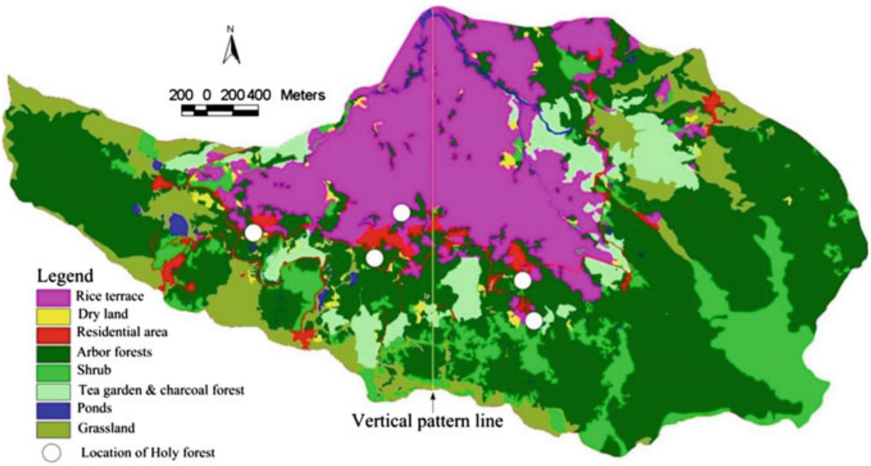
Landscape-based TEW supports a wide variety of landscape functions that are very efficient for a small-scale farming system, especially use of water, materials, and energy by utilizing local topographical changes. The mountaintop forests are banks of water resources, and there are no large artificial reservoirs on top of mountains. By situating their settlement between forests and terraces, local people could make use of the pure water first, which then flowed downward into terraces for agricultural irrigation. Moreover, some of the waste produced by people or animals from the villages could be sent to the terraces following the natural water flow and serve as nutrients for agriculture. To direct the water flow, local residents built an intricate and hierarchical network of ditches, constructed almost parallel to the mountain's contour lines to take maximum advantage of the hillside topography (Fig. 4). Following the ditch system, water ran from the mountaintop forests through the villages to provide drinking water, and then cascaded through all terraces to irrigate the rice fields. Water eventually entered river valleys through this special natural and man-made combined water system.

2.1.2 Culture-Based TEW

Through generations, the Hani people developed a pristine understanding of their relationships with nature. Hani Terraces were inherently coupled with local religious beliefs that conveyed and maintained their strong culture-based TEW. Led by the Migu and Mopi in their village community system, Hani people interrelated



(a) Conceptual landscape structure of Hani Terraces



(b) The landscape map and holy forests of Hani Terraces in Quanfuzhuang village,Yuanyang County

Fig. 2 Conceptual landscape structure and on-site spatial pattern of Hani settlements revealed by cognitive map and GIS analyses

Fig. 3 A Hani village blending into surrounding nature

Fig. 4 Ditches in a Hani village and a terraced field

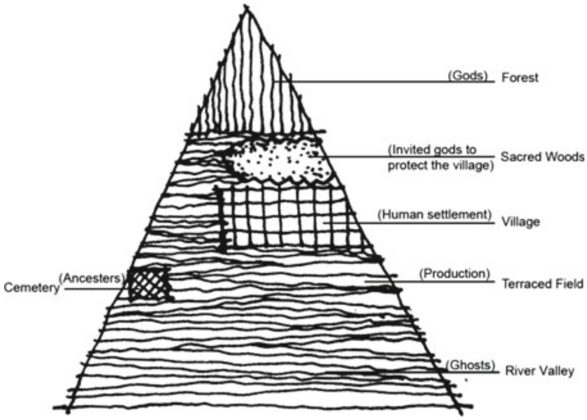
humans and the rest of the ecosystem based on a strong religious hierarchy that was intertwined in the spatial pattern of the Hani landscape. This hierarchy was spiritual and also physical because different components were defined in different vertical altitudes along mountains (Fig. 5). Local people believed that gods originated from the forests, so they protected the primary forests and provided sacred forests to invite gods into their villages. Ghosts were considered to exist in the river valleys and wild natural areas. They used their religious areas to pray and so prevent the intrusion of ghosts. Hani people created their own principles of "Feng-shui" to organize local landscape patterns, which reflected the interconnection of residents' survival with the natural environment, ancestors, ghosts, and gods (Xu et al. 2009). In addition, they developed strong worship for almost all natural objects especially the forests, which were conceptually classified into different holy types for the best protection (Village God, Mountain God, and Terrace God Forest) (Dai 2005). Other key components of the Hani people's faith included totem, ancestry, and soul worship (Jiao et al. 2012; Li et al. 2013). With the innately emotional affiliation of human beings to the environment, powerful religions in the Hani culture were formed to manage the physical landscape and social structure of the local community while passing on moral codes and ecological wisdom from generation to generation. These religious beliefs ensured the constant practice of TEW in the region.

2.2 TEW in Pond–Paddy Fields

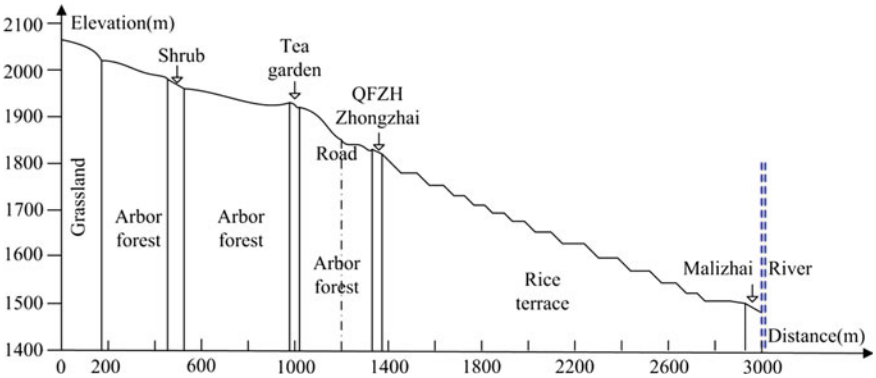
Unlike the strong belief system associated with the Hani Terraces, culture-based TEW in pond–paddy fields in Chongqing is only an inherent part of everyday life for flood and drought adaptation. It can be characterized as a practice–norm system that conveys conventional knowledge and standards of appropriate behaviors for survival in a mountainous and monsoon environment. Far from formal rules or strong spirits, the practice–norm system for pond–paddy fields only provided informal guidelines about collective expectations and social behaviors within the traditional and vernacular landscape of Liangjiang District.

Landscape-based TEW of pond–paddy fields has its own unique characteristics. Distributed along the end of the runoff path and some important drainage channels for floods, this unique landscape concealed multifaceted TEW for drought and flood adaptation. (1) Rural settlements are located in the highest possible position in order to avoid flood hazards. (2) Paddy fields are cultivated along the valley to leave enough room for flood discharge. (3) The water-collecting area is maximized to change stormwater into a resource. (4) Paddy fields are distributed rationally to reduce drought in winter. (5) Economic crops with low irrigation water demand are planted on slopes to save water and conserve moisture and soil.

The physical landscape structure of pond–paddy fields is an integrated water resource utilization and management system. According to different topography and



(a) Conceptual vertical hierarchy of Hani Terraces in their religion



(b) The vertical spatialpattern of the upper reaches of Malizhai River basin in Yuanyang County

Fig. 5 Conceptual vertical hierarchy and on-site spatial pattern of key components in the Hani landscape

the width of paddy fields, there are two basic landscape structures in this mountainous area. The "pond–paddy field" landscape is suitable for narrow and short valleys with high slope, whereas the "pond–paddy field–canal" landscape is suitable for broad and long valleys with small slope. Figure 6 demonstrates the structure of pond–paddy fields distributed along gullies. Local people in Chongqing call paddy fields located in the gullies "Chongchong paddy fields." Ponds are located on the top, in the middle and at the bottom of the landscape, and collect rainwater, irrigate farmland and reduce flooding. Dams are important structures to retain and store water. A water gate or "makou" is for water drainage and diversion.

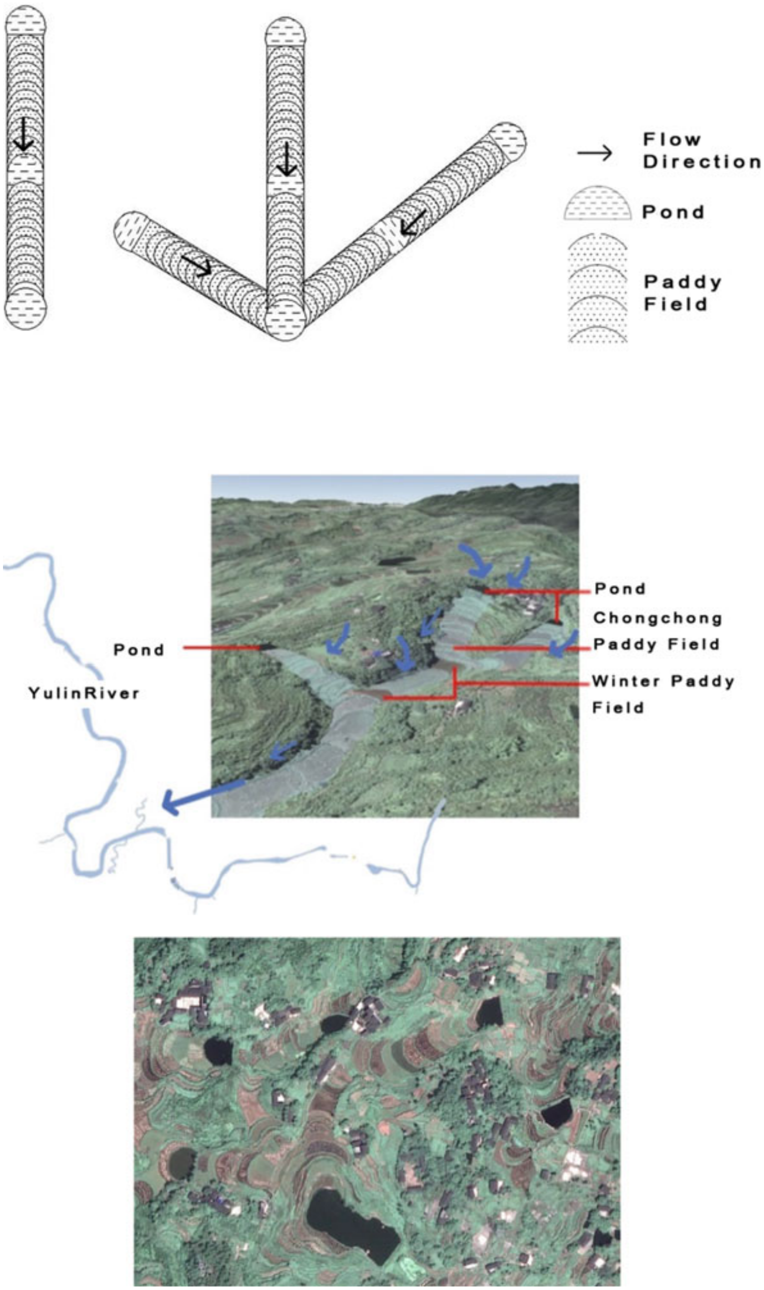


Fig. 6 Pond–paddy field structure

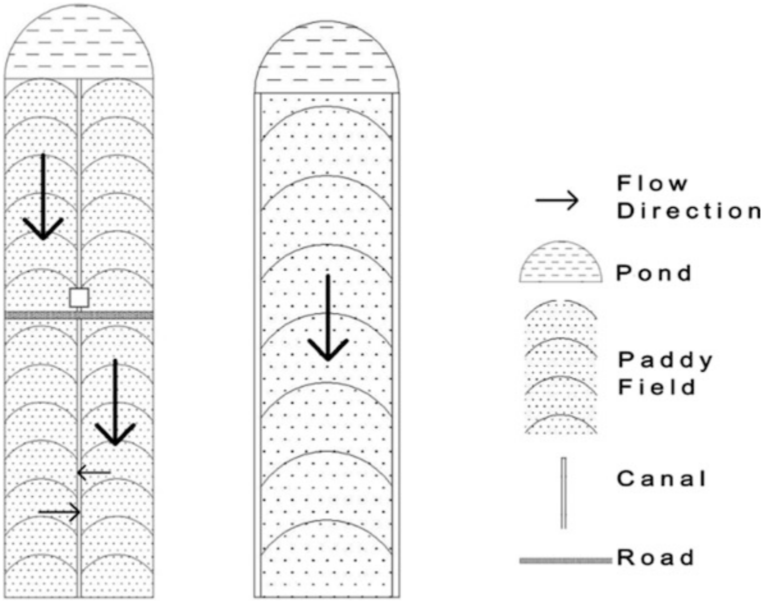


Fig. 7 Pond–paddy field–canal structure

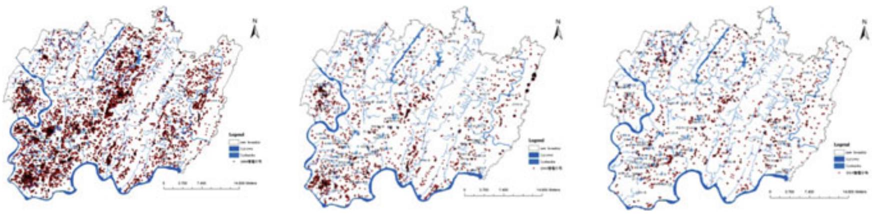


Fig. 8 Spatial distribution of pond systems in Liangjiang District in 1988, 2000, and 2012

The rainwater collecting area of pond–paddy fields is mainly surface runoff from the surrounding area and the pond area. Without canals, the water is distributed to or over the paddy fields primarily by gravity flow. Comparing with pond–paddy fields, the pond–paddy field–canal landscape (Fig. 7) can utilize and regulate much greater amounts of water. This not only collects local surface runoff, but also transfers water and retains irrigation return flow. The drainage ditch of the first-layer pond can be the flood diversion trench for the second-layer pond; the first-layer pond is highest, and it collects, retains, and stores local surface runoff. In addition, the second-layer pond can retain and store overflow from the first-layer pond. A water hierarchy management strategy of water storage, water transportation, drainage, and irrigation is formed by ponds and canals in Chongqing.

3 TEW in Modernization

Before discussing the applicability of TEW in modernization, the evolution of TEW deserves more attention. Our research has concluded that there has been a tremendous loss of TEW and also some limited utilization of TEW without clear proof of efficacy.

3.1 *Loss of TEW*

In both of the studied cases of terraced agriculture, there has been a tremendous loss of TEW both physically and culturally. Culture-based TEW has been far more affected than landscape-based TEW.

3.1.1 Loss of Physical Landscape with TEW

Despite the cultural significance and a political agenda for preservation of the Hani Terraces, their landscape structure has changed greatly. A study of land use changes in Yuanyang Country concluded that forest, paddy field, dry land, and vacant land decreased dramatically during 1974–2000, while bushes and nurseries increased (Li et al. 2011). Except for the central preservation area of Hani Terraces, many paddy fields in Honghe have been reforested due to China's reforestation policy and the labor-intensive management system needed for paddy fields. In addition to the land use changes, the forests have been seriously disturbed by human activities resulting in changes in diversity and community dynamics (Li et al. 2013). The terraces are also susceptible to water shortages and drought due to global climate change. During the 100-year drought in April 2010, about 3300 ha of terraces were damaged (Ren 2010). Social development and global climate change are the key drivers for the loss of physical landscape in relation to TEW in the Hani Terraces.

Unlike the Hani Terraces, urbanization is the key driver for the physical changes of pond–paddy fields (Fig. 8). In 1988, there were 6461 ponds in Liangjiang New Area, Chongqing, with a total area of 58.06 km^2. In 2012, there were 2572 ponds and the total area was only 6.22 km^2. During 1988–2012, the number of ponds reduced by 60.19% and the area by 89.29%. During 1988–2000, more than 70% of ponds on a slope below 25° disappeared and, during 2000–2012, more than 60% of ponds disappeared from slopes above 25°. With the decrease in density and agglomeration of ponds and the increase of average distance, the spatial distribution pattern of ponds became more dispersed compared with 1988. Urban expansion, minimal government investment in micro-water facilities, and the decline in rural populations are the main causes that lead to the supersedence and disappearance of ponds. The loss of ponds will exacerbate droughts in undeveloped villages in remote areas as well as those at the edge of development areas. This will further exacerbate floods in villages in the rural–urban fringes and cause substantial reduction of aquatic habitats.

3.1.2 Cultural Shocks

In both studied cases, culture-based TEW has diminished in recent years. Norms in pond–paddy fields shift quickly because there are other sources of drinkable water, usable materials, and income for everyday life due to the rapid development and urbanization in Liangjiang. Most places have been equipped with water and even sewerage infrastructure, except for some villages in remote mountainous areas. Self-sufficiency is no longer necessary in modern society because food, resources, and materials are exchangeable in the market. Many local residents now have paid employment in cities and so stable agricultural production is no longer indispensable for them. Social behavior, together with informal and collective expectations within local society, has totally changed.

Although there has been less development and urbanization, beliefs associated with the Hani Terraces have faded with modernization because constant interactions with the dominant culture have gradually eroded the value of old beliefs to the local people, especially the young. They have much better education than their parents and increasingly migrate to urban areas for employment. Their worldviews and perception of the surrounding environment are changing due to frequent exposure to modernity through new media and telecommunications infrastructure such as phones, television, and radio. Most of them no longer believe in their spiritual connections to the flora and fauna as did their forebears. The process of tourism development and gentrifier- and state-led gentrification, combined with emigration of indigenous people pose a significant threat to indigenous terrace practices and rice cultivation (Chan et al. 2016). Although the cultural systems and beliefs associated with the Hani Terraces have not changed totally as they have for pond–paddy fields, the survival of traditions and culture that are essential components of the World Heritage Status is challenged by the onslaught of consumer culture in contemporary China.

3.2 Modern Uses

In the modern context, the physical landscape is far more emphasized and studied than cultural wisdom. One of the most significant responses for the maintenance and conservation of TEW is commercialization in the Chinese context. In the two cases considered, the Hani Terraces demonstrate static preservation of a traditional landscape by touristification whereas a traditional landscape was reconfigured in utilizing pond–paddy fields.

3.2.1 Touristification of Hani Terraces

The Hani Terraces have significant reputation as an amazing and admirable masterpiece of earth sculptural art, which is also very labor intensive. Local governments deliberately promote tourism to support regional economic growth under China's Western Region Development program. As a domestic and international tourist destination, the Hani Terraces are attracting increasing numbers of visitors, from 32,000 in 2009 to over 140,000 in 2012 (Chan et al. 2016). The most popular season for the Hani Terraces is the planting season during December–February, when the rice fields are fully flooded with native azaleas and rhododendrons are blooming.

Tourism development has both positive and negative effects on the Hani community. The labor-intensive landscape structure is well maintained using governmental subsidies. Renovated road systems and telecommunication infrastructure together with additional income generated in tourism have improved the community's standard of living. At the same time, the influences of external cultures and consumerism contribute to the commodification of Hani culture and environmental products, which eventually cause social instability and cultural contamination. The costs may outweigh the benefits, as shown in some studies of the social impacts of tourism development.

3.2.2 Commodification of Pond–Paddy Fields in Chongqing

The utilization of pond–paddy fields in Chongqing can be characterized as a process of land reconstruction during rapid urbanization and economic development. The most common procedure after obtaining contracted management of collectively owned land is to enlarge the scale of ponds to raise fish or ducks (Fig. 9). Several adjacent small ponds are combined into a big pond and soil dams are converted to concrete or stone dams for reduced infiltration and year-round stable water level. Our analysis showed that the average pond area in 2012 was 2.3 times that in 2000. Paddy fields are also replaced by cash crops such as orchards to boost income. Land use surrounding the pond–paddy fields changes from grassland or forest into constructed areas such as restaurants and temporary buildings to accommodate visitors from urban areas attracted by the commodification of pond–paddy fields. The pond–paddy fields have been commercialized through total modification of the local landscape structure.

3.2.3 Experimental Ecological Engineering Based on TEW

Beyond fish and duck farming, there are experimental efforts to utilize traditional structures of pond–paddy fields for water pollution treatment. Chen et al. (2014) discussed a modified pond–land terrace system involving hybridizing long-established farming practices from southern China that use water retention

Fig. 9 Commodification of pond–paddy fields for fish and duck farming

Fig. 10 Experimental ecological engineering with vegetation ponds and ditches for local water pollution treatment

ponds at the top, vegetation fields in the middle and a reservoir lake at the bottom. This functional structure and system are proposed to maximize waterfront conservation and associated ecosystem services. Similar eco-friendly land management based on local practices of paddy terracing has recently been investigated in several places (Li et al. 2011). Thus, the value of the ecological knowledge embedded in history has been recognized and utilized.

Figure 10 demonstrates a typical modified system applied in Liangjiang, Chongqing. A water pollution treatment system following the landscape structure of pond–paddy fields has been promoted in rural areas, where wastewater is a challenging issue due to lack of sewage disposal facilities. This experimental ecological engineering is composed of a settling tank, a secondary sedimentation pond, vegetation ponds, and drainage ditches. The vegetation types used for the purification function are mainly *Canna indica* L., *Myriophyllum aquaticum,* and *Cyperus alternifolius* L. Polluted water flows from the higher to lower layers in this treatment system and goes through a process of precipitation, filtration, and purification. Unfortunately, we have observed accumulated pollution in many of these systems due to overloading of pollutants, insufficient water flows, and inappropriate management. Efficacy of these ecological engineering experiments needs further assessment and modification.

4 Discussion and Conclusion

Terraced agriculture carried significant TEW in ancient times, characterized as a practice–belief system in Hani Terraces and a practice–norm system in pond–paddy fields in the two cases of this paper. However, these have been greatly weakened with modernization. There are some experimental utilizations of TEW for contemporary land management, but some of them are subject to misapplication that is lack of wisdom. In discussing the evolution of TEW, the three key components deserve more attention: landscape, culture and science. How should landscape-based and culture-based TEW evolve? What is the role of science in facilitating the applicability of TEW in modern society?

4.1 About Landscape

The easiest and the prevailing way of preserving terraced agriculture in modern China only considers the physical components in some limited utilization of TEW. The physical landscape forms are far more emphasized than the process and the inherent knowledge creating and maintaining these landscapes. The visual manifesto of the Hani Terraces is legally preserved as heritage with government subsidies for continuity of this labor-intensive farming practice in Honghe. Landscape structure is maintained as a frozen representation of the past. Despite many arguments that protecting and improving the physical signs of the past is no longer sufficient, consecutive and appropriate reorganization of indigenous landscapes is always challenging (Brunetta and Voghera 2008). In the case of the Hani Terraces, changes may endanger the authenticity of world heritage.

The ultimate goal of landscape management is not to bring back the past but to preserve valuable structure and elements, while embedding the indigenous landscape functionally in a globalized society. This has been considered as critical in landscape transition from the past to the future (Antrop, 2005). The utilization of pond–paddy fields demonstrate reconfiguration of a traditional landscape in commodification of large ponds for fish and duck farming, as well as ecological engineering experiments utilizing the local agro-structure for water treatment. However, some experimental sites accumulate more pollution than those not treated, together with unpleasant smell and visual appearance. The commodification of large ponds also disturbs the water flow system to maintain stable water levels and greatly contributes to water pollution due to extensive waste and nutrients from the farming process. Current experiments and the commodification of large ponds show a lack of efficacy in maintaining local ecosystem functions. A long journey remains in exploring appropriate solutions for balancing traditional landscape functions and the needs of globalization.

Another suggestion for sustainable evolution of traditional landscapes is to further emphasize knowledge of landscape functions beyond landscape forms and patterns. As ecological wisdom is more about knowledge and procedure in providing permanent good, relationships among landscape components and inherent landscape functions deserve thorough analysis together with procedure knowledge in creating and maintaining these functions.

4.2 About Culture

The lack of effective use of TEW in modern society can be most attributed to the loss of local culture (norms, beliefs, and management structure) during globalization and urbanization. This is a universal challenge beyond the two cases of terraced agriculture considered here. Globally, many traditional and historical rural landscapes are threatened by the rapid social transformations of recent decades (Bell et al. 2009; Nikodemus et al. 2005). To some extent, this is not because we do not want to apply TEW—"the question for us then is whether we still remember enough of our indigenous knowledge, skill and experience to resume the relations our forefathers had with their surrounding" (Veitayaki 2002). In a transition from a traditional introverted to a more open society, most places cannot resist the tensions of modernity and conflicts of a dominant culture.

Cultural preservation with specific purposes, particularly for tourism, can create another tension. Literature on indigenous tourism in China presents cultural exoticism ("freezing" the culture in past representations in accordance with tourists' desire for "authenticity") and cultural commodification (selective modification of culture for tourists' tastes), which can eventually misrepresent indigenous culture in the name of cultural preservation (Swain 1989; Xie 2001; Yang and Wall 2008). Some of these cultural representations are interpreted and controlled by tourism entrepreneurs but not local people (Yang and Wall 2008). The emigration of indigenous people and immigration of tourism entrepreneurs further complicate the continuity of culture-based TEW.

To foster cultural survival and innovation, scholars have been arguing for strategies in promoting respect for and pride in traditional knowledge and practice within communities (Morales 2002; Thrupp 1989). The role of local people in cultural evolution should be more emphasized. This does not mean that tourism and immigration should be discouraged, but all tourist activities should be controlled in such a way that they do not damage traditional culture. This key process is to empower participants and catalyze community action in order to facilitate resistance to impositions of the dominant culture (Thrupp 1989).

4.3 About Science

Despite the fact that TEW is discussed in relation of the shortcomings of modern science, the evolution and applicability of TEW in modern society cannot be separated from modern science. Endorsing scientific analysis of TEW can explore the mechanisms underlying traditional practices and problems and interpret them with respect to a global literature. Appropriate incorporation of modern science—particularly scientific frameworks, analyses, and tools—can fill gaps in local knowledge just as local knowledge fills gaps in scientific thinking (Bentley 1989). However, both Thrupp (1989) and Agrawal (2002) caution against over "scientizing" TEW because some research inevitably prioritizes TEW from specific perspectives such as development, which are isolated from other elements of traditional practices. Once TEW is isolated and recognized as a resource, some local functions and benefits may be overlooked or jeopardized. The complementary and complicated relationships between modern science and TEW are intriguing and inspire a call for more innovative research to understand the mechanisms underlying TEW as a source of ecological solutions to be implemented elsewhere in contemporary society.

Much of the global environment was previously managed by TEW, and the need and potential of TEW to contribute to sustainable ecological designs and management in modern society should be highlighted. "Few would argue for a complete return to old ways, but it is important to understand the wisdom of traditional ecological knowledge and its value of contributing to solving our contemporary ecological problems" (Menzies 2006). The evolution and applicability of TEW in modern society rely not only on further understanding of the procedure, functional, and cultural components of TEW beyond forms and economic concerns, but also on a more strategic integration of modern science and traditional knowledge.

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Part IV
From Built Environments to Living Cities: Architecture and Design

The Wisdom of Looking Forward Through Ecological Design and Planning

Frederick Steiner

Abstract Ecosystem services are presented as a framework for design and planning in the current geological age, the Anthropocene. This time is defined by human modifications of the earth's biophysical processes. Four types of ecosystem services are discussed: those which provide, regulate, support, and contribute to human health and welfare. Eight examples illustrate how ecosystem services concepts can be applied in the built environment. These applications underscore the necessity of ecological wisdom for regenerative design and planning for resilience. Wisdom is grounded in knowledge, experience, and sound judgement. The application of ecological wisdom certainly has practical benefits for people but extends to concern for all life with advantages for other species and our shared futures on this planet.

Keywords Sustainable Sites · SITES · Ecosystem Services · The Anthropocene Green Infrastucture

1 Introduction

We are social animals who interact with other people, with other species, with our physical surroundings. We are biological. We are ecological.

Our impact on the planet is more deleterious than that of other species. The number of people continues to grow as do our effects on environments. We are consequential—so much so that some scientists argue we now live in the human epoch called the Anthropocene. Atmospheric, geologic, hydrologic, and other biophysical processes now exhibit human modifications. Even remote places, such as the Galápagos Islands, display the influences of people.

This dominance affects ecosystem services, that is, what the natural world provides for our health and well-being. Ecosystems provide food, water,

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and materials; regulate climate and disease; support nutrient cycling and pollination; and contribute to our cultures.

The United Nations' 2005 Millennium Ecosystem Assessment stressed the value of ecosystem services. For instance, the authors of the assessment noted:

> The assessment focuses on the linkages between ecosystems and human well-being and, in particular, on 'ecosystem services.' An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the non-living environment interacting as a functional unit. … Ecosystem services are the benefits people obtain from ecosystems… The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services.

For our future, and that of other species, we need to reverse the tendency to deplete ecosystem services for our use. Instead, we should expand services through our actions, especially how we design and plan. In the Anthropocene, we should give back to our planet. This quest will require ecological wisdom.

In just 13 years (2030), 1.1 billion people will likely join us, mostly in dense Asian and African cities (Forman and Wu 2016). Elsewhere on the planet, urban regions are also growing. As a result, ecological wisdom is especially necessary for urban places. However, in the Anthropocene, human influence extends far beyond the city limits.

In this chapter, I explore how we might provide, regulate, support, and contribute ecosystem services. Built works illustrate the utility of the ecosystem services concept.

2 To Provide

Food, water, and raw materials comprise the provisioning benefits that we draw from nature. Since our earliest days, humans have relied on our surroundings for food to eat, for water to drink, and for materials to construct our habitats and to drive our machines.

How do we stop depleting services that provide benefits and begin renewing them?

We can start with soils. The best farmlands should not be developed for other purposes. Soil scientists have identified the most productive lands. These are precious and essential. They should produce food not parking spots.

Instead of losing prime farmlands, we should protect them and build soils. Following the Dust Bowl of the 1930s, the US Soil Conservation Service (now the Natural Resources Conservation Service) took action to conserve soils at the farm and watershed scales. The ongoing efforts of this agency have had many positive, lasting consequences for American agriculture (Steiner 1990).

Composting is one way to augment soils. Composting involves adding organic materials, such as food scraps and yard waste, to the soil to help plants grow better.

In addition to contributing to the soil, this strategy keeps organic materials out of landfills, where they release methane, which is a significant greenhouse gas.

Water is equally essential for our survival. It is foolish to pollute water. We should keep it clean—drinkable, fishable, and swimmable. One strategy is to reconceive parking lots and other paved surfaces. Currently, most parking lots collect polluting materials. When it rains, these materials are rapidly conveyed, unfiltered, into rivers and streams. In addition, impervious surfaces do not allow water to infiltrate. This condition can contribute to flooding. Black asphalt is also hot and can create heat islands.

Conversely, parking lots can be reconceived to function like sponges. Rain gardens can be incorporated to collect water and filter out pollutants. The flow can be slowed as water soaks into the ground. Trees and other plants can help mitigate heat as well.

We use materials from the earth to build our homes, places to work and study, and shrines for worship. Our impact can be reduced by recycling materials from demolished buildings. We can use materials from local sources, which also benefits the economies where we live. More ambitiously, we can emulate natural patterns and structures and even construct buildings out of living materials.

In the USA, buildings consume approximately half the energy used nationally. They also produce roughly 50% of the greenhouse gases in the nation. We mine the earth for fuels. We can conserve the planet by changing how we heat and cool our buildings from non-renewable sources, like coal, to renewable producers, like solar. We can design buildings to be more efficient. For example, the US Green Building Council developed its popular Leadership in Energy and Environmental Design (called LEED) rating system to promote best practices. The wide application of LEED has done much to promote greener and more efficient building systems.

Energy can be reduced through proper site and landscape design, smaller building footprints and room sizes, efficient appliances, good insulation, recycled materials, solar panels, effective windows, tankless water heaters, LED and CFL lighting, programmable thermostats, and proficient heating and cooling systems. In addition, geothermal, wind, solar, wave, and tide energies provide alternatives to using fossil fuels.

Energy and water use are interrelated. Water is necessary to produce energy. Conversely, energy is employed to extract, purify, deliver, heat and cool, treat, and dispose of water. In the USA, city water and wastewater treatment facilities account to up to 35% of the electricity consumed by municipal entities (American Council for an Energy—Efficient Economy 2013). An understanding of this energy–water nexus is helpful to develop strategies to conserve both and maximize the services that they provide.

Two example projects from New York and Washington D.C. illustrate the potential of landscape and building design to improve the regulatory capacity of ecosystems. Both show how water can be cleaned and one also exemplifies how energy can be provided through renewable sources.

2.1 Gowanus Canal Sponge Park, Brooklyn, New York

In Brooklyn, Susannah Drake and her DLANDstudio colleagues have advanced a strategy called "Sponge Park™" for the 1.8 mile (2.9 km) long, 100-foot (30.5 m)-wide Gowanus Canal. They began with a master plan for the 316-acre (128-ha), 70 street block neighborhood (Drake and Kim 2011). The canal is an especially polluted water body, and the surrounding industrial and residential neighborhoods have experienced decline. The Sponge Park concept creates an open space system that cleans surface water while providing new recreational opportunities. This strategy will also renew the adjacent communities.

Constructed in 1881 to facilitate commercial shipping in Brooklyn, today, Gowanus Canal is so highly polluted that it was declared a Superfund site by the US Environmental Protection Agency in 2010. The Gowanus is a "sewershed" for several Brooklyn neighborhoods including Park Slope, Cobble Hill, Carrol Gardens, and Boerum Hill. Raw sewage flows from outflow pipes (used during heavy rains) into the canal (Rizzo 2013). Stormwater carries heavy metals, pesticides, cancer-causing PCBs, litter, bird droppings, dog waste, oil, and antifreeze into the waterway (Foderaro 2015). In response, Drake and her team proposed turning water that had been viewed as a waste into an asset. Sponge Park™ consists both upland bioswales and a series of planted precast connected concrete cells that collect stormwater (Fig. 1). Flood-tolerant plants like asters, *Rosa rugosa*, sumac, clethera, and sedge grasses are used with a system of sand beds and soils designed to hold and filter water (Foderaro 2015). Unlike common bioswales, the planting is mostly woody perennials.

According to Johnna Rizzo, Sponge Park works through five measures: gravity pulls rain runoff from the sloped street into the park; water is absorbed and filtered by a gravel pre-treatment basin to trap silt and larger debris; excess flows to planting area, where it is stored in air pockets in sandy soil and later gets absorbed by plants or drains into groundwater; any unabsorbed water is funneled to the sand filter under a pedestrian path; and excess water flows directly into the canal (Rizzo 2013).

Fig. 1 Sponge Park™, Gowanus Canal, Brooklyn (Photograph by DLANDstudio)

A 2100-square-foot (186 m^2) pilot phase of the Gowanus Sponge Park was completed in 2016. According to Rosenfeld (2013), the "multi-use park lining the polluted canal [is] anchored by soil-filled concrete cells that … retain and filter storm water, while topped with plants capable of soaking up excess water and naturally absorbing or breaking down toxins, heavy metals, and contaminants from sewage overflow." As a result, an urban environmental liability is being transformed into a community asset.

The Gowanus Sponge Park provides new green infrastructure for Brooklyn. Ecosystem services, including improved water quality and open space, are provided. Sponge Park is an example of an urban landscape approach design in that it combines biophysical and sociocultural concerns and outcomes.

2.2 *Sidwell Friends School, Washington, D.C*

Founded in 1883, the Sidwell Friends School is located in Washington, D.C. and Bethesda, Maryland. Its Washington, D.C. middle school building demonstrates both energy and water conservation. The school simultaneously advanced building architecture and landscape architecture as a result of a 2006 renovation.

The Sidwell School achieved Platinum (the highest) LEED certification (Fig. 2). The LEED program involves both a certification program for projects and an accreditation program for professionals "driving ongoing excellence in green building practice" (Green Building Certification Institute 2010). The building project encompassed 72,500 square feet (3112 m^2) of renovation plus a 39,000-square-foot (3623 m^2) addition. The key features of the KieranTimberlake-designed building include a green roof which retains rainwater; a central energy plant; a reclaimed cedar skin; passive solar elements, such as shading and chimneys for ventilation; as well as more active use of solar, such as photovoltaics.

The buildings and the landscape are viewed as educational opportunities about environmental stewardship and Quaker values of egalitarian democracy and

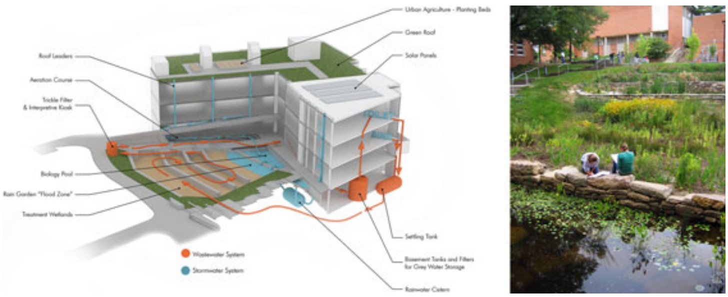

Fig. 2 Middle school and wetland at Sidwell Friends School in Washington, D.C. (Photograph by Andropogon)

non-violence. The complex is used in teaching to illustrate how materials are used and systems function. Classes use the building interiors, the rooftop gardens, and the school's quadrangle that features constructed, terraced wetlands.

Designed by Andropogon Associates, the wetlands use aquatic plants, water, microorganisms, sun, soil, sand, and air to filter and clean rainwater. Wastewater is also treated through biological processes. Native plants were used for their drought tolerance and because they eliminate the need for irrigation. Indigenous vegetation also promotes biodiversity. The National Wildlife Federation recognized the middle school courtyard for the ability of its native plantings, such as red maple, sassafras, oxeye sunflower, turtlehead, and milkweed, to attract important endangered species, such as the snowy owl and monarch butterfly (Kweon and Ellis 2012).

The Sidwell Friends School illustrates how ecosystem services can be produced. In this case, new sources of clean water and energy are provided.

3 To Regulate

Ecosystems help regulate the quality of air and soil and assist in the control of floods and diseases. Human actions can disrupt the ability of ecosystems to contribute such regulating services. For instance, to return to the parking lot example, impervious surfaces can make naturally occurring flood events more dangerous, by increasing storm runoff.

How can we end disrupting and start contributing?

We can begin by planting trees. Vegetation collects water and trees provide shade, thus improving microclimates. Trees and other plants help remove pollutants from the atmosphere, thus cleaning the air. Plants also provide food and habitat for other species. Especially native plants, well adapted to their regions, attract native animals.

Plants have other regulating benefits, as they can help slow erosion and contribute to soil fertility. Wasting soil is unwise. Erosion-control wisdom is well known in agriculture and forestry. With the world becoming more urban, we need to advance strategies to use vegetation to regulate erosion levels and soil health in cities.

Vegetation helps regulate climate because plants store and sequester greenhouse gases. Growing vegetation removes carbon dioxide from the atmosphere and stores it in tissues. Large green areas thus become storehouses for carbon. The creation of green infrastructure enhances and expands this capacity.

Green—or the arguably better term, "ecological"—infrastructure offers one tangible strategy to promote the delivery of ecosystem services in urban areas. The US Environmental Protection Agency defines green infrastructure as "An adaptable term used to describe an array of products, technologies, and practices that use natural systems—or engineered systems that mimic natural processes—to enhance overall environmental quality and provide utility service" (Benedict and McMahaon 2006; Rouse and Bunster-Ossa 2013). By weaving the natural and building environments together, ecological infrastructure serves as "tissue in the urban fabric."

Ecological infrastructure strategies provide an integrated approach to mitigating the negative impacts of extreme weather on vulnerable coastal populations. Coastal regions are home to a large and growing proportion of the world's urban populations, among whom the economically disadvantaged, the disabled, the elderly, and the very young are especially vulnerable to extreme weather events. Ecological infrastructure systems can help improve the lives of people in these vulnerable communities by keeping them safe (Dunn 2010). When properly integrated into a city or region, such systems can also lower costs by increasing the efficiency of service provisions and reducing the burden on existing infrastructure systems (Berkooz 2011). In addition to cleaner air, water, and soil, these interventions can lead to lower utility bills and more climate-change resilient, esthetically pleasing, and walkable urban environments (Gill et al. 2007).

In contrast to gray infrastructure, like holding tanks and tunnels, green infrastructure is a variety of soil-water-plant strategies, such as green roofs, rain gardens, special soils, living walls, and porous surfaces that can be employed to intercept stormwater, such as in the Gowanus Canal Sponge Park example. As a result, some water infiltrates into the ground and other parts evaporate back into the air. Often green infrastructure is designed to mimic the natural hydrologic cycle.

Wetlands and riparian areas are natural components of that cycle which filter waste as it infiltrates into the soil. Microorganisms in the soil break down most waste, thus eliminating pathogens and reducing nutrients and pollution. Without the regulating qualities of wetlands and soils, we would live with more bacterium, virus, and pollution.

In addition to plants, animals are helpful regulators. For instance, with wind, insects pollinate plants. Pollination is essential for the development of fruits, vegetables, and seeds. Some birds and bats contribute to pollination as well, allowing plants to reproduce.

Natural systems regulate pests and vector-borne diseases that affect plants, animals, and people. Birds, bats, flies, wasps, frogs, and fungi act as biological controls of disease. We are healthier as a result. Predators and parasites help control pests and diseases through their actions. For example, bats save the state of Texas over $1 billion a year on pesticides (Klein 2016).

As the planet grows warmer, extreme weather and other natural events have become more common. Daily, we read about the loss of life and property to floods, storms, hurricanes, tornados, tsunamis, earthquakes, wildfires, avalanches, and landslides. Living organisms and other natural systems can create buffers against such disasters, which prevents or reduces the deleterious consequences. Floodplains, for example, store excess capacity after a storm. For that reason, urban development in floodplains is usually unwise because it disrupts this natural function. In addition, people are put in harm's way.

Projects from Colorado and Texas provide examples of how to design and plan places that enhance the ability of ecosystems to regulate. The projects also illustrate successful planning at two scales.

3.1 Stapleton, Denver, Colorado

In 1995, Denver opened a new airport and closed Stapleton International Airport, presenting a redevelopment opportunity for the 7.5-square-mile (19.4 km^2) site. The project became a major urban in-fill opportunity with the city committed to incorporating emerging concepts for green design and planning. To that end, the City of Denver selected the development company Forest City Enterprises to lead the redevelopment effort. Forest City engaged a team of consultants, including Calthorpe Associates, Andropogon Associates, and Civitas, to produce a development strategy. The planning team documented their strategy in a publication that they called "The Green Book."

The Forest City plan borrowed concepts from successful Denver neighborhoods, including parks and tree-lined parkways, while applying regulating aspects of ecosystem services, by planting trees and creating riparian corridors while also adding provisioning services such as water and energy conservation. Andropogon Associates conceived the open space, over a fourth of the site, to mimic the natural drainage system that restored the native landscape and helped manage stormwater (Fig. 3). The Stapleton project was also influenced by the redevelopment of the nearby Lowry Air Force Base (Winslow 2015).

Both the Lowry and Stapleton sites possessed many environmental challenges that had to be remediated. For instance, 1000 acres (445 ha) of pavement and 200,000 tons (182 million kg) of asphalt needed to be removed and recycled at the former city airport. In addition to the environmental issues, the Stapleton site presented many social issues including crime and low property values.

Sustainability was a principal goal of the plan to address both environmental and social concerns while making the development an economic success. In this way, the traditional triad of sustainable development was addressed, that is, the three "e's": ecology, equity, and economics. The new community was designed to mix land uses and to promote connectivity. Homes, offices, schools, community centers, shops, restaurants, and parks were connected by walkways. Parks and open spaces provided the main connective tissue. Stapleton helped to pioneer the green infrastructure concept by providing a tangible and successful example for other projects, such as the redevelopment of the Robert Mueller Airport in Austin, Texas.

Fig. 3 Stapleton drainage system (Photograph by Andropogon Associates)

3.2 *Blue Hole Regional Park, Wimberley, Texas*

Located in the heart of the scenic Texas Hill Country, the cool clean waters of the "Blue Hole" have attracted local swimmers for decades. Threatened by development, the water body and surrounding 126 acres (51 ha) were purchased in 2005 by the small city of Wimberley to protect the cherished paragon, which had nearly been "loved to death" by overuse and mismanagement, and to create a sustainable regional park (Canfield 2013). Informed by a citizen-led process, the design team created a plan that protected and enhanced the site's ecologically sensitive areas, despite the addition of 320,000 square feet (29,729 square meters) of new park features. Today, the park offers swimming, an extensive interpretive education program, many trails, and active recreation amenities for thousands of annual visitors (Figs. 4 and 5). The broad goal of the project was to create an ecologically and economically sustainable regional park that considers environmental and recreational needs and the character of the Wimberley Valley while inviting people to encounter, appreciate, and respect the qualities and beauty of the Texas Hill Country (Canfield 2013).

With the depletion of the underlying Edwards and Trinity Aquifers and an ongoing drought, water use is of particular concern in Central Texas as is the potential for destructive flooding. The employment of rainwater harvesting cisterns, native drought-tolerant plants, biodetention ponds, and swales was crucial to significantly decreasing irrigation requirements. Restoring the creek shoreline with native plants and designating specific entries to the popular swimming hole also creating a resilient landscape that was able to withstand dramatic flooding in 2015.

Fig. 4 Picnic area crafted from repurposed limestone and cedar wood at Blue Hole Regional Park (Photograph by D. A. Horchner/Design Workshop)

Fig. 5 Cypress creek swimming area at Blue Hole Regional Park (Photograph by Tim Campbell, Design Workshop)

Prior to its creation, there was very limited access to parkland in Wimberley. The site now functions as both a regional recreation park and nature preserve serving the city and beyond. Moreover, after construction, the design team conducted a survey to assess the success of the Blue Hole Regional Park project. Users of the park space surveyed reported sizeable improvements in community character, safety, public access, and parking.

The park regulates water flow by controlling storm flow and using drought-tolerant vegetation. Biological diversity has been expanded through the plantation of native hardwoods, prairie grasses, and forbs. These native plants provide habitat for 19 different endangered and threatened species as well as those of concern (Canfield 2013).

A worry of city officials was the cost for building as well as maintaining this park and the possible need to levy the first property tax upon residents to cover the expenses. Instead, visitation increased by 60% in the first year, creating approximately $112,000 in entry fee revenue. In the second year, visitation nearly doubled again to 31,000, producing an estimated $217,000 (Canfield 2013). Long-term, the park is expected to attract 100,000 visitors a year, indicating the significant role the park will play as a regional amenity for years to come. Park revenues continue to cover the cost of operating the park, without new taxes, which is unusual in the

USA and an indication of economic sustainability. Wimberley's Blue Hole Regional Park provides a new model for jurisdictions attempting to strike a balance between preserving a place as an ecological resource and providing recreational and educational opportunities for users (Lady Bird Johnson Wildflower Center et al. 2014; Pieranunzi et al. 2017).

4 To Support

Habitats and genetic diversity are supporting ecosystem services. Diverse ecosystems are the healthiest. The loss of biodiversity threatens both habitats for species as well as the maintenance of genetic diversity.

How do we halt the decline of biodiversity—the variety of life—and commence rebuilding the diversity of the planet?

The wider application of indigenous plants offers a good starting point. They provide ideal habitats to broad ranges of animal species. Habitats supply the materials that plants and animals need to survive—food, water, and shelter; places to hide and hunt; areas to reproduce, to raise the next generation, and to die. Rich ecosystems furnish different habitats for species to use during their lifecycles. Migratory species of birds, fish, mammals, and insects require a variety of habitats as they move from place to place.

Diverse habitats help preserve genetic variety, that is, a mix of genes between and within populations. Such a gene pool is especially valuable for agriculture and ranching. However, the diversity of life across much of the planet is not intact. People are using more and more land for farming and ranching as well as for urban development; for homes, businesses, schools, roadways, and utility infrastructures.

Green infrastructure can also help to support biodiversity, if it is designed for a variety of species and habitats. Climate change is affecting biodiversity and, conversely, biodiversity can help mitigate the impacts of climate change. While this is recognized at the global level, biodiversity is not adequately considered in local planning and design decisions.

The SITES rating system offers a means for local, place-specific decision-making. Developed by the Lady Bird Johnson Wildflower Center of the University of Texas at Austin and others, the system is now managed by Green Business Certification Inc. (GBCI, which also oversees LEED certification and accreditation). According to GBCI, "SITES helps create ecologically resilient communities and benefits the environment, property owners, and local and regional communities and economies" (www.sustainablesites.org).

Grounded in ecosystem services (Windhager et al. 2010), the SITES rating system emphasizes supporting living systems, designing with nature and culture, and fostering environmental stewardship. The ecosystem services addressed in the SITES rating system are linked to specific actions (Table 1) and include reduction of greenhouse gas emissions, filtration of air and water pollutants, water conservation, erosion and sediment control, hazard mitigation, conservation and restoration of pollinator and other habitat functions, waste decomposition and treatment, support for food production, and enhancements to human health and well-being (Pieranunzi et al. 2017). Also, fundamental to SITES is the concept of resilience, defined as the capacity for a system to survive, adapt, and flourish in the face of turbulent change (Birch and Wachter 2008; Fiksel 2006; Hirsch 2008).

The following two projects from Pittsburgh and Washington, D.C. illustrate how design can enable the ability of places to support ecosystems for the benefit of people and other species. Both show how ecosystem services can be enhanced in urban places.

4.1 Center for Sustainable Landscapes at Phipps Conservatory, Pittsburgh, Pennsylvania

As part of the process of designing the SITES rating system, it was tested with many pilot projects. The Center for Sustainable Landscapes (CSL) is the first project in the world to simultaneously achieve LEED Platinum, the Living Building Challenge, and SITES four-star certification (and the only project to attain the highest certification level during the SITES pilot program) (Lady Bird Johnson Wildflower Center et al. 2014; Pieranunzi et al. 2017). Built on a paved-over city maintenance yard, the center is a model of restorative design in an urban context, highlighting architectural and landscape architectural innovations that take inspiration from natural processes (Fig. 6) (Pieranunzi et al. 2017).

The nearly three-acre (1.21-ha) brownfield site supports a new 24,350 square-foot (2262 m^2) research, education, and administrative building; manages all sanitary waste and a ten-year storm event on site using a range of green infrastructure strategies; has successfully reintroduced 150 native plant species; and is net-zero energy and water (Pieranunzi et al. 2017). The CSL building and landscape performance is being extensively researched and monitored to inform the design and construction of similar projects that restore ecosystem services, generate their own energy, and clean/reuse their own wastewater.

To attain net-zero energy, an onsite solar photovoltaic system was employed to achieve 99% of the CSL's annual energy demand, a single wind turbine meets about one percent, and 14 geothermal wells significantly offset the building's heating and air conditioning requirements. The CSL was designed to utilize 50% less energy than a comparable conventional office building. To reach net-zero water, all gray water and blackwater are treated on site with passive systems and ultraviolet filters, then reused as toilet flushing water or converted to distilled water for orchid irrigation. The 2.9-acre (1.2 ha) site's significantly degraded soils were almost entirely paved over but can now manage a 10-year storm event on site (3.3 inches, 8.4 cm, in 24 h). Additionally, 150 native plant species were reintroduced to the 1.5 acres (0.607 ha) of new green space. Underground storage also enables the project to harvest an estimated 500,000 gallons (1,892,706 L) of stormwater runoff annually

Table 1 Guiding Principles of the Sustainable SITES Initiative

Ecosystem services are goods and services of direct or indirect benefit to humans that are produced by ecosystem processes that involve the interactions of living elements, such as vegetation and soil organisms, and non-living elements such as bedrock, water, and air
The United Nations' *Millennium Ecosystem Assessment* 2005 report separated ecosystem services into four categories: Supporting (services that are necessary for the production of all other ecosystem services), Provisioning (products, such as food and water, obtained from ecosystems), Regulating (benefits obtained from theregulation of ecosystem processes such as carbon sequestration), and Cultural (nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences)
The Sustainable SITES Initiative has referenced various existing versions ecosystem services to create the following list of those that a site can protect or regenerate through sustainable land development and management practices
1. Global climate regulation: Maintaining balance of atmospheric gases at historic levels, creating breathable air, and sequestering greenhouse gases 2. Local climate regulation: Regulating local temperatures, precipitation, and humidity through shading, evapotranspiration, and windbreaks 3. Air and water cleansing: Removing and reducing pollutants in air and water 4. Water supply and regulation: Storing and providing water within watersheds and aquifers 5. Erosion and sediment control: Retaining soil within an ecosystem, preventing damage from erosion and siltation 6. Hazard Mitigation: Reducing vulnerability to damage fromflooding, storm surge, wildfire, and drought 7. Pollination: Providing pollinator species for reproduction of crops or other plants 8. Habitat functions: Providing refuge and reproduction habitat to plants and animals, thereby contributing to conservation of biological and genetic diversity and evolutionary processes 9. Waste decomposition and treatment: Breaking down waste and cycling nutrients 10. Human health and well-being benefits 11. Enhancing physical, mental, and social well-being as a result of interaction with nature 12. Food and renewable non-food products: Producing food, fuel, energy, medicine, or other products for human use 13. Cultural benefits: Enhancing cultural, educational, esthetic, and spiritual experiences through interaction with nature

Source SITES v2 Rating System: For Sustainable Land Design and Development

from the roofs of neighboring buildings for reuse as irrigation water in the conservatories (Pieranunzi et al. 2017).

An integrative design process was crucial to the project's success. The vexing site constraints and goals—degraded, compacted, and contaminated soils; steep slopes; limited access; and designing to the highest standards for LEED, SITES, and the Living Building Challenge—required an interdisciplinary team, including the landscape architects Andropogon Associates, to assure a successful outcome. The integration of building, landscape, circulation, and abrupt elevation changes was extraordinarily well done, as was the braiding together of an underground infrastructure network to accommodate the movement, treatment, and storage of storm and sanitary water, as well as geothermal wells. The most noteworthy strategies used to achieve SITES ultimate rating credit include: redevelopment on an existing brownfield; managing stormwater on site; using primarily native plants;

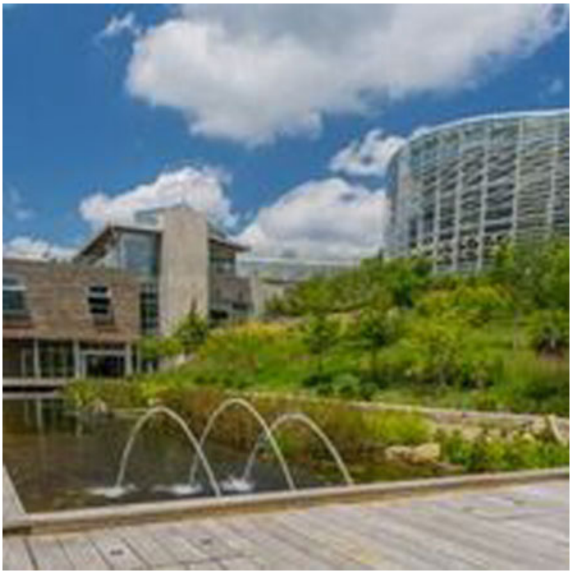

Fig. 6 Phipps' Center for Sustainable Landscapes with lagoon, boardwalk, and terraced garden in foreground (Photograph by Paul G. Wiegman)

sourcing landscape materials from appropriate distances and origin; and sustainably managing the project's waste stream (Lady Bird Johnson Wildflower Center et al. 2014).

Landscape performance is being analyzed to assess the effectiveness of the CSL's green infrastructure strategies. Phipps is working with researchers to monitor performance of the rain gardens and green roof to absorb and filter stormwater (Fig. 7). Phipps is also cooperating with the National Energy and Technology Laboratory to study a range of sustainable variables, relating to sanitary and stormwater quality that will be used to inform the design and management of US federal facilities. Phipps is the project lead on all of these programs and the CSL's building performance is also being monitored in conjunction with the University of Pittsburgh and Carnegie Mellon University (Pieranunzi et al. 2017).

4.2 Washington Canal Park, Washington, D.C

An early park built as part of the District of Columbia's Anacostia Waterfront Initiative, Washington Canal Park is a prototype of sustainability, attaining both LEED Gold certification and a three-star certification as a SITES pilot project (Fig. 8). Located on three acres (1.21 ha) of a former school bus parking lot, this three-block long park is situated along the historic former Washington Canal and has become a popular social gathering place as well as a catalyst for new economic activity in the community (see Salazar 2015; Pieranunzi et al. 2017; Lady Bird Johnson Wildflower Center et al. 2014).

Fig. 7 Phipps' Center for Sustainable Landscapes highlighting green roof with tropical forest conservatory in background (Photograph by Paul G. Wiegman)

Inspired by the area's waterfront, Canal Park's design evokes the history of its location, featuring a linear rain garden and three pavilions reminiscent of the floating barges that once populated its waters. Working with the city and others, OLIN, the Philadelphia-based landscape architecture firm, designed a 9000 square-foot (836 m^2) pavilion to host a café and dining area. Underneath the site's ice rink, 28 geothermal wells provide a highly efficient energy supply for utilities in the park. This is expected to reduce Canal Park's overall energy use by 37%. Native and adapted plants were installed in the rain garden and throughout the park (Fig. 9). Additional sustainable design elements included dark-sky lighting elements, high albedo paving, and site features that encourage conserving practices, such as electric car charging stations, bicycle racks, and recycling bins (Pieranunzi et al. 2017).

Overall, water resilience was a major performance goal for Washington Canal Park. The achievement of this goal required addressing issues of scarcity, flooding, and pollution. The park's focal point, the linear rain garden, functions as an integrated stormwater system that is estimated to save the District of Columbia 1.5 million gallons (5.7 million liters) of potable water each year. With the rain garden, low impact development tree pits, and the capacity to store 80,000 gallons (302,833 L) of water storage capacity, almost all of the stormwater runoff generated by the park will be captured, treated, and reused to satisfy as much as 95% of the park's water needs for fountains, irrigation, toilet flushing, and an ice rink (Fig. 10) (Pieranunzi et al. 2017).

An important element of the project is its contribution to neighborhood sustainability. Canal Park manages a neighborhood-scale program that reaches beyond its boundaries to capture, treat, and recycle roof and site runoff from neighboring buildings. The Canal Park Development Association (a public/private partnership)

Fig. 8 Overall site view at Washington Canal Park (Photograph by Karl Blumenthal, OLIN)

Fig. 9 Middle block seating and planting beds at Washington Canal Park (Photograph by Sarah Coston-Hardy, OLIN)

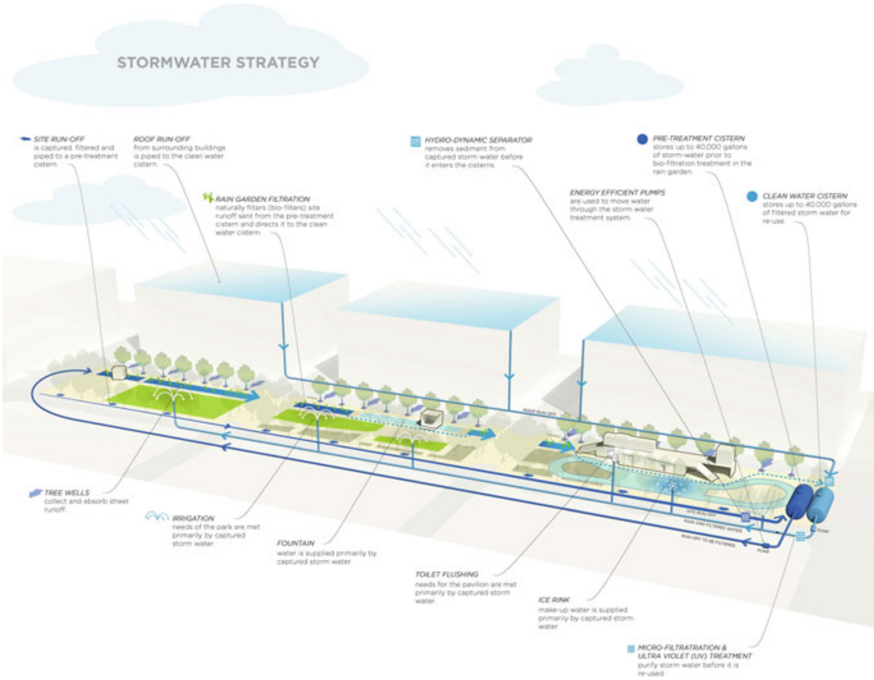

Fig. 10 Stormwater strategy diagram of Washington Canal Park (Photograph by OLIN)

plans to charge a fee to neighboring landowners for the use of this rainwater management service. This will contribute to the long-term economic stability of Canal Park and encourage urban infill development in this former industrial area.

Development of Canal Park involved ongoing collaboration with the Washington, D.C. Department of the Environment. Its success led to the department's adoption of more effective water management policies and water quality protections. The department considers Canal Park a demonstration project, and development of the general schematic, the environmental assessment, and adoption of a maintenance covenant will be used by the agency as the planning and design model for future projects with similar green infrastructure goals (Pieranunzi et al. 2017).

5 To Contribute

Ecosystems contribute to culture and human welfare in several ways. Nature is important for recreation as well as for our mental and physical health. Much tourism depends on pristine and/or special environments. Religions are grounded in nature to varying degrees. Art, music, and design are frequently inspired by the environment.

How do we enrich culture and promote human welfare?

Walking, running, cycling, swimming, and playing sports outdoors are valuable to our physical and mental well-being. People need to relax and require places to recreate. Outdoor spaces are especially important for exercise and reflection.

Many types of tourism depend on ecosystems and biodiversity. In 2016, the US National Park Service celebrated its centennial. Dubbed "America's best idea," national parks in the USA and elsewhere celebrate nature and culture. National parks set aside special places for the enjoyment of all. They are legacies for future generations. They spotlight the importance of place to the human spirit. In the USA, our National Parks realize Henry David Thoreau's Maine Woods vision: "Why should not we, who have renounced the king's authority, have our national preserves…for inspiration and our own true recreation?"

The Garden of Eden provides the creation story for Judaism, Christianity, and Islam. We begin with God creating the heavens and the earth, then water, then plants and animals, and, finally, us. God then would endow us with the stewardship responsibilities, noting in Leviticus: "The land must not be sold permanently because the land is mine and you are but aliens and my tenants. Throughout the country that you hold in your possession, you must provide for the redemption of the land" (25:23–24).

Pope Francis has renewed the attention of Roman Catholics on the environment. This fact was underscored by Pope Francis' compelling May 2015 encyclical letter *Laudato Si'*, in which he addresses ecological wisdom explicitly. In this clarion call for an integral ecology—an ecology of daily life—the pope states: "Given the interrelationship between living space and human behavior, those who design buildings, neighborhoods, public spaces, and cities ought to draw on the various disciplines which help us to understand people's thought processes, symbolic language, and ways of acting."

Furthermore, Pope Francis(2015) noted in *Laudato Si'*, "The climate is a common good, belonging to all and meant for all." And further, "Human ecology … implies another profound reality: the relationship between human life and the moral law, which is inscribed in our nature and is necessary for the creation of a more dignified environment." On September 1, 2016, Pope Francis added the care of the environment as the eighth work of mercy for Catholics. To create more noble environments for people and other species, we should follow nature's lead.

Interaction with the natural world is a common element of both major religions and traditional knowledge. In many places, forests, caves, and mountains are valued as sacred and have religious meaning. In hunting and gathering and agrarian cultures, environmental knowledge—wisdom—was necessary for survival and adaptation. As a result, the natural world was celebrated. It is only an illusion that such knowledge is not necessary for our own well-being.

Traditional religions link beliefs with direct experiences of natural events and places. A goal of many of these religions is to live in harmony with nature rather than to dominate and exploit it. Natural objects, plants, and animals are used both in ceremonies and for medicine. The world is viewed as full of spirits that need to be understood. Even today, plants retain meaning such as red roses for love, anemone for protection from evil, and ranunculus for being dazzled by someone's charms.

With self and society, nature provides a significant revelatory experience for artistic expression. "I took a walk in the woods and came out taller than the trees," Thoreau wrote. Nature is everywhere in art: in literature, in music, in painting, in photography, and in film. Nature inspires art. There is certainly a deep green thread in American literature (Buell 2001). Nature offers complex beauties through its wide array of geometrics and colors.

The artist Robert Smithson (1996), for instance, observed "Nature is never finished" and that "Nature does not proceed in a straight line, it is rather a sprawling development."

Examples from Ecuador and Italy illustrate how nature contributes to culture. Both involve preservation, one the protection of nature, the other of heritage.

5.1 The Galápagos Islands, Ecuador

The Galápagos Islands exhibit ecosystem services at work. After Europeans discovered the archipelago in 1535, these hardscrabble, barren volcanic islands suffered centuries of abuse by buccaneers, whalers, settlers, and scientists before the Ecuadorian government created a national park in 1959. Some 97% of the Galápagos Islands (6000 square miles/9000 km^2) is in the national park. In 1986, the waters surrounding the islands received protection through the Galápagos Marine Reserve.

The Galápagos archipelago rises from the Pacific 620 miles (998 km) off Ecuador's coast at a geologically productive hot spot, a place where a mantle plume melts Earth's crust, resulting in volcanoes. Three ocean currents come together at the Galápagos contributing to its rich biodiversity. During World War II, the US Army found it a strategic place to build an air strip to help protect the Panama Canal. Today, that landing spot on flat, barren Baltra Island is the principal entry port to the islands. Besides the airport, leftover bunkers from the wartime are scattered among a few other random structures.

Ferries at Canal de Itabaca connect Baltra with Santa Cruz and a road across the island to Puerto Ayora, the key access point to the rest of the archipelago, which consists of nineteen islands and some 107 islets and rocks. The elevation changes across Santa Cruz as does the microclimate and vegetation. Scattered, rather poor settlements are found around the village of Bellavista, with the wealth and number of people increasing notably at Puerto Ayora, with its thriving tourist enterprises. Between Bellavista and Puerto Ayora, there are cattle grazing, small banana plantations, and a couple of resort hotels, well hidden from the road by vegetation.

The Charles Darwin Center is located at Puerto Ayora. Its researchers are engaged in various activities, including the breeding of giant tortoises, the creatures that gave the islands their name (Insulae de los Galopegos or Islands of the

Tortoises). Baby tortoises are kept at the center for two years before being released in nature to protect them from rats, an especially nasty, introduced species.

"It is not the strongest of the species that survives nor the most intelligent that survives. It is the one that is most adaptable to change," reads a t-shirt at the Ecuador National Park Service gift store at the Charles Darwin Center. The quote is attributed to Charles Darwin, but he did not write or say this, though it sounds Darwinian. Of course, his brief visit in 1835, which inspired his theory of evolution by natural selection, contributes to the allure and significance of the islands.

Every day, the sun sets dramatically in the Galápagos. The clouds and islands form a uniform purple that is lighter than the darkening blue of the sea. A pink crown tops a clouded island below a powder-blue sky streaked with white and gray clouds. The pink appears to catch fire for a few moments before being extinguished. The gray-white clouds grow pink, too, and look like they catch fire. The Pacific swallows the sun. The light blues become darker blue. The sea turns red purple as dusk fades into darkness.

Declared a World Heritage Site by UNESCO, the national park protects approximately 5000 unique species. Some 1900 are endemic. In addition to the giant tortoise, there are land iguana, blue-footed boobies, and many types of finches. As a result, the park is important for biodiversity, scientific research, and ecotourism.

Global science and the Ecuadorian economy have benefitted from the national park. The Galápagos Islands continue to help generate new biological and geological knowledge.

Meanwhile the archipelago has become a popular destination for tourism and recreation. These activities create jobs and revenue for Ecuador.

The Galápagos Islands are alive, geologically and biologically, changing and adapting to change. One can touch geologic time in the Galápagos, as Darwin did. If our species can learn to think geologically, perhaps we can better adjust to the present and plan for the future.

5.2 *The Pantheon, Rome, Italy*

The Emperor Hadrian dedicated this temple to all the gods of pagan Rome in 125 AD. The Pantheon is one of the most influential buildings in religion and architecture. The temple was rebuilt after two fires, one caused by a lightning strike, and later survived barbarian invasions.

The sacred space is dramatically connected to the outside through its oculus. Clearly the large-domed temple, which became a Roman Catholic Church in 609 AD, was built to last.

The Romans were master builders (Taylor 2003). For the dome, they used a lightweight material with pumice aggregate for some of the concrete employed in the construction of the higher portions. For the bottom of the dome, heavier aggregates, mostly from basalts, were employed (Parker 2009). These volcanic products are common in the landscape near Rome. Volcanic materials were also used in the foundation: layers of pozzolana cement created by grinding together lime and ash from Pozzuoli, Italy (Moore 1995; Parker 2009).

When Michelangelo saw it for the first time, he observed that it appeared to be more like the work of angels rather than humans. The great Renaissance artist is not alone with his expression of awe in first encountering the grandeur and serenity of the rotunda under the coffered magic light changes through the day and during the seasons. Rain drops through the oculus onto the marble floor where slight angles direct it to drains.

The structure is a marvel of both engineering and artistry. One feels the power of the gods under the Pantheon dome as a result of the human framing of nature. The space is both enclosing yet open to the outdoors. Beyond the rotunda, its portico provides a transition between the interior, sacred space and the surrounding city. Through time, plants have colonized the outside walls and roof. The Pantheon serves as a bedrock for ecosystems that inhabit its surfaces. This place built for celebration of all the gods is connected to light and rain, to geology and plant life, as well as the vibrancy of the modern city.

6 Vision

We humans are a clever and adaptive species. Design and planning are two of our most powerful instruments for creating better futures. As Herbert Simon observed, design "devises courses of action aimed at changing existing situations into preferred ones" (1996). Nature provides many lessons for design. Leonardo Da Vinci observed that humans "will never devise any invention more beautiful, nor more simple, nor more to the purpose than nature does; because in her inventions nothing is wanting and nothing is superfluous."

In the Anthropocene, we need to adjust design and planning to incorporate the consideration of the values that ecosystem services provide, regulate, support, and contribute. We must move from depleting those services to protecting and producing them. The examples highlighted here illustrate this is possible. Several of these projects have been used to advance sustainable design and planning.

Although sustainability is a necessary and worthwhile goal, it has proven difficult to achieve beyond the building and site scale and, even then, commitment and wisdom are needed.

Leaving the planet a better place for future generations is common sense. Yet, a more ambitious agenda is necessary for our species. We need to move toward larger-scale regenerative design and planning for resilience.

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Part V
From Built Environments to Living Cities: Engineering and Materials

Sustainable Building Materials Guided by Ecological Wisdom to Combat Environmental Issues

Mengmeng Li and Varenyam Achal

Abstract Developing an ecology of construction is very important step to achieve sustainability in infrastructures that requires adopting ecological principles while choosing building materials. Nature provides some insights into sustainability in the built environment for sustainable construction. However, it is very important to know the concept of ecological wisdom that prevails in nature to get concept of sustainability in the built environment. Ecosystems are the source of important lessons and models for transitioning built environment onto sustainable path that opens option for sustainable building material to construct new infrastructures to fulfill the demand of growing population. Increasing needs for environmental protection has attracted the scientific community to develop building materials with less adverse impact on the environment. The use of plant-based materials or supplementary cementitious materials in concrete can reduce the environmental impacts of concrete and thus provide an option as sustainable building material. Microbial carbonate precipitation is another promising way of emulating nature's sustainable ways that act as building material. The various building materials discussed in this article promote green buildings leading to energy and carbon emission reduction and demonstrate the scope for carbon mitigation options in the construction sector.

Keywords Sustainability · Building materials · Ecological wisdom
Cement · Earth construction

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Highlights

- Introducing ecology of construction is important step to achieve sustainability in infrastructures.
- Ecosystems as a source of lessons and models for transitioning built environment onto sustainable path.
- Earth construction and plant-based building materials bring sustainability in construction.
- It is important to develop carbon-negative cement to use in modern infrastructures.

1 Introduction

It is becoming an increasingly heated topic of discussion among concerned scholars from different fields to look for the way to make cities healthy. The researches carried out to build healthy cities are no longer restricted to urban planners, architectures, or engineers, but ecologists and even microbiologists are also entering into this area.

Urban resilience is now being recognized as the approach to healthier and more sustainable cities facing various challenges (Shao et al. 2016). The infrastructure of any city depends on building materials that could pose potential threat to the environment or ecosystem. However, to accommodate the growing population, rapid construction of infrastructure is obvious. Among the materials of construction, concrete is the world's most consumed man-made material. It is in fact most widely used material on this earth after water. However, the production of Portland cement, an essential constituent of concrete, leads to the release of significant amounts of CO_2, a greenhouse gas (GHG); production of one ton of Portland cement produces about one ton of CO_2 and other GHGs (Naik 2008). A review of the recent trends in the global production of cement in 2015 shows that the estimated amount of cement produced over the world was 4.6 billion tones (Fig. 1), where China alone consumed 51.3% of it (CEMBUREAU 2015).

In the current global setting, building construction and operation result in 50% of all emissions worldwide. In order to city become sustainable, the construction industry must manage its environmental impact in an optimal fashion. Table 1 summarizes quantities of energy and CO_2 produced by common building materials. Due to its negative impact on the environment, cement is not considered at all a sustainable material. Thus, urban sustainability problems due to cement usage can be categorized as the wicked one (Rittel and Webber 1973).

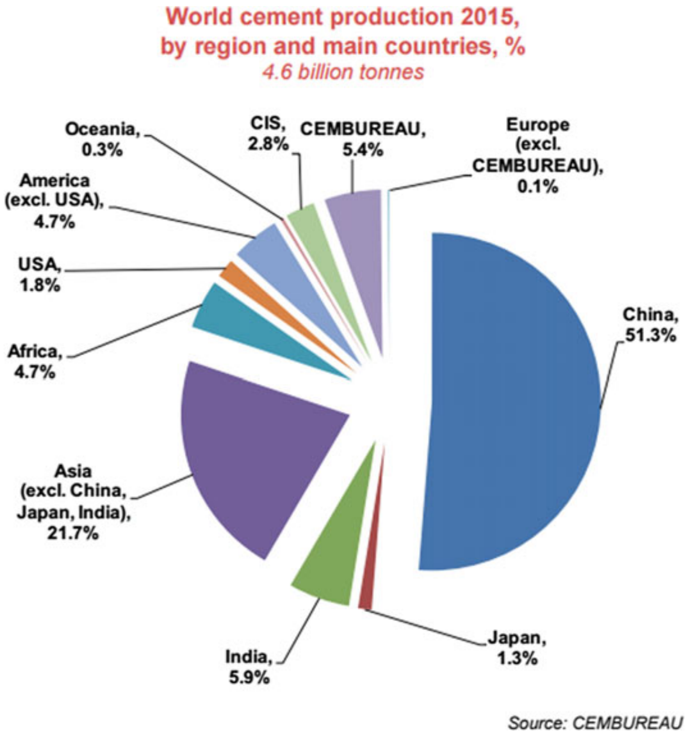

Fig. 1 World Portland cement production in 2015

Table 1 Embodied energy and emission of building materials

Material	Energy (MJ/kg)	Carbon (kg CO_2/kg)
Aggregate	0.083	0.0048
Concrete (1:1.5:3, e.g., in situ floor slabs, structure)	1.11	0.159
Concrete (e.g., in situ floor slabs) with 25% PFA RC40	0.97	0.132
Concrete (e.g., in situ floor slabs) with 50% GGBS RC40	0.88	0.101
Bricks (common)	3.0	0.24
Concrete block (medium density 10 N/mm^2)	0.67	0.073
Aerated block	3.50	0.30
Limestone block	0.85	–
Cement mortar (1:3)	1.33	0.208
Steel (general—average recycled content)	20.10	1.37
Steel (section—average recycled content)	21.50	1.42

(*Source* http://www.greenspec.co.uk/embodied-energy.php)

2 Ecological Wisdom for Sustainable Construction

The concept of ecological wisdom as explained in Xiang (2014) prevails in the nature and provides sustainable solutions to combat environmental issues associated with cement. In case of building materials, ecological wisdom is manifested in the results of millions of years of experiments on sustainable habitats by nature (Achal et al. 2016). In ecologically meaningful engineering projects are developed in harmony with the existing ecosystems for overall environmental benefit. Ecological wisdom reminds responsibilities that all citizens on earth should bear in mind and carry out in fighting against the ecological crisis and provides a blueprint for human beings to develop a low carbon economy of sustainable development (Xu et al. 2012). Ecosystems are the source of important lessons and models for transitioning built environment onto sustainable path. Green (or ecological) infrastructure is one strategy to enhance and expand ecosystem services (Steiner 2016), and sustainable building materials are highly required for it.

Buildings are the most significant components of the built environment that are perhaps also the most significant embodiment of human culture (Kibert et al. 2002).

In the modern era of building design, ideas of several eminent architects and planners like Neutra, Mumford, McHarg, and Wells have coalesced into today's ecologically sustainable construction (Kibert et al. 2002). Neutra pointed out how badly flawed human products are compared with nature and also provided concept on how building structures mimic nature's system. For example, a reinforced concrete structure bears more than glancing similarity to the skeletal structure of a vertebrate. Neutra advocated connections between living spaces and the green world of organic (Neutra 1971). Lewis Mumford, on the other hand, advocated ecotechnics that rely on local sources of energy and indigenous materials in which variety, craftsmanship, and vernacular are important and add value to ecological consciousness (Luccarelli 1995). McHarg put emphasis on integrating environmental sciences, ecology, and biological sciences in planning for sustainable built environment (McHarg 1969). Malcolm Wells supported approach to ecological design and gave importance on knowledge of biological foundations by architects (Wells 1991).

Since the beginning of the 1990s, construction industries, architectures, and engineers have been articulating a concept, commonly known as 'sustainable construction' that seeks to change the nature of how the built environment is designed, built, operated, and disposed of it (Kibert et al. 2002). This was long time back advocated by Neutra, Mumford, McHarg, and Wells, a nature-based design. Sustainable construction is the creation of built environment that follows ecologically sound principles, and thus, type of building materials used in it plays a great role to reduce environmental and resource impacts.

Ecological wisdom provides us necessity to use new concept building materials mostly inspired from nature (or nature-based design) in the construction industry to achieve sustainability. It is very important to integrate ecology in construction engineering and to make construction behaving in a natural manner (Kibert et al. 2002).

Thus, construction ecology supports building materials, which are integrated with eco-industrial and natural systems and preserves natural system functions.

Nature always develops the design solutions with fine-tuned mechanical properties especially of biological origin that inspire engineers in designing structures by mimicking them (Ehrlich 2010). Anthills or coral reefs are natural building habitats made in a sustainable manner for millions of years. Such biological systems of nature serve as prominent inspirational source due to their remarkable variety of simple to complex structures and functions, which confer a huge impact on sustainable materials since several decades (Jain et al. 2013). These habitats work with nature to combat any difficulty and construct sustainable building structures (Fig. 2). Anthills are extremely tall structures made on this earth compared to their construction engineers, of high mechanical strength with cementing material coming from saliva of termites in the form of lignin. On the other hand, corals use carbon dioxide as raw material to form reefs that act as the most prolific mineralizer on the planet. Corals build reefs by natural interaction between CO_2 and water that precipitates as $CaCO_3$ after reaching equilibrium (Kleypas et al. 1999). The reef formation process is totally opposite to cement production, where carbon dioxides

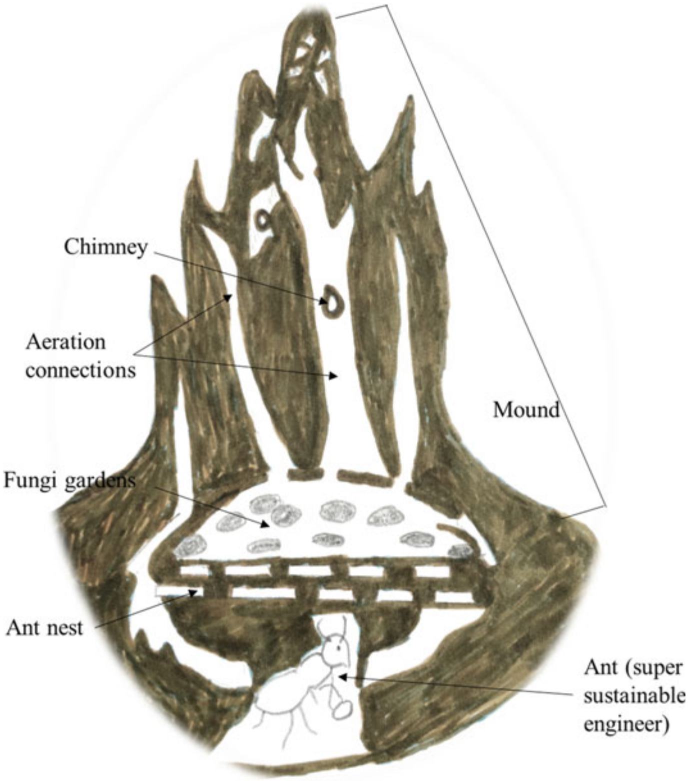

Fig. 2 A representative diagram of anthill: sustainable building practice by ants

are released into the environment. Biomimicking such process could lead to the production of low energy cement, and amount of cement can be reduced during construction significantly. Answers to many environmental problems remain practically unanswered; however, there is always solution through understanding the principle of ecological wisdom to achieve sustainability. Many such building materials (anthills, coral reefs, silk, teeth, bone, skin, shells, and many more) based on such concept have been summarized in detail (Achal et al. 2016).

In order to ensure sustainable cement production in the current era, the construction industry needs to change. The two most important challenges facing the industry are a pressing need to reduce CO_2 emissions and improve energy efficiency (Imbabi et al. 2012). Thus, it is very important to find green, environmentally, and economically sustainable alternative building materials of lower embodied energy that emit less CO_2. Even in Europe itself, buildings are responsible for more than 40% of the energy consumption and greenhouse gas emissions (Lechtenbohmer and Schuring 2011); thus, the use of building materials with lower embodied energy becomes a priority area under the sustainable development concerns of Horizon 2020 (Pacheco-Torgal 2014).

The easiest way for architects to begin incorporating sustainable design principles in buildings can be achieved by careful selection of environmental sustainable building materials. Natural materials are generally lower in embodied energy and toxicity than man-made materials. They require less processing and are less damaging to the environment. When low embodied energy natural materials are incorporated into building products, the products become sustainable (John et al. 2005). Some of the building materials that can bring sustainability in modern infrastructure constructions are described below.

3 Clay-Based Building Materials

The use of clay as a sole binder to make building materials has been used in construction date back to thousands of years ago (Staniec and Nowak 2011). It is also often known as earth construction. Clay-based construction technologies (such as rammed earth, adobe, and wattle and daub) have been widespread because of simplicity of manufacturing procedure and availability of raw materials (earth). Around 30% of the world's population lives in earth-made constructions (Houben and Guillard 1994), with approximately 50% of them located in developing countries. Among it, adobe constructions are very common basically in Latin America, Africa, the Indian subcontinent, and other parts of Asia, Middle East, and Southern Europe.

Adobe literally means sun-dried brick is one of the oldest and most widely used natural building materials, which presents some attractive characteristics, such as low cost, local availability, the possibility to be self-/owner-made with unskilled labor, good thermal insulation, and acoustic properties (Varum et al. 2014).

Some ancient structures built centuries back are still performing satisfactorily. One example is Hakka rammed earth buildings (also known as Fujian Tulou), in Fujian Province of China with a history of 3000 years. Figure 3a shows a typical Tulou building, while Fig. 3b presents a whole view of Hakka village. These rammed earth buildings have thick ($\sim$1 m) outer walls, and inner wooden structures make up floors and rooms. They are 3–5 stories in height and round or square in shape. Each building has hundreds of rooms and could accommodate 800 people. The buildings have great engineering values in terms of low energy consumption for comfortable living, sustainability, and durability (Liang et al. 2013), which inspired modern construction to learn lessons from traditional earth buildings.

The clay-based material suitable for buildings is generally exploited from soil in site with a proper composition essentially of clay and other elements, such as aggregate (stone, gravel, sand), natural fibers (straw, bamboo, wood). Clay consists of particles <2 μm, works as a binding agent, and akin to cement in concrete. In earthen architecture load-bearing walls, infilling of walls, roof structures can be constructed from earth.

Clay-based materials show important advantages over conventional ones (concrete, masonry), in particular concerning with significantly low embodied energy, manufactured in site, using simple technological manipulations, readily reused, and recycles at the building end of life (Akbari et al. 2012; Darling et al. 2012). Thus, the energy consumed and carbon emission of clay-based materials create a striking contrast with concrete; clay-based materials create nearly one-fifth compared to that of concrete blocks during production (Fetra et al. 2011). Moreover, clay has affinity for water, can absorb water vapor in excess, or release it when it is scarce. Furthermore, clay-based construction has better performance in terms of thermal comfort. A case study carried out by Jaturapitakkul et al. (2007) showed that indoor temperature reduced by 3 °C compared to that of cement block walls with clay-based building structure, indicating lower energy demand to maintain thermally comfortable buildings with clay-based construction.

Fig. 3 **a** A typical Tulou building and **b** a whole view of Hakka village. *Source* http://www.china.com.cn/aboutchina/zhuanti/fjtl/node_7047538.htm

However, the main concern in the use of clay-based materials is regarding its durability. As clay is the only binder in mortars to ensure the strength and stabilization (Montana et al. 2014), clay-based materials tend to generate cracks after shrinkage through which water can penetrate into wall, which reduce the mechanical strength (Hamard et al. 2013). Moreover, the negligible tensile strength and limited capacity to dissipate energy also affect the durability (Ernest et al. 2016). Also, over-exploitation of natural resources has placed a greater threat to the environment. Therefore, developing alternative materials has been considered a priority in sustainable design and construction (Kariyawasam and Jayasinghe 2016). Overall, earth construction or clay-based building material is associated with low embodied energy, low carbon dioxide emissions, and very low pollution impacts.

4 Modern Clay-Based Building Materials

The properties of rammed earth can be improved by stabilizing it by chemical means, especially by mixing with cement. Cement stabilization has gained popularity due to higher and faster strength gain, durability, and ability to obtain acceptable properties with low percentage of cement. Stabilizing earth with cement forms cement-stabilized rammed earth (CSRE), a building material with sufficient strength and durability but low in embodied energy (Kariyawasam and Jayasinghe 2016).

The case study by Reddy et al. (2014) demonstrated the scope for reducing the carbon emissions in the construction sector through the use of cement-stabilized rammed earth construction. They constructed CSRE school complex area of 1691.3 m^2 that consisted of 15 classrooms, an open-air theater, and a service block (Fig. 4). The construction involved a very simple procedure where soil, sand, and cement were mixed in a rotary drum mixer and used to construct school building. The reconstituted soil contained 13% clay fraction, while 8% ordinary Portland cement was used as a stabilizer. The data showed low embodied energy of 1.15 GJ/m^2 for the CSRE building as against 3–4 GJ/m^2 for conventional burnt clay brick load-bearing masonry buildings. Considerable amount of embodied energy was saved by the use of CSRE and other alternative building concepts. This case study clearly demonstrated the scope for reducing embodied energy of buildings in the construction sector by adopting modern rammed earth construction.

In some types of ancient earthen techniques (such as adobes and cobs), natural fibers are added in the earth mortars to distribute shrinkage cracks throughout the wall mass and enhance cohesion and shear resistance (Keefe 2005). Moreover, strengthening system consists of high-performance fibers (such as glass fiber, carbon fiber) which are embedded into the earth matrices so that externally strengthen structures was developed (Liu et al. 2014). The reinforcing system could help to increase the dissipate energy in flexion, which could increase the ability of earthquake resistant (Ernest et al. 2016). Besides, mixing a chemical-based agent

Fig. 4 View of the CSRE school complex. Reprinted with permission from Reddy et al. (2014)

other than clay, such as cement and lime, could gain higher mechanical compression strength and resistance to erosion with low percentage of cement (Minke 2012). Although the chemical modification makes up the defect of clay-based material, the modified earth material with inorganic binders is hard to reuse and recycle at the end of life of the building, resulting in the waste of farmland resources. Modern clay-based materials provide a sustainable and healthy alternative to conventional masonry materials (Pacheco-Torgal and Jalali 2012).

5 Plant-Based Building Materials

Global warming, energy savings, and life cycle analysis issues contributed to the rapid expansion of plant-based materials for buildings, which can be qualified as environmental friendly, sustainable, and efficient multifunctional materials (Amziane and Sonebi 2016), and it brought the concept of 'agro-concrete.' Agro-concrete is a mix between granulates from lignocellular plant matter coming directly or indirectly from plants, which form the bulk of the volume, and a mineral binder (Amziane and Arnaud 2007).

The use of crushed hemp (shiv), flax, and other plants associated with mineral binder represents the most popular solution adopted in the beginning of this revolution in building materials. Bio-based aggregates come from the stem of plants cultivated either for their fibers (hemp, flax, etc.) or for their seeds (oleaginous flax, sunflower, etc.). In addition, wild plants such as bamboo, dis stem, lechuguilla fibers, kenaf bast fibers, wood shaves, sulfite pulp fibers, and eucalyptus kraft pulp are often used to make lightweight concretes (Amziane and Sonebi 2016; and references therein).

Hempcrete is one special type of well-researched bio-based building material obtained by mixing hemp wood with 70% slaked lime, 15% hydraulic lime, and 15% pozzolana (Amziane and Arnaud 2007). It is estimated that approximately 1.8 tons of CO_2 are sequestered for every ton of hemp shiv used, and thus, taking into account the CO_2 emitted for binder production and depending on the recarbonation of the lime, 117–18 kg of CO_2 are sequestered into a one cubic meter of hempcrete (references in Amziane and Sonebi 2016).

Kenaf (*Hibiscus cannabinus*) fibers are emerging as promising alternative building materials that will provide a much-needed boost to the construction industry. Kenaf plants have property to absorb and decompose carbon dioxide in the atmosphere very rapidly to fix carbon as an integral component of fibers, and thus, it is assumed that building materials constructed with this plant will sequester carbon dioxide. Further, the use of plant-based fiber reinforcements as building materials is regarded as a significant step to achieve the construction with sustainability.

The unique selling point of bio-based building materials made with plant aggregate is its ability to effectively insulate a building, using a natural material. However, bio-based building materials typically exhibit a comparatively low mechanical strength (Amziane and Sonebi 2016).

6 Supplementary Cementitious Materials (SCMs)

The addition of supplementary cementitious materials makes cement more attractive for sustainable building purposes. It is used to replace clinker in cement or cement in concrete because they possess pozzolanic and cementitious properties and, under certain conditions, are capable of enhancing concrete properties (Mehta 1985). Supplementary cementitious materials are often incorporated in the concrete mix to reduce cement contents that ultimately reduces CO_2 emission. Further, it improves workability, increases strength, and enhances durability of concrete structures. More importantly, SCMs are often industrial by-products; thus, the use of such materials lowers the environmental impact. The use of supplementary materials for clinker replacement can reduce CO_2 emissions up to 12% compared to the maximum 5% achieved by other strategies when a 10% of SCM is increased in the mix (García-Gusano et al. 2015). Development of construction materials capable of reusing a high waste content is an important research line in order to fulfill the resource efficient Europe 2020 milestone related to the management of waste as a resource (Pacheco-Torgal 2014).

Fly ash, granulated blast furnace slag, silica fume, rice husk ash, and sugarcane bagasse ash are industrial by-products, very commonly used as SCMs in the partial replacement for cement (Bapat 2012). As it reduces the amount of cement needed for concrete, it lowers the energy and CO_2 impacts of concrete.

The use of fly ash in cement to avoid carbon emissions from the production of clinker should be considered from an integral and holistic perspective for sustainable building practices (Vargas and Halog 2015). The substitution of 25% of Portland cement with fly ash has been shown to reduce the greenhouse gas emissions of 25 and 32 MPa concrete blends by 13 and 15%, respectively (Flower and Sanjayan 2007).

Concrete has been successfully constituted fly ash as up to 50% of the cementitious material. However, it is often used to replace typically 30% of the mass of Portland cement in a concrete mix, for example, to lower permeability and reduce initial heat evolution (Imbabi et al. 2012).

Granulated blast furnace slag (or slag) is a by-product of the iron and steel industry. Greenhouse gas emission reductions up to 39% have been reported with granulated blast furnace slag (Blankendaal et al. 2014). The possibility to use slag aggregates, as a partial replacement in concrete, should make the recycling procedure more attractive for steel manufacturers.

Silica fume is a by-product of the production of silicon and silicon alloys in electric arc furnaces. It is added to cement to produce high-performance concretes that are much stronger and more durable than other concretes made using blended cements, in addition to reducing the permeability of concrete and therefore able to better protect steel reinforcement (Imbabi et al. 2012). According to the US Environmental Protection Agency, 1 lb of CO_2 is avoided for every 2.2 lbs of SCM substituted in a cement, or 0.432 kg of CO_2 per kg of SCM (Norchem 2011).

7 Agro-Cement

Plant by products such as rice husks, sugarcane, and corncobs can produce biosilica. When residues containing biosilica are burned and then blended with Portland cement, the final product is called biocement (Hosseini et al. 2011). This biocement is other than of microbial origin; thus, we are using the term agro-cement (as most of the plants used in it are of agricultural values) for such cement in this article. The use of agro-cement has shown environmental, economic, and technical benefits. It reduces clinker consumption and its related energy use and CO_2 emissions.

A literature review on recent development of biocement (agro-cement) research is presented in Hosseini et al. (2011). Agro-cement coming from plant by-products of sawdust, rice husk, corncob, sugarcane, wheat straw, bamboo leaf is known to improve the compressive strength of mortar ranging from 18 to 103 MPa when added to replace 6–20% of the Portland cement in a mixture (Hosseini et al. 2011; and references therein). Thereby, agro-cement is treated as an environmentally friendly product that reduces CO_2 emission by partially replacing Portland cement, thus reducing the volume of this material produced by cement manufacturers.

Rice husk ash as high as 30% improved the resistance to water permeability of the resulting concrete with compressive strength similar to that prepared with Portland cement alone was reported (Saraswathy and Song 2007), while agro-cement with high content of rice husk ash had also good sulfate and chloride resistance than ordinary Portland cement (Chindaprasirt et al. 2007, 2008).

Agro-cement made with vetiver grass ash considerably improved mortar resistance against acid or chemical attack, probably because calcium hydroxide reacts with the biosilica to form C-S-H gel. Moreover, such mortar had better resistance to water permeability than cement from Portland cement alone (Nimityongskul et al. 2003). Mortars blended with corncob ash cement were also investigated with respect to improved impermeability and acid resistance (Adesanya and Raheem 2010).

Agro-cements such as sugarcane bagasse ash, wheat straw ash, oil palm ash also improved the sulfate resistance of concrete when partially replaced with ordinary Portland cement, and resistance was higher than concrete made up of Portland cement alone (Singh et al. 2000; Jaturapitakkul et al. 2007; Binici et al. 2008). The various researches indicate that plant by-products that produce silicon-rich residues could be good candidates to consider for efficient partial replacement for ordinary Portland cement.

8 Carbon-Negative Cements

It is very important to find alternate building materials or cement that could replace conventional Portland cement to achieve carbon reduction, and it is subject of interest by researchers worldwide to develop the next generation of cements.

Calcium sulfoaluminate cement is one of such novel cement that uses limestone as one of the raw materials in their production and provides similar performance to Portland cements. It offers a 20% reduction in CO_2 emissions by requiring a lower kiln firing temperature and therefore burning less fossil and fossil-derived fuels (Imbabi et al. 2012).

Calcium aluminate and calcium alumina silicate cements are special type of cements used for its ability to reach high strength at a very early stage. Their production reduces the amount of CO_2 emission; however, these are more expensive and less readily available than Portland cement.

Another type of novel cement is based on water-activated magnesium oxide that requires 30% less energy for its production; however, it was commonly used well before Portland cement ever came into existence. Based on its advantages over Portland cement that include its permeable nature to make it in terms of heat regulation and control in the design of dwellings, a working formulation of ‘carbon-negative cement’ derived from magnesium silicates is undergoing (Imbabi et al. 2012). Magnesium-based cement is known to absorb more CO_2 than it produces during the manufacturing process. Carbon-negative cement has yet to become marketable product capable of competing with the common Portland cement.

The four companies who have used multiple techniques to develop a successful carbon-negative cement product are Novacem of Britain, Carbon Sense Solutions of Nova Scotia, Canada, and Calera and Blue Planet both from California. Each company has been developing its own unique technology to create carbon-negative cement. Unfortunately, most have been unsuccessful and are out of business.

The cement of Novacem is based on magnesium oxide (MgO) and hydrated magnesium carbonates. The company claimed that the production process to make 1 ton of Novacem cement absorbs up to 100 kg more CO_2 than it emits, making it a carbon-negative product (Novacem 2011). On the other hand, Carbon Sense Solutions uses carbon curing technology to retrofit concrete plants to recycle waste products into creating a 'greener' concrete.

The Calera Corporation has a process that mimics marine cement, similar to what is found in the coral reef, taking the calcium and magnesium in seawater and captured carbon dioxide from effluent gases to form carbonates. This technology absorbs CO_2 during the production of cement rather than emitting it.

Blue Planet also mimics nature's process for hardening tissues in living organisms based on carbon capture and mineralization technology. As per their principle, wherever there is saltwater near fresh water, there is an untapped, universal, and abundant power source that forms osmotic pressure between salt and fresh water and generates alkalinity. Blue Planet's alkaline solution is combined with CO_2 from flue gas to form carbonates (Blue Planet 2016).

9 Biocement

Biocement is microbial-based building material. It is the product of biomineralization where cementing material comes from microbially induced carbonate precipitation in the form of $CaCO_3$. It has three constituents, namely alkalophilic microbes, substrate solution (urea), and calcium ion solution (Achal et al. 2013; Rong and Qian 2012).

Biocement is treated as novel material that is able to improve compressive strength of cement-based materials, reduce porosity, and thus diminish diffusion of moisture and other deleterious materials. By reducing intrusions, biocement improves the durability of structures that is another step toward sustainability. The importance of biocement as a sustainable building material has been explained in detail in Achal et al. (2015).

10 Conclusion

The concept of ecological wisdom leads us to understand natural systems and let us attempt to emulate some of nature's sustainable ways in infrastructural construction by means of sustainable building materials. There is enormous global demand for cement or replacement of this non-sustainable building material in construction industry. The industry is looking for ways to reduce CO_2 emissions from the construction of modern infrastructures. The prevalence of ecological wisdom brings sustainable materials in the form of clay-based or plant-based building materials, new carbon-negative cements, new supplementary cementitious materials, agro-cement, or biocement that can be blended with ordinary Portland cement to reduce environmental impacts without compromising strength and durability of infrastructures, thus creating sustainable construction.

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Part VI
Planning Living City and Regions: Rural to Urban

Living with Floods: Ecological Wisdom in the Vietnamese Mekong Delta

Kuei-Hsien Liao

1 Introduction

Globally, flooding is the most widespread natural hazard, posing especially high threat to cities, where the majority of flood damage occurs (Ashley et al. 2007; Dewan 2013). Despite the extensive implementation of flood control infrastructure (e.g., levees, dams, channelization, diversion channels, weirs, and pump stations) to prevent flooding, cities around the world remain vulnerable to flood hazards (Andersen and Shepherd 2013). Flood control infrastructure cannot cope with extreme flows that exceed its design capacity, and it can fail unexpectedly by smaller flows. The recognition that flooding cannot be completely prevented gave rise to "integrated flood risk management" that incorporates non-structural measures and addresses basin-scale management (Parker 2000). However, in many cities non-structural measures (e.g., warning systems, insurance, and land-use control) only play a supplementary role to flood control. Basin-scale management, which emphasizes floodwater retention in upstream rural areas to reduce downstream flood risks, addresses neither pluvial flooding nor the eventuality of fluvial flooding in downstream urban areas. Despite the change in theory, flood control still dominates the practice in urban areas (Dewan 2013). The ideology that flooding should be prevented in the first place—the "flood control paradigm"—remains unchallenged (Liao 2014). With increasing urbanization and flood risks associated

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Liao KH, Le TA, Van Nguyen K (2016) Urban design principles for flood resilience: learning from the ecological wisdom of living with floods in the Vietnamese Mekong Delta. Landscape and Urban Planning, 155:69–78.

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with climate change, relying solely on flood control for hazard mitigation would make cities even more vulnerable. To promote flood resilience for cities, this paper argues for the alternative “flood adaptation paradigm,” which concerns preventing damage when flooding occurs. We explore the ecological wisdom of living with floods in the Vietnamese Mekong Delta (VMD)—an example of the flood adaptation paradigm—and extract lessons for modern cities.

The flood control paradigm assumes that flooding is disastrous in cities; however, it is not true if cities were resilient to floods. The concept of resilience receives growing attention in flood management but is often associated with post-disaster recovery. Adopting an ecological perspective (see Walker et al. 2004), we consider resilience relevant in not only post-disaster recovery but also hazard mitigation. Flood resilience is interpreted as the capacity to tolerate flooding to avoid disaster when *undergoing*—not preventing—flooding; or when physical damage and socioeconomic disruption still occur, the capacity to reorganize quickly (Liao 2012). In short, flood resilience requires either “flood tolerance” or “quick reorganization.” This concept is important to cities, which should plan for the uncertainties and eventuality of flooding in the face of climate change. Moreover, although globally flood fatalities have decreased thanks to better warning systems and evacuation programs, economic losses are increasing (Dewan 2013). Most losses are building-related (Scawthorn et al. 2006), which means intolerance of floods at the property level.

This paper focuses on the aspect of flood tolerance of flood resilience. Flood tolerance is the capacity to remain undamaged and functional when flooded, which requires adapting the built environment to floods (Liao 2012). In climate change literature, “adaptation” often all-inclusively means adjustments to actual or expected climatic conditions and their effects (UNISDR 2009), which also include flood control (e.g., Wilby and Keenan 2012). Here, “flood adaptation” contrasts with flood control, an attempt to change the flood regime. It is narrowly defined as measures to fit for the actual and expected flood regime *without attempting to change it*. The term “living with floods” also has divergent interpretations. We interpret it differently from that of the Vietnam Government’s ongoing “Living With Floods” program, which concerns relocating landless poor households from VMD’s flood zones (Danh and Mushtaq 2011). “Living with floods” here refers to a flood-tolerant lifestyle based on flood adaptation at the property level. It is a manifestation of ecological wisdom, which we define as wise decision concerning how humans interact with the environment based on the knowledge of it.

Nowadays, the living-with-floods lifestyle is only found in rural areas in developing countries (Laituri 2000). Although such a lifestyle appears vastly different from modern urbanism, it has enlightened flood management discourses (e.g., Cuny 1991; Thaitakoo et al. 2013; Zevenbergen et al. 2011). However, literature documenting in detail the physical aspect of living with floods is limited. The paper aims to respond to theme 2 “Ecological wisdom as actionable and practical knowledge” in the editorial by Xing (2014), with two objectives: First, it provides an account of the living-with-floods lifestyle in VMD, focusing on physical adaptation. Second, it draws from it practical lessons for urban design to promote flood resilience.

In what follows, we first introduce the background of VMD and the hamlets—Vinh An and Ha Bao—where fieldworks were conducted. We then report the fieldwork results of how the hamlets live with floods, followed by a discussion of the lessons from the ecological wisdom for modern cities. Next we propose three urban design principles for flood resilience and outline the challenges to the flood adaptation paradigm.

2 Background of the Vietnamese Mekong Delta (VMD)

The longest in Southeast Asia, the Mekong River runs 4800 km through China, Myanmar, Thailand, Laos, Cambodia, and forms a delta in Vietnam before entering the sea. VMD is a watery landscape consisting of Mekong's two main distributaries and a dense network of numerous natural and artificial channels (Fig. 1). It contributes to 75% of Vietnam's total agricultural-fishery-forestry production, over 50% of agricultural exports, and 90% of rice exports such that it is commonly called the "rice bowl" of Vietnam.

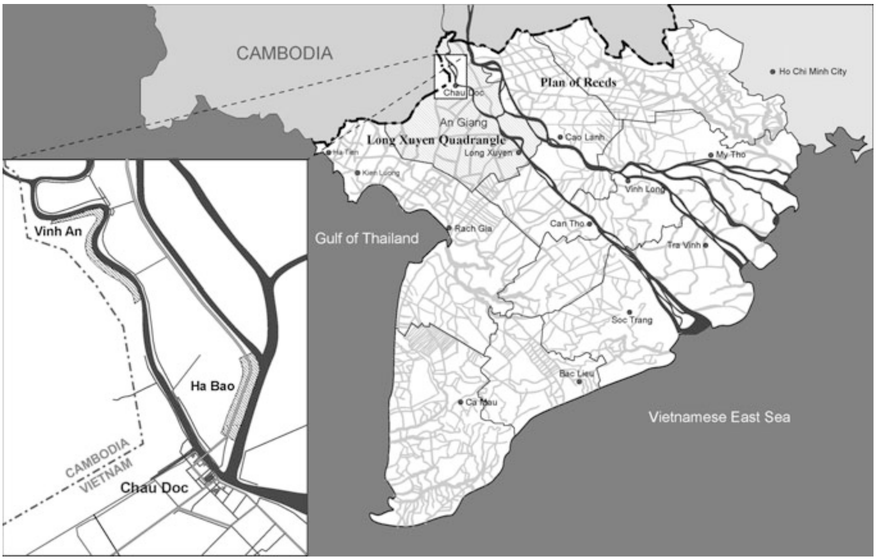

Fig. 1 Vietnamese Mekong Delta (VMD) and locations of two study hamlets

2.1 Seasonal Flooding

During the monsoon season, a total area of 12,000–19,000 km^2 is naturally flooded. The flood regime varies across VMD. Near Cambodia, the Long Xuyen Quadrangle and the Plain of Reeds are two topographically depressed and deepest flood zones, where the flood could reach 3–4 m in some years.

For most people, flooding implies harm, but it also has economic and environmental benefits (Green 2010). In VMD, seasonal flooding is a critical development resource (Ehlert 2012). It serves as a source for agricultural irrigation and domestic water uses, increases wild fishery resources, brings alluvium to fertilize farmlands, washes out salts and toxins from the sulfate soils, carries away wastes, eliminates rats and insects, and recharges groundwater (Biggs 2010; Brocheux 1995; Tuan et al. 2007). The Vietnamese term for "flood season" is *mùa nước nổi*, which translates directly as "rising-water season" (Tuan et al. 2007). Far from harmful, the flood usually comes and goes very slowly that a local farmer likened it to a turtle (Ehlert 2012). Fishermen consider the flood season as "income season" because it brings extra fish in the flooded field; some would even call it *ổng về* (he returns), implying the flood as a friend (Nguyen and Alexander 2014).

Different floods are clearly differentiated (Tuan et al. 2007). A moderate flood (*lũ vừa*) is also called "beautiful flood" *(lũ đẹp*) because it brings livelihood resources. A small flood (*lũ nhỏ*) and a high flood (*lũ lớn*) are undesirable, for the former results in less fish and promotes weed infestation in the field after the flood and the latter can lead to disasters (Danh and Mushtaq 2011; Ehlert 2012; Nguyen and Alexander 2014).

2.2 Increasing Flood Control and Disappearing Lifestyle

However, the living-with-floods lifestyle is disappearing in VMD. Traditionally, people grew the native rice variety "floating rice" (*lúa nổi*) that adapts to seasonal flooding. It can grow as fast as 5 cm/day and reach 2–3 m high to survive the rising floodwater (Catling 1992). This single-cropping rice has been largely replaced by high-yield varieties to achieve multiple crops. Since the 1990s famers started to build low, "semi-dykes" to prevent floodwater from entering the field until the high-yield rice crop is harvested in July, after which the dykes are overtopped or breached and the field flooded to still benefit from the alluvium deposit. Meanwhile, the Vietnam Government also started to build "full dykes" and implemented numerous other drainage and flood control projects to reduce the area affected by seasonal flooding to maximize rice production and improve living standards. Today in VMD, there exists 13,000 km of full dykes, more than 900 sluice gates, and over 1000 pumping stations (Vietnam-Netherlands Cooperation 2011). Cities also have raised the overall ground elevation above the flood level. Across VMD more and more lands are under flood control. As of 2011, the seasonally flooded area is reduced to 10,000 km^2.

2.3 The Study Hamlets—Vinh An and Ha Bao

As the area subject to seasonal flooding reduces, the living-with-floods lifestyle is only found in relatively remote, often poor, rural areas such as An Phu District of An Giang Province, where the study hamlets are located (Fig. 1). Vinh An and Ha Bao are within the Long Xuyen Quadrangle and experience similar flood regimes: Seasonal flooding starts in mid-July/early August and lasts for 3–4 months; it peaks in October to 1–1.5 m from the ground but has completely drained by mid-November; and it rises and falls slowly at 2–5 cm/day. The hamlets also share the same spatial pattern like many others in VMD: The settlement is sandwiched between the field and the river, and the houses are distributed linearly on the river's natural levees, the flat delta's natural higher grounds (Fig. 2). Each hamlet also happens to have a part that is not subject to seasonal flooding. A cluster of houses in Vinh An is on filled land, as a result of a resettlement project for the landless poor in 2002. In Ha Bao, the houses on the field side are not seasonally flooded, as flooding has been controlled in field since 2012 for triple rice cropping.

There are also major differences. Unlike Vinh An's main road, Ha Bao's was elevated in 2003 to act as a full dyke such that it remains dry during flooding.

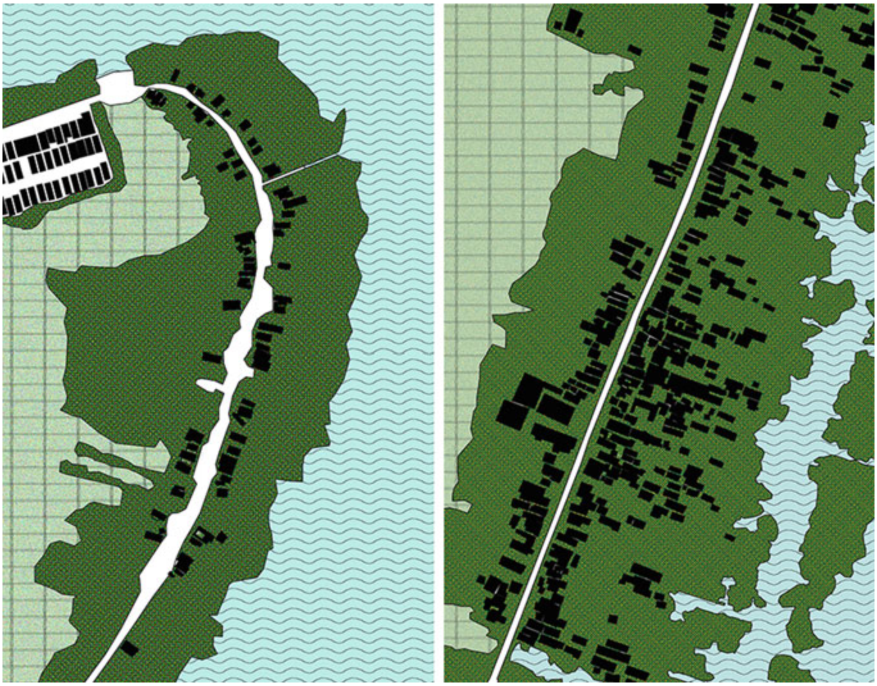

Fig. 2 Spatial patterns of Vinh An (left) and Ha Bao (right)

Moreover, Ha Bao is close to a major town and more densely populated, while Vinh An is remote, accessible only by boat. The two hamlets are chosen because of these differences, not for comparative study, but to include multiple traits of the built environment to learn more about the adaptation details in different built conditions.

While lives in both hamlets are not easy, Vinh An is worse off, where 42% of the households are officially defined as either poor or near-poor. Households in both hamlets typically generate income across a wide range of activities, the majority of which include farming, fishing, and wage labor. In Ha Bao, many also work as street vendors and some live on raft houses for aquaculture. Although there are few professional fishermen, most households in both hamlets engage in "floodplain fishing"—fishing in the flooded field that is considered a public fishing ground—with simple nets or bamboo traps. Floodplain fishing is particularly important for landless households as a major source of income or for subsistence.

2.4 Fieldwork Methods

We conducted semi-structured interviews in May, August, and November in 2014—right before, during, and right after seasonal flooding. A total of 34 households (16 in Vinh An and 18 in Ha Bao) were interviewed, with the male householder as the interviewee but in some cases other family members were also involved. The chosen interviewees are elderly, long-term residents, assumed to be most familiar with the living-with-flood lifestyle; and most were locally born. All interviewed households are at locations subject to seasonal flooding, except two in Ha Bao. Each interview lasted for 1.5–2 h, with questions regarding the flood regime, flood-related house design and renovation, traveling during flooding, flood experiences and perceptions, etc. Additionally, we also interviewed the hamlet heads of the hamlets to understand the overall conditions of the hamlets. Field observation was also conducted with regard to the overall setting of each hamlet and the physical conditions and surroundings of each interviewed household.

3 Living with Floods in Vinh An and Ha Bao

The Vietnamese term for the flood season—*mùa nước nổi*—connotes a time where all things appear floating on water. It is because people try to stay *above water*. This simple yet pivotal strategy allows everyday life to continue during prolonged flooding of 3–4 months. In this section, we report the interview results of physical adaptation strategies to stay above water, people's flood perceptions, and livelihood impacts of seasonal flooding.

3.1 Living in Stilt Houses

A common form of vernacular architecture in VMD, the stilts houses (*nhà sàn*) dominate the hamlets (Fig. 3). In the past, a typical stilt house would have a thatched or tiled roof; and its floor, walls, and stilts were made of bamboo or wood. Nowadays, more common are durable granite and concrete stilts and sheet metal walls and roofs. Gaps between the floor panels are purposefully left to enhance ventilation and to reduce the force of the waves against the floor during a stormy high flood. How high the house is raised above ground depends on the flood peak, and a household would plan to further elevate the house if the flood inundates the floor in consecutive years. However, limited financial capacity can prevent the household from building the house at a preferable height and delay further elevation.

Before 2000, the peak flood would inundate the floor of many houses almost every year for several days, even weeks. Nevertheless, people managed to live in the flooded house by elevating and staying on the bed. Most households would also uplift some floor panels to build a temporary floor on top of the submerged one. The flood in 2000 was the highest in recent decades, after which most households have managed to raise the house to more than 2 m above ground. The flood has not gone higher since. Most interviewees consider their houses high enough for now but also know that a higher flood is always possible.

The frequent inundation of the houses in the past caused limited economic losses. The floodwater drained easily because of the floor gaps. Floodwater carried away smaller household items, but most furniture and the wooden floor remained usable until a few years later. For most households, the hazard in the flood season is not inundation of the floor but when the high flood level coincides with a storm to produce large waves that could collapse the house. To mitigate the hazard, the better-off households build structurally stronger houses and deeper foundations; others reinforce the houses in the advent of seasonal flooding by tying bamboo poles between the stilts, for example. However, households in more densely

Fig. 3 Stilt houses in Vinh An (left) and Ha Bao (right)

populated Ha Bao don't worry about the waves, which are buffered and dissipated by many other houses and densely planted trees.

The space underneath the floor is called *sàn* in Vietnamese. In the dry season, it is used for various purposes, such as shelter from the heat; raising poultry; and storage for firewood, agricultural machinery, and fishing gears (Fig. 4). During flooding, the poultry are moved either to a filled ground by the house or a floatable pen. Items stored in *sàn* often stay but are repositioned higher from the ground, but in many cases *sàn* is designed with multiple levels of shelves to avoid such trouble. If floodwater reaches the shelves, the household would build a temporary storage platform by the house.

3.2 Maintaining Mobility with Boats and Footbridges

The major transportation means in the dry season are motorcycles and bicycles, which give way to boats during the flood season. Most people have learned to paddle by the age of 9 or 10. However, not every household owns a boat; some are too poor to afford one. In Vinh An, 80–90% of the households own boats, compared to 30% in Ha Bao. The low boat ownership in Ha Bao is due to the year-round accessibility of the road-dyke; moreover, most alleys are too narrow to navigate by boat. Therefore, temporary footbridges are also widely used to maintain mobility during flooding.

For short-distance trips and when the water is low (less than 2 m), people often choose to use footbridges as opposed to boats. The footbridges also have another purpose—to avoid soil erosion of the dirt road when walking in the water. In Ha Bao and more densely settled parts of Vinh An, numerous makeshift footbridges spring up in the flood season, and "monkey bridge" (*cầu khỉ*) is a popular bridge form because of its structural simplicity (Fig. 5). In Ha Bao, the footbridges are built along the alleys to connect to the road-dyke; in Vinh An they are used to connect to the nearby houses and then to the nearby grocery store. Usually of the

Fig. 4 *Sàn*—the space underneath the house

Fig. 5 Makeshift bridges in Vinh An (left; a monkey bridge) and Ha Bao (right) during the flood season

same clan, the households linked together by the footbridges would build them collectively. Most footbridges are made of low-quality materials such as bamboos or those readily collected from the surroundings. More durable materials would be reused in the following year, while others chopped up as firewood. In Ha Bao, there are also permanent concrete bridges, often belonging to the houses along the road-dyke or on large plots.

The height of the temporary footbridge does not depend on the peak flood but is increased incrementally as floodwater rises. During the flood season, a footbridge is usually adjusted 2–3 times. Although troublesome, it is to ensure that the footbridge is within 20–50 cm above water to minimize harm when one falls from it.

3.3 Flood Perceptions

Consistent with previous research conducted elsewhere in VMD (e.g., Ehlert 2012; Nguyen et al. 2013; Nguyen and Alexander 2014), our interview results show that seasonal flooding is mostly harmless and people recognize its multiple benefits. Even those not engaged in farming and floodplain fishing know that it deposits alluvium to fertilize the field and brings more aquatic lives. Moreover, flooding supports non-potable water uses. When the sediment-laden floodwater is settled to become clear, many households use it directly for dishwashing, laundry, and/or bathing, despite others consider it too contaminated by fertilizers, pesticides, and human wastes to use. The free floodwater particularly benefits poor households, who otherwise have to pay more for tap water.

It is also understood that floods are not created equal. In general, a moderate flood comes with multiple benefits so is benign and optimal. A small flood is problematic because it not only brings less fish but also impedes waste disposal. In Vinh An, few households have sanitary systems, and a garbage collection mechanism doesn't exist. Households deal with garbage by burning in the dry season and by floodwater removal in the flood season. In Ha Bao where garbage is collected, flooding is still considered important for environmental cleansing. Too little floodwater could lead to stagnation, waste accumulation, and consequential sanitation problems. A high flood alone is tolerable but undesirable, as it requires building higher footbridges that are less stable, temporary storage platforms, and even temporary floors in the houses. A high flood with waves is dangerous as it could collapse houses. A prolonged flood is acceptable as long as the level is not too high; it is beneficial for floodplain fishing because the longer the field is flooded, the more time for fishing.

Although seasonal flooding is mostly harmless, most however consider it an inconvenience, for it takes more effort to travel on water than on the ground. Paddling is not difficult but involves risk: A boat could overturn in the wind, particular in the flooded field that resembles the open sea. Walking on the makeshift footbridge, especially balancing on the monkey bridge with heavy things, is taxing. Therefore, many people—particularly the elderly—tend to stay at home during the season, with social activities greatly reduced. The season is also a time of worries about the safety of children who have yet to learn swimming and about an unpredictable stormy high flood. Because of the inconvenience and worries associated with seasonal flooding, most interviewees consider the non-flooded counterparts of the hamlet (i.e., the resettlement area in Vinh An and the field side of Ha Bao) a better living environment. Nevertheless, for households that have easy access (e.g., permanent bridges) to the road-dyke in Ha Bao, everyday life differs little between the dry and flood season.

3.4 Livelihood Impacts of Seasonal Flooding

Regardless whether their houses are seasonally flooded, people who work as wage labors in agriculture often see reduced income during season flooding, because it decreases agricultural activities—job opportunities—in the region. Although seasonal flooding provides an alternative livelihood of floodplain fishing, in recent years the amount of wild fish has dramatically decreased. Furthermore, the harvest depends heavily on the fishing gears, and poor households can only afford cheaper gears for subsistence fishing, and the yield is highly unstable. However, for those not engaged in primary industries, e.g., street vendors and traders, seasonal flooding has little impact.

4 Lessons for Modern Cities

Brocheux (1995: 2) uses "amphibious ecology" to describe the interaction between humans and the watery landscape in VMD during 1860–1960. The term still applies to Vinh An and Ha Bao today, as shown in the previous section. To prosper in the delta, people must learn to cope with indistinct land–water boundaries. Naturally, flood-prone cities are not different from the study hamlets, in that absolute land–water boundaries do not exist. To survive in a future of hydrologic uncertainty, modern cities need “amphibious urbanism” that is capable of operating at both dry and wet conditions. While the rural hamlets studied here are dramatically different from modern cities, the underlying ecological wisdom that gives rise to the amphibious ecology should be applicable across the board, as it concerns the fundamental relationship between humans and flood dynamics. We discuss the following lessons from the living-with-flood lifestyle for modern cities.

4.1 Ecological Wisdom Requires Ecological Knowledge

While flooding is not always preferable, it is tolerable in the study hamlets. Despite the inexistence of flood control infrastructure, today the hamlets can stay safe and sound and remain functional at a prolonged flood as high as 2 m, which would likely devastate most cities around the world. Challenged by the hydrologically dynamic environment, the ecological wisdom is manifested in the act of adaptation as opposed to control. Such wisdom is rooted in the knowledge of flood ecology in the understanding of the ecosystem services of flooding. Such ecological knowledge is generated not through scientific research but through observations by one generation after another (Brocheux 1995; Ehlert 2012). When the ecosystem services of flooding are appreciated, the design of the built environment works around as opposed to suppress flooding.

This is opposite to the case in modern cities that practice flood control, which has been criticized as ecologically destructive. While the degradation of riverine habitats is obvious, the more detrimental impact on fluvial hydrology is obscure to the general public. Periodic flooding, with which native species co-evolve, is key to the ecological health of floodplain rivers (Ward and Standford 1995), yet is largely eliminated. Polluted, channelized, leveed, regulated upstream, and with little natural floodplain left, many urban rivers have lost most ecosystem services (Grimm et al. 2008). Without the ecological knowledge of flooding, it is unlikely for cities to cultivate ecological wisdom to better interact with the natural phenomenon of flooding.

4.2 Key Properties of Flood Resilience

It is argued that flood resilience requires learning from floods (Liao 2012), as research shows that socio-ecological resilience to a disturbance arises from learning from that very disturbance (Berkes et al. 2003). Urban flood resilience is theorized to have three key properties: localized flood-response capacity, timely adjustments after every flood, and redundancy in subsystems (Liao 2012). We observe the first two qualities in the study hamlets, both of which are the results of exposing to, thus learning from, flooding year after year. We note that the learning need not come only from painful experiences—flooding in the study hamlets is mostly harmless, as mentioned repeatedly.

Localized, as opposed to centralized, flood-response capacity means that each household would take measures to respond to flooding (Liao 2012). By living in stilt houses, using boats and footbridges to maintain mobility, reinforcing the stilts, making temporary platforms during higher floods, etc., the households in the study hamlets essentially rely on themselves—without expecting any external agency (e.g., government) and mechanism (e.g., flood control infrastructure)—to mitigate flood hazards for them. It is flood-response capacity at the most local, property level, which derives from numerous flood experiences. On the contrary, flood control is a centralized approach, in that the authorities are entrusted to mitigate flood hazards for people, which consequentially don't feel the need to take any measure. Without local flood-response measures, flooding becomes disastrous when the centralized measure fails. Flood control infrastructure often produces a false sense of security (Pielke 1999), which erodes resilience through reducing flood risk awareness (Colten and Sumpter 2009).

Resilience does not come without cost. While many interviewees feel burdensome having to stay alert for a stormy high flood, we argue that it is exactly the wariness that constitutes risk awareness, which continues to reinforce localized flood-response capacity that make the hamlets resilient. In fact, despite the complaint about having to stay alert, most interviewees consider themselves more capable of coping with a larger flood than those who seldom experience flooding. Flood resilience of modern cities requires their residents to have flood risk awareness in the first place, such that they are willing to take property-level measures.

Another resilience quality seen in the study hamlets is timely adjustment, which is also a form of learning from floods. The adjustment needs be timely because the next big flood can occur anytime. Soon after the stormy high flood in 2000, many households in the hamlets reinforced and further elevated their houses before the flood season of 2001. This prevented them from suffering from the 2001 flood that was almost comparable to the 2000 flood. The financially limited households, although unable to do so sooner, took it a high priority and saved for it. If better off or helped with subsidies, each hamlet could have achieved system-wide, hamlet-level adjustment much earlier. On the contrary, upgrading flood control infrastructure often takes years, if not decades; for example, it took New Orleans seven years after Hurricane Katrina devastated the city. We hypothesize that when flood hazard mitigation measures for a city are localized at the property level, timely system-wide adjustments are more likely.

4.3 Agility as Opposed to Rigidity

It is argued that hazard-resilient communities are agile (Adger et al. 2004; Park et al. 2011). Because of localized flood-response capacity and timely adjustment, the study hamlets are agile communities. The agility also manifests in the "amphibious nature" of the hamlets, which can easily transform themselves to operate in wet conditions. When flooded, the hamlets preserve overall functionality by making changes in the subsystems, including livelihoods (from farming to fishing), transportation (from walking/biking to traveling on boats and footbridges), and physical arrangement of the houses (changing uses of *sàn* and making the temporary platforms and/or floors). Modern cities, however, are relatively rigid. Because of the dependence on centralized flood control infrastructure, many physical systems (e.g., vehicular transportation) can only operate in the dry condition and become dysfunctional when it turns wet. To become flood-resilient, cities need agility.

4.4 Shifting from Flood Control to Flood Adaptation Paradigm

To reiterate the lessons so far, modern cities need ecological knowledge to nurture ecological wisdom, and need to become agile by developing localized flood-response capacity, striving for timely system-wide adjustment, and turning amphibious. However, these are not possible without a shift from the flood control to flood adaptation paradigm in flood hazard mitigation. The flood adaptation paradigm, of which the study hamlets are manifestations, allows flooding to occur because it is not considered always disastrous. Only when the city periodically experiences flooding can it learn from it to nurture resilience.

In the study hamlets flooding brings inconvenience and worries, and in some cases income reduction, as reported earlier. The former problems are mainly due to the lack of resources to have structurally sound houses and footbridges, and the latter related to livelihoods in agriculture and fishery that are sensitive to environmental changes. As also reported, flooding has little impact on those with easy access to the road-dyke and other livelihoods. Therefore, if modern cities were to be flooded periodically, the same problems are unlikely to occur because cities generally have more resources and most urbanites don't engage in primary industries. Furthermore, the flood condition—prolonged flooding of 3–4 months—of the study hamlets is vastly different from what many cities are naturally subject to, which might be significantly shorter durations of flooding.

We stress that the argument for the flood adaptation paradigm is not to romanticize the lives of the study hamlets, where many households suffer from poverty. While debatable, whether their poverty is associated with seasonal flooding is beyond the scope of this paper. But many interviewees commented that lives were much better when there were much more fish during the flood season when the river was less polluted.

Although today's cities are more complex and connected, it is not impossible for cities to transition to the flood adaptation paradigm and become flood-tolerant in the long term. It requires a shift of the focus of flood hazard mitigation from the river to the built environment and the approach from engineering to urban design.

5 Urban Design Principles for Flood Resilience

The aforementioned lessons from the ecological wisdom in VMD are practical for urban design, here refers loosely to the design of the urban built environment. While it involves many professions, this section mainly concerns design and planning. Urban design professionals have strived for unconventional relationships between urbanism and hydrologic dynamics that are not mutually exclusive (Shannon 2013). Increasing flood catastrophes, coupled with climate change impacts, have given rise to urban design concepts that take flood hazards into accounts (e.g., Rodriguez et al. 2014; Thaitakoo et al. 2013). To make the lessons of the ecological wisdom of living with floods actionable, we translate them into three urban design principles: Urban design should (1) anticipate and accommodate flooding, (2) incorporate the ecological process of flooding, and (3) reveal the flood dynamics to the public. These principles complement the existing concepts. We explain each principle and provide existing design examples and emerging design solutions to demonstrate its actionability.

5.1 Urban Design Should Anticipate and Accommodate Flooding

A consequence of the flood control paradigm is that urban design rarely factors in the eventuality of flooding and assumes flood hazard mitigation a business of hydraulic engineering. The study hamlets demonstrate an environmental design that anticipates and accommodates flooding as a normal part of the living environment. It is often asserted that the city, densely populated with high land values, has no spare space for floodwater. However, such assertion is not valid because there exist design measures that could allow cities to anticipate and accommodate flooding (Liao 2014; Shannon 2013; Zevenbergen et al. 2011).

Pilotis architecture—buildings supported by ground-level columns—is essentially the modern form of the stilt house. It is not uncommon in urban areas and has been built at a large scale, as exemplified by Singapore. Eighty-five percent of the city-state's population resides in public housing estates that are high-rise buildings on pilotis. Locally known as the "void deck," the ground floor of the building serves as open space, while promoting ventilation and public security (Fig. 6).

Fig. 6 "Void deck" of a public housing block in Singapore

Also allow buildings to accommodate floodwater are permanent flood-proofing measures, such as utilizing water-proof flooring, wall, and furnishing; and raising the electrical fixtures (Bichard and Kazmierczak 2012). Furthermore, "amphibious houses" that sit on land but can float vertically during flooding have been materialized in the Netherlands and UK. In the short term, the government can incentivize the adoption of flood-proofing measures that do not require structural changes. However, in the long term it is best that all buildings in the low-lying areas are elevated or can float above the highest flood level. It is especially necessary where the waters are severely polluted and flooding can cause disease outbreaks. To achieve system-wide (i.e., at the district or city scale) architectural adaptation, the government might need to subsidize the flood adaptation for the financially challenged households.

Compared to buildings, it is relatively easier to accommodate flooding in open space. An early example is Boston's Emerald Necklace designed by Fredrick Law Olmsted in the 1870s. Arguably, allowing open space to flood has emerged as a trend in recent years. A recent example is the Bishan-Ang Mo Kio Park in Singapore, designed to flood periodically by the river running through it, functioning both for recreation and flood hazard mitigation. Design professionals also engage themselves in decentralized sustainable stormwater management. Bio-swales, rain gardens, and wetlands are increasingly incorporated into open space to encourage stormwater retention, storage, and infiltration; such that green spaces increasingly become green infrastructure to have the hydrologic benefit of flood mitigation (Gill et al. 2007). Hard-surfaced plazas, playgrounds, and sports fields can also accommodate flooding, as exemplified by the Watersquare Benthemplein in Rotterdam.

As for mobility during flooding, modern cities can also utilize aboveground linkages as the study hamlets do. For example, in HafenCity, a riverfront development in Hamburg, a network of permanent bridges exists to connect different buildings above the flood level (Fig. 7). It should be easier to establish an aboveground pedestrian and vehicular network in high-density, mixed-use urban areas where sky bridges and elevated highways have existed, such as Hong Kong. Lower-density urban districts would have to depend on temporary footbridges set up during flooding, as has been practicing in Venice. Where neither a permanent nor a temporary bridge network is feasible, public boats or amphibious vehicles could be a solution.

5.2 *Urban Design Should Incorporate the Ecological Process of Flooding*

Ecologically more sensitive mitigation approaches have appeared in recent years, as demonstrated by the "Building with Nature" program in the Netherlands and the

Fig. 7 A bridge in HafenCity, Hamburg that would allow connection between the buildings aboveground during flooding

European Water Framework Directive that encourage flood hazard mitigation to work with nature (Barbedo et al. 2014; Green 2010). In ecological restoration, "controlled flooding" has been carried out as part of environmental flows in some rivers in developed countries (Poff and Matthews 2013). However, cities are often excluded from these ecological approaches.

While in the study hamlets the beneficial medium floods are clearly distinguished from hazardous stormy high floods, in cities flooding is considered nothing but hazardous. Flood control infrastructure seldom discriminates between different floods such that smaller, ecologically critical floods are eliminated along with larger, hazardous ones. Making cities flood-tolerant would provide a chance to re-introduce ecologically critical flooding and could consequentially restore some ecosystem services of urban rivers (Liao 2014). The restoration of flooding as an ecological process can first take place in riverfront parks that used to be part of the natural floodplain. By re-naturalizing the open space and the river channel to resemble the natural channel-floodplain environment, a new ecosystem could emerge as periodic flooding shapes the aquatic and riparian habitats over time. For example, the restoration of River Isar in Munich demonstrates that a riverfront park can go beyond recreation and mitigation to also embrace the ecological process of flooding.

5.3 Urban Design Should Reveal the Flood Dynamic to the Public

The study hamlets intimately interact with the physical and ecological aspects of flood dynamics and therefore are capable of harnessing and preparing for seasonal flooding. However, urban rivers are often segregated from the public by levees or floodwalls, out of sight, out of mind. Furthermore, the flows are often regulated that urban rivers appear unchanged all year round. The lack of river–people interaction and flow regulation lead to little public concern with river health and a low awareness of riverine dynamics, including the failure to appreciate flooding as a natural phenomenon.

Accommodating harmlessly floods in the city, particularly in open space, can reveal the flood dynamics to the public, which could lead to a better public understanding of it. The concept of eco-revelatory design—design that reveals natural processes (Brown 1998)—has been around for a while. The decentralized features of sustainable stormwater management can be considered eco-revelatory designs that reveal the hydrologic processes of stormwater runoff. Similarly, a riverfront park that incorporates the ecological process of flooding can make visible a series of phenomena associated with flood dynamics, such as seasonal changes of water level; increases in fish and other aquatic species; sedimentation, debris deposition, and erosion; water quality improvement; and the development of biotopes out of the sediments and debris brought by a flood over time.

These phenomena would serve for valuable public education of flood ecology and help cultivate public appreciation of the positive side of flooding in the city.

6 Challenges to the Flood Adaptation Paradigm

We have demonstrated the plausibility of a shift to flood adaptation paradigm through three urban design principles and associated design solutions, inspired by the ecological wisdom of living with floods in VMD. Nevertheless, today flood control is still widely considered paramount for cities. When flood control is the priority in flood management, it is unlikely to widely implement flood adaptation measures. Two perceptional challenges need to be overcome to make the paradigm shift possible.

First, the negative image of flooding continues to be promoted through media and government policies. Even in VMD, where people harness the benefits of flooding, contemporary media frequently imply it as an enemy (Nguyen and Alexander 2014). Around the world most flood management schemes deal with flooding solely as a problem, entirely ignoring its ecosystem services. The public may understand how flooding can be beneficial in rural areas but may be difficult to consider so in urban areas. Flood hazard managers, urban designers, and river ecologists need to collaborate to further explore the ecosystem services of flooding in cities and communicate the findings to the public.

Secondly, since the flood adaptation paradigm focuses on localized flood-response capacity, it means more responsibility for property owners. However, the perception that the government is solely responsible for hazard mitigation is prevalent, and it has prevented wider implementation of adaptation measures (Bichard and Kazmierczak 2012; Johnson and Priest 2008). For example, research in the Netherlands and UK shows the most people would not invest to prepare for flooding because they consider the government responsible for flood control (Bichard and Kazmierczak 2012; Terpstra and Gutteling 2008). In the study hamlets, however, most interviewees consider without hesitation that themselves, rather than the government, should be most responsible for damage prevention. The reasons behind the perceptional discrepancy require further investigation. Nevertheless, it is argued that local flood risk awareness, a sense of ownership of the problem, and financial incentives are important for people to willingly adopt flood adaptation measures (Lamond and Proverbs 2009; Wilby and Keenan 2012). In recent years, policy makers in Germany and UK have started to promote personal responsibility in flood safety (Green 2010; Johnson and Priest 2008). With the political will, the challenge might be overcome if the government would redirect the tremendous resources in flood control to flood adaptation.

7 Concluding Remarks

Ecological wisdom can be actionable and practical knowledge. Studying the ecological wisdom of living with floods is not merely a nostalgic journey to recognize a traditional, yet disappearing lifestyle. We also demonstrate that it has important implications to modern cities, informing actionable and practical urban design principles for flood resilience. Fundamentally about mediating the relationship between human activities and hydrologic dynamics, flood management requires ecological wisdom. The living-with-floods lifestyle in VMD exemplifies a more harmonious, as opposed to conflicting, relationship. For cities to cultivate a similar relationship, it should be recognized that flooding is a natural part of urban dynamics and can be socioeconomically benevolent. The relationship between the city and flooding should not be reduced to hazard management. A paradigm shift from flood control to flood adaptation could lead to a future, in which urbanites safely live with and benefit from flooding, akin to the time-honored ecological wisdom in VMD. Urban design plays an indispensible role to realize the paradigm shift. We have put forward the actionable design principles and solutions. The challenge, next, is to take the real actions.

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Multifunctioning Urban Waterfront: Inspirations from the Ecological Wisdom of Working with Reservoir Flooding in the Three Gorges Reservoir Region

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Abstract This chapter argues for a new ecological-economic vision for flood management through examination of human–reservoir interactions in the Three Gorges Reservoir region, highlighting local ecological wisdom derived from observing, knowing and working with, rather than against natural forces. To make these lessons actionable for contemporary urban waterfront landscaping projects, especially those exposed to natural or manipulated flood, the practical and theoretical inspirations are summarised in terms of landscape structure, components and maintenance that echo with landscape design in the real world. We then provide a design scenario for the lakeshore landscaping of Kaizhou, new city of Chongqing Municipality that demonstrates the wisdom-inspired "doing" process. Based on this full cycle of case study–theory–application, we conclude ecological wisdom is the art of achieving balance between human and nature, grounded on accumulated knowledge of local, traditional and scientific understanding, and being able to adjust according to the changing circumstances.

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1 Introduction

Since the nineteenth century, two-thirds of the world's rivers have been regulated by over 45,000 large dams (New and Xie 2008). Although "dam fever" has subsided in developed countries since the 1980s (Graf 1999), the boom continues in developing countries (Grumbine and Pandit 2013). By 2013, China had built 98,000 hydroelectric dams of various sizes compared with just 40 small ones up to the late-1940s (Yang and Lu 2014). This dramatic increase, given the growing demands for clean energy, is likely to continue (DOE 2004). On the other hand, with population growth and urban sprawl, dams and reservoir environments have been steadily encroached upon by expanding cities and suburbs and are thus becoming "urban reservoirs". This creates more conflicts between development, human well-being and the environment.

The nascent intention for building such infrastructure is to deliver a variety of direct and indirect ecosystem services for humans, such as clean power generation, transportation, flood control, agricultural irrigation and urban water supply. Surprisingly to most people, the primary service of the Three Gorges Dam (TGD), one of the greatest dams in the world, is regional flood control that protects many towns, cities and megacities distributed along the Yangtze River. Paradoxically, dam and reservoir construction has often been criticised for elevating flood risk, especially in today's context of extreme weather events associated with global climate change. A possible reason is that dam construction often involves channelising, straightening and concreting watercourses for the purpose of speeding up stormwater to reservoirs and protecting banks from erosion. However, such practices alter the original hydraulic regime and ecological integrity and have been implicated in biodiversity depletion, surface water degradation (Kenwick et al. 2009; Theriot et al. 2013) as well as loss of cultural heritage and waterscape aesthetics (Cole 2012; Junker and Buchecker 2008).

Whereas dams and other relevant water facilities (e.g. levees, weirs and drainage) will continue to exist, ecologists and environmentalists advocate ecological or "soft" approaches to hydrological management for flood mitigation, e.g. stormwater retention and filtration in basins and wetlands on site instead of rushing it downstream (Barbedo et al. 2014; Collentine and Futter 2016; Thomas et al. 2016). Such an approach can also bring other environmental and economic benefits to people who live around the river and often cultivate flood-affected land. Historical examples include one of the oldest agricultural civilisations on the Nile River Delta of Egypt dating back to 3100 BC and traditional dike–fish ponds in the Pearl River Delta of China. These local people, over generations of careful observation and testing ideas, have developed a package of practical knowledge that works with the flood regime and temporal availability of resources.

Such people living on and depending on the land have to develop integrated lifestyles and local wisdom for survival. Traditional cultures like these are found worldwide in rural or remote areas. They have inspired natural resource management, such as coastal habitat conservation (Drew 2005), endangered species protection (Tang and Gavin 2010), wildfire suppression (Diaz et al. 2016; Ray et al. 2012), community-based biodiversity conservation (Ruiz-Mallen and Corbera 2013), reservoir conservation (Yuan et al. 2013) and forest management (Falkowski et al. 2016). These practices that deal with living environments are explicit reflections of long-established ecological wisdom that we now interpret as wise decisions leading to productive outcomes with minimal environmental and ecological cost (Xiang 2014). However, there has been a reluctance to apply naturalistic approaches to urban or peri-urban environments since, in today's lexicon, "urban" has been depicted as a separate domain from the natural and rural worlds where nature dominates.

In this paper, we argue for an alternative ecological-economic vision for flood management through the elaboration of local life–work styles in the Three Gorges Reservoir (TGR) region. We first provide a discourse on the traditional and contemporary life–work styles in the region, highlighting ecological wisdom derived from observing, knowing and working with, rather than against natural forces. This section focuses on technical and physical aspects in details based on fieldwork, participant observation and interview. The coupling of people and reservoir dynamics, and associated economic benefits, is discussed, followed by derivation of practical and theoretical inspirations for urban waterfront landscaping. Lastly, we develop a design scenario for the lakeshore landscaping of Kaizhou, new city of Chongqing Municipality that incorporates this learning. This study explores "how the ideas, principles, strategies and approaches of ecological wisdom become (more) actionable and practical in informing the contemporary practice of landscape and urban planning…" as advocated by Xiang (2014) at the "International Symposium on Ecological Wisdom for Urban Sustainability". The Kaizhou case study serves more generally as a model for viable, sustainable city development.

2 Background of the Three Gorges Reservoir Region

2.1 From Natural to Manipulated Flooding

The Three Gorges Reservoir (105° 49′ ~ 111° 50′E, 29° 16′ ~ 31° 25′N) is located in the middle reaches of China's largest river (also the world's third longest river), the Yangtze River. Naturally, the river levels were around 60 m above sea level (asl). One of China's largest flood catastrophes occurred in 1998, affecting 29 cities/towns/counties. It caused the death of over 3000 people, 15 million homeless and a 166,600 million Chinese Yuan economic loss (ca. US$20,072 million) accounting for around 3% of annual national GDP (Zong and Chen 2000). To ameliorate these effects while harnessing regional flooding and fulfilling the need for hydro-power, the TGD construction officially started in 1993 and was fully completed and filled to 175 m asl in 2010. Since then, water levels in the TGR have been manipulated between 145 m in summer to 175 m in winter. Each year, the

Fig. 1 A series of photographs taken at the same location during 2014–2015 showing reservoir water level fluctuation and how local people use the flooded land. *Source* All photographs taken by Hui Cheng

water starts rising in early September and takes 2 months to achieve the 175 m peak level where it remains for another 2 months before receding in early January. Recession is slower and minimum standing water level of 145 m is not achieved until mid-May (Fig. 1). Such a rhythm is contrary to the natural river flooding pattern. The total area of the TGR region is around 58,000 km^2, including the entire peak water body and 21 administrative counties, towns and cities along the reservoir. The standard operation of the water level, to optimise for flood relief, navigation and power generation, creates a broad zone of seasonally flooded land with an area of 348.9 km^2. This zone previously comprised 43.7% agricultural land and 35.9% forest/grassland with good alluvial soil, indicating potential opportunities for ecological purposes.

The region is characterised by diverse topography of plains (4.3%), hills (21.7%) and mountains (74%) (Zhang et al. 2009). It has a northern subtropical humid monsoonal climate with an average annual precipitation of 1200 mm, 60–80% concentrated between April and September. The mean air temperature is 18.2 °C; there are fewer than 20 frost days per year and only seldom does it snow above 1000 m asl in the mountains. The predominant soil types are yellow-brown soils and purple soils that support subtropical broad-leaved evergreen forests as the regional climax vegetation.

2.2 *Local Livelihoods*

Over 33 million people live in the TGR region with 40% being farmers. Because of the predominantly mountainous topography, arable land is scarce. Local communities till any suitable slopes and form a patchy terraced landscape (Fig. 2). The primary cash crops include citrus, rice and corn. Additionally, people often catch fish in the river or their household ponds and raise poultry as family supplements. Along with rapid urbanisation and economic development since the 1980s, this

Fig. 2 Photographs illustrating local terraced landscapes that are flexible in terms of available land, crop type and size of planting area. *Source* All photographs taken by Chundi Chen

region is subjected to a wide range of environmental stressors, such as water degradation, soil erosion and biodiversity depletion. To protect sensitive hilly and river environments, the national projects of "Shelterbelt Construction" and "Grain for Green" since the 1990s and the newly promoted "Ecological Barrier Zone of TGR" since 2009 are still ongoing. These projects mainly involve returning cropland to forest or grassland. Farmers can obtain annual subsidy for such transformation. Thus, most farmers, especially those living near a river, maintain non-intensive cropland for self-supply on a small scale. Such practices have formed a mosaic landscape pattern of many small agricultural patches embedded in a heterogeneous natural matrix (Chen et al. 2016b). This spatial pattern is strongly advocated in our work since it directly benefits biodiversity maintenance in conjunction with ecosystem integrity, production and landscape heritage (Forman 1995).

2.3 Field Survey and Measurement

We chose the typical reservoir margin towns, Kaizhou, Yunyang, Zhongxian and Wanzhou, as the field study areas to survey local life–work styles and their impacts and benefits concerning farming, poultry- and fish-rearing practices. Research methods include a combination of field observation and associated measurements, semi-structured household interviews and participatory farm work with locals, in line with social science methodology (Balram and Dragićević 2005; Farizoa et al. 2014; Jim and Chen 2006). These qualitative research methods enable direct interaction with respondents and observation of the full range of human activities in their natural work settings.

Based on demographic information from the Population and Family Planning Commission of Kaizhou, we interviewed a total of 156 respondents randomly chosen from residents living in the study area (Fig. 3). The interview questionnaire was divided into eight parts. We asked respondents about their age, education, occupation and economic status to learn about their general living situation. Then details relating to their farming activities were requested, including types of crops, planting and harvesting time, poultry and how they rear them, what conservation measures they adopted for their land, plants or other domestic animals. This, in

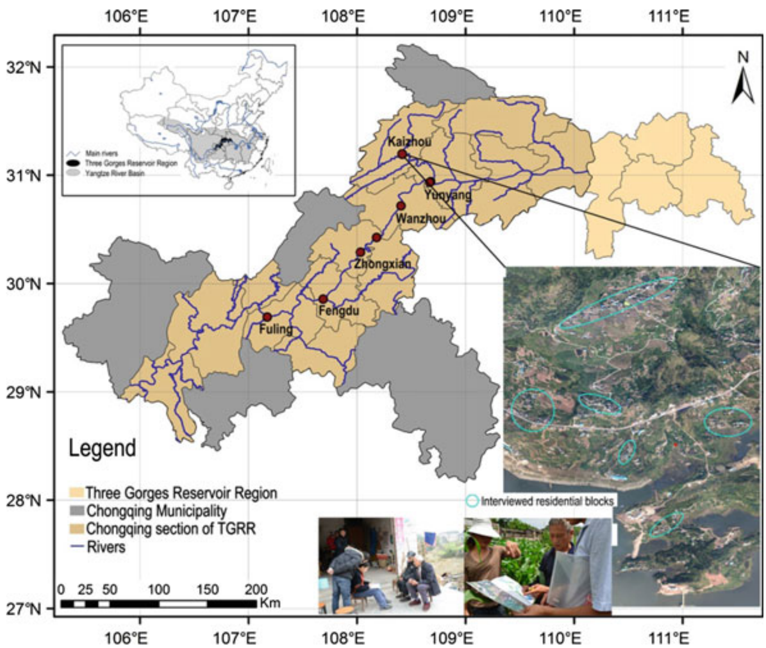

Fig. 3 Field survey areas and interviewed residential blocks

parallel with our direct observations, enabled us to quickly learn the whole picture. Working alongside farmers in their fields, such as planting, manuring cropland, removing weeds and harvesting dry plant residues, deepened our understanding of their interpretations and practices in the real world (Huntington 2000; Pinto-Correia and Kristensen 2013). For specific land uses, we conducted field measurements to quantify their performance; for instance, we evaluated a land conservation treatment of terraced slopes with straw mulching and found less runoff and soil erosion than on slopes without such treatment.

Local farmers, who are not trained ecologists, may take their practices for granted without necessarily recognising their ecological meanings and functions (Berkes et al. 2000). This collaborative learning process enabled the search team to become intimately familiar with the farmers' work and accurately interpret and report any ecological knowledge that locals considered to be practical and desirable.

Economic benefits and environmental resource costs among the three farming systems, cropping, poultry and fish rearing in the flooded land of TGR were evaluated based on emergy analysis. Our purpose was to identify the impact of the reservoir flooding on local livelihood. It was conducted through field survey of 25 households and total population of 106 people within the Wuyang Bay of the Pengxi River of Kaizhou. For the details of the emergy method, see Ulgiati and Brown (1998) and Odum (1996). This enables evaluation and comparison on a common energy basis and to quantify the external environmental costs that are normally considered free (Zhang et al. 2007). This method has been widely used to assess agricultural systems across a range of scales and land uses, from single farm to region-wide system, with regard to their resource-use efficiency, productivity, environmental cost and overall sustainability.

3 Local Life–Work Styles

Here we report the field survey results of local agricultural and aquacultural practices, the livelihood impacts of reservoir flooding, local attitudes towards flooding and the physical and theoretical inspirations derived from the above analysis.

3.1 Local Agricultural and Aquacultural Practices

The majority (86.5%) of respondents had been resident in Kaizhou for several generations, while some are immigrants from surrounding towns/villages through marriage. We summarised their self-reported and observed practices in Table 1. These practices are not separate but interlinked with each other and co-evolving.

3.1.1 River Valley Terracing

Local farmers have practised terraced farming for rice, crops and vegetables for thousands of years in mountainous areas. Terraced fields are transformed from natural slopes into a receding series of platforms that can impound shallow water. The platform surface is optimally recommended to be 5–10 m wide with a slope of less than 5° in order to impede the overland flow and favour infiltration (MOST 2010). Through field survey and measurement, we found the surface width ranges between 1.5 and 10 m depending on the slope. Because of significantly limited available land in the mountainous areas, the site selection, shape and size of the terrace fields are determined somewhat arbitrarily or according to the particular circumstances. Therefore, they may not be recognised as impressive and magnificent as those of the iconic terraced landscapes, but rather are down-to-earth cultural landscapes intimate to people and their needs. Such practices are based on the accumulation of local empirical experience, topographic constraints and verified by modern scientific measurement and analysis.

Table 1 A summary of local practices based on field survey (modified from Chen et al. (2016b)

Practices	Description	Ecosystem services	Illustrations
River valley terracing: change slopes to flat steps (some wet for rice, some dry for vegetables)	Generally on medium-to-steep lands: local people inclined to utilise the slopes of river valleys, make the crop/vegetation fields as steps and take full advantage of river flooding (water and nutrient deposits)	Water storage; soil conservation; nutrient efficiency	
Scattered agricultural patches with multi-species crops	Developing multi-species crops in various small plots along with remnant forest	Effective use of hilly land; biodiversity maintenance with pool of pollination, beneficial insects for pest biocontrol	
Contour ridges and strip cropping	Ridges are made along the contour lines at regular intervals on low-to-medium slope lands to strengthen soil. Crops are planted on raised ridges	Retard runoff and drain out to shallow ditches located near the ridges	
Bed-surface cultivation	Row crops are cultivated on wide beds surrounded by shallow ditches or mud roads	Capture and store water and nutrients; increase infiltration into ditches	
Household ponds	Generally near the house or agricultural plots as household activities rely on ponds, e.g. clothes washing, irrigation.	Harvest monsoon rainwater for dry season; retain and process wastewater; irrigate fields	 Downslope is cropland.
Intercropping and crop/vegetables rotation	Growing two or more crops/ vegetables to produce a greater annual yield	Better temporal use of resources; weed and pest control; maintain soil quality	 Corn - sweet potatoes rotation

(continued)

Table 1 (continued)

Practices	Description	Ecosystem services	Illustrations
Burning crop residues/straw for fertiliser	Periodically burn crop residues on the fields after harvesting	Reduce artificial fertiliser input; dispose of agricultural waste; enrich soil organic	
Crop residues/straw mulching	Using crop residues/straw on the soil surface; Sometimes, the crop residues carry some grain and feed the poultry	Reduce soil evaporation; suppress weeds; increase efficiency of irrigation; increase infiltration; control soil erosion	
Organic fertiliser	Mud from fish ponds, waste from cropland (e.g. residues), domestic poultry and humans	Reduce artificial fertiliser input; treat agricultural and household waste	 Generally farmers carry waste from family's toilet pool, to fertilise newly
Fish and poultry polyculture	Culture two or more fish species in one pond, generally combining bighead carp, black carp, silver carp, grass carp, turtles and ducks	Optimum use of trophic and spatial niches in ponds; maintain biodiversity; weed control	
Utilisation of riparian zone: living with fluctuation: water rises—people retreat; water recedes—people plant	Reservoir water recedes from May to September, the major part of growing season in China. Local people adapt to this rhythm and plant suitable crops/vegetables in accordance with water recession timetable	Better use of water, land and nutrients brought by flooding; reconstruct food web; compensation for loss of land	 When reservoir water recedes, local farmers plant crops and vegetables.  Establishing fishing net

3.1.2 Planting Forms

In order to maximise infiltration of rainwater into soil, several techniques have been employed. On gentle slopes, farmers create planting beds. On low-to-medium slopes, crops are planted on raised ridges generally following the contours. On

Fig. 4 Sugar canes were planted around 174–175 m asl. *Source* Photograph taken by Chundi Chen

slopes above crop/vegetable plots, hedgerows were planted. Species included trees (e.g. trimmed mulberry trees), shrubs (e.g. orange or tea trees) and/or larger crops (e.g. corn, or sugar canes; see Fig. 4). According to locals, the purpose is to prevent runoff, sedimentation or soil creeping downslope of cultivated land. Recent evidence also supports the efficacy of contour hedgerows on water and soil conservation in the TGR region (Ng et al. 2008; Shen et al. 2010).

3.1.3 Household Ponds

Pond building is of particular interest to Asian countries, especially in rural areas where there is an imbalance in rainfall distribution geographically and seasonally, and local people rely heavily on ponds for water collection and storage. Chinese people have a long history in building and utilising ponds, such as the well-known dike–fish pond system in Southeast China (Ruddle and Zhong 1988). There is a stronger desire for ponds in hilly areas, especially now to ameliorate the consequences of extreme weather such as drought and flooding. More than 180,000 small man-made ponds exist across the hilly region of Chongqing Municipality (CQWRB 2015). Because of the topography and summer monsoon, they conveniently harvest rainwater for family supply and crop irrigation during the dry season. Many household activities rely on such ponds, e.g. clothes washing, food cleaning, livestock drinking water, irrigation, fire control and recreation, and so are known as “household ponds” (Table 1, also see Chen et al. 2016a). The large number of ponds within a mosaic of forests, farmland and local settlements across the hills form a distinctive, variegated eco-cultural landscape.

According to elderly local people in the study area, most household ponds were actually built during the 1950s and 1960s when the land was under collective ownership in China. Pond construction was organised by communes or local governments as an important part of water infrastructure throughout the rural areas. The main purpose at the time was for agricultural irrigation. During subsequent generations, these originally built ponds have undergone changes. Some are maintained with regular dredging, but others have been filled to (re)create more usable land. Since then, new ponds have also been constructed by individuals or families because China implemented a land contract system where individual occupiers may decide where and how to build ponds on their land and what size of their ponds (Chen et al. 2016a).

3.1.4 Selection of Plant Species

Local farmers focus on crops and vegetables that seem little relevant to urban waterfront landscaping, but plant selection reflects some interesting and useful ecological principles. First, plants are selected that are suitable for the regional climate and specifically have life and production cycles that match the submergence regime at the varied topographic positions, such as *Ipomoea aquatica* and *Eleocharis dulcis*. Second, full use is made of spatial and temporal diversification by intercropping and rotating crop/vegetables. Local farmers prefer intercropping (e.g. mixtures of corn and leguminous soybean) over monocultures for yield, diversity and easy management (weeds suppression by competition, pest/disease resistance, soil enrichment or reduced artificial fertiliser spread). Practising crop rotation is very common in local communities, e.g. rice and various vegetables, such as Chinese flowering cabbage (early spring)—cucumber (summer)—turnip or Chinese cabbage (winter) as summarised in Fig. 5.

The vegetation survey also identified notable patches of native trees which were planted by locals for special family events like childbirth, marriage or death ceremonies. Species include *Pterocarya stenoptera*, *Bischofia polycarpa* and *Vernicia fordii*, which are excellent specimen trees for southern cities of China. Many studies have demonstrated the importance of such patches to nature conservation as they may preserve endemic or sensitive species and provide "stepping stones" to facilitate species' dispersal (Forman 1995; Shafer 1990).

3.1.5 Maintenance

Several techniques to preserve soil health and water quality include the application of mulch and recycling/reusing organic matter or waste instead of expensive application of artificial fertilisers. But timing is critical when using organic fertilisers. According to local experience, it is not wise to spread manure in the autumn when it may be dispersed into the reservoir by rising water and affect water quality.

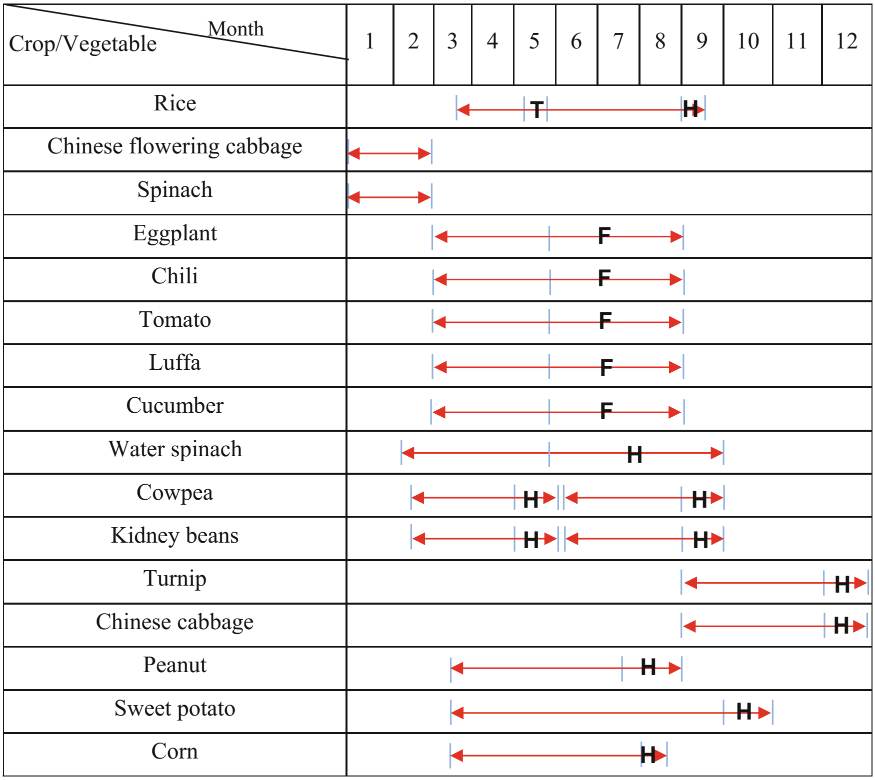

Fig. 5 A summarised planting and harvesting calendar for one seasonal cycle of crops/vegetables by local communities. Red arrows represent the plant lifespan. T: transplanting; H: harvesting; F: fruiting. Accordingly, local people have various combinations of vegetables and crops throughout the year. Reprinted from Chen et al. (2016b), with permission from Elsevier

Burning crop residues was formerly popular, but is now officially forbidden because of negative impacts on air quality.

It is found that the essentials of local resource management are optimal use of trophic, topographic and spatial niches, and optimised balancing of the water/land ratio. The fish–poultry polyculture is a typical example. The main types of fish raised in the study area are grass carp (*Ctenopharyngodon idellus*), bighead carp (*Aristichthys nobilis*), black carp (*Mylopharyngodon piceus*) and silver carp (*Hypophthalmichthys molitrix*). They are generally reared together since their niches are differentiated. Silver carp live in the top layer feeding on phytoplankton, bighead carp in the top-middle layer feeding on zooplankton and waste from grass carp (partially digested grass), grass carp in middle-bottom layer feeding on pond grass and weeds, and black carp at the bottom feeding on zoobenthos. Locals have a “rule of thumb”: one grass carp sustains three bighead carps through its waste. Generally, the ratio of grass:silver:bighead:black carp is around 20–30%:40–

50%:20–30%:5–10%. Additionally, rearing grass carp has proven to be an effective solution to controlling the spread of aquatic weeds (Pipalova 2006). Therefore, keeping a variety of fish, together with the cropping system (intercropping and rotation), provides useful lessons for riparian landscape maintenance.

3.2 *Livelihood Impacts of Manipulated Flood*

A diagram elaborates the material and energy flows of the overall cropping, poultry- and fish-rearing systems within the novel conditions of the flooded land of the TGR region (Fig. 6). Regarding the cropping system (paddy rice, corn, peanut, potato and vegetables), the decreased area and shortened growing seasons have caused overall crop yields to decline. Based on the local market price of agricultural products in 2014, cropping income was 336,774 Chinese Yuan (ca. US$54,760). However, it seems that the surrounding people did not complain much about this since most of the crop harvest was for self-supply, although most people considered it was inconvenient to cultivate flooded land. Then there is the return from the poultry-rearing system (87,480 Yuan, ca. US$14,224) and fish-raising system (32,400 Yuan, US$5268). Chicken and duck are the main poultry species chosen by locals; most are free range fed on the food from crop fields or household ponds. Presumably, as compensation for reduced crop production, most families prefer to

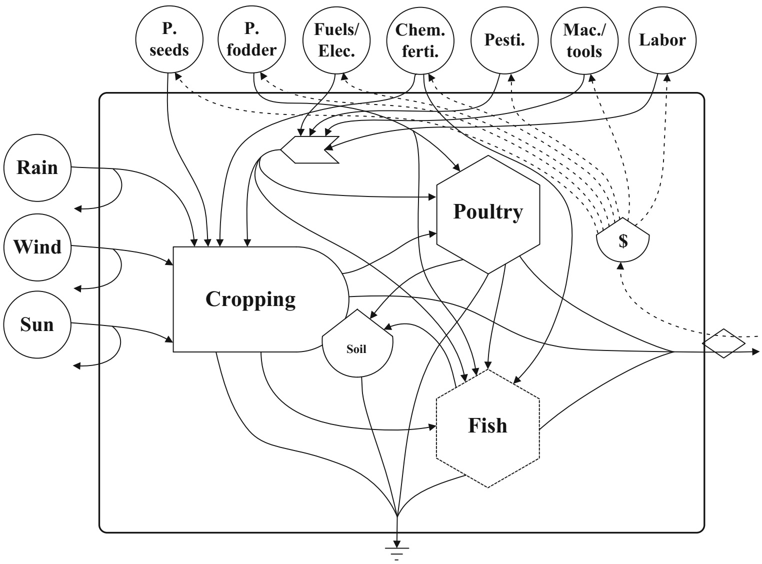

Fig. 6 Emergy flow diagram of the cropping, poultry- and fish-rearing systems in the flooded land of the TGR (solid lines: material flow; dashed lines: cash flow; P.: purchased; Elec.: electricity; Chem.: chemical; ferti.: fertilisers; Pesti.: pesticides; Mac.: machines)

Table 2 Emergy indicators of the cropping, poultry- and fish-rearing systems

Index	Definition	Formula	Cropping	Poultry	Fish
Renewable fraction	Ratio of renewable environmental resources to total emergy input in a system	$\%R$ = (renewable environmental resources + renewable purchased input)/Total input	0.48	0.81	0.72
Emergy investment ratio (EIR)	Ratio of the emergy input from the economy to the emergy input from the free environmental or natural resources	EIR = (non-renewable purchased input + renewable purchased input)/(renewable environmental resources + free non-renewable environmental resources)	3.98	4.63	5.87
Environmental loading ratio (ELR)	Ratio of total non-renewable emergy input to total renewable emergy input	ELR = (non-renewable purchased input + free non-renewable environmental resources)/(renewable environmental resources + renewable purchased input)	1.06	0.23	0.39
Emergy sustainability index (ESI)	Ratio of Emergy yield ratio (EYR) to environmental loading ratio	ESI = EYR/ELR EYR = Total yield/(non-renewable purchased input + renewable purchased input)	2.23	41.15	9.1
Economic output/input ratio	Ratio of economic income to purchased resources	/	4.45	38.03	16.2

rear more poultry than before. By contrast, not much seems to have changed for fish harvest. Household ponds are inundated by flooding every year, so farmers must collect fish before the flooding. The rising reservoir level from 145 to 175 m expands the water body area. People, especially near narrow river courses, consider this as favourable since extra fish resources then come into the flooded area.

We calculated the emergy indicators such as environmental loading ratio (ELR), emergy sustainability index (ESI) and economic output/input ratio to quantify the environmental and economic performance of these three systems (Table 2).

Although the cropping system has a comparatively higher economic output, it consumes much more non-renewable input such as fertilisers and pesticides than the other two systems with a higher $\%R$ and economic output/input ratio. The cropping system is also less environmentally sustainable than the other two systems as indicated by lowest EIR and ESI, and the highest ELR (Table 2). Therefore, reduction in agricultural land seems to be not such a bad thing. Compared with other similar agricultural systems in the non-flooded-lands of other regions, the index of economic output/input ratio of these three systems is actually higher (Zhang et al. 2012). This may support the theory that water, soil and nutrient resources are comparatively abundant in the flooded land and may be used ecologically for economic purposes without requiring fertilisers or pesticides (Mitsch et al. 2008). Additionally, our findings support restructuring proportion of these three systems that allow more poultry and fish production to weaken reservoir flooding influences and improve local livelihoods; while at the same time not having much of a negative impact on the reservoir environments.

3.3 Local Attitudes Towards Flooded Land

Agriculture and associated cultivation have been officially forbidden in the flooded land by local governments out of consideration for people's safety and concerns that conventional agricultural practices would cause non-point pollution to the reservoir (see Fig. 7 with forbidden slogans in Chinese). However, it is quite common for the surrounding residents or farmers to use the land during the low water period. The authorities seem to acquiesce to this so long as it is confined to self-supply; not for commercial purposes. The reason probably is that such small-scale, family-based farming activities generally do not use much inorganic fertiliser nor pose a health risk to the wider population (according to anonymous government officers). During our survey, some respondents hinted that the flooded land, not surprisingly, tended to be softer and more fertile compared with their other upslope farmland, and they could get quite good crops or vegetable yield compared with their more intensively farmed uplands. Presumably, winter flood water entrains nutrient-rich sediment, especially nitrogen and phosphorus from the surrounding uplands. Then as water recedes in the summer growing season, part of the nutrient from siltation and decomposition of dead vegetation would be retained to fertilise

Fig. 7 Signs showing the policy slogan of "Forbid agricultural activities in the flooded land of the TGR". *Source* All photographs taken by Chundi Chen

the bank (Guo et al. 2012). When the reservoir floods back, local farmers also establish nets for catching fish (Table 1). This yearly cycle demands an appropriate rotational management strategy, enabling self-recovery. Moreover, flooding supports non-potable water uses, such as cropland irrigation, filling household ponds for clothes washing, food cleaning and livestock drinking water (Chen et al. 2016a). Local farmers have rapidly adapted to this new regime.

Regarding hazards and safety in the flooding season, most respondents indicated that they were familiar with the reservoir water level regime and have learnt how to deal with it. It might be regarded as a kind of present-day knowledge that local people have developed a harmonious way of working with the novel "natural" conditions—the "new normal". The key message is to follow the new flooding rhythm. This adaptive spirit, especially in terms of suitable plant species selection and spatio-temporal configuration of different landscape components, was particularly inspirational.

3.4 Physical Inspiration

This section explores the practical and legible way in which the physical and tangible aspects of local life–work practices inspire urban waterfront landscaping. It is a key step in the whole design procedure and a great challenge since design seems not to follow in a fixed sequence of steps such as scientific research. In order to make the derived learning clear and explicit, we broadly classify and propose three broad aspects in accordance with the nature of the landscape design process (Booth 1990; Simonds and Starke 2006). This work was mainly performed by landscape designers, who were trained to capture such detailed information. They initially drafted sketches of the overall landscape, including the configuration of the various components. Crops, vegetables and other plants for recreation or amenity were documented. Such field recording may not be immediately ready-to-use for design, but is helpful in providing guidance for later design work.

3.4.1 Landscape Structure and Components

Landscape structure refers to the overall pattern, arrangement and order of all the components included in a design. The components are the plants, water, stones, pavements, roads and other material details like colour and texture. Modern cities commonly pursue a neat, tidy and orderly appearance of the landscape with low structural diversity. Conventional waterfront landscaping and greening often flatten the riparian land and then apply a classical picturesque style with trees in regular groups and a smooth shaven lawn, or engineered hardscape for flood and erosion control purposes. On the contrary, the local people in the TGR region demonstrated a different, more organic vision to shaping the land and landscape through moderate agricultural activities. Such practices include river valley terracing, scattered agricultural patches with multi-species crops, contour ridges and strip cropping, and bed-surface cultivation (Table 1). They all exhibit a pattern of diversity and heterogeneity in terms of land use, landform, macro- and micro-habitats and other environmental gradients. Though the rural environments studied here are dramatically different from modern cities, the underlying rationale of the systematic arrangements and configurations of different natural and man-made elements from these agro-ecosystems, such as ponds, ditches and crops/plants, have great potential to assist cities seeking multifunctional design for micro-habitats, biodiversity maintenance, stormwater and contaminant management.

3.4.2 Landscape Maintenance

Although landscape maintenance may not be a focus in the design stage, it is a pivotal item for building sustainable landscapes (Hostetler et al. 2011). Ecological wisdom is essentially related to natural resource management. Therefore, we consider the maintenance-related solutions based on the practices discussed above.

Modern cities carry out routine landscape maintenance, such as weed removal, pruning, mowing and cleaning litter and rubbish. The organic waste is generally carried away for treatment like other rubbish. However, the practices of local life–work styles suggest that landscape maintenance can also support tangible economic benefits. Urban parks often plant specimen trees that potentially have economic value, such as *Ginkgo biloba* and *Castanea mollissima* (chestnut tree). Their fruits could be better collected like farmers harvest vegetables, fruits and pond fish before the flooding. An analogue to how farmers collect straws and plant residues as mulch for other cropland, as poultry fodder or firewood, is that the organic matter such as trimmed branches, woodchips and foliage from urban parks and gardens could also be collected for mulching the green space to suppress weeds and retain moisture. Such harvesting, collecting and organic cycling bring ecological benefits and create healthier ecosystems and importantly (re)connect people to the organic cycle. Since cities generally have access to more resources and most urbanites do not engage in agricultural activities, this calls for more responsibility and leadership by urban landscape designers and administrators who can make overall systematic maintenance plans and schedules that can better suit urban settings and sustain urban landscapes.

3.5 Theoretical Inspiration

As an emerging domain, it is a challenge to explicitly define ecological wisdom in a tangible sense. We suppose that one essential trait for wisdom is that it should not just be confined to physical practices. More importantly, it should contain some universal principles that can be interchangeable across different circumstances. Although our studied area is different from modern cities, the underlying rationale that gives rise to the wisdom should be applicable in urban settings. In this section, we highlight two principles inspired from working locally with reservoir practices that may be used for waterfront landscaping of modern cities.

3.5.1 Localised Responses

Here, "localised" refers to both the local environment and the local people. Any ecologically sound approach should be site-specific based on a full understanding of local biogeophysical characteristics and natural processes (Van der Ryn and Cowan 2007). In most cases, planners, designers and policy-makers are outsiders, whereas local people have been on the land for generations and possess a wealth of practical knowledge about the flora and fauna, habitat suitability, changing environmental conditions, natural disaster reduction, interactions between living beings (including humans) and their environment (Martin et al. 2010; Syafwina 2014; Thornton and Scheer 2012). This knowledge is not accumulated in one day; rather, it relies on long-term experience and co-evolution of "learning by doing" and nonlinear "trial-and-error" processes, now termed adaptive management (Berkes et al. 2000). Although the TGR has been in operation for only a decade, the local people have quickly formed their particular personalised responses based on their previous practices in other river valleys of this region. Then the new knowledge was created and improved through (re)adjusting plant species, cultivation and fertilising time according to new circumstances. The means of utilising the flooded land in the TGR region is a representative example.

Although modern science and technology has largely provided analytical models and tools to simulate how nature proceeds in the real world, the results often are limited and sometimes fail to cope with complex circumstances (Liao 2014). For such situations, local approaches and the underlying adaptiveness provide valuable primary data for seeking better practical solutions to complex problems. Science may then become a useful supplementary companion and bring new layers of interpretation and verification. In practice, this calls for applying case-by-case information to appreciate variation in human–nature systems and for close collaboration between local people, designers and ecologists.

3.5.2 Appreciating the Balance

Today, two mainstream "faiths" exist in treating urban waterfronts. One goes for hardscape with biologically simple and low-statured greening; the other asserts a naturalistic style with a "wilder is better" approach (Efroymson et al. 2010). Both disregard the basic ecosystem goods and economic services provided by the waterfront. But such functions were indispensable back before the industrial revolution when the global environment was predominantly altered and managed by agricultural activities. Over the last two hundred years, such practices have been gradually replaced by large-scale dependence on fossil fuels and concrete construction in cities. Only in recent years, primary industry has returned to the spotlight in cities, commonly known as urban agriculture (Goldstein et al. 2016). Arguably, incorporating non-commercial economic functions into urban green space has emerged as a trend, including fruit, vegetable and herb gardens by private individuals or communities (Provè et al. 2016). An increasing number of studies indicate that this can encourage the engagement of local people and communities that play an important role in supporting the integrity of land (Evans and Birchenough 2001; Proshansky 1978). Such support is one of the most important key factors in maintaining the long-term success of ecology-related projects (Aswani and Hamilton 2004; Bohensky et al. 2013; Johannes 2002) and is more cost-effective than the conventional top-down approach (Berkes et al. 2000).

When considering agricultural activities in urban landscaping, the key issue consists in the delicate synergistic balance between conservation and utilisation. When utilising the limited land resource, the locals do not blindly pursue yields and profits (although this is possibly a consequence of geophysical constraints). This balanced, multi-value thinking, although not perceived as "ecological wisdom" per se by people on the land, has guided traditional land users towards an integrated ecosystem—a variegated mosaic of natural and agricultural patches with comparatively high biodiversity and resilience. Compared with the standard treatment for waterfronts, it provides a different direction that depends on a holistic ecological-economic feasibility to understand the thresholds in leveraging the balance between viable human activities and ecosystem functions in human-dominated systems. Such an integrated vision challenges urban planners, designers, engineers and policy-makers to explore appropriate, direct benefits and services that allow native species to co-exist with human land uses and be revelatory to urbanites.

4 A Design Scenario for Hanfeng Lakeshore (Kaizhou, Chongqing)

Transformation from the comfort zone to a new vision needs a prolonged period of time. The process will be a "trial-and-error" adaptive procedure, rather than an instant outcome. This "doing" process is a matter of practical wisdom, i.e. being wise—the right way to do the right things to stand the test of time in the real world (Xiang 2014). Eventually in this section, we confront the practical challenge and demonstrate the "doing" process by taking an urban riparian landscape restoration project as an example. Here, we only present the substance directly related to wisdom inspiration. For the detailed results of environmental analysis and design elements determination, refer to Chen et al. (2014a).

4.1 Case Study Area

Hanfeng Lake, a section of Pengxi River (one of the largest tributaries of Yangtze River), became the second largest urban lake in China as a result of the TGR formation within Kaizhou, which is a new district of Chongqing Municipality partly relocated to higher ground to make way for the TGR. With its special landscapes, it has been designated a national urban wetland park with a total area of 13.03 km^2. Controlled by both the Three Gorges and the Hanfeng dams, the Hanfeng Lake water levels alternate between 170.28 m in summer to 175 m asl in winter, creating a 3.74 km^2 seasonally flooded land. As with all other areas in the TGR region, the magnitude of the water impoundment has brought environmental and aesthetic challenges to the new town. The local government wish to take some innovative solutions to this unique flooded land. Our demonstration project (31° 10′ 55″N, 108° 27′ 45″E) is being carried out between the 170.28 to 179 m elevation on Wuyang Bay of Hanfeng Lake since this bay has comparatively gentle slope and good soil conditions. The total project area is 1.6 ha. Previous land uses were paddy fields, dry cropland and sparse forests which still remain on steep slopes and side gullies above the peak water line (Fig. 8).

4.2 Landscape Structure and Components

4.2.1 Overall Structure

We modified and (re)arranged the essential elements of the household pond and terraced field farming (Table 1) to form an overall structure for our hilly waterfront landscaping. This configuration includes water-harvesting ponds at the top of slope for storing monsoon rainwater, landscaped terraces in the middle and the reservoir at the bottom, as shown in Fig. 9. Compared with traditional dike–fish pond systems that are typically practised in flat waterlogged lowlands (Ruddle and Zhong 1988), the significant modification we have made is to widen the dike and form them into terraces to better fit into the hilly topography and in accordance with the river hydrological conditions. The upper landscaped pond performs a water-retention role by capturing runoff from the uplands and releasing it slowly during the dry season, with similar functions as “household ponds” (Table 1).

Behind this structure, there would be external and internal resource cycling. Externally, during the summer monsoon, upslope runoff carries nutrients and sediment to the water-harvesting ponds as the reservoir water recedes. After sediment has settled, nutrient-rich water can be used to irrigate the fields and is filtered by plants on the terraces before it reaches the reservoir. When the reservoir floods back in winter (also the rainless period), the rising water replenishes these ponds and fertilises the land for the subsequent plant-growing season.

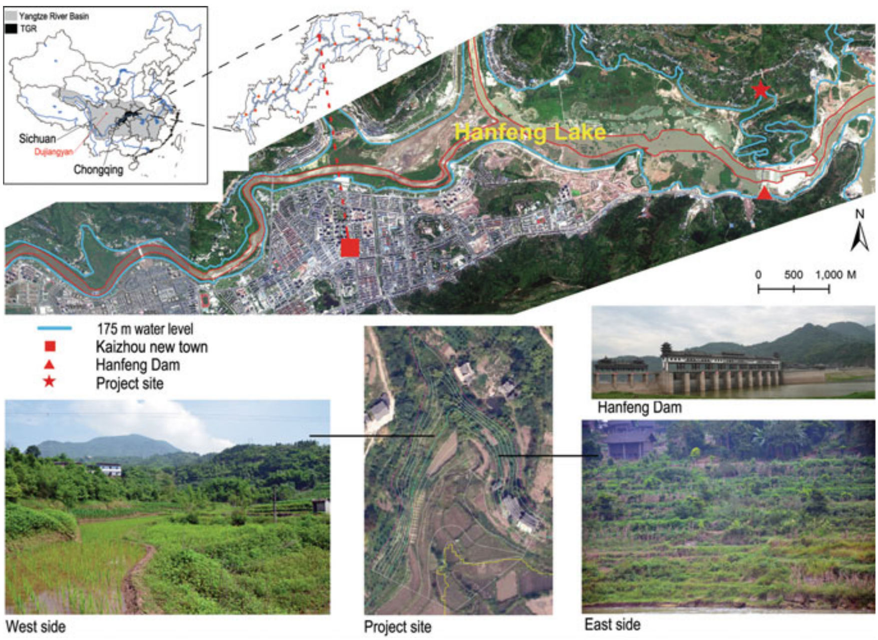

Fig. 8 Location and illustrations of the project site on Hanfeng Lake. Reprinted from Chen et al. (2016b), with permission from Elsevier

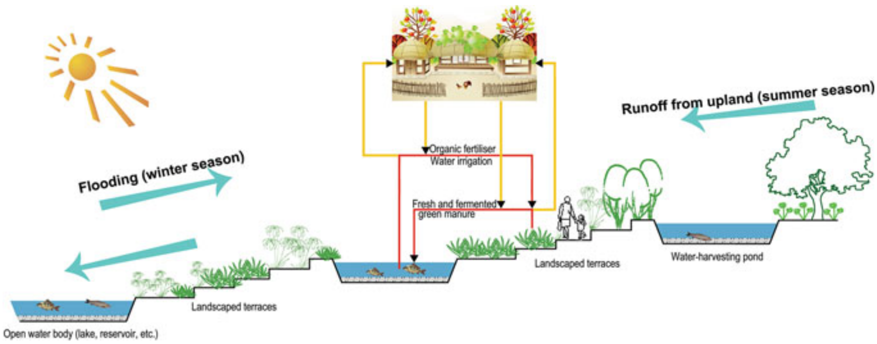

Fig. 9 Conceptual landscape design for Hanfeng Lakeshore. Reprinted from Chen et al. (2016b), with permission from Elsevier

Internally, material cycling occurs between the ponds and land. First, suspended silts both in the water-harvesting pond and lower reservoir strengthen and fertilise the landscaped terraces while water is liberally used for irrigation. Second, the terraces supply fresh and fermented green manure for pond fish. This system can provide tangible benefits for nearby communities. Apart from pond fish and water supply as demonstrated in "household ponds" (Table 1), plant residues are still widely used for household cooking and raising poultry according to our observation. This is also important for overall maintenance of the project since too much plant residue submerged by water will result in decomposition and may degrade water quality.

4.2.2 Planting Design

The scientific analysis of riparian vegetation reveals a plant distribution pattern that statistically responds to the water fluctuation gradients (Chen et al. 2014b). Annual herbs dominate 0–3 m above the low water level, while more perennial herbs are found above the 3–5 m zone, dotted with some flood-tolerant shrubs and trees. A similar pattern is also mirrored in local farmers' cropping systems on the flooded land: larger crops or fruit trees/shrubs are found on the upper slopes, whereas short-lived but fast-growing vegetables are planted downslope as they are able to complete a life cycle within the water recession period. Therefore, mimicking nature and cultural planting practices, together with selecting inundation-tolerant annual/perennial herbs, informs the first planting strategy for such special waterfront areas. Other selection principles also included creating diverse micro-habitats and fulfilling general riparian greening requirements, such as bank stability and aesthetically pleasing park vistas. Based on these principles and results from literature and vegetation survey, we finally determined 27 candidate species. Eight species were recommended by locals, including *Stellaria media*, *I. aquatic*, *Cynodon dactylon*, *Saccharum sinense*, *P. stenoptera*, *E. dulcis*, *Trapa bispinosa* and *Sagittaria trifolia* var. *sinensis.* Most of them are locally common cash crops/vegetables.

Taking account of all the environmental factors of elevation, micro-topography, soil and hydrological conditions, the resultant planting design is shown in Fig. 10. Some remnant forest is preserved as bush patches within the terrace matrix to enrich landscape diversity, provide seed sources for regeneration and ultimately increase the overall naturalness. Different elevation zones were correspondingly planted with suitable plants selection. On the 171.5 m terrace (average width of 6.5 m), the flood-free period is between 8th February to 3rd October, its soil is clay loam with pH 6.3, and accordingly, we proposed a sown mixture of *Phalaris arundinacea* and *Oryza rufipogon,* with a total area of 811 m^2. Whereas at 179 m above the flood zone, *Metasequoia glyptostroboides, P. stenoptera, Salix variegata* and mixed ground cover species *(Digitaria sanguinalis* and *C. dactylon)* were selected. This unit covers 548 m^2.

4.3 Landscape Maintenance Suggestions

Every year, before the reservoir water rises (around September), plants in the flood zone would be carefully and specifically handled depending on the life forms of the

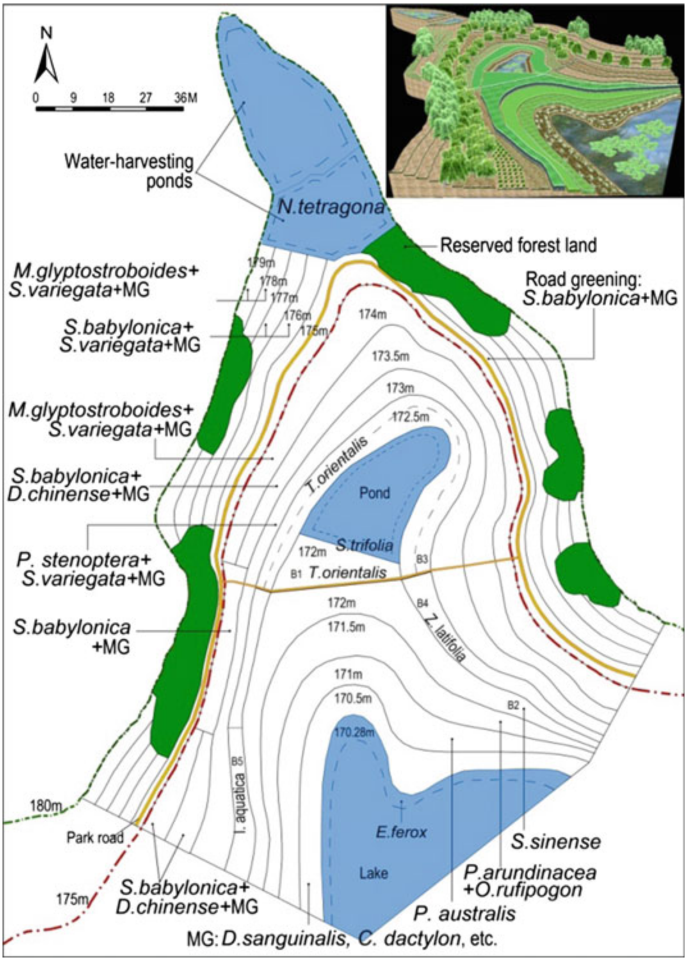

Fig. 10 A landscape design proposal for Hanfeng Lakeshore. Reprinted from Chen et al. (2016b), with permission from Elsevier

plant species. Herbs would be removed in order to avoid decomposition in the reservoir. The collected plants can be used by nearby farmers for livestock feed. Fruits from cash crops, such as *S. sinense*, *Sagittaria trifolia* and *T. bispinosa*, would be collected simultaneously. In the initial days of the reservoir water receding, the flood-deposited refuse would be carried away to avoid tarnishing the visual landscape and spreading pathogens.

Grass carp, bighead carp and goldfish (*Cyprinus carpio*) are proposed for the ponds for the multiple purposes of consumption, aesthetic interest and recreational fishing. As locals practise it, they are generally reared together since they have niche differentiation. The recommended stocking density of grass carp is 600–800 individuals per hectare. Therefore, a lake with an area of 1600 m^2 will accommodate 96–128 grass carp. The lake is open. No built structures separate it from the wider lake. Instead a net is set up to contain the fish. When the water level rises, the net is adjusted accordingly. The lake becomes deeper during the winter, which is preferred by over-wintering carp. The carp also helps remove the residual fresh and fermented vegetation left in the terraced fields submerged during winter.

Putrefaction of the pond water is prevented by windmills that agitate and periodically bubble air through the bottom mud as required. This enhances the hygiene of the ponds and reduces disease risk of the sediment extracted for field fertilisation and pond fish. Testing would be carried out to ensure standards are maintained, with chlorination a fallback solution.

5 Discussion

5.1 Ecological Wisdom in Action

Ecological wisdom has a wide range of meaning. We see it as the art of achieving balance between human and nature, based on accumulated knowledge and being able to adjust to changing circumstances. Clearly, it is beyond knowledge that on its own is neutral and can be used for either good or evil, depending on where and how it is used. Wisdom emphasises the conscious and reflective practices from knowledge towards sustainable and ethical purposes, termed "ecophronesis" by Xiang (2016). It requires planners, designers, engineers and policy-makers to engage in critical thinking based on ecological knowledge and has the ability to address potential conflicts and (re)adjust the actions. For example, in our case study, the practice of "burning crop residues/straw and returning to land" per se is good for recycling and naturally fertilising the cultivated land. But, in today's China, urban environments are suffering heavy air pollution, so it is not allowed to apply this practice. Therefore, the right decision should be grounded in the new circumstances. Additionally, there was a divergence over particular planting patterns with respect to slope. The majority advocated contour planting but some planted their corn perpendicular to the contours. Both could be appropriate depending on local circumstances. Through observation and scientific analysis, we found that comparatively large- and shallow-rooted plants such as corn are suitable for growing perpendicular to the contours to avoid slope waterlogging. These highlight a distinct line between knowledge and wisdom, and the importance of design with context and the appropriate combination of holistic scientific knowledge to make good judgments.

5.2 Challenges to Actions

To frame and achieve the new vision requires moving away from conventional isolated models that are based on linearity and conformity; we have to embrace a model that is rooted in customising and "personalising" the circumstances. Here, the broader and more interdisciplinary fields and participatory approaches can be of greatest value. Increasing numbers of studies recognise that urbanisation is both an ecological and social process; urban ecology-related studies are truly interdisciplinary (Alberti et al. 2003; Kattel et al. 2013; McIntyre et al. 2000). Whereas land-based farmers have generations of experience and know what works for them locally, scientists have a different accumulated pool of knowledge from a legacy of evidence-based, peer-reviewed research that can answer specific questions and project future outcomes. Though it is undoubted that, in some cases, local people are pre-occupied with economic production, especially in developing countries with resource shortages, scientific knowledge has its own constraints. Importantly, they must be married to ensure the decisions are going in the right direction.

We support the idea of sustainable harvesting of the land so that nearby people can actually be involved in the land maintenance and management. In our design demonstration, we consider the studied lakeshore as a multiple use entity, i.e. conservation, recreational, cultural and economic values are all taken into account. Therefore, the applicability and success of wisdom-inspired systems stand not entirely on how well biodiversity is maintained on its own but that socio-economic criteria are an integral part of the equation. This requires the designers and research teams to have the constructive capacity to integrate competing interests among social, political, economic, cultural and ecological integrity based on systematic scientific knowledge. We argue that this balanced, joined-up thinking is the key on which ecological wisdom is grounded, yet it is the greatest challenge to the process of acquisition, transmission and application of ecological wisdom.

6 Conclusions

Our study explores the ecological wisdom around an ecological-economic vision of reservoir flooding in the TGR region and demonstrates the plausibility and goodness of this vision in an urban lakeshore project through wisdom-inspired solutions.

To make wisdom more actionable, we directly connected with the landscape design in the real world: landscape structure, components and maintenance. One must be clearly aware that knowledge that may transform into wisdom is closely integrated with the dynamics of complex site-related systems and thereby reflects a holistic worldview. The ways in which they enlighten us go beyond our three aspects. The scope of ecological wisdom and associated direct/indirect applications in our case study is not an end but rather a starting point for further identification of social–ecological linkages and their contribution to urban sustainable development.

It should also be (re)emphasised that this kind of study requires place-based models since the particularity of and interaction between nature and society is situated in particular places (Berkes 2004). Additionally, the exploration of ecological wisdom is not about a one-time extraction of information; instead, it demands a long-term collaborative development of information and co-creation of solutions to new problems as they emerge. Researchers should fully interpret the complexities of landscapes and analyse their dynamics, making ecological, social and economic senses of resource-use practices that have created these landscapes. We hope this study can become an exemplar for urban ecosystem management that embodies locally meaningful and balanced development and conservation.

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Part VII
Planning Living City and Regions: Urban

EcoWisdom for Climate Justice Planning: Social-Ecological Vulnerability Assessment in Boston's Charles River Watershed

Chingwen Cheng

Abstract Climate change has exacerbated socioeconomic and environmental stresses in places where social and ecological vulnerability persist. With a growing population projected to occur in the Boston metropolitan area, more socially vulnerable groups are likely to bear the burdens from climate change-induced hazards. Understanding the interlinked relationship between social and ecological vulnerability is critical to understand the resilience of social-ecological systems in communities. This paper aims to provide a social-ecological assessment framework that serves as a resilience planning tool to inform growth management and incorporate EcoWisdom for climate justice planning. This study employed a *Social-Ecological Vulnerability Matrix* to examine climate justice hotspots where social vulnerability intersects with ecological vulnerability of a place in the Charles River Watershed. Four climate change scenarios derived from a climate sensitivity study were investigated. The results provided implications for four planning strategies corresponding to the four quadrates of the matrix. This paper demonstrated a planning tool to inform policies for enhancing resilience under a range of climate change impacts and to integrate equity planning for local climate justice.

Keywords Vulnerability assessment · Climate change · Flooding
Climate justice · Resilience

1 Introduction

The concept of EcoWisdom has guided land development to promote the health of people and their environment since landscape architecture was first established by Frederick Law Olmsted (1822–1903). His iconic masterpiece, New York City's Central Park, is nicknamed "the lungs of the city." It demonstrates that thoughtful ecological design of a public space can develop multiple ecosystem services that

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support citizen wellbeing (e.g., health, good social relations, security, freedoms of choice and action) (Eisenman 2013). By supporting ecological planning, EcoWisdom integrates equity in land development processes to achieve just outcomes in physical planning. Environmental justice describes spatial patterns of disproportionate exposure to environmental hazards (e.g., toxic waste and disposal, pollution, landfills) among minority and economically distressed communities that often have less capacity to cope (Bullard 1990; Mohai et al. 2009). The concept of environmental justice serves as a foundation for framing climate justice in ecological planning.

The notion of climate justice was initiated globally at the United Nations Climate Change Conferences considering unjust distributions of the causes and burdens of climate change impacts among countries that contribute to greenhouse gas emissions (developed countries) and those with lower carbon emissions (e.g., island nations) that suffer the most from environmental changes (e.g., sea-level rises) (Page 2013). To put climate justice in local context, socially vulnerable groups in the USA (e.g., elderly, children, women, migrants, minorities, the poor) bear an inequitable burden of socioeconomic impacts from climate change-associated environmental hazards (e.g., extreme heat, cold, floods, droughts, fires, air- and water-quality degradation) as extreme weather events become more frequent and intense (Adger et al. 2006; IPCC 2014; Melillo et al. 2014). As a result, people with the least capacity to respond, mitigate, recover, and adapt to the risks are likely to suffer most.

Understanding the interlinked relationship between ecological vulnerability (e.g., climate change impacts on flooding hazards) and social vulnerability (e.g., social capacity to manage risks) is critical to understand the resilience of social-ecological systems in communities (Walker and Salt 2006). In his seminal 1969 book, *Design with Nature*, Ian McHarg outlined systematic landscape planning methods assessing both social and ecological factors for land development suitability analysis. Unfortunately, ecological planning has not fully integrated equity planning to address the intersections of environmental justice, climate change, and land use planning. This paper aims to provide a social-ecological assessment framework that serves as a resilience planning tool to inform growth management and incorporate EcoWisdom for climate justice planning.

2 Background

2.1 Resilience Planning in Social-Ecological Systems

Resilience in linked social-ecological systems describes the adaptive capacity to absorb shocks from disturbances and return to the state of foundational function and allow for transformative capacity toward sustainability (Holling 1973, 2001; Walker and Salt 2006; Folke et al. 2010). Social-ecological systems are dynamic and integrated systems in which social, biological, physical, and built components interact with one another (Cadenasso and Pickett 2013). They are often interchangeable with the concepts of "coupled human and natural systems" or "human–environment systems" (Liu et al. 2007). Resilience theory provides systems thinking in dealing with complex issues such as climate change in the dynamically linked social-ecological systems (Walker and Salt 2006; Folke et al. 2010).

Resilience planning can help communities enhance their capacity to manage climate change-associated hazards, reduce vulnerability, and allow for adaptive and transformative actions that overcome risks in society. Vulnerability is the key to understanding risks, managing disasters, and becoming resilient. It is crucial to include both social and ecological dimensions in vulnerability assessment to develop comprehensive planning strategies that improve community resilience to cope with climate change (Folke et al. 2010).

2.2 *Vulnerability Assessment for Climate Justice*

The concept of "hazard" is derived from the notion that a hazardous agent will threaten the livelihood of human beings, materially (e.g., property damage, economic loss), physically (death or injury), and mentally (distress or traumatized illness) (O'Riordan 1986). Disaster risk involves the extent of hazard exposure and the degree of vulnerability. In other words, disasters occur when vulnerable populations are exposed to eco-geophysical vulnerability of a place (Cutter 1996). Modernization with technocratic and structural solutions for natural hazard mitigation has inextricably intertwined natural and man-made hazards. In addition, socioeconomic and political structural changes in society have imposed more risk on marginal groups (Pelling 2003; Blaikie 1994). Hurricane Katrina in 2005 was a vivid and tragic example in which an extreme storm event was compounded by levee breaches, leading to flooding in thousands of homes in low-lying areas historically occupied by minority and economically disadvantaged people (Colten 2006). As a result, scholars called the aftermath of Katrina an environmental justice incidence (Bullard and Wright 2009). What is more, the term "climate justice" has been used for local disasters to emphasize that the hazards associated with climate change can have inequitable societal impacts (MacCallum et al. 2014). Vulnerability assessment includes three dimensions: (1) exposure to specific social or environmental stresses, (2) sensitivity to those stresses, and (3) adaptive capacity to cope with impacts from those stresses at multiple scales from an individual to collective institutional resources (Birkmann 2006). Vulnerability assessment for climate jutice particuarly emphasizes the risks to climate change associated hazards and adaptive capacity in coping with climate change (Cheng 2016).

Flooding is the most prevalent hazard worldwide, and climate change increases storm intensity and frequency (IPCC 2014). Researchers have found significant correlations between exposure to coastal flooding and the most deprived populations in the UK (Walker and Burningham 2011) and exposure to riverine flooding under climate change impacts to socially vulnerable populations in the watersheds of Michigan's Huron River (Cheng 2016) and Boston's Charles River (Cheng 2013). This paper expands on a climate change-induced flooding hazard study of the Charles River Watershed (Cheng et al. 2017) for further assessment and discussion of climate justice planning.

3 Study Area and Context

The Charles River Watershed comprises 778 km^2 with a population over 600,000, including a large portion of eastern Boston. The 182-km-long main channel flows eastward and discharges into Boston Harbor. The watershed is 44% urbanized (i.e., commercial, industrial, residential, transportation, institutional, junkyard, utilities) with minimal agriculture (3%) and recreational (3%) land use. The other half of the watershed is dominated by natural areas including forests (36%), wetlands (11%), and water bodies (3%). This study included 33 municipalities in the watershed and within the Boston Metro Area (Fig. 1).

The Boston Metro Area is home to 3.16 million people and is the tenth most populous in the nation (U.S. Census 2010). By 2030, it is expected to have 52,000 new residents and convert upwards of 61,500 ha of open space into the developed land (MAPC 2009). Planning efforts have been undertaken to address future growth and sustainable development goals. At the city scale, the Mayor's Office of Boston set a goal to increase the urban tree canopy from 29% estimated in 2005 to 35% by 2020 through planting 100,000 new trees (Grow Boston Greener program 2012–2014). This policy has been examined to determine if it addresses mutual benefits between environment and equity through the lens of environmental justice in low-income neighborhoods (Danford et al. 2014). At the regional scale, the Metropolitan Area Planning Commission (MAPC) developed the *MetroFuture* plan to counter the sprawling nature of current regional development trends (MAPC 2009). At the state level, the Commonwealth of Massachusetts Executive Office of Energy and Environmental Affairs established an Environmental Justice Policy to help address the disproportionate share of environmental burdens and assets among lower-income people and communities of color. The Massachusetts Office of Geographic Information has developed a spatial layer of environmental justice populations based on income, minority group, and English language isolation criteria. The Boston Metro Area comprises about one-third of the state's environmental justice populations, while the Charles River Watershed consists of about one-third of the environmental justice populations in the Boston Metro Area (Fig. 1). Recent extreme weather events and serious non-coastal flooding in 2010, 2011, and 2012 suggest the need for further research on climate-induced inland flooding and vulnerability assessments. As stated in Massachusetts's Climate Change Adaptation Report, "the need to perform risk and vulnerability assessments was widely recognized across all sectors" (Cash 2011, p. 3).

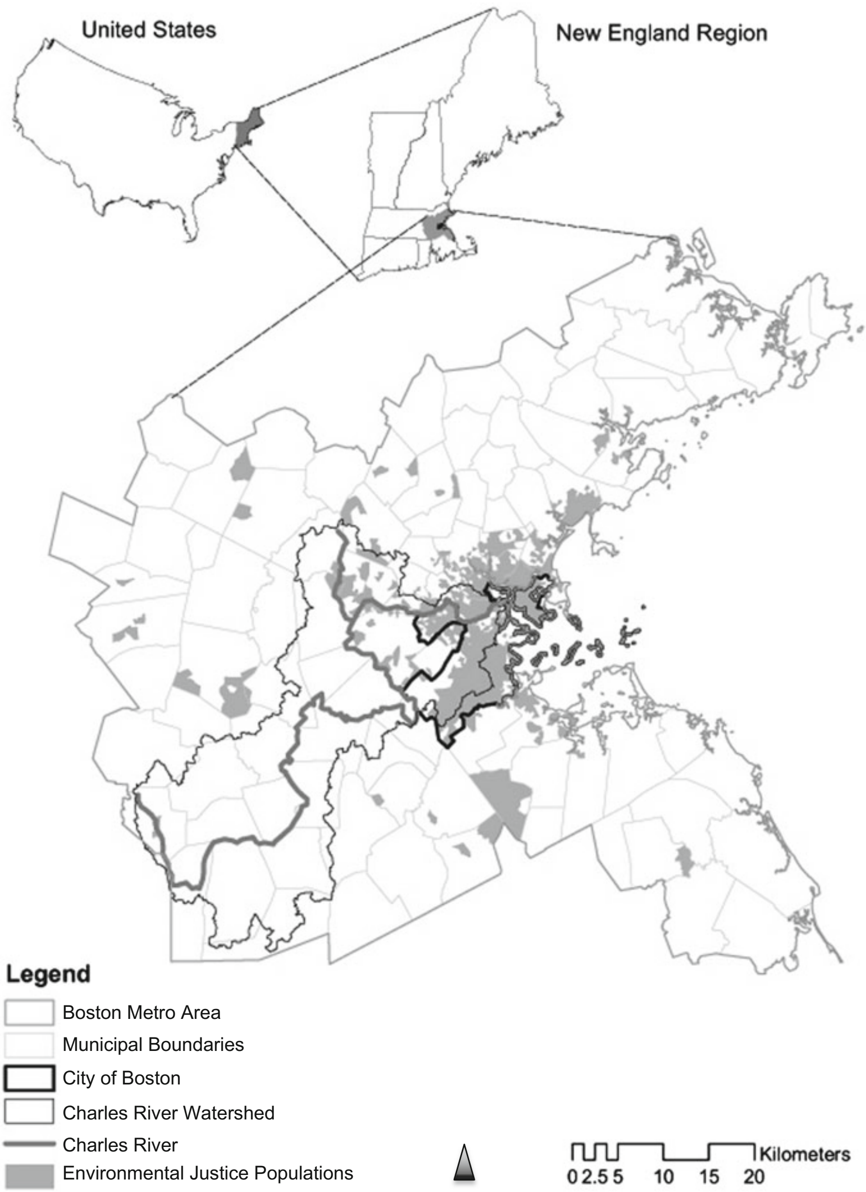

Fig. 1 Charles River Watershed study area and environmental justice populations in the Boston Metro Area defined by the Commonwealth of Massachusetts

4 Methodology

This study developed two indices: an *Ecological Vulnerability Index* using flooding hazards as a proxy for geophysical environmental conditions with climate change impacts; and a *Social Vulnerability Index* to describe community vulnerability to environmental hazards. Each index was then categorized into deciles in a *Social-Ecological Vulnerability Matrix* and spatially overlaid to reveal exposures using Geographic Information Systems.

4.1 Ecological Vulnerability Index (EcoVI)

A climate change-induced flooding hazard index is used in this study as an indication for ecological vulnerability. The flooding hazard index was defined as a probability of daily stream flow volume exceeding the bankfull discharge based on a hypothetical 45-year period. The bankfull discharge volume—the water volume that represents the maximum holding capacity of the river channel—was determined by the 2-year return period. Daily stream flow volume was simulated through hydrological modeling using the Soil and Water Assessment Tool (SWAT) (Arnold and Allen 1996). A climate sensitivity study testing for the watershed was conducted via SWAT modeling to include 150 climate conditions (combinations of mean temperature changes of 0, +1, +2, +3, +4, +5 °C; mean precipitation changes of 0, ±10, ±20%; and precipitation variation changes of 0, ±10, ±20%). The detailed model calibration and sensitivity study results were described in a separate paper demonstrating a general trend that increasing temperature would decrease flooding hazards, while greater precipitation in both quantity and variation could increase flooding hazards (Cheng et al. 2017).

Informed by climate projections in the next 50 years in terms of the ranges of temperature and precipitation changes provided by the General Circulation Models (GCMs) for the U.S. Northeast region, four climate change scenarios were selected for further study (Cheng et al. 2017). The *Baseline* current climate conditions were modeled with 0 °C temperature change and 0% increase in both mean precipitation and precipitation variation. The *Low Impact* scenario was modeled for an increase of 3 °C in mean temperature, an increase of 10% in mean precipitation, and zero change in precipitation variation. The *Medium Impact* scenario was assumed to have an increase of 2 °C in mean temperature and 10% increases in both mean precipitation and precipitation variation. Finally, the *High Impact* scenario was conducted based on an increase of 1 °C in mean temperature and increases of 20% in both mean precipitation and precipitation variation.

4.2 Social Vulnerability Index (SoVI)

Vulnerability reflects a community's dynamic socioeconomic and cultural structures and varies from place to place. Social vulnerability provides a lens through which to study the dynamic socioeconomic structure that affects the abilities of populations to respond to, adapt to, mitigate, and recover from disasters and associated socioeconomic impacts (Cutter 1996).

There is neither a single definition nor single measure for social vulnerability agreed upon in the literature. Nevertheless, there is a consensus that race, gender, education, immigration status, and socioeconomic factors limit access to information, financial resources, and political power and are closely related to coping capacity in response to disasters (Blaikie 1994; Colten 2006; Yohe and Tol 2002; Satterfield et al. 2004). Fielding and Burningham (2005) found that environmental inequality correlated with flooding hazards and suggested that even though higher socioeconomic status groups tend to be exposed to flooding hazards, it is lower socioeconomic status groups that are most at risk. Furthermore, other indicators such as single female households, large family structures, insufficient medical and social infrastructures for the elderly, low-income groups, people who work in services and occupations dependent on natural resources extractions, and both rural and urban populations tend to increase social vulnerability (Cutter 1996; Cutter et al. 2003; Lynn et al. 2011).

Cutter (1996) developed the *Social Vulnerability Index* (SoVI) for measuring social vulnerability to environmental hazards under a framework of hazard-of-place model that integrates biophysical and social vulnerability at a specific geographic location (Cutter 1996; Cutter et al. 2003; Cutter and Morath 2013). The SoVI is a benchmark for a quantitative and systematic approach in measuring social vulnerability. It has been used successfully in several national and regional vulnerability studies including one of the most flood- and hurricane-prone regions in the southeast USA (Cutter et al. 2003; Cutter and Finch 2008; Borden et al. 2007).

Thirty variables were included in this study using 2010 US Census data and American Community Survey (ACS) data for 5-year estimates in 2010 at the census tract level (Table 1). Valid data of 277 census tracts within the Charles River Watershed were used to construct the SoVI through several steps. First, the variables were normalized as a function of either percentage, per capita, or density. Next, the variables were standardized through z-score with a mean of 0 and standard deviation of 1. Third, principal component analysis was conducted using a varimax rotation and the Kaiser criterion for component selection. Then, variables with highly correlated values (greater than 0.5 or less than −0.5) were selected as influential and listed within each component. Each component illustrated a variance helped to describe the concept of social vulnerability. The first identified component was composed of the most variables, and the number of variables decreased as more components were identified. The results revealed eight components that explained 72% variance among the variables for describing social vulnerability (Table 2). The final step was to sum all components based on their positive (add to) or negative (subtract from) influence on social vulnerability from the identified concepts.

Table 1 Descriptive statistics of Social VulnerabilitySocial vulnerability Index (SoVI) variables

Variables	Description	Mean	SD
HODENT	No. of housing units per sq. mile	7614	8980
HOSPTPC	Per capita no. of community hospitals	0.0001	0.0002
M_C_RENT	Median monthly contract rent ($)	1161	371
MEDAGE	Median age	35	7
MHVAL	Median value of owner-occupied housing units	491,358	175,570
MIGRA	% foreign born citizens immigrating in 1990–2000	0.081	0.069
NRRESPC	Per capita residents in nursing homes	0.005	0.014
PERCAP	Per capita income ($)	41,042	20,479
PHYSICN	No. of persons per 100,000 employed in healthcare & technical jobs	0.001	0.001
PPUNIT	Ave. no. of people per household	2.392	0.427
QAGRI	% employment in farming, fishing, & forestry	0.001	0.003
QASIAN	% Asian & Hawaiian Islanders	0.088	0.083
QBLACK	% African American	0.134	0.213
QCVLBR	% population in the labor force	69.139	10.559
QCVLUN	% unemployed civilian	4.900	3.666
QED12LES	% population ≥ 25 years old with no high school diploma	0.105	0.108
QFEMALE	% female population	0.514	0.064
QFEMLBR	% females in the labor force	0.521	0.070
QFHH	% single female headed households	0.124	0.108
QINDIAN	% Native American	0.002	0.006
QKIDS	% population <5 years old	0.053	0.025
QMOHO	% of mobile homes	0.001	0.003
QPOP65O	% population ≥ 65 years old	0.114	0.052
QPOVTY	% population below poverty line	0.145	0.139
QRENTER	% renter occupied housing units	0.501	0.265
QRICH	% households earning $\geq \$100,000$	33.837	18.533
QSERV	% employed in service industry	0.167	0.118
QSPANISH	% Hispanic	0.119	0.139
QSSBEN	% population collecting social security benefits	0.211	0.080
QTRAN	% employed in transportation, communications, and other public utilities	0.038	0.023

4.3 Social-Ecological Vulnerability Matrix

To demonstrate a full range of probability of flooding hazards, the flooding hazard index scores for baseline current conditions and all four climate change scenarios (277 census tracts with 4 climate conditions) were combined to rank the *Ecological Vulnerability Index*. Since the flooding hazard index scores represent the absolute probability of long-term flooding hazards, a total of 1108 samples were categorized

Table 2 Principal component analysis of Social vulnerability index

Component	Component Cardinality	Concepts	Accumulative variance explained	Dominant variables	Correlation
1	(+)	Socio-economic	27.07	PERCAP	−0.87
		Status		QRICH	−0.86
		Race		MHVAL	−0.69
		Education		M_C_RENT	−0.66
		Occupation		PHYSICN	−0.63
				QRENTER	0.60
				QPOVTY	0.66
				QBLACK	0.70
				QCVLUN	0.70
				QSPANISH	0.77
				QFHH	0.79
				QED12LES	0.85
				QSERV	0.88
2	(+)	Age/Socio	39.95	HODENT	−0.76
		Economic		QRENTER	−0.68
		Status		MEDAGE	0.60
				QKIDS	0.60
3	(+)	Gender	47.35	QFEMALE	0.95
				QFEMLBR	0.97
4	(+)	Occupation	52.96	QCVLBR	−0.88
5	(+)	Age/social	58.23	QPOP65O	0.52
		Dependence		NRRESPC	0.68
6	(+)	Race/	62.99	QMOHO	−0.76
		Immigration		QASIAN	0.51
		Status		MIGRA	0.51
7	(+)	Ethnicity/	67.63	QINDIAN	0.55
		Occupation		QAGRI	0.64
8	(−)	Infrastructure provision	71.94	HOSPTPC	0.61

into deciles based on their probability values (Fig. 2). The minimum flooding hazard index value was 0.0032 (0.32% probability), and the maximum value was 0.0448 (4.48% probability). Consequently, each decile was calculated based on the tenth of the range, 0.00416, for representing the lowest (1) to highest (10) ecological vulnerability.

The SoVI scores ranged between −30 and 21 (low and high social vulnerability, respectively) in relative values rather than absolute (Fig. 2). For instance, a census tract with a score of 10 has relatively higher—not ten times higher—social vulnerability than a census tract with a score of 1. Based on ascending order from

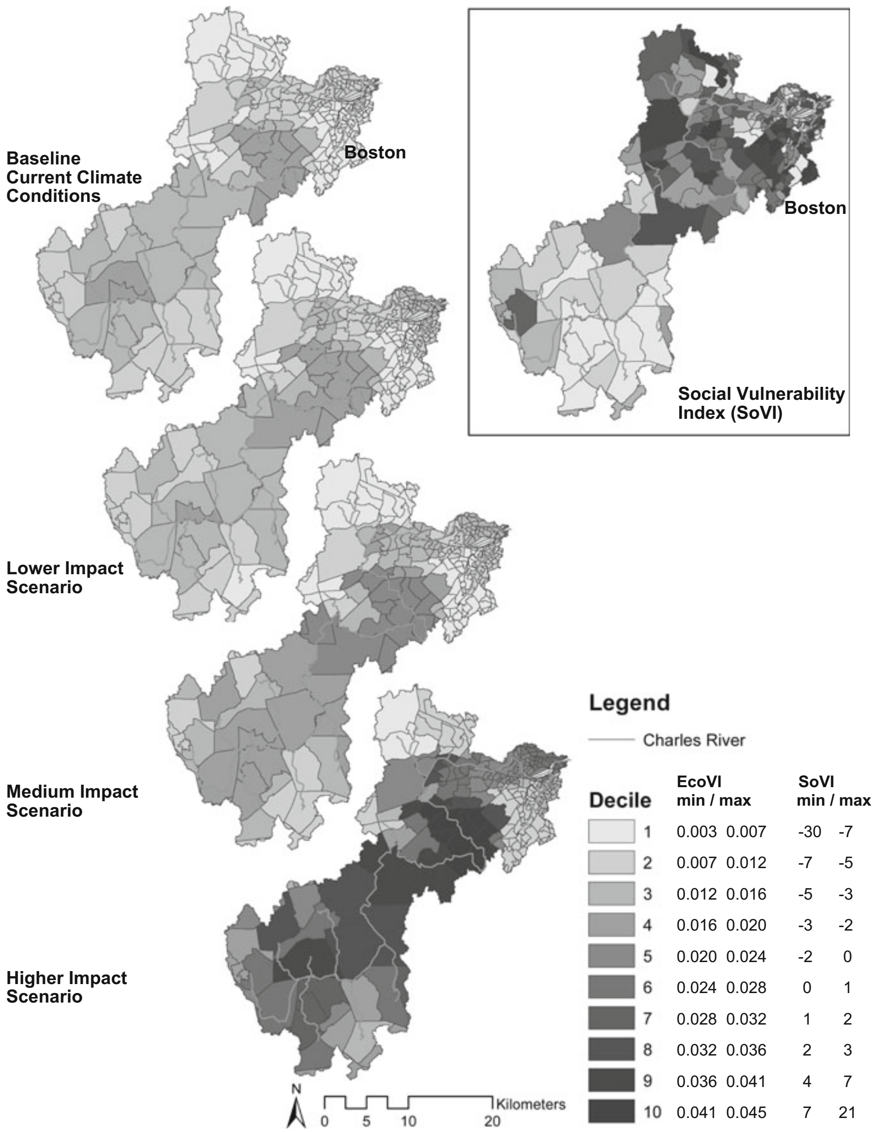

Fig. 2 Social Vulnerability Index (SoVI) and Ecological Vulnerability Index (EcoVI, represented by flooding hazard index) under four climate change scenarios ranked by decile from the lowest (1) to the highest (10) social-ecological vulnerability in the Charles River Watershed

the lowest to highest value and ranked consecutively for 277 census tracts, each tenth of the ranked tracts was defined as one decile from the lowest (1) to highest (10) social vulnerability. Each census tract therefore falls into respective deciles of social and ecological vulnerability in corresponding climate conditions.

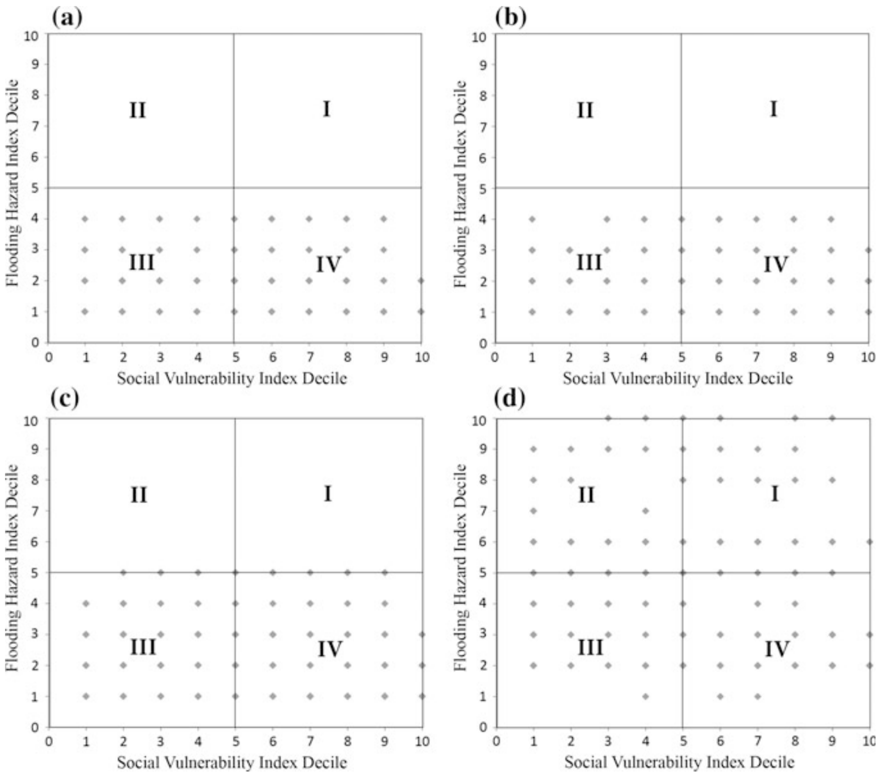

Fig. 3 *Social-Ecological Vulnerability Matrix* illustrates distribution of census tracts with corresponding decile of *Social Vulnerability Index* and *Ecological Vulnerability Index* (represented by flooding hazard index) in four quadrants and in four climate change scenarios: **a** *Baseline* current climate conditions. **b** *Low-impact* scenario. **c** *Medium-impact* scenario, and **d** *High-impact* scenario

Finally, scatter plots were generated to illustrate the *Social-Ecological Vulnerability Matrix* for each of the climate change scenarios (Fig. 3).

5 Results

5.1 Social-Ecological Vulnerability Hotspots

Social vulnerability is highest in and around the City of Boston at the lower basin of the watershed (northeast corner) and lowest at the upper basin (southwest corner) (Fig. 2). A few census tracts that have low social vulnerability in Boston and nearby municipalities were areas with large portions of parks and open space. One census tract in the upper basin that appears to have relatively high social vulnerability is located in a town that serves as a regional hub and is home to large numbers of minorities and immigrants with lower income.

Ecological vulnerability represented by the flooding hazard index is highest at the lower basin (northeast portion) of the watershed and lowest in Boston and upstream of subbasins (i.e., north and south portions of the watershed) (Fig. 2). The *High Impact* climate change scenario carries a significantly high probability of long-term flooding hazards compared to the other two scenarios.

Figure 2 reveals the hotspots of combined social and ecological vulnerabilities at the middle of the lower basin, where the main river channel flows toward discharge into Boston Harbor. Those census tracts appear to have relatively higher social vulnerability overlaid with a consistent high probability of flooding hazards, with the highest ecological vulnerability under climate change scenarios that exacerbate flooding hazards. The hotspots are located outside the City of Boston yet are inside the Boston Metro Area, suggesting that the suburbs have greater social-ecological vulnerability with climate change.

5.2 Social-Ecological Vulnerability Matrix Quadrates

Figure 3 illustrates the results from the quadrates of *Social-Ecological Vulnerability Matrix*. The *Low* and *Medium Impact* scenarios show similar patterns compared to the baseline of current climate conditions. All census tracts lie in the third and fourth quadrants, representing lower ecological vulnerability with a wide range of social vulnerability (Fig. 3). The *Medium Impact* scenario carries a slightly higher ecological vulnerability and reached the fifth decile. Scores in the fifth decile are considered to have high ecological vulnerability under climate change impacts in the Charles River Watershed. The *High Impact* scenario reveals significant variation in ecological vulnerability, and several census tracts fall into the first and second quadrants.

6 Discussion

6.1 Resilient Growth and Climate Justice Planning Implications

Figure 4 illustrates the Charles River Watershed with potential planning strategies in each census tract corresponding to a *Social-Ecological Vulnerability Matrix* under four climate change scenarios. Since ecological vulnerability was ranked based on the range of potential climate change impacts in coming decades, the implication for policy implementation is particularly helpful for planners to adapt long-term spatial planning under the uncertainty of climate change impacts.

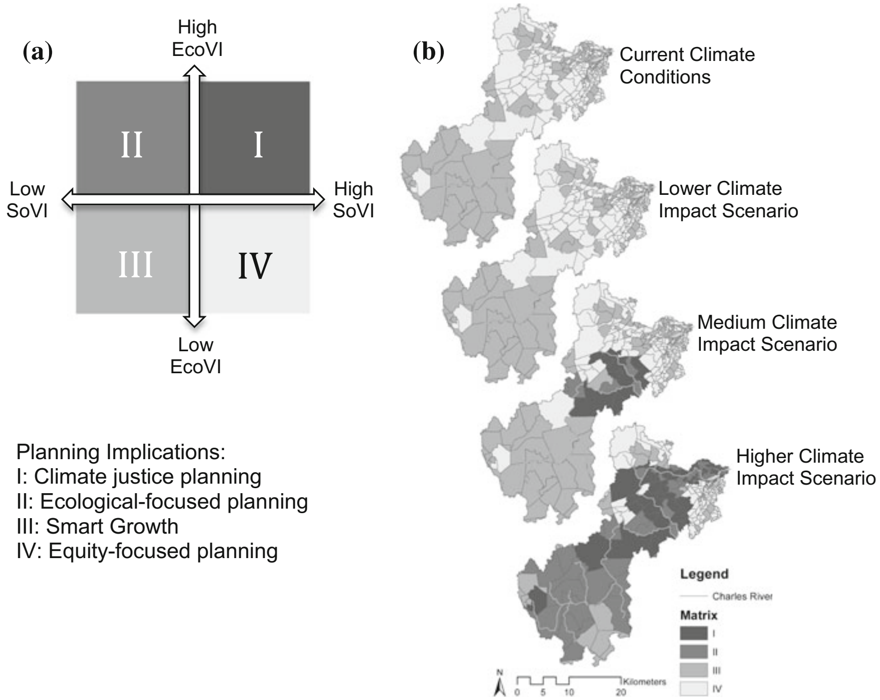

Fig. 4 **a** Social-Ecological Vulnerability Matrix in four quadrants representing four planning implications in climate justice planning and urban growth policies. **b** Corresponding policy implications in each census tract for each climate change scenario in the Charles River Watershed

Corresponding to the four quadrants illustrated in the above social-ecological matrix, each quadrant represents policy implications that respond to social vulnerability and ecological vulnerability as follows:

I. *Climate Justice Planning*: The first quadrant represents both high social and ecological vulnerability, which implies a high alert for climate justice. Places affected by climate justice should be given the highest priorities for an integrated social-ecological planning approach that addresses both the biophysical environment to mitigate hazards and the community's adaptive capacity to cope with climate change.

II. *Ecological-focused planning*: The second quadrant represents low social vulnerability and high ecological vulnerability, which indicates that these areas should focus on retaining, restoring, and enhancing the environment's ecological health. New developments in these areas should be carefully evaluated and designed to minimize environmental impacts (Berke 1998).

III. *Smart Growth*: The third quadrant represents both low social and ecological vulnerability. These areas are suitable for a *Smart Growth* approach that applies growth management practices considering both environmental quality and place-making for communities usually in areas without specific vulnerability concerns. *Smart Growth* principles do not emphasize vulnerability assessment use in the planning process and tend to overlook equity goals in sustainable community development (Godschalk 2004).

IV. *Equity-focused planning*: The fourth quadrant represents high social vulnerability and low ecological vulnerability, implying that equity planning should take priority in those communities to address social needs through planning policies (Krumholz 1990).

6.2 Limitations

This study limits the ecological vulnerability assessment to flooding hazards. Future research could include multiple climate change-induced hazards such as extreme heat and cold, fire, and sea-level rise. In addition, there is no single universal methodology for constructing social vulnerability. For example, Flanagan (2011) applied percentile ranking to each variable and summed the rankings into concepts of socio-economic status, household composition and disability, minority status and language, and housing and transportation. Each methodology could produce a different spatial pattern, and there is no consensus in the literature regarding which methodology is better suited for different scales or hazard types. In addition, the census data-based quantitative social vulnerability index overlooks the highly contextualized nature of cultural and political conditions. A place-based approach incorporating community input on social vulnerability would improve the representation and implication of using a social vulnerability index for policy recommendations. Füssel (2007) suggested using four domains of internal and external socioeconomic and biophysical spheres as a framework for conducting vulnerability assessments for climate change research.

7 Conclusions

Ecological, equity, and spatial planning have emerged to achieve community resilience by addressing both social and ecological vulnerabilities to climate change-associated hazards. Vulnerability assessment provides a factual basis for comprehensive planning strategies to address growth management, climate change, and social justice. In light of increasing climate change-associated hazards with localized social-ecological impacts, local governments should be encouraged to build strong partnerships across municipal boundaries to effectively mitigate climate change-induced hazards by moving vulnerable populations living in hazardous areas in addition to implementing social programs and planning instruments to enhance institutional resilience capacity. Effective risk management requires communities to incorporate physical planning that addresses social-ecological vulnerabilities in their growth management policies, as well as climate justice at a local scale. Applying ecological planning must be prioritized to build more resilient and healthier environments for communities to thrive. Eventually, ecological planning will serve as a catalyst for social sustainability.

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Part VIII
Planning Living City and Regions: Regional

Synergetic Evolution of Social and Natural Systems: Ecological Wisdom of Human Settlements in "The Land of Abundance"

Wentao Yan

Abstract Since the industrial revolution, the relationship between human and nature has not improved in line with technological and social innovations. In this paper, we chose the Chengdu plains, known as the Land of Abundance, as our study subject. We adopt methods of comparing settlements in different eras. The results indicate that natural processes played a crucial role in determining human settlements in the Land of Abundance. Relationship between human and nature in these four phases reflects the transition from *submission to nature, respect for nature*, *reconstruction of nature*, and finally to the *conquest of nature*, respectively, in the pre-construction period, original construction period, development period, and modern period. We have revealed the deep wisdom of the harmonious coexistence between social and natural systems from the five aspects of the holistic view of *daoshengwanwu*, the practice view of *daofaziran*, the social view of *sharing benefits across*, the ethical view of *Tao controls technology*, and the good governance view of *spontaneous order*. Lastly, this paper points out several principles of landscape and urban planning in the presence of deep urban sustainability challenges: coevolution of natural and social systems would help promote sustainability of human settlements; nature-guided human settlement practice can maintain various healthy life-support systems; planning practice should be emphasized to maintain or reconstruct healthy natural process; modular units should be constructed through integrating environmental management units with planned unit development; self-governance organizations could be fostered likely based on modular units; and finally but not lastly, technology applications should be subject to restriction of environmental ethics.

Keywords Ecological wisdom · Human settlements · Synergetic evolution
Natural and social systems · The Land of Abundance

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1 Introduction

The world has urbanized at an accelerating rate over the past century: more than 50% of the global population now lives in urban areas (Wu 2008). The large-scale spatial agglomeration of population and industry has induced far-reaching changes in the spatial patterns of human settlements during this urbanization process (Reiner and Parr 1980; Antrop 2004; Wu et al. 2011; Pickett et al. 2011; Chen et al. 2013). Urbanization has become "the dominant human settlement pattern" (Rees 1997, p. 63) and has had profound and pervasive effects on natural system from local to global scale, especially in developing countries. Harmonious relationship between man and nature is facing significant challenges (Wilson 1984; Kalnay and Cai 2003; Alberti 2005; Cohen 2006; Seto et al. 2010; Wu 2014).

A sustainable human settlement model should follow a human-nature mutualism model. The model should emphasize interdependence in the sense of symbiosis and commensalism (Doxiadis 1968; Berry and Kasarda 1977; Liu et al. 2007a). Natural and social systems may be linked through the dependence on natural resources of communities and their social activities (Adger 2000). The social relationship among people is forged during interactions between human and nature. The harmony between human and natural systems will eventually be determined by the coordination between human and social systems (Wood 2007; Liu et al. 2007b). If we depart from the perspective of social systems, the urgent environmental and resources issues faced by the modern world cannot be understood and resolved fundamentally. Since the industrial revolution, the relationship between human and nature has not improved in line with technological and social innovations (Grimm et al. 2008; Newman et al. 2009). As we have attempted to resolve space and environmental issues in human settlement by engineering technological and materials innovations, other environmental issues have arisen (White 2002; Yan et al. 2012).

The nature of the human settlement environment issue is an issue of uncertainty. We cannot eliminate these problems, but we could potentially address environmental issues in a variety of ways (Xiang 2013). However, the question is whether we truly understand the extent of the transfer or transformation of environmental issues with respect to spatial and temporal dimensions. If these issues are not understood, and environmental issues are simplified into a linear technological issue, then the goal of sustainable human settlements will not ultimately be achieved (White 2002). Contemporary urban planning practices so far have focused on the construction of the physical systems of human settlements (e.g., residential facilities, infrastructure, commercial facilities), rather than on the construction and improvement of social systems. As a result, these physical systems will be unable to operate properly and effectively in the case of the diseased social systems, which might lead to failure in sustainable planning practices (Friedmann 1987, 1992; Johnson 1989; Wu et al. 2011; Wu 2014). In the face of global resource and environmental problems, do policy-makers, planners, program managers, and practitioners realize how social systems and natural systems interact with each other? This knowledge might influence the direction of action in the implementation of sustainable planning (Friedmann 1987; Kellogg 2002).

There is little doubt that human civilization is destined for disaster if human settlement models continue to grow and spread as they have since the industrial revolution. At this critical transitional stage from the industrial to the post-industrial age, substantial explicit evidence indicates that humanity has reached a crucial turning point in its relationship with nature (Naveh 2000). As there exist insurmountable problems with developmental model in the industrial age, can we extract more actionable and practical principles of ecological wisdom from human settlements practices in the pre-industrial age? In this paper, we chose the Chengdu plain, known as *Tianfuzhiguo* (天府之国, the Land of Abundance), as our study subject. It is necessary to note that this paper is not a technological summary of the Dujiangyan Irrigation System (DIS). Rather, it attempts to explore historical evolutions of relations between humans and water and summarizes the ecological wisdom of the longevity of the Land of Abundance. Furthermore, some inspirations for contemporary sustainable planning practices are proposed. This paper aims to answer the following questions: first, how did the interaction between human and water influenced human settlements patterns? Second, what kind of ecological wisdom of the Land of Abundance can guide the practice of sustainable human settlements? Third, what values and inspirations can this historical ecological wisdom offer?

2 How Did the Relationship Between Mankind and Water Influence Human Settlement Patterns?

The history of the Chengdu Plain is a chronicle of prosperity in which the presence and management of water have characterized the relationship between humans and nature. Since construction of the DIS, the Chengdu Plain earned the fame of "the Land of Abundance" for 2269 years. This water system still demonstrates great comprehensive functions to date. This natural system, built on a network platform of irrigation system, has offered tens of millions of people across generations the benefits of agricultural irrigation, a municipal water supply, navigation, aquatic production, ecological conservation, and tourism (Li and Xu 2006; Peng 2008; Tan 2009; Cao et al. 2010; Xiang 2014). The history of human settlements of the Chengdu Plain is divided into four stages: the pre-construction period, the original construction period, the development period, and the modern period (Cao et al. 2010). Here, we compare settlements in different eras and investigate historical changes of the human–water relationship and water conservancy approaches over time. The results enable us to investigate the spatial structure properties of the human settlements, to reveal relationship between human and nature during t different periods, and to elucidate how the relationship between humans and water influenced human settlement patterns.

2.1 Pre-construction Period (256 BC): Intuitive Concession Patterns Based on Flood-Avoidance

As a result of tectonics and topography, the Chengdu Plain, as an alluvial fan, tilts in a NW-SE orientation. Increased sedimentation forms the Dujiangyan–Pixian–Chengdu ridgeline that oversees the northern and southern fan edges. The raging rapids of the upstream Min River flow along the low-lying terrain fan and are discharged from the northern and southern fan edges. By examining the evolution of ancient settlement patterns in different eras, we determined that prior to the construction of the DIS, the settlement ruins were primarily distributed in the alluvial plain area with an altitude of 473–675 m and that the settlement history could be divided into three stages (Tan 2009). In the first stage, settlements migrated from the upper reaches of the Min River to the Min riverside area of the southern fan edge. This migration was likely driven by people's need to live at the waterside to satisfy basic water requirements during the transition from a fishing–hunting civilization to a farming civilization. In the second stage, the ancient settlements gradually shifted from the southern fan edge, which neighbored the river trunk and was severely affected by floods, to the northern fan edge, where the flood threat was relatively less severe. In the third stage, because the northern fan edge, which belongs to the Min River diversions, was still subject to flood, the ancient settlements gradually penetrated deep into the central plain area along the Dujiangyan–Pixian–Chengdu ridge line. This area, which is occupied by central Chengdu city today, was distant from the Min River trunk but not deficient in water sources. Additionally, it posed the lowest flood threat.

During this era, mankind revered Mother Nature and attempted to emotionally influence the goddess through prayer and worship whenever they were confronted with the disasters of flood and drought. Thus, the relationship between humans and water manifested as a pattern of *passive adaptation*. Consequently, the water management approach was dominated by *flood avoidance*. During this period, natural processes determined the human settlements patterns. Humans lived in areas in which the natural conditions were relatively safe and that offered rich natural resources. Thus, the inhabitants developed a simple mode of production in which primitive techniques were employed to acquire the means of subsistence, whereby a tribal-based social organization was sustained. Possibly because of the floods that flushed the plain, the human settlements developed in a spatial structure feature of small, dispersed *waterside colonies* (逐水而居, *zhushuierju*). In summary, the relations between humans and nature exhibited a paradigm of *submission to nature* (Fig. 1). As a result, *intuitive concession* spatial patterns of human settlements were gradually formed. Because the environmental capacity on the natural system was sufficient, the human settlements and activities had negligible effects on natural processes. Humans and nature were in a primitive harmony state.

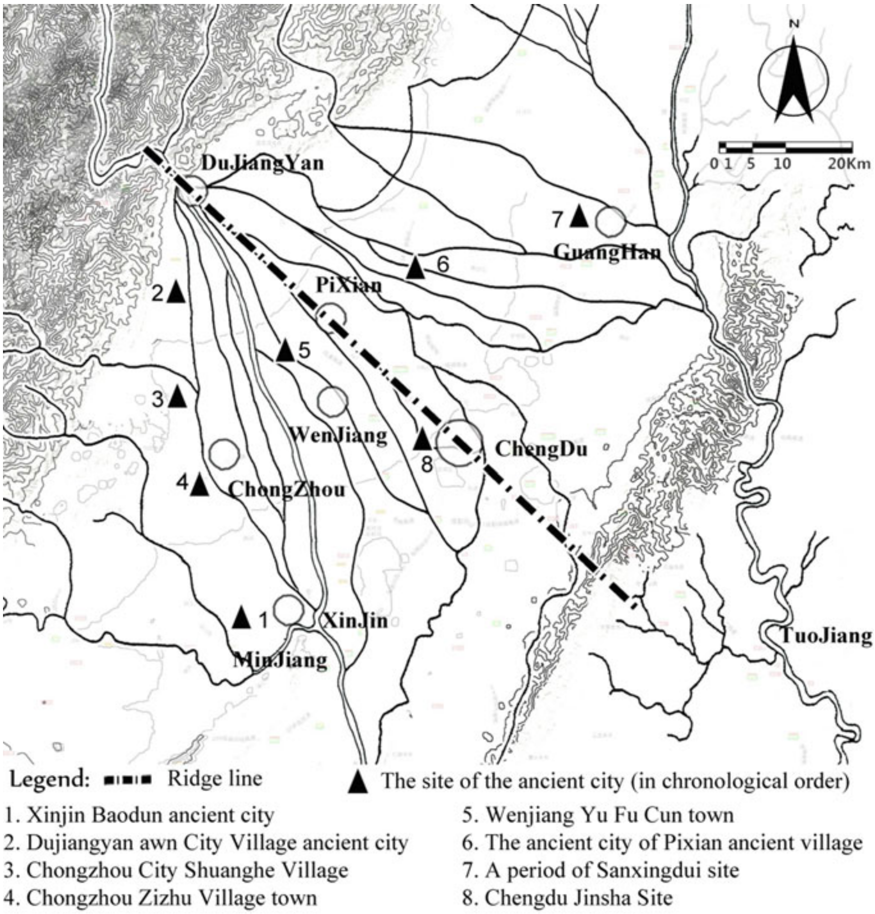

Fig. 1 Main site distribution in the ancient Chengdu Plain. Modified from Zhang (2010)

2.2 Original Construction Period (256 BC–206 BC): Natural Guidance Patterns Based on Water Following

In 256 BC, the Governor of Shu Prefecture of Qin State, Li Bing, presided over the construction of the DIS. The system consisted of the ancient headwork, a one of a kind self-regulating hydraulic system, which includes Fish Mouth (鱼嘴, *yuzui*, a diversion embankment), Flying Sand Sluice (飞沙堰, *feishayan*, a sediment and overflow spillway), Baopingkou (宝瓶口, *baopingkou*, a bottleneck-shaped irrigation gateway), and the canal network, which was constructed on the basis of the natural waterway and travelled through the Chengdu Plain (Jin 1988; Li and Xu 2006; Tan 2009; Cao et al. 2010; Xiang 2014). Thanks to the non-dam intake approach that was taken throughout the DIS, the whole system remains robust after two millennia of operation. The DIS played a crucial role in the evolution of the spatial structure of human settlements during this period and later. After the system's completion, water disasters were under control, and a stable, abundant water source was available in the Chengdu Plain. In addition, the canal system provided channels for navigation and floodway, which catalyzed an unprecedented increase in agriculture and in the handicraft industry. Correspondingly, the population in the plains migrated toward the cities of Chengdu, Pixian, and Dujiangyan and was mainly distributed along the ridgeline and along the banks of the Botiao and Zouma Rivers, which were connected to the inner stream of the Min River (Tan 2009). Importantly, the Pi and Jian Rivers integrated multiple functions (e.g., transportation, irrigation, and flood drainage) and therefore played crucial roles in Chengdu's urban morphology and economic development (Fig. 2).

During this period, human could already understand and make use of nature forces and correspondingly employ a series of remarkable scientific ideas and extraordinary water management techniques when challenged with flood and drought. These techniques continue to inspire engineers today. Overall, the relationship between humans and water during this stage could be described as *following nature*, and the primary water management approach was *following the water*. Thus, although natural processes exerted a tremendous influence on the human settlements patterns, human, despite the lack of modern technology and materials, could guide natural processes to reap a relatively high ecological benefit, which was facilitated by their overall improved understanding of the natural events. Large-scale human settlements and activities could be maintained. To take advantage of the benefits of water but to avoid their negative environmental effect, a spatial pattern of relatively concentrated human settlements along the rivers emerged. This spatial feature was characterized by *waterway decorating towns* (依水珥城, *yishuiercheng*). Thus, the relations between human and nature exhibited a paradigm of *respect for nature* (Fig. 2). As a result, these spatial patterns of human settlements could be summarized as *nature guidance*. Because the natural waterway was followed and guided to generate the inner stream system of the Chengdu irrigation area, the human presence did not affect the overall natural processes and had little impact on the natural systems and their immense environmental capacity. Mankind and nature remained in a state of relatively high harmony.

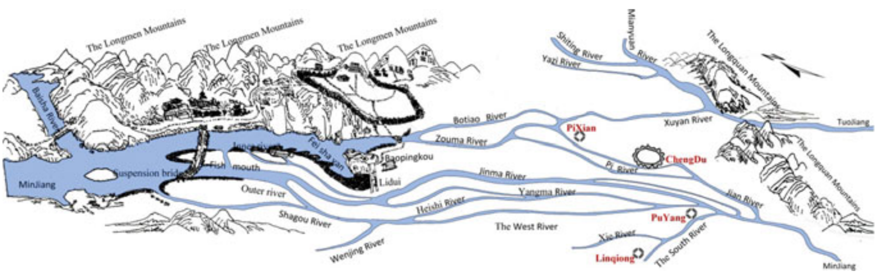

Fig. 2 Qin dynasty human settlement patterns and Dujiangyan Irrigation System. Modified from Tan (2009)

2.3 Development Period (206 BC–1930s): Conscious Organization Patterns Based on Water Handling

In the era of the Han and Tang dynasties (206 BC–961 AD), the canal systems of the Chengdu irrigated plain was further repaired and improved. The construction work followed the engineering principle that was proposed by Li Bing when the project was launched. Specifically, the non-dam intake approach was systematically adopted to generate the historically most comprehensive inner stream waterway. As the water management technologies were improved, the handicraft industry in the Chengdu irrigated plain experienced additional growth, which was accompanied by the rapid development of waterway-based navigation. Consequently, Chengdu became one of the busiest ports in China (Fig. 3). Consequently, major cities were distributed along the ridgeline and the banks of the important trunk canals, which resulted in the development of many medium and small towns along the waterway system.

Between the Northern Song and Qing dynasties (960 AD–1820 AD), the Chengdu Plain witnessed two episodes of war-related calamity and recovery. Correspondingly, the DIS also experienced two episodes of abandonment and reconstruction. It was estimated that each reconstruction process required approximately 10–20 years, after which the headwork and canal system reacquired its original form. During this period, the main canals of the inner stream underwent no substantial changes except that a large number of canal branches (Willmott 1989), and ditches were constructed to accommodate the increasing population of the Chengdu irrigation area. Thus, a favorable human settlement environment and stable social production were maintained, which resulted in the emergence of numerous small rural colonies along the canal branches and ditches.

By this period, human had acquired several capabilities to regulate nature. After over a millennium of evolution, the inner stream network of the DIS gradually matured. The massive construction of secondary canals and ditches expanded the irrigation area, which in 1938 reached 1720 km^2, including 920 km^2 irrigated by the inner stream and 800 km^2 by the outer stream (Tan 2009). The relationship

Fig. 3 Tang dynasty human settlement patterns and Dujiangyan Irrigation System. Modified from Tan (2009)

between human and water could be summarized as *dependence and alteration* in which human primarily employed a strategy of *terrain-based water regulation to handle water*. That is, human had gradually developed the ability to actively modulate natural processes. Correspondingly, their settlements gradually migrated inland along the major waterways and formed a spatial feature based on *water regulation* (理水择居, *lishuizeju*). This human settlement pattern displayed a high level of integration between the settlements space and the waterway network and blended seamlessly into the nature. During this period, the relation between human and nature exhibited a paradigm of *reconstruction of nature*. This spatial pattern of human settlement could be summarized as *conscious organization*. Although a substantial construction effort was devoted to the terminal waterway of the DIS, generally, the principle of following nature was observed and those projects did not influence natural processes on the macro scale. Moreover, autonomous rural units emerged in the irrigation zones of the terminal waterway. This evolution of the social system effectively promoted the maintenance of the ecological functions of the Chengdu irrigation area (Li and Xu 2006).

2.4 Modern Period (Since the 1940s): Regional Sprawl Patterns Based on Water Cutting

Modern hydrotechnics from Western countries generated a profound impact on the reform of the DIS. On August 26, 1933, an earthquake in the upstream area of the Minjiang caused a landslide which dammed the river. On October 9, the dam collapsed and subsequently completely destroyed the headwork and canal network. Similar flood damage also occurred in 1936. In 1939, a plan to permanently repair Dujiangyan was about to be launched in which the hallmark of modern Western hydraulic engineering, a gigantic dam, would replace the traditional non-dam intake project that had operated for 2000 years. Although the plan was questioned by water conservancy scientists and was eventually abandoned, the plan's design reflected the characteristics of Western hydraulics technology at that time. To boost the flow of the inner stream during the non-flood season and to satisfy the ever-increasing demand for irrigation water, in 1974, a modern concrete outer river checkgate dam was constructed and replaced the traditional outer river checkgate dam in the outer opening of the Fish Mouth, diverting all of the water of the Min River into the Chengdu irrigation area during the non-flood season. This construction caused discontinuation to the trunk of the Min River in the non-flood season (Tan 2009; Cao et al. 2010). To avoid damage to the Dujiangyan by earthquakes and floods, the Zipingpu reservoir was constructed in 2006. This reservoir, which is located in the Min River watercourse 9 km upstream of the Fish Mouth, prevented the destruction of the Chengdu Plain barrier lakes during the Wenchuan Earthquake of May 12, 2008 (Cao et al. 2010).

During this period, mankind mastered the modern science and technology of hydraulics and reached its historic peak in the ability to control water. This development is evidenced by the enormous alteration in water management strategies. For example, the construction of the modern outer river checkgate dam expanded the irrigation acreage in Chengdu to 6687 km^2. As an attempt to dictate natural processes using industrial technology, the relationship between human and water manifested a new norm of *conquering and controlling*, in which humans primarily adopted a strategy of *engineering and technology-oriented water regulation to keep water* (e.g., large dam). As a result, the traditional spatial patterns of human settlements were swiftly transformed. Correspondingly, these original waterway-oriented spatial features were gradually replaced by the transit-oriented spatial features of *farewell to water (*离水而去*, lishuierqu)*, in which the scale and number of individual settlements have increased exponentially and coalesced to form a giant planar structure. In this way, the relation between human and nature represented a new paradigm of *conquest of nature*, which resulted in spatial patterns of human settlements that may be referred to as the *regional sprawl*. In the Chengdu Plain, floriculture has replaced most traditional irrigation-based agriculture, which, in conjunction with public transportation-oriented regional urbanization, has resulted in an alteration in the major functions of the local irrigation system. Thus, the collaborative, symbiotic relationship between the natural and social system risks is being weakened. It will be a difficult task to strengthen the human–water relationship and effectively protect the ecological functions of the DIS.

3 The Ecological Wisdom of Harmony Between Mankind and Nature in the Land of Abundance

Nowadays, DIS still play a fundamental role in agricultural irrigation, municipal water supply, navigation, aquatic production, ecological conservation, aesthetics, and tourism (Li and Xu 2006; Peng 2008; Cao et al. 2010). The Chengdu Plain remains as the famed Land of Abundance (Cao et al. 2010; Zhang et al. 2013; Xiang 2014). In this section, we attempt to explore the ecological wisdom of its longevity to provide guidelines and norms for the contemporary practice of sustainable human settlements, learned from the Dujiangyan experience.

We summarize the ecological wisdom of the harmonic coexistence of man and nature in the Land of Abundance from the perspective of worldview, view of practice, social values, ethics, and governance. Exploring the worldview and the practice view of human settlements in the Land of Abundance can allow us to understand the ideological basis and guidelines for action that underlie sustainability. Exploring social norms can help us understand the influence of social systems on changes in human settlement environments, while exploring ancient engineering ethics allows us to understand the restriction of environmental ethics on engineering techniques. The coevolution of natural and social systems in the Land of Abundance is achieved by exploring the principle of sustainable governance. Through summarizing the ecological wisdom as actionable and practical knowledge from these five perspectives, we find these ideas have continuing relevance and scope in modern times.

3.1 Worldview of a Holistic Environment System of Daoshengwanwu (道生万物, All Things Arise from Tao)

The great achievement of the DIS lies in its comprehensive and systematic thought, which was developed gradually over a long period of history (Peng 2008). Since the early stage of construction, the entire system considered the requirement to balance the comprehensive needs of the up- and downstream, as well as inner and outer rivers in the Chengdu irrigation region. Therefore, the long-lasting harmony between man and nature in the Land of Abundance has been attributed largely to the holistic principles Li Bing established at the onset, which guided every step of the project lifecycle, from planning, design, and construction of the system, to its operation, maintenance, and management (Cao et al. 2010; Xiang 2014). These holistic principles originate from the idea of *daoshengwanwu* (道生万物, *all things arise from Tao*) of *Taoism*, as described by the Chinese philosopher Laozi (571 BC–471 BC) of the late Spring and Autumn period, which means "the Tao gives birth to all things" (Chap. 42*, Tao Te Ching* by Laozi). This idea refers to the concept that all worldly things, including human, arise from the "Tao" and that there is a common origin for humans and all worldly beings. The principle of Taoism views human and nature as a highly coordinated and unified whole, which emphasizes the holistic and organic character of the interaction between man and nature (Richard and David 1988; Peerenboom 1992; Verellen 1995).

The philosophy of holism in *daoshengwanwu* is reflected in the macroscopic river patterns and specific construction of the Chengdu Plain. The changes in the natural elements up- and downstream and in the inner and outer rivers impact related natural and social elements. In other words, changes to any single element of the various social and natural systems, such as flood control systems, irrigation systems, navigation systems, and water supply systems, will distinctly impact the other elements. In addition, operation of these systems achieves compromise and overall balance in its mutual constraints. The non-dam intake project, which is similar to natural waterways, blends with the nature systems, and it is difficult to distinguish man-made water systems from natural waterways. Furthermore, harmony and imbalances between humanity and nature were considered when planning the reconstruction of the human settlement environment in the Chengdu Plain, thus the "the intrinsic state of heaven and earth" was not altered (McHarg 1969; Alexander 2008). In other words, the social and natural systems in the Chengdu Plain, as well as various systems in the outskirt of Chengdu Plain, harmonized with each other. Without the guidance of the philosophical views of the ancient holism, the complex and effective DIS could not have been achieved.

3.2 The Idea of the Ecological Practice of Daofaziran (道法自然, Following Nature's Lead)

Daofaziran is another important philosophical thought of Laozi, and it can provide us a methodology for sustainable practices. *Daofaziran* suggests that the operating rules for all things must comply with the laws of nature; that is, they must respect the intrinsic character of nature, comply with the laws of nature, conform to the trends of nature, and restore the original natural relationships between Tao, heaven, earth, and mankind (Chap. 25*, Tao Te Ching* by Laozi; Verellen 1995; Steiner 2002). During more than 2000 years of history between the design and construction of the water systems in the Chengdu Plain and the present, human activities have always followed the concept of *Daofaziran*. One of the longest lasting and the remaining water systems, characterized by a non-dam intake project, applied the idea of the ecological practice of *daofaziran* perfectly in the Chengdu Plain. The concept of the ecological practices of *daofaziran* is mainly reflected in the aspects of the water system construction methods and traditional water-diversion techniques in the Chengdu Plain.

The water system patterns in the Chengdu Plain were constructed based on the regional geological condition and hydrological processes. Different levels of canals in the Chengdu Plain generally mimic the morphology of natural rivers, and the contour lines of the vertical irrigation region show a dendritic distribution throughout the Chengdu Plain. The principle of "guide according to the trend" has been observed throughout the entire history of the evolution of human settlements on the Chengdu Plain, and the water system that supports the critical environmental processes has been maintained on a regional scale (Li and Xu 2006; Zhang et al. 2013). The self-regulating function is realized naturally, without external force, based on the hydraulic conditions of natural rivers. Differences between the large dam produced by modern technology and non-dam diversion embankment in the DIS represent completely different philosophies of the relationship between humans and nature. Dams contend forcefully with and strongly repress water, which represents the head-on collision of man and nature; but non-dam diversion embankment "guide according to the trend" of the water, such that the natural character of the water is not violated while achieving the goal of water diversion, without concern for outbursts. These hydraulic engineering facilities, which have such ecological significance, are natural and exquisite that they feel more like a natural site instead of an artificial facility when observed in person. This simple practice of following ecological law even resolves the potential disaster presented by the sedimentation observed in modern waterworks.

3.3 *Social Behavior Criterion of Jianlitianxia (兼利天下, Sharing Benefits Across)*

The sustainability of social system is the heart of the sustainability of human settlement. In other words, a human settlement without a social foundation is definitely unsustainable. The social code of conduct of *jianlitianxia,* i.e., all things benefit, underlies the social foundation of the sustainable development of the Land of Abundance: The social behavior of mankind should be conducive to the growth of all things. We have appreciated the ecological principle of the DIS. However, we obviously will not be able to comprehend the social connotations of DIS if we view it as an isolated non-dam intake project. In fact, the water-diversion principle of the Dujiangyan is not merely for flood control and sediment diversion. Moreover, the social concept of *jianlitianxia* is also reflected. Modern large dams represent a principle of upstream first and upstream only, and they lead to social conflict and strain between the up- and downstream areas (McCully 2001; Tilt et al. 2009; Ma et al. 2012).

In contrast to modern water facilities, the principle of "equitable rights in the watershed" is reflected in the DIS. The water division principle of *jianlitianxia* provides the social foundation for the sustainable development of the human settlements in the Chengdu Plain and embody the balanced relationship between man and nature. If it is possible to limit the total water usage to between 40 and 60% of the total water runoff of the watershed, and 60–40% of the water from upstream were able to flow into the ocean, the conflict between the up- and downstream regions and the strained relationship among transportation, fishing and scenery would be nonexistent (Tennant 1976; Jowett 1997). If there exist inharmonious factors among the relationships between human and nature in human settlement practices, the physical systems of the human settlements are less likely to persevere and perform permanently. While DIS is widely appreciated by all of us, many people are adopting completely contrary principles and are using "exclusive" principles to challenge the "benefits for all" principle. Once a balanced relationship is broken, it is less likely that contemporary human settlement practices could endure.

3.4 *Ethics of Yidaoyushu (以道驭术, Tao Controls Technology)*

Yidaoyushu has two meanings. The first refers to technical activities under the law of nature to achieve results that are conducive to the survival and development of natural system and to emphasize the natural ethics of technical activities. The second refers to constraints of social ethics on the activities and applications of technologies to restrict and eliminate the negative social impacts of improper applications of technologies and to emphasize the social ethics of technical activities. A technological "can do" is not necessarily a "should do" in the ethical sense. Technological development without constraints by the laws of nature and social ethics might lead to the misuse of technology and the use of unscrupulous tactics for utilitarian purposes (Radder 2004). "Good" is what is considered to be right according to moral standards or religious beliefs; furthermore, the goal of "real and permanent good" can only be achieved by activities that follow the natural law of development. In this respect, "do[ing] real and permanent good" refer to what are the technically right things to do as well as what are the morally good things to do (Higgs et al. 2000; Brey 2007; Wong 2012). Therefore, the ethics of *yidaoyushu* provides a behavioral benchmark in achieving a paramount level of "do[ing] real and permanent good in this world."

The technological conduct of the construction, maintenance, and renovation of the DIS throughout different periods of history has always been constrained by the law of nature and social ethics. The ethics expressed by the concept that *yidaoyushu* has specified the code of conduct for people's technological activities in the DIS. This code of conduct involves coordinating the relationships among the operators, materials and tools, and between man and nature during technical activities, and it involves harmonizing the all-important elements of technical activities. The "three-character primer" of water control and the "eight-character pithy formula" for the river works have been condensed from the technical specifications that are in line with the nature of the DIS from over two thousand years of historical experience and lessons learned. Therefore, the harmony between various important elements of technical activities is achieved; this achievement not only includes harmony between the technical operators and their tools but also includes harmony between people, between technical activities and social systems, and between technical activities and natural systems (Wong 2012). However, on transitioning into the modern era, modern technical activities have gradually let the constraint of the "Tao" lapse. For example, the "Dujiangyan Permanent Cure Plan" proposed in 1939 reflected the character of modern Western water technology in its planning mindset. Another example is the concrete modern outer river checkgate dam that replaced the traditional outer river checkgate dam at the fish mouth outer estuary in 1974 for the purpose of increasing inner river flow during the non-flood period. All the water of the Minjiang River was diverted into the irrigation region during the non-flood period (Cao et al. 2010). As a result, breaking the water division rule led to the drying up of the main flow of the Minjiang River during the non-flood season.

3.5 Good Governance Concept (政善治, Zhengshanzhi) of Spontaneous Order

The aforementioned four aspects of ecological wisdom have played an important role in the construction of the physical systems for the human settlements in the Land of Abundance. However, the physical systems for the human settlements will not effectively operate and their functionality will not be permanently maintained without the establishment of good governance of the social system (Doxiadis 1968). The Dujiangyan has had over 2000 years of history, and it plays a functional role even now; in a sense, this is the continuation of good governance (Jin 1988; Li and Xu 2006). Among these governances, the idea of *zhengshanzhi* based on spontaneous order is another secret of how the Chengdu Plain became the Land of Abundance (Beng 2013). The *zhengshanzhi* of the Dujiangyan is mainly reflected in the following perspectives.

First, the gradual diversification of the governing body must be considered. The early works of construction in the Dujiangyan were important projects that were directly managed by the central government. The unified basin-management system was gradually perfected during the Han through Ming dynasties. The irrigation region management of the Qing dynasty gradually divided the official main canals system, as well as the private branch canals system. In the private branch system in the lower system that was outside the reach of government management control, end user water systems managed by the rural social organizations formed through the wide participation of water users in the irrigation region. The managers of the private branches system were generally installed by election or a system of rotation to represent the diverse management methods and tools in the governance of the branch canals system.

Second, the collaborative and dependent relationship between the state and the rural community is important. State management of the DIS ultimately played a role through rural community organizations. A temple was built for Libing during the Han dynasty that complied with national worship ceremony rules and that produced ceremonies and rituals with religious character in the irrigation region. The religious activities of Water God worship became the connecting link among government regulatory agencies, the official professional bodies and civil society organizations in the irrigation region. This kind of spiritual link can unite all forces for the maintenance and management of a water system that requires large amount of labor. The lowest level of social management organizations was established through the construction of small shrines dedicated to Libing at various levels canals. The harmonious blending of Water God worshipping, annual repairs, and irrigation ceremonies provided a bridge of communication and cooperation between the irrigation administration and grassroots community organizations. This injection of vitality into the continuation and effectiveness of the management of the Dujiangyan irrigation projects was conducive to maintaining the normal order of the social management of the irrigation region and fostered the spiritual and emotional recognition of the irrigation region's population toward the river dikes (Tan 2009).

Third, multi-party interactive management processes emphasize the involvement of the managed objects. Due to the complexity of the DIS, there are major conflicts regarding water usage between the up- and downstream regions and between the inner and outer rivers, the management method of issuing orders from the top will lose resilience and may not achieve the goals of resources and environment management. To coordinate the water-usage disputes, local rules, and regulation were established through discussion meetings such as the "Irrigation Engineering Symposium"; specifically, public contracts with the power to limit the behaviors of all parties were established (Li and Xu 2006; Tan 2009). Through the participation of and consultation with representatives of all parties' interests, a flexible mechanism to express the parties' interests is conducive to the implementation and enforcement of local management systems. This form of multi-party participation in meetings emphasizes stakeholders should participate in the management of the use of natural resources.

4 The Inspiration of the Ecological Wisdom of the Land of Abundance

The sustainable human settlements have been the ultimate goal pursued by human society, and the central issue of human settlements is the issue of harmony between human and the environment (Doxiadis 1968). The secrets to over 2000 years of long-lasting history in the Land of Abundance contain a wealth of ecological wisdom. We propose several inspirations for contemporary urban development and planning practices in the presence of deep sustainability challenges.

First, cities should be treated as a holistic settlement system consisting of both natural and social systems. Coevolution of natural and social systems would help promote sustainability of human settlements. Harmony between human and nature ultimately depends on the coordination of these systems (Doxiadis 1968; Colby 1991). The development of human society depends on the natural system on both the global and local scales and significantly impacts the ecological service functionality of the natural system. It is imperative to examine the problems of various systems from a global and regional perspective and implement various systems in cities and sites scale (Forman 2008). The continuity of key elements at different planning stage (e.g., regional planning, master planning, and site planning) should be emphasized. From the perspective of the impact of human society on natural systems, we need to understand more about the impact of a dynamic social process (e.g., competition, conflict, accommodation, cooperation, assimilation) on natural system function and services. Furthermore, we would propose a new social governance model that can improve upon the natural system functions (Yan et al. 2012). On the other hand, from the viewpoint of the impact of natural systems on human society, we also need to understand the impact mechanism of dynamic natural processes (e.g., biological, geological, and hydrological processes) on social systems to assess the potential resulting social effects (both positive and negative) and thereby construct urban resilience patterns that adapts to natural processes (McHarg 1969; Walker et al. 2002; Alberti and Marzluff 2004; Vogel et al. 2007; Adger 2000; Ahern 2013; Cumming 2011; Resilience Alliance 2014). Therefore, human settlements sustainability may refer to a set of "dynamic balance conditions" formed by the synergy of various systems, which reflect the symbiotic relationship between human and nature in the temporal and spatial dimensions (Wu 2014). In other words, social and natural systems are themselves linked, in ways which scholars in the fields have referred as "synergistic and co-evolutionary relationships" (Adger 2000: pp. 350).

Second, nature-guided human settlement practice can maintain various healthy life-support systems. We should maintain or reconstruct healthy natural process through planning practices. The laws of nature should be followed with respect to both urban spatial patterns and engineering implement; the cost of contradicting the laws of nature may mean that we face higher risks and greater economic costs (McHarg 1969; Berke 2008). Therefore, human settlement patterns should "*follow nature's lead*" in terms of mimicking essential cycles and life-support functions of natural systems (Steiner 2002). On a regional scale, various natural processes are the driving factors for urban structures. In order to rebuild cities in balance with nature and to achieve dynamic balance between urban expansion and regional natural evolution processes, we should protect and preserve some supporting structures for crucial natural processes (Register 2006; Yan et al. 2012). On a city or community scale, the original natural processes will be transformed as a result of inevitable high-density development. Urban planning practices should not only involve the passive protection of natural systems but rather should actively embed ecological elements into urban and district spatial structures, which could regulate and rebuild healthy natural processes and improve urban and district environmental capacity (Kellogg 2002). We should treat physical structures for crucial natural processes as supporting elements of the urban space structure, which could enhance the compatibility of spatial forms and environmental processes. Moreover, we should construct ecological urban patterns that based on regional natural evolution processes, as a result, it could provide spatial carrier for symbiosis between man and nature.

Third, modular units should be constructed through integrating Environmental Management Units (EMU) with Planned Unit Development (PUD). Furthermore, we should explore self-governance mode based on modular units. There is a difference in each modular unit in terms of environment and economic function. Consequently, modular systems that have diversity of functions can be produced. It is similar to the rural organizations based on various irrigation units in the Chengdu Plain. Urban patterns will be designed as an overall distribution model of "large concentration of small decentralization." These modules are relatively more tightly linked by man-made infrastructures on the urban area than on the countryside. This urban patterns will help promote the continuity of the diverse historical culture and local knowledge, which based on unique environmental characteristics of various modules. In addition, diverse modules contribute to promote capability of responses to shocks. Community residents will actively participate in decision-making processes for various planning because they are closely associated with their own modular unit. As a result, self-governance organizations could be fostered likely based on modular units. By learning from the ecological wisdom of the Land of Abundance, these types of social organizations can effectively manage community-scale natural systems and are an essential protection for maximizing public interests (Kono 1997). Stakeholder participation can produce actions that conform to the common standard of social values, and such participation is the source and social foundation of planning authority legitimacy (Friedmann 1987, 1992; Johnson 1989). Various forms of participation in the decision-making process are conducive to prevent and resolve conflicts between citizens, between citizens and government agencies, and between citizens and the relevant economic organizations while avoiding the problem of corruption caused by political associations between the government and economic organizations. This collaborative and diversified management style can also avoid the social risks faced by the full reliance on a unidirectional imperative style of management from a single unit leader or government.

Fourth, the introduction of environmental ethics in the field of urban planning to guide planning value selection and planning system reform can provide value criteria for urban planning. A series of value judgments and selection by the planners exists in the whole process of urban planning (Yan et al. 2012). All decisions and judgments are driven by values rather than technical factors; therefore, their final resolution depends on the value system of the decision-makers, though the technical, economic, and institutional factors are still important (Jenks et al. 1996). In the practice of urban planning, value criteria of natural and social capitals should be assessed, and the continuity and consistency of value assessment should be maintained at various planning scales and stages, which then in turn provides reference for the value choices of the planners. Our traditional urban planning theory and practice pursue the "scientific nature" of the complete separation of facts and values, which has caused many planning results to be contrary to environmental ethics guidelines and has exacerbated social conflicts. Therefore, we should re-examine our responses to global and local environmental issues through landscape and urban planning practices from the perspective of environmental ethics. In addition, because urban planning includes a series of technical characteristics, excessive focus on planning tools, technology and methods, and empirical and quantified expression can easily lead to replacing value standards with technical standards, resulting in "doing the wrong thing with the correct method" or "do[ing] real and permanent bad." Thus, we need to reassess the natural and social ethics of planning techniques, engineering measures and materials; the application of some technologies could be restricted in an environmental ethical sense (e.g., large dam technology).

5 Concluding Remarks

The Dujiangyan Irrigation System, which is based on a non-dam intake project, creates a form of harmonious coexistence of man and water. After more than 2200 years of history, it still performs the functions laid out by the original designers and nurtures the vast and fertile Land of Abundance. It has created natural and social systems based on the DIS, accomplished long-lasting brilliant achievements in the Land of Abundance, and formed sustainable paradigm of human settlement practice.

The history of the Land of Abundance is a history of prosperity based on water conservancy, and the relationship between man and nature is epitomized in the relationship between man and water. Human settlements in the Land of Abundance have undergone four major phases. Relationship between humans and nature in these four phases reflects the transition from *submission to nature*, *respect for nature*, *reconstruction of nature*, and finally to the *conquest of nature*. On this basis, the spatial structures of human settlements in the Land of Abundance have formed with the characteristics of *waterside colonies* (逐水而居, *zhushuierju*), *waterway decorating towns* (依水珥城, *yishuiercheng*), *water regulation* (理水择居, *lishuizeju*), *farewell to water* (离水而去, *lishuierqu*). We have revealed the deep wisdom of the harmonious coexistence between man and nature in the Land of Abundance by studying the history of the evolution of human settlements and from the five aspects of the holistic view of *daoshengwanwu*, the practice view of *daofaziran*, the social view of *sharing benefits across*, the ethical view of *Tao controls technology*, and the good governance view of *spontaneous order*. These historically formed ecological wisdoms—like navigation marks lighting the sea—guide the direction of action for the lasting prosperity of the Land of Abundance.

The ecological wisdom in the Land of Abundance provides not only knowledge for local sustainable development but also inspiration for facing the profound challenges to our contemporary urban sustainability. Urbanization has produced a widespread and profound impact on human settlements on both the local and global scale. Urban sustainable development should not maximize the human welfare of a single social system but rather should optimize the integration of natural and social capital as a whole system. We pursue the "balance conditions" and "symbiotic relationship" formed by interactions within a variety of systems in the time and space dimensions, and our pursuit is of a coevolution model of social and natural systems in these dimensions. Through understanding the regional natural evolution process, we can construct a spatial structure of urban ecology and provide material support for the creation of a symbiotic system between man and nature.

Compared with their ancient counterparts, contemporary cities tend to be bigger in "physical size and ecological footprint," faster in their growth rate in terms of both population and urbanized area, and more complex in their system configurations (Wu 2014). Therefore, we cannot adopt a "one size fits all" bureaucratic system of urban management (Resilience Alliance 2014). However, we could provide a viable path to address the complexity and uncertainty of urban management issues by integrating EMU with PUD, as well as forming self-governance modules. By combining the environmental characteristics of different modules (including religious activities), a diverse geographical culture that connects people can be formed to inject different spiritual values and meanings into the modules (Worster 1990). Environmental ethics can provide value criteria in landscape and urban planning for "do[ing] real and permanent good" (Xiang 2014). Only by doing so can we strike a balance between social systems and natural systems to achieve a virtuous circle of sustainable development.

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Watershed Ecosystem Goods and Services Sustaining Urban Socioecological Systems: Planning and Management Through Ecological Wisdom

Duncan T. Patten

Abstract Early urban establishment occurred along continental coasts, large interior rivers, and where rivers entered the sea. Sustainability of modern urban centers continues to depend on these rivers and their associated watersheds for goods and services. The quantity and quality of water that sustains urban centers from watersheds are directly related to the ecological condition of the supporting watershed. Management of watersheds and their rivers has changed over the years as the complexity of the watersheds increases. The interaction among urban centers and their supporting watersheds composes an integrated socioecological system to be managed as a unit. Management of this system requires integrated procedures that sustain and/or restore the functions that allow the resource to continue to offer ecosystem goods and services. Guiding these management procedures is an appropriate role for ecological wisdom, an integrating process. Use of ecological wisdom as an organizing framework for developing planning and management guidance for watersheds requires inputs from many disciplines including science and human values, as well as governmental networking. This is demonstrated in a conceptual model showing the centric nature of ecological wisdom. Examples of management of large watershed systems serving two large urban centers in the USA, New York City, and Los Angeles are used to demonstrate how ecological wisdom could be used for sustainable watershed planning and management. Until ecological wisdom is recognized as a guiding process for planning and management, existing approaches will continue to be used, often to the detriment of the riverine/watershed systems.

Keywords Ecological wisdom · Watershed · Socioecological systems
Sustainability · Ecosystem goods and services

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1 Introduction

Early urban establishment occurred along continental coasts or large interior rivers. Coastal cities were often located where large rivers entered the sea. All of these locations suited several purposes: transportation; an assured source of clean water for domestic, agricultural, and industrial use; aquatic food sources; and a repository for waste. These are all ecosystem goods and services. Sustainability of modern urban centers continues to depend on these goods and services from rivers and watersheds, whether the watershed is nearby or some distance supporting large continental rivers.

The quantity and quality of water that sustains urban centers are directly related to the ecological condition, or health, of the supporting watershed (Postel and Thompson 2005). Management of watersheds and their rivers has changed over the years based, in part, on an increasing need for sustainable high-quality water for downstream urban centers. The interaction among urban centers, that is, network governance (Scarlett and McKinney 2016) and their supporting watersheds and rivers composes an integrated socioecological system to be managed as a unit. Sustainability of water sources for urban centers will not be achieved with poor watershed management. Consequently, a water source of sufficient quantity and quality to sustain a city requires a sustainable watershed and riverine ecosystem producing these goods and services (e.g., Daily 1997; Mooney and Ehrlich 1997). A good example is found in South Africa where water law includes assurance of sufficient good-quality water required to protect basic human needs and aquatic ecosystems to secure ecologically sustainable development and use (Jewitt 2002).

Management of water sources requires integrated procedures that sustain and/or restore the functions that allow the resource to continue to offer ecosystem goods and services (Shuang et al. 2013). Guiding these management procedures is a role appropriate for ecological wisdom, an integrating process. I discussed the role of ecological wisdom in guiding management of water for urban socioecological systems and emphasized that it integrates many inputs from science to philosophy to ethics (Patten 2016). The output from this integration then can be used as a primary guide of planning and management of watersheds. This theme is emphasized here using examples from large urban areas to demonstrate the importance of applying ecological wisdom to planning and management of watersheds that serve these centers.

2 Maintaining Sustainable Water Sources

Essential to maintaining sustainable water sources for urban areas is development, maintenance and appropriate planning, management and restoration of riverine/ watershed systems. Because rivers and their associated watershed ecosystems are critical assets in nature and for human well-being, how they are used and managed influences their sustainability and thus ability to continue to offer goods and services. For example, low-level human impacts on headwater rivers continue to allow these rivers to produce abundant, clean water and maintain their resilience to external environmental perturbations. Additionally, appropriate operations of controlled rivers through proper dam management, for example, may also produce sustainable water resources. However, mismanagement of these critical systems may reduce their resilience, sustainability, and production of goods and services.

Managing rivers for sustainable goods and services may require some form of restoration as well as just maintenance of natural riverine processes. The form of restoration to return the system to a "healthy functional system" may vary from passive to very active, or in many cases a combination of both. In general, passive restoration includes removal of stressors that have altered the system and then letting "nature take its course." This could be the removal of hydrological constraints, for example, eliminating dewatering or reduced flows of the riverine system and/or returning "natural" flows (i.e., a natural hydrograph). In some cases, it may also include modifying land use practices that influence the riverine ecosystem, for example, grazing and forest harvest near the river. Additionally, passive restoration may approach forms of active restoration by returning stream geomorphic conditions such as restoring stream banks. On the other hand, active restoration requires some form of physical modification of the ecosystem from rechannelizing the river to planting riparian vegetation. Active restoration alone should be a last resort, but active combined with passive may be the best approach for restoration and management of most rivers. Selection of the appropriate form of restoration when needed is an appropriate role of ecological wisdom.

Under the best of conditions, one would expect to use passive restoration first. Often, limitations prevent using passive restoration alone. However, to test this assumption, "experiments" that modify different stressors over time will help guide, through the integrating processes related to ecological wisdom, future decisions on the form of restoration and its magnitude should active restoration be considered. An "experiment" that appears to fail is not a failure at all but a lesson to be applied to future "experiments" or restoration/management approaches. Lessons from nature do not come easily or quickly; thus, patience in steps determining restoration and/or management procedures is essential to success.

Use of experimentation in determining restoration and management procedures exceeds how we once addressed management of rivers for human well-being. In early river management, goods and services were primary; thus alterations, controls, diversions, and other processes were used to supply water to areas of human settlement and agriculture. This approach dates back many centuries. For example, in 256 BCE the Chinese developed a major irrigation diversion system on the Min River (a tributary of the Yangtze) near Dujiangyan which continues to function today. In the North American Southwest, the Hohokam diverted the Salt River from about 300 CE to about 800 CE for irrigation. Both of these examples demonstrate river diversion as the management scheme but with little consideration of the long-term sustainability of the whole riverine system.

Also, essential to maintaining sustainable water sources for urban areas is development and maintenance of appropriate environmental flows in rivers and their supporting watersheds. Environmental flows are the quantity, timing, and quality of water required to sustain freshwater and estuarine ecosystems and the human livelihood and well-being that depend on these ecosystems (Brisbane Declaration 2007). This definition of environmental flows recognizes the importance of sustainability of both the natural freshwater system, the source, and the receiving systems that include urban centers or other human habitation and activities. It is also widely accepted that a naturally variable flow regime is required to sustain freshwater ecosystems (Poff et al. 1997; Bunn and Arthington 2002; Postel and Richter 2003; Poff et al. 2010; Poff and Zimmerman 2010).

3 Watershed Management and Ecological Wisdom

Planning and designing an appropriate watershed management program may require guidance from many disciplines, science and non-science, and governmental networks (Scarlett and McKinney 2016). For example, Richter et al. (2003) offer a six-step framework for developing an ecologically sustainable water management program, in which human needs for water are met in a fashion that will sustain or restore the ecological integrity of affected river and watershed ecosystems. Development of an appropriate water management system also depends on understanding the natural variability of the water source (Landres et al. 1999; Keane et al. 2009). This understanding can guide the selection of management and restoration processes based on existing and desired conditions. Basically, management is guided by science and human values and theory. Ecological wisdom incorporates many of these ideas in "organizing" a guiding approach to watershed and riverine management for sustainable urban water resources.

I emphasize the importance of ecological wisdom to water resource management, but what do I consider ecological wisdom to be and how might it be used? It is both a philosophical construct and practical instrument. As shown in the model of ecological wisdom (Fig. 1) (modified from Patten 2016), it integrates knowledge from many sources into guidance for action. Rooted in aboriginal societies across the globe, in its simplest form it has played an important role in human–nature coevolution for thousands of years. Only in the late twentieth century has it been recognized in the realm of ecology. Knowledge used in the development and application of ecological wisdom is obtained from many sources, all shown as inputs in Fig. 1. Ecological wisdom, the integration of all these inputs, can then guide adaptive management or other management schemes which is then applied to restoration or management of ecosystems whether they are holistic ones composed of interactions between urban systems and natural systems which supply goods and services, or simpler systems such as natural watersheds or small rivers. These systems are considered simple only because they do not have any "hands-on"

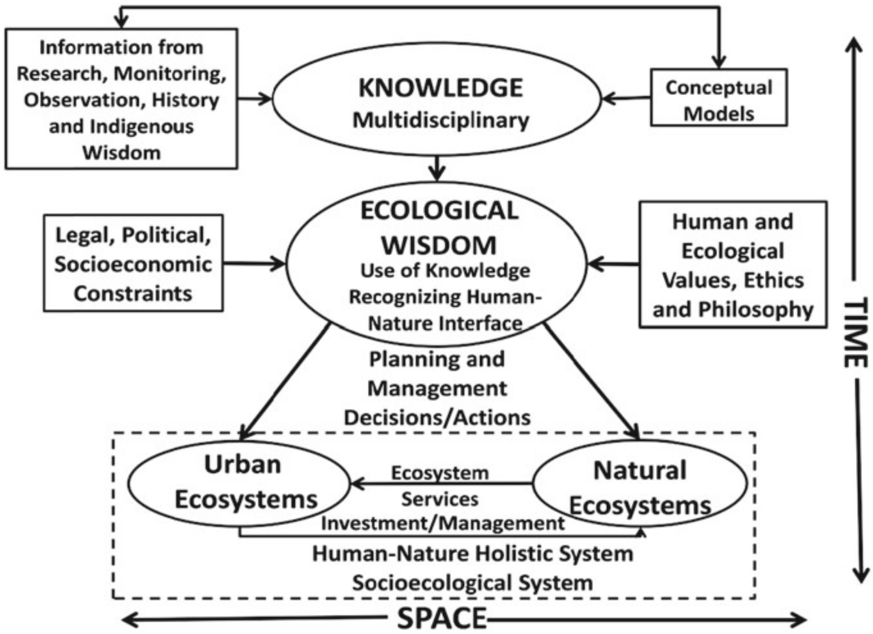

Fig. 1 A conceptual diagram of factors that influence ecological wisdom showing how ecological wisdom as an integrating centric process influences planning and management decisions that, in turn, determine the output of ecosystem services from natural ecosystems (e.g., watersheds) that sustain holistic socioecological systems. (Adapted from Patten 2016)

human influence with modifications. The outcome of these efforts can thus be cycled back as input to improving the guidance developed by ecological wisdom.

In the ecological wisdom-centric model (Fig. 1), two of the primary inputs to ecological wisdom are (1) information from research, monitoring, observation, etc., i.e., "ecological practical wisdom," and (2) human and ecological values, ethics, and philosophy, i.e., "ecological theoretical wisdom." These two concepts are fundamental to ecological wisdom as described by Xiang (2016), that is, ecophronesis or ecological practical wisdom, and ecosophy or ecological theoretical wisdom. In addition, the description of ecological wisdom above as a multifaceted process for decision making applied to complex systems is more complex than that used by Wang et al. (2016) who defined it for urban planning and design "as a means of knowing, understanding, and applying ecological information in order to guide urban planning and design professionals." They also explain that "ecological wisdom calls for knowing, understanding, and applying ecological information to enhance the quality of life." There are obvious overlaps between these definitions and use of the concept of ecological wisdom. Their applications of ecological wisdoms to planning are different from that used for watershed management; consequently, development of the definitions differs.

4 Using Ecological Wisdom in Watershed Management

Throughout the world, there is gaining recognition of the need to maintain or restore watersheds for sustainable water output. Using examples of watersheds and riverine systems that are sustainable and some that are not, the role of ecological wisdom through guiding management decisions demonstrates the importance of conservation and restoration processes in sustaining urban water sources. This is accomplished through holistic watershed management that sustains the processes that produce ecosystem goods and services.

Today, the concept of sustainability of a riverine system is an essential output of ecological wisdom and its use in river management as it not only assures production of water for human use but maintenance of an ecosystem that supports many other ecological processes and species. In this way, ecological wisdom can be a guiding process for adaptive management. Ecological wisdom, conceptually the backbone of adaptive management of resources, uses many input attributes such as goal setting, conceptual models, and legal constraints along with outputs from experimentation. Adaptive management as a process has been in practice for several decades, while recent thinking about ecological wisdom guiding adaptive management is quite recent. Adaptive management has helped guide management procedures toward outcomes better than earlier approaches that were based on resource demands rather than ecosystem functions. Although adaptive management is an important approach to management and/or restoration of riverine/watershed systems, the approach is incomplete. In "Restoration of Wetland and Riparian Systems: The Role of Science, Adaptive Management, History, and Values" (Patten 2006), I emphasize the role not only of science in management and restoration but of history (e.g., lessons learned) and values including human and ecological values, all inputs to ecological wisdom which is an overarching concept. Landres et al. (1999) have demonstrated how our values come into play when determining approaches to management and restoration. Using concepts from their paper, management and restoration goals and decisions may be based primarily on achieving riverine characteristics and processes that approach the "natural range of variability" for the system. However, they point out that goals and approaches may vary outside the natural range of variability based on human values, desires, and needs relative to a particular ecosystem. These are concepts important to ecological wisdom.

Examples of watershed management for urban use vary across the globe. Examples of large coastal urban areas that depend on properly managed interior watersheds and water conveyance systems for sustainable water resources include, for example, New York and Los Angeles in the USA; Shanghai, China; and Sydney, Australia. New York City and Los Angeles with quite different watersheds, and thus different management schemes, are used to illustrate the role of ecological wisdom in watershed management.

Managing an aggregation of water sources requires procedures for managing watersheds, rivers, reservoirs, aqueducts and canals, and distribution systems.

The process of adaptive management is inadequate for systems this complex with several watersheds and often several watershed owners and/or managers. Considering the concept "guidance through ecological wisdom," how might these large cities apply this concept to managing their complex watershed/river supply systems? To address this, water sources for the two urban areas in the USA described above, New York City and Los Angeles, are used as "test cases" of the application of ecological wisdom to watershed management. Together, these urban areas are representative of watersheds and water sources for other major urban areas across the globe. They also represent the two major types of water rights in practice in the USA, riparian rights found mostly in eastern USA which allows those owning land along the river to have reasonable use of the water flowing by the property, and prescribed water rights found mostly in western USA which is based on "first in use, first in right," that is, water rights to which legal title is acquired by long possession and use. To apply ecological wisdom to representative urban areas, features of the watershed systems and management activities for these urban areas are related to the major inputs to, and outputs of, ecological wisdom illustrated in the ecological wisdom model (Fig. 1).

5 Assessing New York City Watershed Management Based on Ecological Wisdom Principles

Sound watershed management goals of big cities are perhaps best described by New York City's Environmental Protection program which states that "watershed management reflects needs of all stakeholders including nine million urban users in several urban centers plus the diverse flora and fauna of the entire watershed ecosystem." New York City's water system is based on an extensive, highly managed set of watersheds well outside city limits (NRC 2000; Platt et al. 2000; Pires 2004). These include the Delaware System (watershed of the Delaware River), the Catskill System (watershed of the Catskill River), and a smaller watershed, the Croton System near the city. In the Catskill/Delaware watershed (ca. 1 million acres or 405 thousand hectares), New York City owns 6% of the land, 20% is owned by the state and maintained as a forest preserve, and the remainder (ca. 74%) is privately owned. New York City continues to spend $ millions to buy undeveloped land possessing features that are water quality sensitive (e.g., proximity to intakes, streams, and reservoirs). Certain parcels of land are exempted from outright purchase, but for these lands the city purchases conservation easements to prevent major development. Rivers in all these parcels flow to large reservoirs that release water through aqueducts to small reservoirs near the city and then through tunnels to the city. The mix of ownership requires the city to work closely with state and private landowners. Consequently, the first principle is that water managers should recognize the ownership complexity of the watersheds and that management requires inputs from those entities that influence the watershed, receive benefits from it, or understand its changing complexities. These points are critical components of inputs in the development of management schemes using ecological wisdom. Each represents an example of major inputs explained by Patten (2016). Some of these are inputs to a multidisciplinary knowledge base, some are socioeconomic or legal constraints, and some relate to human and ecological values.

The New York City's Department of Environmental Conservation which manages the watersheds describes the major components that guide its management philosophy. It lists these as follows:

Monitoring—The Division of Water gathers information on the health of the state's water bodies by monitoring and sampling.
Assessment—The Division of Water assesses water quality in all water bodies in New York.
Planning and management—The Division of Water develops water quality protection and restoration plans for many water bodies and watersheds in New York.
Implementation and permitting—The SPDES permit program is the primary way the Division of Water implements its water protection and restoration activities.
Compliance and enforcement—The Division of Water uses a variety of processes to ensure that permit requirements are met.
Watershed stewardship—Take action to help preserve and protect our water resources.

Using the department's description of their guiding elements, the fit of these into the major inputs used to guide ecological wisdom (Fig. 2) can show whether ecological wisdom can, or should, be the foundation of watershed management.

Monitoring is a critical source of data input to the multidisciplinary knowledge base necessary to the development of guidance coming from ecological wisdom. Assessment of water quality usually follows monitoring or is a component of it.

Planning and management are outcomes of a decision process that would flow from actions recommended by guidance coming from ecological wisdom. In the diagram (Fig. 2), management drives the interaction between natural and urban ecosystems. This interaction is determined, in part, by the implementation of a planning process, a component of NYC management philosophy.

Compliance and enforcement are forms of legal and socioeconomic constraints placed on the development of ecological wisdom. These do not necessarily limit the output of ecological wisdom but may put some "sideboards" on the output.

Watershed stewardship brings into play many of the human inputs so important to guidance coming from ecological wisdom. These may include human and ecological values as well as economic drivers. Stewardship also is a critical component of the foundation of ecological wisdom, that is, "use of knowledge recognizing the human–nature interface" (Fig. 1).

In conclusion, the philosophy used by New York City for managing its watersheds and water delivery system fits well into the concept of "guidance by ecological wisdom." However, ecological wisdom may often require more extensive information input or more interaction with humans and their history and values,

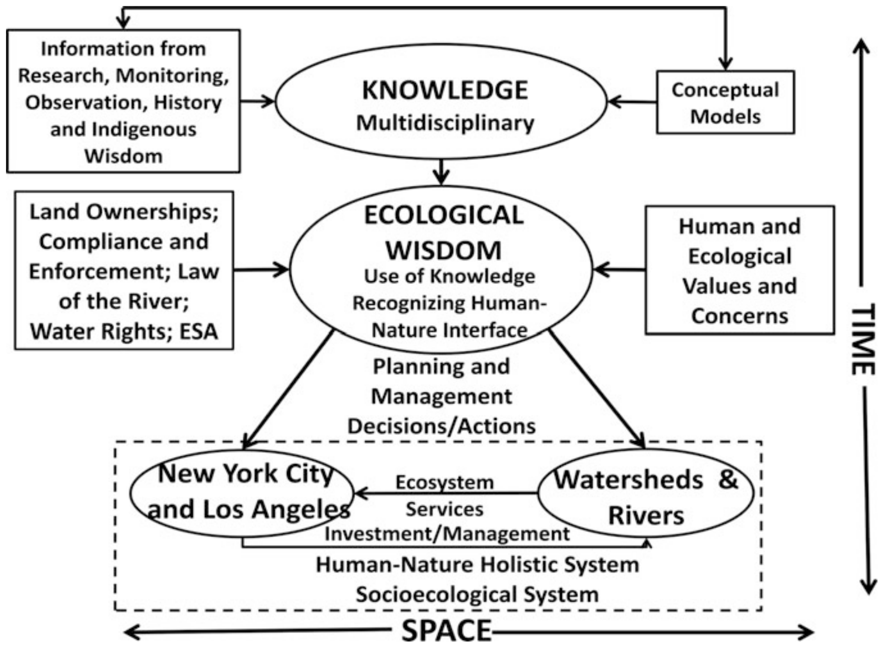

Fig. 2 Using the conceptual diagram from Fig. 1 and applying it to the examples of New York City and Los Angeles presents a complex set of inputs. Many of these inputs are found in Fig. 1 as inputs to ecological wisdom that guides management of the complex interactions between urban systems (i.e., NYC and LA) and natural systems (i.e., watersheds and rivers)

including indigenous wisdom. Based on the New York City example, it is uncertain whether modern watershed management for that city recognizes these.

6 Assessing the Los Angeles Watershed/Water Resources Management Approach Based upon Ecological Wisdom

The water sources and watersheds utilized by Los Angeles are much more complex than those utilized by New York City. Los Angeles is located in a semi-arid region of North America with limited local water inputs, while New York City is in a mesic or moist region with sufficient rainfall/snowfall on regional and local watersheds that it can depend on these for its water. Consequently, assessing the management processes for Los Angeles water sources and applying the “concepts of ecological wisdom” to those processes is much more complex than that for New York City. Although Los Angeles Department of Water and Power (LADWP) is the local supplier of water to the city, it manages only a part of the city’s water sources. It obtains much of its water from sources on both sides of the Sierra Nevada

Mountains managed by other entities. The Sierras runs north–south along the eastern side of California and catches storms coming off the Pacific Ocean. Consequently, management decisions and philosophies may differ among the water managers but eventually require a form of "network" governance mentioned earlier (Scarlett and McKinney 2016).

On the west side of the Sierras, watersheds in the north feed the Sacramento River, and watersheds in the central mountains feed the San Joaquin River. These rivers join and flow into San Francisco Bay. Some water from these rivers is shunted south to the Harvey Banks pumps that pump water uphill into the California Aqueduct, a system of canals, tunnels, and pipelines that convey water collected from the Sierra Nevada Mountains and valleys of northern and central California to southern California. The California Aqueduct, over 400-mile (640 km)-long, is the principal feature of the California State Water Project (SWP).

Water for Los Angeles also comes from the eastern side of the Sierras where the Owens River, fed by several tributaries, is shunted into the Los Angeles Aqueduct which carries water 419 mi (674 km) to the Los Angeles metropolitan area. This system is managed by the Los Angeles Department of Water and Power (LADWP) . This is the sole watershed complex managed by LADWP, perhaps better described as water source complex as the watersheds, mostly on public land, include watersheds that feed the upper Owens River on the east side of the Sierras and watersheds outside of the Owens River watershed, for example Mono Basin, that have been tapped to supplement the upper Owens.

In early years, the philosophy of LADWP was to take the water, including some groundwater in the Owens' valley, and send it to Los Angeles regardless of impacts on the local communities, farmers and ranches, or ecosystems such as Owens Lake (now Owens Dry Lake) and Mono Lake. That philosophy certainly does not fit into the ecological wisdom model (Fig. 1) which includes "human and ecological values" as important inputs to ecological wisdom. More recently, for several reasons including legal constraints, another input to ecological wisdom, LADWP, is using some of the water from the upper eastern Sierra watersheds to "restore" local ecosystems that have suffered as a result of the water withdrawal from that region. These include allowing water to flow into Mono Lake to maintain its water elevation and rewatering the Upper Owens River to restore that riverine ecosystem. Regardless of these efforts, LADWP continues to remove much of the surface water from the Upper Owens River and Mono Lake watersheds.

The agencies that manage the watersheds on the western side of the Sierras normally have greater natural inputs from snow and rain than on the eastern side and thus have "control" of much more water than LADWP has on the east side. Much of the control is through dams and diversions, although sufficient water is released downstream to supply needs of cities, including Los Angeles (i.e., LADWP's needs), as well as to maintain some semblance of natural riverine ecosystems. These western Sierra rivers have had extensive research and monitoring; thus, the knowledge base is extensive and can be a major input to the multidisciplinary knowledge needed as input to ecological wisdom (Gleick 1987; Knowles and Cayan 2004). These western Sierra rivers also have some legal constraints based on endangered species issues, again an important input to ecological wisdom. Modeling of these watersheds to understand their hydrology for future management decisions is also an important input to the ecological wisdom process (e.g., Knowles and Cayan 2002). Consequently, for planning and management of Sierra watersheds that supply water to Los Angeles, ecological wisdom could be the primary decision process.

The other major water source is the Colorado River delivered to the city by the Metropolitan Water District of Southern California (MWD) which manages the Colorado River Aqueduct. The Colorado River watershed is highly managed, studied, and modeled (Gleick and Chalecki 1999; BOR 1995). How ecological wisdom might have been the management procedure for operating the Glen Canyon Dam, an important dam on the Colorado River that controls the flows between the Upper Basin states and Lower Basin states, is explained by Patten (2016). The description and model diagram in that paper are hypothetical and do not apply to the Colorado River watershed as a whole. Perhaps, it could be expanded to include operations of more dams along the river and its tributaries (fourteen in total), but the philosophy of upstream agencies and human values of an extensive portion of the western USA (much of the Colorado River watershed) would have to be built into the ecological wisdom process that could guide management of the many tributary watersheds of the river. This is an extremely complex process and requires a well-organized network of governance, although the Bureau of Reclamation (BOR) which "manages" most of the Colorado River watershed would take leadership of any management decision-making process. One then must question whether such a large bureaucracy could embrace the concept of "guidance through ecological wisdom." This question might also be asked of LADWP, although, unlike BOR for the Colorado River, it does not have overall control of the rivers emanating from the Sierras and thus the outflows from those watersheds.

7 Discussion

The complexity of the two watershed examples is quite different. New York City has limited water sources/watersheds compared to Los Angeles. This difference is mostly driven by the climatic differences between the mesic eastern USA and the semi-arid western USA. Consequently, watershed management decisions affect fewer people and communities in the east than in the west. Regardless of the number of communities and watersheds that are included in the management decision process, they all have similar inputs of information and action. The complexity of these inputs, if ecological wisdom is used as the guiding decision-making process, is illustrated in Fig. 1. In comparing the two cities, comparison of the diverse inputs to the decision-making process is essential. Both systems require complex hydrological data based on research and monitoring at the watershed level. Both systems have some form of legal or socioeconomic constraints, and both systems consider human and ecological values. The difference between the systems is the complexity of each of these inputs. New York City has two primary watersheds that can be monitored and managed in a much more simple way than Los Angeles which is dependent on many watersheds spread out across the west and in two major mountain ranges, Sierras and Rocky Mountains. That alone makes the decision process for planning and management more difficult for Los Angeles.

What does not come forward in reviewing the management procedures used by New York City and Los Angeles is the complexity of the human aspect of the watersheds. New York City has two watersheds with a limited diversity of the citizenry due, in part, to smaller watersheds than those serving Los Angeles. On the other hand, the watersheds that are the sources of Los Angeles' water have a very diverse population base ranging from urban dwellers to farms and ranches, national parks, monuments and forests to Indian reservations. The cultural and ethnic diversity thus is much greater in the western watersheds than in eastern watersheds.

Because ecological wisdom as a decision process uses knowledge recognizing the interface between humans and nature, it must also include aspects of humanity that often management overlooks. These include qualities such as history of a watershed, wisdom of indigenous peoples if they are located in or near the watershed, and human values and ethics. In some form, most of these inputs are, or may be, considered in the watershed management process of both New York City and Los Angeles (Fig. 2). One of these more related to western watersheds is indigenous wisdom.

Many western watersheds encompass Indian reservations; this is especially true of the Colorado River watershed although there are several reservations in the California watersheds. Many of these are small compared to some in the Colorado River watershed although when Shasta Dam was constructed on the upper Sacramento River it inundated traditional Native American lands. Decisions on watershed management often do not include input from the reservations which are within that watershed. The age-old experiences and information of the various Indian tribes may be an invaluable input to how the watersheds have functioned over centuries. It is perhaps a longer set of information over time than any written history of the area. The need for this input to decision making is one reason that guidance of ecological wisdom in watershed management may be the most appropriate, if not the best, form of decision making.

One example of the use of indigenous wisdom in water management was the development of the rules for operating Glen Canyon Dam on the Colorado River (EIS). As part of data and information gathering to develop the Environmental Impact Statement (EIS) for dam operations, interviews with members of the various tribes whose reservations abutted the Colorado River were included. The concerns and "histories" offered by these tribal members were important in considering the effects of dam operations on reservation lands and tribal sacred sites. The importance of this input was illustrated in the discussion and figure in Patten (2016) where ecological wisdom was applied to Glen Canyon Dam management.

8 Conclusions

Ecological wisdom as used in this paper is an integrating process that uses extensive information as input to guide planning and management decision making. Using a description of ecological wisdom in planning by Wang et al. (2016) "as a means of knowing, understanding, and applying ecological information in order to guide urban planning and design professionals," one can apply this concept to watershed planning and management. The primary terms are "ecological information" which in essence is a composite of information relating to organisms (e.g., people) and their environment (all factors that influence people's livelihood and well-being). As such, it can play a useful role in management decisions for watersheds throughout the world. Watersheds are complex systems that require complex decision processes to guide how they are managed. Two examples of management of complex watersheds for large urban areas described in this paper show how ecological wisdom would be useful in the planning and management phases. Use of science and watershed modeling are obvious tools to include in management decisions, but other inputs often not considered such as human values, social constraints, and inputs from local citizens are critical to sound decision making. Ecological wisdom is a process that requires these inputs are part of the decision-making process leading to sound watershed planning and management outcomes. Consequently, although ecological wisdom may presently be recognized for urban planning and design, more direction needs to be given to those who make decisions on management of resources and their goods and services to consider the use of ecological wisdom in the decision-making process. If this can be accomplished, broader and wiser decisions may be made.

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Epilogue: Ecological Practice: Original Flaw, Wickedness, and the Beacon of Ecological Wisdom

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Ecological practice is the action and process that humans involuntarily engage themselves in with the aim to bring about a secure and harmonious socio-ecological condition that serves human beings' basic need for survival and flourishing. To achieve this goal, ecological practitioners, whether in planning, design, construction, restoration or management, must simultaneously attend to two distinct yet intertwining sets of relationships—the human-nature (ecological) relationship, and the human-human (social-economic-political) relationship within the human society. In doing so, ecological practitioners find themselves trapped in the messy swamps of *the original flaw* and *wickedness* in the jungle of socio-ecological systems where the ecological practice takes place.

The Original Flaw of Ecological Practice

The human-nature relationship ecological practitioners attend to is dominated by the extraordinary power of *nature's logic*. Irrational and opaque to human beings appears this logic in its own right. Not only does it operate in its own way that is entirely beyond human disposition, but it also makes sense in a deeper way that is often beyond human understanding (Laozi 2009, p. 46; Taleb 2012, pp. 348–349; Wang 2010, p. 325). As such, the unilateral dominance of nature's irrational and opaque logic in the human-nature relationship, according to American statistician and essayist Nassim Nicholas Taleb, prescribes peremptorily a concomitant feature of *original flaw* for human actions and science, which is best described in his 2012 book "Antifragile: Things that gain from disorder":

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> Just as there is a dichotomy in law: *innocent until proven guilty* as opposed to *guilty until proven innocent*… [in the human-nature relationship—the author] what Mother Nature does is rigorous until proven otherwise; what humans and science do is flawed until proven otherwise. (Taleb 2012, p. 349)

As one of "what humans and science do" that is subject to the dominance of nature's irrational and opaque logic, ecological practice is inevitably a recipient of the *original flaw* designation to its ontological identity. This prescribed designation can be stated as an inference from Taleb's proposition:

> Because "what humans and science do is flawed until proven otherwise", as one of "what humans and science do", ecological practice is also flawed until proven otherwise.

As a defining characteristic of ecological practice, *original flaw* is like the sword of Damocles hanging over ecological practitioners and the people they serve. It reminds everyone in ecological practice—practitioners, scholars, stakeholders, the public, and political leaders—to act prudently.

The Wickedness in Socio-Ecological Systems

The human-human (social-economical-political) relationship ecological practitioners involuntarily attend to is overwhelmingly contaminated by *wickedness* in socio-ecological systems where ecological practice takes place.

Wickedness refers to the ubiquity of wicked problems in socio-ecological systems (Xiang 2013, p. 2; 2016, p. 58). Wicked problems are a class of intractable and often unsolvable issues pertaining to the human-human relationship, whether it is by nature social, economic, or political. They may also be triggered by issues in the human-nature arena. These problems are wicked because they "are ill-formulated, [taking place in socio-ecological systems] where the [available] information is confusing, where there are many clients and decision makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing… [such that] proposed 'solutions' often turn out to be worse than the symptoms" (Churchman 1967, p. B-141, phrases are added by the author for contextual clarity). Collectively identified and articulated by American planning scholars Horst Rittel, Mel Webber, and West Churchman in the 1960s and 1970s (For a recent review on their seminal works, see Xiang 2013), wicked problems are widely recognized to be present in almost all pressing issue areas that matter to the human society today, including those that are directly related to ecological practice. These include, but are not limited to, issues pertaining to global climate change, sustainability, resource management, urbanization (Xiang 2013, p. 2), and the use of high technologies in environmental management [for example, the use of nanoparticles in groundwater remediation, Kysar (2006, p. 7)].

There are two distinct yet related characteristics of *wickedness* that are especially relevant to ecological practice. The first is what I call *the conservation law of wickedness* which states that *wickedness* (not necessarily individual wicked problems) co-exists with socio-ecological systems and co-evolves (Xiang 2013, p. 2).

Metaphorically speaking, the beast of *wickedness* will not extinguish but only change its appearance from one to another as the jungle of socio-ecological systems succeeds (*Ibid*.) The co-evolution part of the law highlights the second more pertinent characteristic of *wickedness*—"solutions-are-often-worse-than-the-symptoms" (Churchman 1967, p. B-141), and explains the abundance of *iatrogeneses* in ecological practice[1]—the plethora of mutated wicked problems induced by practitioners' actions to resolve existing wicked problems.

The Beacon of Ecological Wisdom

How can ecological practitioners be "muddling through" (Lindblom 1959) the messy swamps of *original flaw* and *wickedness* in their practice?

They evidently had a time-honored beacon already. *Ecological wisdom*, that is. This reverable human virtue inspired and guided generations of human ancestors throughout history to work effectively with the daunting social reality of *original flaw* and *wickedness*, and as showcased in this book series, contributed to many great achievements in ecological practice. Despite the unfortunate underappreciation it endures during the contemporary "crisis of science without wisdom" (Maxwell 2007, p. 99), once restored and illuminated, the beacon of ecological wisdom will shine again on the jungle of socio-ecological systems to guide ecological practitioners through the messy swamps.

Let the Beacon Shine, Again

To reactivate the beacon and make it shine again, an important task ecological practitioners and scholars in the EcoWISE enterprise need to undertake immediately is to "unearth the treasure of ecological wisdom", as the late American planning scholar Robert Young once said in 2014 at *the First International Symposium on Ecological Wisdom for Urban Sustainability* in Chongqing, China,[2] and echoed by many scholars from around the world (For example, Dubos 1973; Liao and Chan 2016; Wang et al. 2016; Wang and Xiang 2016; Xiang 2014). Integral to this task are the inquiries about *ecological wisdom principles*, the moral tenets for human action and scientific endeavor in ecological practice:

[1]In medicine, iatrogenisis (医源性疾病, in Chinese) refers to an illness or symptom induced inadvertently by a physician or surgeon or by medical treatment or diagnostic procedures. Etymologically the English word is from the Greek standing for a disease that is "brought forth by the healer". In the arena of social welfare, including ecological practice, it refers to a problem induced by the means of resolving a problem but ascribed to the continuing natural development of the problem being resolved. For more discussions, see Taleb 2012, pp. 110–133.

[2] A special ecological wisdom issue was developed by Xinhao Wang and Wei-Ning Xiang (Wang and Xiang 2016) on the basis of this symposium and published in the journal *Landscape and Urban Planning*, Volume 155, 2016.

What are the time-honored ecological wisdom principles in ecological practice? *How* are they kept up-to-date and effective in contemporary ecological practice?

More specifically, not only does this endeavor aim to revive ecological wisdom principles that had guided human ancestors through the messy swamps of *original flaw* and *wickedness*, but it also strives to keep these principles up-to-date and effective in the even messier modern-day ecological practice. With the rapid and massive increase in the human capability of "wrecking havoc" on the Earth (Maxwell 2007, p. 99), this task of unearthing ecological wisdom presents an exciting yet shrinking window of opportunity for ecological practitioners and scholars in the EcoWISE enterprise to make a difference in ecological practice. Actions, prudent but immediate, are therefore requested.

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