Chapter 1
Decision Science for Future Earth: A Conceptual Framework

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Abstract The purpose of this chapter is to review progress in our understanding of human behavior and decision-making relevant to future earth research agenda, and propose Decision Science as a hub of knowledge networks connecting disciplinary and interdisciplinary sciences with the practice of problem-solving. This review is composed of four sections. First, we describe the conceptual framework of "decision science for a sustainable society" and argue that evolutionary biology of the human nature is key to construct this framework. Second, we review how our group decision-making often fails due to various cognitive biases and argue that participatory approaches of co-design and co-production do not guarantee reasonable decision-making. Third, we review success stories of problem-solving in local communities and consider how we can connect those successes in local communities to successful national and global decision-making. Fourth, learning from both failures and successes, we argue that the adaptive learning of society is a process enabling us to transform our society toward a sustainable future. We review some positive global trends toward sustainability and consider the cognitive processes and behavioral mechanisms behind those trends that would provide clues for finding successful ways to transform our society.

Keywords Adaptive learning · Adaptive comanagement · Cognitive biases · Evolution · Social transformation · Trans-disciplinary science

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1 Introduction

Since the *Homo sapiens* started their migration from Africa to other continents around 60,000 years ago (Ingman et al. 2000), our population has continuously increased until now (Hawks et al. 2007). The increasing pressure on the environment has resulted in global environmental problems such as climate change, eutrophication, ocean acidification, and biodiversity loss (Diamond 2005; Rockström et al. 2009; Hoegh-Guldberg and Bruno 2010; Hooper et al. 2012). Considering evidence suggesting that mankind's growing influence on the environment may depart significantly from the natural behavior of the planetary environment, the term "Anthropocene" was proposed to characterize the present human-dominated geological epoch, following the Holocene (Crutzen 2002). In this Anthropocene, human communities are facing an array of challenges called Grand Challenges (Reid et al. 2010) that will have a serious influence on human well-being and the sustainability of the environment. Addressing these major challenges, an internationally coordinated research program, Future Earth, was launched in 2013 by integrating three environmental change research programs: IGBP, IHDP, and DIVERSITAS (Future Earth 2013; Leemans 2016). Subsequently, the Sustainable Development Goals (SDGs), including goals for ending poverty, protecting the planet, and ensuring prosperity for all people, were adopted at the UN Sustainable Development Summit in 2015 (UN 2015). Future Earth is expected to play a leading role in developing science to support the achievement of SDGs.

In its Initial Design document, Future Earth (2013) identified three highly aggregated research themes covering both natural and social sciences: dynamic planet, global development, and transition to global sustainability. The organization proposed new approaches to co-designing and co-producing solution-oriented science, knowledge, and innovation for global sustainable development. These proposals are based on the concept of transdisciplinary science that emphasizes the importance of co-design with stakeholders (Mauser et al. 2013). However, the development of the Future Earth research platform initially created many tensions between the interdisciplinary activities of earlier environmental change research programs and the leadership of the highly aggregated agenda, and the transdisciplinary approach of the Future Earth transition team, the funders, and the sponsors—including ICSU/ISSC (Leemans 2016). Those tensions were resolved by accepting all the previous projects of the global change programs under the three-themed research platform of Future Earth, but further efforts are needed to fill the gap between the researchers in the original international global change programs and the new transdisciplinary research agenda of Future Earth. In particular, the transdisciplinary research agenda remains highly conceptual, and the following key questions remain open for further exploration and discussion:

1. How can we successfully co-design our projects with various conflicts of interest?
2. How can we develop solution-oriented trans-disciplinary science by integrating natural and social sciences?
3. How can we transform our society for a sustainable future?

Here, we propose that Decision Science, an integrative science of human behavior and decision-making, is key to answering those questions, although it is not the only key, and other possibilities are of course worthy to be considered. Every social problem is a consequence of human behavior and decision-making. The need to consider human behavior and decision-making in the development of Future Earth is already identified in the Strategic Agenda 2014 (Future Earth 2014) in which 62 key research priorities are listed as a result of consultation processes with global environmental change research communities and stakeholders as well as an open online survey. Among those priorities, the following key questions on human behavior and decision-making are clearly addressed under the three-themed research framework of Future Earth.

- Dynamic planet: How can computational models of human individual and collective behavior be integrated into Earth system models of global environmental change? What new aspects need to be developed, combining neuroscience, psychology, anthropology, sociology, and economics? How do such models alter our understanding of future behaviors, risks, and trade-offs?
- Global development: What are the strengths and weaknesses of different decision-making approaches for balancing trade-offs inherent in socio-environmental systems from local to global scales? What are their impacts on the provision and regulation of ecosystem services?
- Transformation toward sustainability: What is the nature and role of narratives (particularly around development, futures, justice, risk and disasters, and conflicts) in driving human behavior and social change, including decision-making? In what ways might these narratives influence risk mitigation and inspire transformative action toward sustainability?

To answer those questions, we need to integrate various disciplinary perceptions of human behavior and decision-making including psychology, anthropology, economy, sociology, philosophy, and evolutionary biology. Recent efforts for this integration resulted in the publication of some seminal books, including Kahneman (2011), Pinker (2011), Haidt (2012), Greene (2013), and Henrich (2017), and many peer-reviewed papers reviewed in those books. However, this progress has been mostly neglected in the discussions to develop Future Earth since the proposal of the Grand Challenges (Reid et al. 2010).

The purpose of this chapter is to review progress in our understanding of human behavior and decision-making relevant to Future Earth research agenda, and propose Decision Science as a hub of knowledge networks connecting disciplinary and interdisciplinary sciences with the practice of problem-solving. This review is composed of four sections. First, we describe the conceptual framework of "decision science for a sustainable society" and argue that evolutionary biology of the human nature is key to construct this framework. Second, we review how our group decision-making often fails due to various cognitive biases and argue that participatory approaches of co-design and co-production do not guarantee reasonable decision-making. Based on this understanding of cognitive biases, we propose a guideline for co-design in transdisciplinary projects of Future Earth. Third, we review success stories of problem-solving in local communities and consider how we can connect those successes in local communities to successful national and global decision-making. Fourth, learning from both failures and successes, we argue that the adaptive learning of society is a process enabling us to transform our society toward a sustainable future. From a viewpoint of evolutionary biology, this process is analogous to the adaptive evolution of organisms and understanding this analogy provides a key to integrating natural and social sciences toward solution-oriented studies contributing to a sustainable society. We review some positive global trends toward sustainability and consider the cognitive processes and behavioral mechanisms behind those trends that would provide clues for finding successful ways to transform our society.

2 Conceptual Framework of Decision Science for a Sustainable Society

2.1 Science of IDEA Cycle, an Iterative Process of Decision-Making and Adaptive Learning

Decision-making is a process of linking scientific knowledge with solutions to social problems: disciplinary and interdisciplinary sciences such as environmental, disaster, health, and social sciences provide stakeholders with some knowledge-based options for solving a social problem whereas stakeholders must make a decision on a particular option to be prioritized and executed (Fig. 1.1). In this decision-making process, knowledge-based options are usually hypothetical because our knowledge on a particular social problem such as ecosystem deterioration is always associated with high level of complexity and uncertainty as well as conflicts of interest (Matsuda et al. 2005; Ravetz 2006). Thus, to determine which option is "better," we need efforts for building consensus or developing compromise among stakeholders through participatory approaches. This process of decision-making is influenced not only by objective knowledge but also by the subjective nature of human cognition that is often largely biased (Kahneman 2011). For managing this

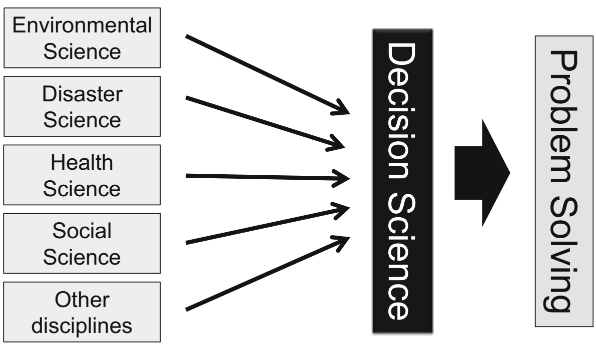

Fig. 1.1 A role of decision science, connecting between disciplinary and interdisciplinary sciences and problem-solving processes

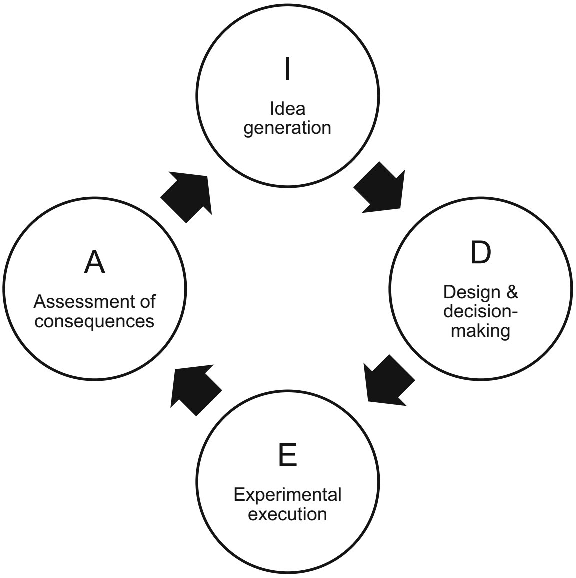

Fig. 1.2 A framework of IDEA cycle composed of four phases; idea generation (I), design and decision-making (D), experimental execution (E), and assessment of consequences (A)

decision-making process, we need to deepen our understanding of the human cognition systems behind various human behaviors that are designed as an outcome of evolution (Pinker 2011).

Future Earth is trying to fill the gap between science as the active knowledge producer and society as the passive recipient in the knowledge production process by promoting a process of co-design and co-production of knowledge (Mauser et al. 2013). We regard this participatory process as a cycle of idea generation (I), design and decision-making (D), experimental execution (E), and assessment of consequences (A) designated as the IDEA cycle (Fig. 1.2). Decision science for a sustainable society is trying to deepen our understanding of the IDEA cycle by considering how we can develop cooperation in each phase of the cycle.

"I" (Idea generation) is a phase where we generate various ideas by framing problems, understanding the system behind problems, developing hypotheses, and creating various options. Because many social problems remain unsolved by ordinary thoughts (Ravetz 2006), it is often crucial to discover overlooked ideas that may be effective for solving problems. Thus, the idea generation process with stakeholders needs not only scientific idea generation for solving problems but also so-called design thinking including consideration of the emotional content of the situation (Simon 1969; Brown and Kātz 2009). In science, an idea generation process to find the simplest and most likely hypothesis is called abduction (Peirce 1903) that is now a target of intensive studies in computer science (Magnani 2011) and cognitive science (Thagard 2014). While design thinking is widely used in business sectors (Brown and Kātz 2009), it is mostly neglected in scientist communities, including Future Earth; the unpublished thesis by Perderwitz (2017) may be the only exception. Integration of scientific and design thinking would be helpful in facilitating participatory processes of co-design and co-production.

"D" (Design and Decision-making) is a phase where we design and select a specific option from various options developed in the I phase. In scientific research, this phase corresponds to the process of designing experiments. In environmental policy-making, cost-benefit analyses have been widely used to find optimal decisions but as linkages of various problems have been recognized, many different categories of benefits and cost must be evaluated, such as health impacts, property damage, ecosystem service losses, and other welfare effects (Pearce et al. 2006). More recently, risk-benefit analyses have been developed and the importance of risk communication considering various cognitive biases to risks has been widely recognized (Fischhoff and Kadvany 2011). The conflicts due to different interests and different allowances of risks would be resolved under the process of Experimental execution and Assessment of consequences, stated below, if stakeholders could agree on a particular option. However, consensus building among stakeholders is a challenging process in many circumstances. To manage conflicts, it is important to allow many stakeholders to participate in the option design process.

"E" (Experimental execution) is a phase for executing the adopted option with the collaboration of various stakeholders. In this phase, maintaining cooperation of community members is essential for success. On the other hand, it is well known that cooperation in a large community is unstable due to the increase of non-cooperating members (Dunbar's number: Dunbar 1993). This problem has been noticed and categorized in different disciplines as the tragedy of the commons (Hardin 1968), collective action problem (Olson 1965; Sanders 1992), free-rider problem (Grossman and Hart 1980), and social dilemmas (Axelrod 1984; van Lange et al. 2013). How we can protect the commons and develop cooperation for a sustainable society by overcoming social dilemmas remains a big question of decision science.

"A" (Assessment of consequences) is a phase where we assess and learn from the consequences of Experimental execution that often result in unexpected and unfavorable results. Learning from assessments is a process associated with adaptive management (Holling 1978; Walters 1986; Gunderson and Holling 2002), an iterative process of decision-making now widely adopted in the management of natural resources and environments in the face of uncertainty. Through this process, we can accumulate knowledge and improve our capacity for solving problems by "learning by doing" (Borrini-Feyerabend et al. 2004) or "learning from doing" (Bell and Morse 2013). In this phase, it is important that we are constantly "adaptive" by assessing consequences and improving options under the changing conditions.

2.2 Relationship of the IDEA Cycle with Some Previous Concepts

The concept of the IDEA cycle is based on some preceding ideas. First, IDEA cycle is a modification of the PDCA or PDSA cycle widely used in the quality management initiatives of the mass production industry (Moen and Norman 2009) and healthcare (Taylor et al. 2013). The PDCA or PDSA cycle has its roots in Shewhart

(1939) who corresponded the three steps in the mass production process (specification, production, and inspection) to the steps in the scientific method (making a hypothesis, carrying out an experiment, and testing the hypothesis), respectively. Later, Deming (1950) added the fourth step of research and emphasized the importance of constant rotation of the cycle composed of design (Plan), production (Do), sales (Check), and research (Action), now called the PDCA cycle. Therefore, while the PDCA cycle was designed for quality control of mass production, the four steps correspond to the dynamic process of acquiring scientific knowledge. However, in the case of participatory or transdisciplinary processes for solving social problems, we need to clarify the decision context by defining what problem is being addressed, why it is important, and how it is related to other decisions previously made (the first step of the structured decision making; see Gregory et al. 2012). This process is corresponding to the review process in the scientific method and the Introduction part of the standard structure of scientific papers. In the three steps of the scientific method modeled by Shewhart (1939), this review process is lacking. In the IDEA cycle, this process is categorized as the I phase. Following this I phase, the D phase is placed in the IDEA cycle instead of the P phase of the PDCA cycle. This phase is named D (Design and Decision-making) in order to emphasize the importance of experimental design for a countermeasure to be implemented and group decision-making based on consensus building among various stakeholders. Following this D phase, the E (Experimental execution) phase is placed instead of the Do phase in the PDCA cycle. Here, experimental nature of this execution process is emphasized. The Check and Action phases of the PDCA cycle are merged into the A (Assessment) phase of the IDEA cycle. The four phases of the IDEA cycle can be related to Introduction, Material and Methods, Results, and Discussion in the standard structure of scientific papers.

Second, the IDEA cycle incorporates the idea of adaptive management developed independently of the PDCA cycle by Holling (1978). Adaptive management is an iterative approach to environmental impact assessment and management of ecosystems in the real world with many uncertainties, aiming at reducing uncertainty over time via repeated ecosystem monitoring. It is a learning process to improve management in the future by getting new knowledge through monitoring, while trying to achieve the best short-term outcome based on current knowledge. Holling et al. (2002) referred to an idea of transformational learning that involves several levels in the process of adaptive management, but did not use the term adaptive learning. The term adaptive learning has been used to describe artificial intelligence web-based educational systems (Brusilovsky 2003), but here we propose to use “adaptive learning” for describing iterative learning processes in general by including learning through adaptive management. Reed et al. (2006) used this term to describe a learning process in which participatory approaches and expert-led methods are integrated to develop sustainability assessment at local scales. The IDEA cycle as a whole can be viewed as a process of adaptive learning. This is a kind of selection process similar to the adaptive evolution of organisms (Ridley 2016) but the similarity and difference between adaptive learning and adaptive evolution remain to be clarified.

Third, the scheme of the IDEA cycle is partly similar to the conceptual model of transdisciplinary study developed by Lang et al. (2012) which includes a sequence of three phases: Phase A of problem framing and team building, Phase B of knowledge creation, and Phase C of integration and application. Those three phases correspond to co-design, co-production, and co-dissemination steps proposed for Future Earth (Mauser et al. 2013). However, neither conceptual models (Lang et al. 2012; Mauser et al. 2013) specify the decision-making phase. As is explained above, by adopting a particular option for further steps of experiment and learning ("learning from doing"), we select a particular option among some hopeful candidates. This is corresponding to a process of science in which scientists select a particular hypothesis to be tested and design experiments to test it. Because of the high uncertainty, it is often difficult to determine which hypothesis is most likely. In addition, the most preferable hypothesis (option) may differ among stakeholders due to differences of interests, values, and risk perceptions. Thus, decision-making should not solely rely on the optimization under cost-benefit tradeoffs but consider cognitive processes of various interests, values, and risk perceptions (Fischhoff and Kadvany 2011). This decision-making can be made only by building consensus or developing compromise under some trust among stakeholders. On the other hand, it is important to design the "experiments" well so that the hypothesis can be tested by the results or consequences (Barnerjee and Dufro 2011).

Fourth, the IDEA cycle is related to the idea of Structured Decision-Making (SDM; Gregory et al. 2012) in which the decision-making process under different interests is considered as a series of structured processes. SDM is a decision-structuring approach for public resource management under conflicts derived from multi-stakeholders with different perspectives. This difference impedes the technical analysis of the problem because the problem is often emotionally charged. Therefore, despite existing technical decision tools and theory, we often fail to dissect the problem and decide where to apply those tools, due to people's mental shortcuts, biases, or groupthink. To encourage focusing on facts rather than conflicts and controversies, SDM proposes a sequence of collective thinking realized by six processes: (1) Clarifying the decision context, (2) Defining objectives and evaluation criteria, (3) Developing alternatives, (4) Estimating consequences, (5) Evaluating trade-offs, and (6) Implementation and monitoring. In SDM, it is recommended to focus on understanding objectives, measures, uncertainty, and ranges of alternatives by avoiding weighing the alternatives and pursuing consensus, which may cause unnecessary conflicts among stakeholders with different values. The agreed-upon objectives and measures constitute evaluation criteria and methods that form a framework for comparing alternatives. After setting the framework, searching and developing creative alternatives by participants will be critical to problem solving by deepening participants' understanding about objectives and constraints to the objectives. Open dialogues about the trade-offs can contribute to deriving negotiable points by clarifying agreed and disagreed points among stakeholders. SDM also incorporates the adaptive management approach in the Implementation and monitoring phase where it is expected that local people can establish skills in monitoring, just as in the A phase of the IDEA cycle.

SDM provides a practical guide to build a common understanding under trust and partnership among stakeholders so that decision-making on agreeable alternatives can be negotiated. This SDM approach has been successfully applied to the

Table 1.1 Comparison of five models for decision-making processes

IDEA cycle	Adaptive management	PDCA cycle	Future earth	SDM
Set-up	Set-up			Problems, objectives
Idea generation				Alternatives
Design and decision	Decision making	Plan	Co-design	Consequences, trade-offs, optimization and decision
Experimental action	Monitoring	Do	Co-production	Action
Assessment	Assessment	Check, action	Co-dissemination	

management of environmental problems spanning water use planning, air quality, climate change, wildfire risks, parks and recreation, fish and wildlife harvest, and oil and gas development by assisting stakeholders in constructing their own solutions (Gregory et al. 2012). Despite these successes, SDM has some shortcomings relating to its applicability. As shown by the multiple processes, participants should commit to each process implementation that may be technically intensive, although the knowledge itself is provided by initially organized technical working groups and expert panels. In addition to considerable efforts for understanding technical issues, participants should enjoy long discussions to achieve agreements on objectives and measures, which should be demanding on the participants. How we can maintain the cooperation of participants over this long process of SDM remains a question to be considered in further studies.

Among the five models of decision-making processes (Table 1.1), IDEA cycle identifies the first step as a process reviewing the backgrounds of a problem and developing various ideas for its solution. This process is corresponding to processes (1)–(3) in SDM, where the context behind a problem is reviewed, objectives of a problem solving are discussed, and alternative options are developed. This review process is not specified in PDCA cycle, adaptive management cycle, and the three-stage model of Future Earth.

As is summarized above, the three-stage model of transdisciplinary science in Future Earth is one of the few ideas for facilitating the collaboration of scientists and stakeholders toward social problem solving. Compared with other ideas, this model has some shortcomings, given the complexity of decision-making processes under social conflicts, difficulty of cooperation under social dilemmas, and the importance of adaptive management and learning to reduce uncertainty and find better options. The IDEA cycle helps recognize those issues by incorporating ideas developed by previous studies including adaptive management (Holling 1978) and structured decision-making (Gregory et al. 2012) into a simple, four-phase framework.

More specifically, the IDEA cycle helps to identify the following key questions in decision science for a sustainable society. How can we integrate scientific and design thinking in the idea generation phase? How can we build consensus on a particular option to be adopted (or a hypothesis to be tested)? How can we organize and maintain cooperation through experimental executions under social dilemmas? How can we improve our capacity for solving problems through adaptive learning? All of those questions are related to human cognition, decision-making, and behavior that are at least partly genetically determined as a consequence of evolution from our ancestors to modern humans. Thus, understanding human nature from the viewpoint of evolutionary biology provides a fundamental base of decision science for a sustainable society. This viewpoint is explained in further detail in the following section.

2.3 Evolutionary Theory as a Basis of Decision Science for a Sustainable Society

Future Earth is aiming at developing research to better understand changing "social-ecological systems" (Berkes and Folke 1998; Gunderson and Holling 2002; Folke et al. 2005) by integrating different disciplines from the natural and social sciences, engineering, and humanities (Future Earth 2013). However, achievements of previous efforts for this integration are not fully reviewed in the design process of Future Earth. Here, we briefly review that an integration of natural and social sciences and humanities has been successfully developed by using evolutionary theory as a universal integrator, or "universal acid" (Dennett 1995), and this integration is relevant to sustainability science. Dennett (1995) called Darwin's theory of evolution by natural selection "Darwin's dangerous idea" in that it "eats through every other explanation for life, mind and culture." This vision of the integration of natural and social sciences goes back to the proposal of Sociobiology (Wilson 1975). Although this proposal triggered a strong controversy (Segerstrale 2000), social scientists and humanity researchers gradually accepted evolutionary theory and developed new disciplines of human cognition and behavior including evolutionary psychology (Barkow et al. 1995; Dunbar et al. 2005; Dunbar 2014; Buss 2014) and behavioral economics (Kahneman 2003, 2011). Further, as was predicted by Dennett, evolutionary theory has been incorporated into studies of almost all aspects of human life, including institutions (North 2005), morality (Haidt 2007, 2012; Greene 2013), politics (Heath 2014), and human history in relation to the environment (Diamond 2005), violence (Pinker 2011) and many other aspects of our society (Pinker 2018; Ridley 2016). Consequently, many themes of social science and humanity research are now at least partially integrated with the rapid advance in natural science on human nature, including human genome research and neuroscience. Those integrations provide many innovative understandings of human behavior and decision-making that are relevant to sustainability science.

First, there is increasing evidence that human populations are genetically variable in political attitudes, moral foundations, personalities, and cognitive ability, all of which can influence human behavior and decision-making. The dichotomy of cooperation and confrontation in human societies may result partly from this variability. Genetic variation in political attitudes (e.g., conservative vs. liberal) is now well documented (Bouchard et al. 2003; Gerber et al. 2010; Hatemi et al. 2011; Oskarsson et al. 2015) and the heritability of various traits associated with political attitudes is 30-60% (Hatemi and McDermott 2012). This variation of political attitudes is associated with difference in moral beliefs among people (Haidt 2012). According to the moral foundation theory (Haidt 2007; Graham et al. 2013), human morality is derived from multiple innate mental systems called moral foundations including care, fairness, loyalty, authority, and sanctity, each shaped by a different evolutionary process. Graham et al. (2013) suggested that care foundation is advantageous for parents to protect their own child, fairness foundation is advantageous for an individual to develop cooperation with one's own direct interaction partners in non-zero-sum exchanges, like trades, loyalty foundation is shaped up by intergroup competitions, authority foundation is shaped up by dominance hierarchies, and sanctity foundation is derived from the emotion of disgust that evolved to avoid risks from pathogens and parasites. Haidt and Graham (2007) and Graham et al. (2009) showed that more conservative people have moral intuitions with more emphases on loyalty, authority, and sanctity foundations and less emphases on care and fairness foundations than more liberal people. Gerber et al. (2010) showed that political attitudes vary with openness, one of Big Five personality traits associated with creativity and intelligence and more liberal people tend to have higher openness. Further, Oskarsson et al. (2015) showed that political attitudes vary with cognitive ability and suggested cognitive ability is a causal mechanism linking genes and political attitudes. Both openness and cognitive ability are highly heritable (Bouchard and McGue 2003). These findings suggest that we are genetically different in attitudes to various social issues and thus for transforming our society toward sustainability, we need to develop social environments that facilitate cooperation among people with different moral beliefs.

Second, our species is highly cooperative, violating the standard economic assumption that everyone in the economy is rational and selfish (Bowles and Gintis 2011). Theoretical and experimental research has been accumulated to understand how humans can continue to work together to overcome the temptation to exploit other people's efforts (Yamagishi 1986; Sigmund et al. 2001; Fowler 2005; Henrich 2006; Rockenbach and Milinski 2006; Egas and Riedl 2008; Boyd et al. 2010). This cooperative nature is widely observed in not only modern societies but also hunter-gather societies where band-level cooperation on sharing a large game is maintained under strong consensus about holding down dominant behaviors (Boehm 2008, 2012). Boehm (2008) suggested that this "egalitarian syndrome" is considered to be a consequence of natural selection on the self-monitoring and self-controlling capacities to avoid punishments from the society (bond) when breaking the rules that was shared and internalized by language. Whereas the details of selection pressure on human cooperation remain controversial (Bowles and Gintis 2011), strategies such as direct/indirect reciprocity, retaliation, and reputational considerations are hopeful mechanisms for maintaining cooperation among individuals. Although cooperation incurs significant cost to individuals, if people live in small groups, interact repeatedly, distinguish each other, and expect like treatment from others, then cooperation can evolve with the help of these mechanisms (Nakamaru and Iwasa 2006; Sigmund 2007; Puttermann et al. 2011; Guala 2012; Iwasa and Lee 2013). Under these mechanisms, ingroup favoritism or empathy within the group can also evolve because discrimination of ingroup members from outsiders can promote cooperation by allowing a person to interact with more reliable co-players. While ingroup favoritism or empathy within the group provides a basis of cooperation in a community, it also causes conflicts among communities. To solve various social problems, we need to develop some agreement or meta-morality to avoid conflicts among groups or "them" and develop cooperation in a larger community or "us" (Greene 2013).

Third, our decision-making based on a moral foundation is intuitive and driven by a cognitive system called System 1 (Haidt 2012; Greene 2013). According to Kahneman (2011), human cognitive systems are composed of System 1: responsible for intuitive decision; and System 2: responsible for rational decision. This dual-process model was first proposed by Evans (1989) and has been supported by subsequent psychological studies (see Evans 2008; Evans and Stanovich 2013), and also by brain research (Brewer et al. 2011; Brewer 2017). This is, of course, a much-simplified model of highly complicated systems but useful to understanding many cognitive biases inherent in System 1. While System 1 is always operating to instantaneously respond to information continuously inputted from external environments to the brain, System 2 is driven by sending a particular task to the brain by paying attention. System 2 is a costly process consuming much sugar in the brain and paying attention means paying a biochemical cost. Thus, our brain tends to make decision-making by System 1 unless careful thinking using System 2 is required by alarming signals or social requests. System 1 is considered to have evolved as an adaptation to minimize the cost of responding to various external signals. Therefore, System 1 is usually effective in our ordinary life, but it has many cognitive biases that often cause serious mistakes in decision-making (Kahneman 2011). For example, once a person accepts a belief or hypothesis, System 1 seeks and accepts evidence supporting the accepted belief or hypothesis and avoids thinking well using System 2 by paying attention to inconvenient evidence. Even scientists are not free from this trend, known as confirmation bias (Nickerson 1998), and thus they often claim conflicting views on social issues, accelerating social confrontation. Those cognitive biases discovered by psychologists demonstrated the background of the limitation of our rationality (boundary rationality, Simon 1947). As such cognitive bias became widely known, the difficulty of rational problem-solving has been emphasized by distinguished scholars thinking about the transformation of our societies (Haidt 2012; Greene 2013; Heath 2014). In the co-design process of transdisciplinary research in Future Earth, we should carefully avoid failures from those cognitive biases. This issue is considered in detail in the next section.

3 Learning from Failures and Guidelines for Co-design

3.1 Vulnerability of Group Decision-Making

Future Earth emphasizes the importance of co-design with various stakeholders (Mauser et al. 2013), but group decision-making, including co-designs between scientists and stakeholders, does not necessarily result in successful outcomes (Janis 1972, 1982; Kerr and Tindale 2004; Brodbeck et al. 2007). Co-design by scientists, government, and the private sector is a process that has been widely pursued in Japan and successfully supported the high economic growth since the 1950s. However, decision makings based on co-design by scientists, government, and the private sector resulted in some big accidents including the Fukushima nuclear power plant disaster (Aoki and Rothwell 2013; Labib and Harris 2015). According to Labib and Harris (2015), the likelihood of a serious accident was foreseen, but design shortcomings were neither investigated nor addressed. To avoid such a failure in the co-design process, we need to understand how group decision-making can fail in general. It is well known in social psychology that group decision-making often fails due to various cognitive biases (Kahneman 2011; Lu et al. 2012; Montibeller and von Winterfeldt 2015). In this section, we first review our current understanding of vulnerabilities and cognitive biases associated with group decision-making. Second, we consider how we can deal with those vulnerabilities and cognitive biases and propose guidelines for avoiding co-design failures in transdisciplinary projects.

Janis (1972) coined the term "groupthink" to describe the failure of group decision-making based on a comparative analysis of high- and low-quality decisions made by policy-making groups during six historical events in the United States. He found that some of the historic fiascos were the result of faulty decision-making by groups dominated by concurrence-seeking behavior, which refers to the tendency of group members to avoid controversy and reach a consensus decision without a critical evaluation of alternative viewpoints. Janis (1982) concluded that "groupthink," which he defined as "a mode of thinking that people engage in when they are deeply involved in a cohesive ingroup, when the members' strivings for unanimity override their motivation to realistically appraise alternative courses of action," often resulted in a tragic outcome. Janis (1982) identified the following three major antecedent conditions that make a group vulnerable to "groupthink": cohesiveness of a group, structural fault like homogeneity of members' background, and context like high stress and low self-esteem. Further, he identified three major symptoms of "groupthink," including overestimation of the group, closed-mindedness, and pressures toward uniformity, while seven symptoms of defective decision-making lowered the probability of successful outcomes, including incomplete survey of alternatives and failure to work out contingency plans. Janis's "groupthink" model is described in many social psychology textbooks even though empirical tests do not always support the relationship between the antecedent conditions and symptoms (Baron 2005; Rose 2011). Baron (2005) argued that "we are familiar with groupthink symptoms and processes because the concurrence seeking, illusion of consensus, self-censorship and ingroup defensiveness described by Janis are far more widespread phenomena than he envisioned."

While the concept of "groupthink" is a heuristic approach to evaluate the quality of policymaking, some critiques of the model have appeared since the early 1980s (McCauley 1989). First, Longley and Pruitt (1980) criticized that the "groupthink" theory is not a logical progression of ideas, but a grab-bag of phenomena that were correlated with each other in sampled cases. Second, Hart (1991) criticized that some cases of policy failure were chosen first, and then "groupthink" analysis was applied to see whether the decision process was affected by it. This methodology is biased toward selective interpretation of the case study material. Baron (2005) and Rose (2011) have reviewed other critiques as well as evidence supporting or dismissing the "groupthink" model. As is summarized by Baron (2005), Janis (1972, 1982) assumed that strong group cohesion is likely to induce "groupthink" when supported by some secondary conditions, such as insulation of the group, directive leadership, lack of fair group norms, and homogeneity of member attitude or ideology. However, it remains uncertain how primary and secondary conditions influence outcomes of group decision-making.

As far as we know, the mathematical model of Furuta and Kondo (1992) is the only available tool for analyzing the influence of group cohesion and secondary conditions on outcomes of group decision-making. In their "group reliability analysis," they developed a mathematical model describing the success probability (the probability of correct judgment by a group) as a sigmoid function of the judgment ability of each member and the influence from other members (strength of group coherence). They found that the success probability generally increases with the strength of group coherence, but decreases above an optimal level of group coherence if group members are isolated from outside information and criticism by sharing a common attitude or if a group contains members with insufficient judgment ability. This study theoretically supported the idea of Janis (1972, 1982) that group cohesion can evoke the failure of "groupthink" when supported by some secondary conditions (particularly, the insulation of the group). It is notable that the model of Furuta and Kondo (1992) was developed in the Department of Nuclear Engineering, with the goal of improving group performance and safety in the nuclear power sector. This indicates that Japanese scientists involved in the nuclear power sector were aware of the susceptibility to "groupthink," but this knowledge was not successfully utilized to improve nuclear power policy.

Some research topics related to the "groupthink" model have been studied rather independently. First, the hidden profile paradigm (Stasser and Titus 1985; Stasser 1988) directed a surge of research on the failure of group decision-making due to people's tendency to discuss and incorporate shared (known to all members) information rather than unshared (known to a single member) information (Wittenbaum et al. 2004; Brodbeck et al. 2007; Lu et al. 2012; Sohrab et al. 2015). This hidden profile paradigm provides a demonstration of the concurrence-seeking tendency specified by Janis (Baron 2005). Second, group polarization (Myers and Lamm 1976; Sustain 2002), a phenomenon where a group tends to make decisions that are more extreme than the initial preference of its members, has been extensively studied by social psychologists. This phenomenon occurs because the tendency to conform is so strong in our society that group members adjust their judgments to the dominant one even if it requires them to abandon the direct evidence of their own senses (Sustain 2002). Third is pluralistic ignorance, a phenomenon where all members in a group tend to reject a norm privately, but finally accept it because everyone incorrectly assumes that the other members are agreeable to it (Katz and Allport 1931). A classic example of this phenomenon can be seen in "The Emperor's New Clothes," a well-known fairy tale written by Hans Christian Andersen. Pluralistic ignorance has been demonstrated by organizational studies in various social contexts (Halbesleben and Buckley 2004; Miyajima and Yamaguchi 2017). Even though members individually disapprove of the status quo or have a better plan, the group finally makes a decision without anybody's real support. Fourth, various cognitive biases in individual decision-making have been extensively studied (Kahneman 2011; Montibeller and von Winterfeldt 2015). Those cognitive biases influence group decision-making tendencies, including concurrence-seeking and group polarization. Watkins and Bazerman (2003) argued that cognitive biases are one of the main causes of organizational failure to prevent predictable crises like the accident at the Fukushima nuclear power plant. In the next section, we consider the argument of Watkins and Bazerman (2003) and review how cognitive biases cause group decision-making to fail.

3.2 Predictable Surprise

Watkins and Bazerman (2003) coined the term "predictable surprise" to describe the failure to prevent predictable crises. To distinguish unavoidable surprise from predictable surprise, they developed the so-called "RPM process" composed of recognition, prioritization, and mobilization. If the leader fails to recognize the threat, prioritize appropriate options to mitigate the threat, or mobilize effective responses to the threat, the resultant failure is a predictable surprise. They analyzed various cases where leaders and organizations failed to take effective measures against foreseeable crises, and identified psychological, organizational, and political vulnerabilities that were behind such failures (Watkins and Bazerman 2003; Bazerman and Watkins 2004). Among them, psychological vulnerabilities are associated with various cognitive biases of System 1 (Kahneman 2011).

While more than 180 cognitive biases have been proposed (Manoogian 2016; Ellis 2018), there is no widely accepted classification of those biases. Here we adopt the Haselton et al.'s (2015) three-way classification of heuristics, error management biases, and artifacts because it is based on an evolutionary understanding of the human cognitive systems. According to Haselton et al. (2015), heuristics and error management biases are consequences of adaptive evolution, whereas artifacts arise when we encounter situations that are not adapted in the process of evolution. Among those three categories, heuristics and error management biases are relevant

Table 1.2 Psychological vulnerabilities listed by Watkins and Bazerman (2003) and evolutionary classification of cognitive biases

Classification based on EMT	Terms in predictable surprise (Watkins and Bazerman 2003)	Synonyms and relevant theory
Heuristics	Vividness –Greater exposure to media coverage distorts people's judgment	Availability heuristic
	Scanning failure (selective attention) – Selective attention occurs when decision makers dismiss or ignore information that is inconsistent with their expectations	Confirmation bias
Error management: threat-relevant bias	Positive illusion (Unrealistic optimism about the future) and Excessive disregard for the future – People's tendency to prefer present benefit over future benefit – Would you prefer to receive $10,000 today or $12,000 a year from now? – Most homeowners fail to buy more expensive, energy-efficient appliances even though they would recoup the extra costs in less than a year	Normalcy bias, time inconsistency, present bias, prospect theory
	Maintain the status quo – People's tendency to hesitate over trade-offs that require the infliction of a smaller harm to avoid a situation that would cause greater harm	Status quo bias, omission bias, prospect theory
Error management: biases in interpersonal perception	Interpret events in an egocentric manner (egocentrism) – Our views on environmental and societal issues, such as acid rain and global warming, are biased in a self-serving manner – Difficulty in the fair distribution of responsibilities and costs for global environmental issues	Self-serving bias, Ingroup favoritism
Error management: biases in self-judgment	Positive illusion (unrealistically positive self-evaluations) – People's tendency to overestimate their achievements and underestimate their negligence	Self-enhancement, better-than-average effect, reduction of cognitive dissonance
	Positive illusion (illusion of control) – Experienced dice players believe that "soft" throws are more likely to result in lower numbers	Self-deception

to psychological vulnerabilities discussed by Watkins and Bazerman (2003) (Table 1.2).

3.2.1 Heuristics

Heuristics, often called mental shortcuts, are a limited number of rules by which people can reduce the complex tasks of assessing likelihoods and predicting values into simpler judgmental operations (Tversky and Kahneman 1974). Because these rules work well in many situations, cognitive systems rely on heuristics to solve adaptive problems to reduce the cost of decision-making (Gigerenzer 2007; Gigerenzer and Gaissmaier 2011; Haselton et al. 2015). However, these rules often lead to systematic errors of decisions. Tversky and Kahneman (1974) argued that three heuristics underlie a wide range of false intuitive decisions: representativeness, availability, and anchoring.

In the representativeness heuristics, people estimate the likelihood of a person pursuing a particular occupation based on the degree to which he or she is representative of, or similar to, the stereotype of an occupational role. Using the representativeness heuristics, we tend to assume that a doctor in charge of emergency surgery is a man, not a woman. In the availability heuristics (Tversky and Kahneman 1973), people assess the probability of an event by the ease with which instances could be brought to mind. Using availability heuristics, people find it easier to recall bad pieces of news, and consequently tend to believe that the world is getting worse. Also, the availability heuristic makes people underestimate unfamiliar events. Anchoring is a phenomenon where different starting points lead to different estimates, which are biased toward the initial values that people assume at the starting point.

These heuristics are associated with confirmation bias (Wason 1960), or the tendency of people to seek information that matches their expectations and to fail to detect new crises, even when information that contradicts expectations is available. Confirmation bias emanates from a cognitive shortcut or heuristic that simplifies complex inferential tasks (MacCoun 1998). Watkins and Bazerman (2003) described this situation as “scanning failures,” which they argued occur when organizations focus on familiar information and fail to collect available information. In the case of the 9/11 attacks in the United States, there was a widespread belief among the domestic intelligence community that Osama bin Laden was unlikely to strike within the country and likely to attack an overseas facility of the United States, even though available information indicated the threat of attack on an internal facility (Watkins and Bazerman 2003).

3.2.2 Error Management Biases

According to the error management theory (EMT) (Haselton and Buss 2000; Haselton and Nettle 2006), which applies the principles of signal detection theory for the evolution of cognitive biases, error management biases can arise as a consequence of evolutionary adaptation in cases where biased responses resulted in lower error costs than unbiased responses. According to EMT, the cognitive mechanism can produce two types of errors: (1) false positives (an error caused by taking an action that would have been better not to take), and (2) false negatives (an error caused by not taking an action that would have been better to take). EMT predicts that an optimal decision would minimize not the total costs of false-positive errors and false-negative errors, but the net effect of errors on fitness. If one error consistently reduces fitness more than another error, a bias will evolve toward avoiding the former error. Haselton and Nettle (2006) explained this asymmetry by means of an example of an animal detecting a snake. For that animal, the cost of expected death by approaching a potentially venomous snake is much larger than the cost of moving away from the snake. Thus, it is advantageous to acquire a predator avoidance strategy for snakes. In fact, it is well known that many animals, including humans, are predisposed to produce a fear response to snakes and spiders (Shibasaki and Kawai 2009; Hoehl et al. 2017).

Taylor and Brown (1988, 1994) reviewed psychological research associated with mental health, and determined that people hold positive illusions in three domains: (1) people view themselves in unrealistically positive terms, (2) people believe they have greater control over environmental events than they actually have, and (3) people hold views of the future that are brighter than base-rate data can justify. Positive illusions include previous psychological findings such as better-than-average effect (Festinger 1954), optimism bias (Weinstein 1980), self-deception (Gur and Sackeim 1979), self-enhancement (Shrauger 1975), and illusion of control (Langer 1975). EMT explains that positive illusions are caused by the asymmetrical costs between a false-positive error and a false negative toward a future success. If a future victory provides a splendid reward, trying and failing (false positive) does not matter, whereas failing to try (false negative) could be costly, especially in competitive contexts (Haselton et al. 2015). Positive illusions drive organizational leaders to ignore the risk of crises and make poor decisions as they respond to emerging crises with mildly distorted positive perceptions of themselves, an exaggerated sense of personal control, and overly optimistic expectations about the future (Taylor and Brown 1988; Taylor and Armor 1996).

In addition to positive illusions, EMT also explains status quo bias, or the tendency of "doing nothing or maintaining one's current or previous decision" (Samuelson and Zeckhauser 1988; Ritov and Baron 1992). This is the tendency to avoid trying an action that may fail (false negative) when the cost of trying and failing (false positive) is larger than the expected benefit of trying. Status quo bias makes organizational leaders or organizations stick to a current option or default situation if they believe that changing the current state of affairs would be costly, even when a rational alternative is available. Normalcy bias (Omer and Alon 1994) is another type of error management bias causing false-negative errors. It is the tendency of people to underestimate the likelihood of and damage from a catastrophe even in the face of signs of the disaster. They consequently believe that it would not affect them and that they are safe, while hesitating to evacuate even after the occurrence of the disaster. It is one of the main causes of the cognitive failure to detect a predictable surprise. For people in an emergency situation, such as rising floodwater levels around their house, failing to traverse a submerged area (false positive) seems much more costly than failing to evacuate by staying at home (false negative).

Failures of group decision-making are caused by not only personal cognitive biases, but also structural faults of organization and errors resulting from group dynamics. Watkins and Bazerman (2003) listed four types of organizational failures to respond to predictable crises. First, "scanning failures" occur when a group fails to scan the environment and collect sufficient information, due to the lack of organizational resources or inadequate attention toward predictable crises. Second, even if a group succeeds in collecting sufficient information, "integration failures" occur when it fails to assimilate fragmentary information possessed by individuals or subgroups and to analyze that information to produce actionable insights. Third, "incentive failures" occur when people fail to act on available insights for predictable crises because they lack the incentive to do so. Fourth, "learning failures" occur when a group fails to glean lessons from past failures and disseminate those lessons to a relevant part of the group.

In the process of co-design and co-production in transdisciplinary research with various stakeholders, we should make efforts for avoiding these failures. Many of these failures are associated with the vulnerabilities of group decision-making, such as groupthink, hidden profile paradigm, group polarization, and pluralistic ignorance, as we reviewed above. However, decision support schemes, such as IDEA cycle and SDM, do not focus on the impact of cognitive biases and group dynamics on the outcome of decisions. In the next section, we consider the guidelines to deal with these vulnerabilities.

3.3 Guidelines for Co-design Among Stakeholders

Reducing or eliminating cognitive biases from decision-making, called debiasing, is a process that is crucial for ensuring successful group decision-making in co-design involving multiple stakeholders. In his influential textbook, Fischhoff (1982) pointed out that the debiasing process requires a psychological approach to change human behavior. Following a more recent review (Larrick 2004), Bazerman and Moore (2008) recognized psychological barriers to change human behavior and suggested a general debiasing strategy by applying the Lewin's change model (Lewin 1947) to debiasing processes. The Lewin's change model is a three-step model of human behavioral changes consisting of unfreezing, changing, and refreezing processes. First, unfreezing is the process of motivating individuals to change their decision-making strategies. This process unfreezes the notion that their decision-making processes do not require improvement by making individuals aware of vulnerabilities to biases using such means as the quiz-and-feedback format. Second, changing is the process of learning improved decision-making strategies and replacing old strategies with new ones. This process includes explaining concrete examples of general biases related to decision-making, and training people to consider the opposite or alternative hypothesis to their tentative conclusions. Third, refreezing is the process of making new decision strategies permanent. In order to secure the change, frequent applications of new strategies and overviews of past training are necessary. Further details of debiasing techniques are summarized in "A User's Guide to Debiasing" (Soll et al. 2015).

The debiasing technique summarized above is called the "modify the decision maker" approach (Soll et al. 2015). Another approach called "modify the environment" (Soll et al. 2015) seeks to provide the environment in which people naturally make a better decision when unaided (Klayman and Brown 1993). "Nudge" (Thaler and Sunstein 2003) is a way to influence human behavioral changes by pushing individuals toward better choices without limiting their liberty. An example of "nudge" is the presumption of consent, rather than unwillingness, to increase the number of organ transplant donors. Under such a policy, citizens are presumed to be consenting to become donors if they suffer brain death, even though they have the opportunity to register their unwillingness to donate by checking the box on their driving license. This is the strategic use of status quo bias. However, there is criticism that such a policy is a kind of paternalism. Gigerenzer (2014) argued that it is more important to improve citizens' judgment ability and risk literacy rather than assuming that citizens' decision-making needs to be guided by the government.

The studies summarized above focused on biases in decision-making by individuals. Few studies have focused on biases or errors in group decision-making, such as groupthink, hidden profile paradigm, group polarization, and pluralistic ignorance (Schulz-Hardt et al. 2006; Schwenk 1990). Co-design is the collective process to elicit an agreement among various independent stakeholders and to make a decision using their collective wisdom. To manage this co-design process, we must highlight the importance of not only debiasing for individuals, but also reducing biases or errors in group decision-making.

There are two classical techniques of debiasing in group decision-making: devil's advocacy (Herbert and Estes 1977) and dialectical inquiry (Mason 1969). Devil's advocacy is the technique for stimulating conflicts. In devil's advocacy, a group member or a subgroup is assigned the role of the devil's advocate whose task is to criticize the options on the table. When a consensus is reached on a particular option as a solution to the decision problem, the devil's advocate creates counterarguments to this solution and tries to identify its weaknesses. The group should then investigate these criticisms. Following the review, the particular option is either accepted or rejected.

Dialectical inquiry is the technique of investigating competing ideas or perspectives and involves the following steps. First, teams of decision makers are established. Second, each team is instructed to generate and evaluate alternative options and then recommend the best one. Third, after hearing each team's recommendation, the teams' and the organization's top leaders discuss and select the best parts of each option and synthesize a final plan.

These techniques and conditions are effective in considering counterarguments and evaluating options fairly based on reason or the controlled process of decision-making (Haidt 2006). On the other hand, Haidt (2006) argued that we need to pay more attention to emotion or the automatic process of decision-making. His argument is based on the dual-process model of decision-making. He differentiated between the automatic and the controlled processes corresponding to System 1 and System 2 of Kahneman (2011), respectively. He explained why we are vulnerable to biases using the metaphor of a rider on the back of an elephant. In Haidt’s metaphor, the elephant (emotional side) influences most of the rider’s (rational side) decisions. The elephant rider seems to be in charge, but actually has limited control over what the elephant does. Thus, for effective decision-making, we need to strike a balance between the emotional and rational sides. Whereas both devil's advocacy and dialectical inquiry are debiasing techniques that rely on reason (using controlled processes or System 2), we need to develop communications that appeal to emotion (using automatic processes or System 1) by building trust and resolving conflicts among stakeholders.

Conflicts among stakeholders are associated with both relationships and tasks. While relationship conflicts among group members often decrease group performance, task conflicts increase group performance only when those are weakly associated with relationship conflicts (de Wit et al. 2012). Trust building is important in mitigating the negative influence of relationship conflicts on group performance (Simons and Peterson 2000). In past studies on building trust and resolving conflicts, the role of good leaders (Hahn et al. 2006), face-to-face discussions (Wilson et al. 2006; McKnight et al. 2002), collaborative efforts (Sherif et al. 1954), and agreeable common goals (reframing) has been highlighted. Controversy in group decision-making is associated with high group performance and high-quality decisions under mutual trust and cooperative relationships among group members as we reviewed above. Devil's advocacy or dialectical inquiry provides a direct way to structure controversy cooperatively by organizing critical subgroups. However, these are not commonly applicable for the co-design process in decision-making, where there is often no hierarchical relationship between stakeholders and it is uncomfortable for many stakeholders to organize critical discussion among them without emotional entanglement. To keep the co-design process in group decision-making constructive and cooperative, we make the following recommendations that can serve as a guideline to ensure diversity of opinions among group members based on the “modifying the environment” approach:

1. Group decision makings often fail if group members sharing a common attitude are isolated from outside information and criticism. To avoid this failure, do not exclude stakeholders with different views from the process of co-design. Also, actively listen to the opinions of diverse groups of people.
2. Group decision makings often fail due to group dynamics including the tendency to conform. To avoid this failure, open the information required for decision-making and the process of discussion to the public.

3. Group decision makings often fail if critiques and competing ideas are neglected. To avoid this failure, perform an external review of the co-designed research plan.
4. Trust building is important in mitigating the negative influence of critical discussion on group performance. Build trust among stakeholders with different views by setting agreeable common goals and promoting face-to-face discussions and collaborative efforts.

4 Learning from Successes in Local Communities

4.1 Seeds of a Good Anthropocene and Efforts for Adaptive Comanagement

Whereas Earth system changes can have catastrophic and irreversible impacts on human societies (Lenton et al. 2008; Schellnhuber 2009; Rockström et al. 2009; Future Earth 2013), efforts to prevent deleterious changes in local environments have developed steadily and have been successful, at least on a local scale. Bennett et al. (2016) called these initial successes "seeds of a good Anthropocene" and developed a database of 100 initiatives representing a diversity of practices, worldviews, values, and regions. The seeds were categorized into six classes: agroecology, green urbanism, future knowledge, urban transformation, fair futures, and sustainable futures. The database can help researchers understand the processes that lead to the emergence and growth of initiatives that fundamentally change human–environmental relationships.

Bennett et al. (2016) clustered their six classes of seeds into two major categories: seeds of local socioecological systems (agroecology, green urbanism, and urban transformation) and seeds of knowledge and institutions (future knowledge, fair futures, and sustainable futures). As an example of the former (agroecology), Bennett et al. (2016) introduced Satoyama, a traditional Japanese agricultural landscape system, in which different land uses including farm fields, rice paddies, irrigation canals and ponds, and settlements form a cohesive system, providing a diversity of ecosystem services (Takeuchi 2010; Dublin and Tanaka 2014). As an example of the latter (future knowledge), they introduced GreenMatter, an initiative aimed at driving transformation in graduate-level skills associated with biodiversity conservation in South Africa. While the "seeds of a good Anthropocene" can be classified into these categories, some efforts, including the Satoyama Initiative (International Partnership for the Satoyama Initiative [IPSI] 2010), are directed toward both sustainability of socioecological systems and knowledge generation for sustainable futures.

In parallel with the "seeds of a good Anthropocene" project, the International Social Science Council (ISSC) promoted its Transformations to Sustainability (T2S) program for innovative, social science-led research on sustainable futures. In 2014, T2S, funded by the Swedish International Development Cooperation Agency (Sida) and implemented in partnership with the National Research Foundation of South Africa, selected 38 projects for funding. The early achievements of these projects are introduced in a special issue of *Current Opinion in Environmental Sustainability* (Moser 2016a). Papers in this issue describe 16 case studies in which researchers spent 6 months developing trust and co-designing projects with various stakeholders (Moser 2016b). In one example, the DIALAQ (DIALogic exploration of futures and pathways for sustainable farming on overexploited AQuifers) project involved farmers, public administrators, municipalities, nongovernmental organizations (NGOs), elected representatives, and various academic partners, building on trust that had already been established (Richard-Ferroudji et al. 2016). In the “research-for-action” project, focused on rangeland sustainability, participants from diverse regions including Mongolia, Kenya, and the United States built trust and fostered a learning community by allowing for cross-cultural, cross-sector, and cross-discipline differences (Galvin et al. 2016). Some of these projects faced the challenge of working across differences in background, training, experiences, needs, ideologies, and interests (Moser 2016b).

While Future Earth is promoting transdisciplinary projects co-designed by scientists and stakeholders, as in the T2S program, global efforts to close the gap between science and society in knowledge generation processes have been ongoing since at least the 1970s. First, the UNESCO Man and the Biosphere Programme (MAB), launched in 1976, used collaboration among various stakeholders (including local communities and scientists) to maintain ecological and cultural diversity and secure ecosystem services for human well-being by harmonizing conservation efforts with the local development needs. Second, since the 1990s, many efforts have been made to develop adaptive comanagement of various natural resources including forests, fisheries, bodies of water, wildlife, wetlands, protected areas, coasts and coral reefs, and agriculture (Berkes 2009; Plummer et al. 2012). Third, in the International Partnership for the Satoyama Initiative (IPSI) founded in 2010, collaboration between local communities and scientists has been pursued to develop sustainable comanagement of socioecological production systems.

The MAB is a UNESCO Intergovernmental Scientific Programme that aims to establish a scientific basis for the improvement of relationships between people and their environments (UNESCO 1996; Reed and Price 2019). Each biosphere reserve designated under the MAB Programme is composed of three elements: core areas, a buffer zone, and a flexible transition area. The buffer zone surrounding core areas is an area used for activities that contribute to conservation objectives, such as ecotourism, education, and research. The flexible transition area is an area containing farmlands and villages, and the resources in that area can be sustainably used by various stakeholders.

From 1976, when the MAB Programme started, to 1995, 324 biosphere reserves were designated in 82 countries (UNESCO 1996). By May 2020 this network had grown to include 701 sites in 124 countries (UNESCO 2020). At the International Conference on Biosphere Reserves held in 1995, the program’s early achievements were reviewed, and a new strategy and statutory framework for biosphere reserves were developed (UNESCO 1996). The statutory framework identified three functions of biosphere reserves: biodiversity conservation, sustainable economic and human development, and logistic support for education, research, and monitoring. The new strategy emphasized efforts to involve various stakeholders in decision-making processes and stated that "Bring together all interest groups and sectors in a partnership approach to biosphere reserves both at site and network levels," in one of ten key directions (UNESCO 1996). Subsequently, adaptive comanagement of natural resources, involving diverse stakeholders in decision-making processes, has been developed in multiple biosphere reserves, and its effectiveness has been supported by performance analyses (Schultz et al. 2011; Plummer et al. 2017).

Adaptive comanagement (ACM) is an extension of adaptive management (Holling 1978; Walters 1986) that incorporates participatory approaches (Berkes 2009). Plummer et al. (2012) suggest that attempts at adaptive comanagement began with a pioneering project at the Center for International Forestry Research (CIFOR) in 1997, but the biosphere reserve strategy (UNESCO 1996) is another root. Plummer et al. (2012) reviewed the history and achievements of adaptive comanagement since the 2000s, drawing on 108 sources. While this systematic review revealed considerable variability in defining what constitutes success or failure in ACM, it identified social networks, learning, and stakeholder participation as three important factors contributing to success, and conflicts of interest, power asymmetries, and insufficient resources as three major factors contributing to failure. However, the authors argue that it is difficult to determine how these variables contribute to particular goals and outcomes, because many studies do not adequately define the goals of ACM. After this review, Plummer et al. (2017) examined processes and outcomes in four UNESCO biosphere reserves where the goals of ACM were clearly specified. They showed that ACM efforts in all four reserves had many positive results, including ecological and livelihood effects. Similarly, Cosens et al. (2018) reviewed ACM, or adaptive governance, in water management projects for six watersheds in the United States, in which goals for sustainability and water resource resilience were clearly defined. Again, they found many positive results and identified the role of laws in triggering and facilitating adaptive governance. In addition, Leach and Pelkey (2001) reviewed 37 studies on watershed partnerships and identified 28 lessons for successful management by synthesizing 210 conclusions collected from these studies. Among these lessons, the two most frequently identified keys to success were funding and effective leadership. Wondolleck and Yaffee (2000) published a book entitled "Making collaboration work," reviewed many practices of American natural resource management, and derived 8 lessens for success, including common ground building, interaction among diverse groups, collaborative process, open and holistic mind-set, a sense of responsibility and ownership, partnerships of people, proactive and entrepreneurial behavior, and resources from numerous sources.

ACM has been developed in the activities of IPSI that was organized during the 2010 Convention on Biological Diversity (CBD) COP10. IPSI serves as a global effort for biodiversity conservation through the revitalization and sustainable management of socioecological production landscapes and seascapes, or SEPLS (International Partnership for the Satoyama Initiative [IPSI] 2010). IPSI promotes activities that maintain the typical mosaic pattern of land and water uses and natural habitats in SEPLS, which ensures the maintenance of biodiversity and the sustainable provision of ecosystem services for human welfare. IPSI also provides a platform for sharing traditional and modern knowledge that can contribute to the sustainable management of SEPLS (International Partnership for the Satoyama Initiative [IPSI] 2010; Duraiappah et al. 2012). IPSI has grown to comprise 240 member organizations spanning many sectors, with activities in most countries listed as parties to CBD. IPSI published four volumes of thematic assessment reports (UNU–IAS and IGES 2015, 2016, 2017, 2018), collecting more "seeds of a good Anthropocene" and reviewing successful case studies from various countries.

IPSI adopted the following three approaches to maintaining and rebuilding socioecological production systems in which land and natural resources are used and managed in a more sustainable manner: (1) consolidating wisdom on securing diverse ecosystem services and values, (2) integrating traditional ecological knowledge and modern science to promote innovation, and (3) exploring new forms of comanagement systems or evolving frameworks of "commons" while respecting traditional communal land tenure. The IPSI webpage introduces 280 case studies from Africa, the Americas, Asia, Oceania, and Europe, of which 38 are reviewed in detail in the thematic assessment reports (UNU–IAS and IGES 2015, 2016, 2017, 2018). In the second report, Subramanian et al. (2016) identified the following general principles for successful management of SEPLS: (1) mobilize knowledge toward action, (2) foster and leverage inclusive participation, and (3) use adaptive planning and management for activities. These three principles are similar to the key directions identified by the MAB Programme, and the second and the third principles are based on the concept of adaptive comanagement (Folke et al. 2002; Carlsson and Berkes 2005; Plummer et al. 2012).

4.2 Lessons Learned from Efforts for Adaptive Comanagement

As summarized above, both global and local efforts for sustainable natural resource management resulted in a convergent view emphasizing adaptive comanagement (Folke et al. 2002; Carlsson and Berkes 2005; Berkes 2009; Plummer et al. 2012), which combines the learning function of adaptive management (Holling 1978; Walters 1986) with the linkage function of collaborative management (Carlsson and Berkes 2005; Folke et al. 2005). Efforts have been made to review the achievements of various adaptive comanagement projects and identify lessons learned (Folke et al. 2005; Plummer et al. 2012; Chaffin et al. 2014; Cosens et al. 2018). These reviews have identified at least three factors contributing to the success of ACM. First, adaptive learning, or iterative knowledge generation, is critically important to manage socioecological systems, in which social and ecological systems are strongly coupled and their changes are often nonlinear and complex (Folke

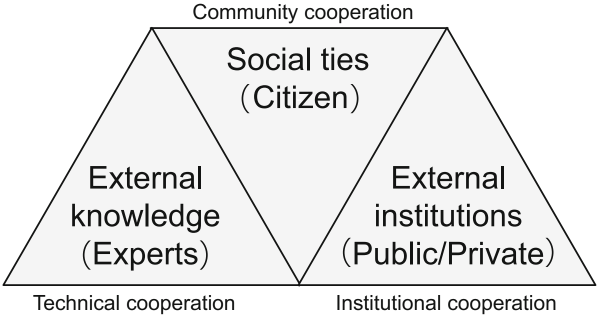

Fig. 1.3 Cooperation triangle: a scheme of community governance supported by external knowledge and external institutions

et al. 2005). Second, institutions, including markets and laws (North 2005; Cosens et al. 2018) and self-organization of communities (Ostrom et al. 1999; Ostrom 2000, 2009) can support cooperation in large communities by reducing instability under collective action problems (Olson 1965; Sanders 1992) or social dilemmas (Axelrod 1984; van Lange et al. 2013). Third, visionary leaders play a key role in building trust, making sense, managing conflict, linking actors, initiating partnerships among actor groups, compiling and generating knowledge, and mobilizing broad support for change (Folke et al. 2005).

Based on these reviews as well as our own experience (described later), we propose "cooperation triangle" as a general scheme of organizational cooperation in adaptive comanagement practices (Fig. 1.3), in which cooperative governance in a local community is supported by external knowledge and external institutions. Using this scheme, we emphasize the importance of promoting the evolution of external knowledge and institutions and internal social ties in local communities that connect local governments, social capital, and social memory. In this scheme, we distinguish between knowledge and institutions from outside a community and those available inside the community, because most co-design processes start from interactions between community insiders and outsiders that provide access to new knowledge and institutions (Folke et al. 2005; Moser 2016b). While a community has its own local knowledge and institutions, external knowledge and institutions also play critical roles in local processes of adaptive governance and problem-solving. As noted above, the two most frequently identified keys to success for watershed governance are funding and effective leadership (Leach and Pelkey 2001); these are associated with external institutions and knowledge.

In the scheme of cooperation triangle (Fig. 1.3), we distinguish between knowledge and institutions because each has different historical trajectories of change, defined by different processes of cultural evolution (Richardson and Boyd 2006; Ridley 2016; Henrich 2017). Much as language evolves through the gain and loss of homologous words through time (Bouckaert et al. 2012), knowledge evolves through the gain and loss of alternative ideas (Parson and Clark 1995). In particular, scientific knowledge evolves through the gain and loss of alternative hypotheses examined through empirical tests. Adaptive learning is another way of describing this process of knowledge evolution. On the other hand, the evolution of institutions involves not only learning but also designing. For example, new or revised laws are designed by governments to meet the needs of society.

Scientists are now one among many actors involved in knowledge generation, rather than serving as objective and independent specialists expected to deliver knowledge to managers and citizens (Folke et al. 2005). Recently, there have been at least three notable changes in knowledge generation processes. First, the rise of citizen science has enabled nonexpert citizens to engage with science, particularly on environmental issues, in collaboration with scientists working in local contexts (Bonney et al. 2014; Wals et al. 2014). Consequently, the gap between scientists as active knowledge producers and society as passive recipients (Mauser et al. 2013) has been bridged. Second, there has been increasing appreciation for insights from traditional knowledge, which often supported sustainable natural resource use for hundreds or thousands of years (Ludwig et al. 2001), as well as for local knowledge embedded in ordinary community life (Folke et al. 2005; Henrich 2017). The Intergovernmental Platform of Biodiversity and Ecosystem Services (IPBES) conceptual framework (Diaz et al. 2015) explicitly included efforts for integrating indigenous, local, and practitioners' knowledge with modern science. Third, in adaptive comanagement processes in local communities, science cannot be separated from social, ethical, and economic issues, including values and equity, and nobody can be an expert in all aspects of these complicated issues (Ludwig et al. 2001). Thus, mutual learning among diverse experts and stakeholders is needed to share and integrate knowledge from various disciplines and finding agreeable and effective options.

Under these changes, not only scientists but also other stakeholders are now active in compiling and generating the knowledge required for problem-solving and adaptive governance in local communities. As a result, it is increasingly challenging to mobilize knowledge from various disciplines and sources, develop common understanding among stakeholders, and finding agreeable visions and options for solving problems. To respond to these challenges, solution-oriented transdisciplinary science has been developed by integrating natural and social sciences and other knowledge useful for stakeholders involved in problem-solving practices. As is described in the next section, technical collaboration among diverse experts trained for transdisciplinary science is extremely helpful for ecosystem comanagement, post-disaster recovery processes, and other solution-oriented social projects.

External institutions including government agencies, the private sector, and NGOs can provide funds and human resources to help solve problems through adaptive governance in local communities. Funding is key to the success of adaptive comanagement (Leach and Pelkey 2001), and laws can provide both barriers and bridges to adaptive governance (Cosens et al. 2018). A good example of the role of law in adaptive governance is found in Japan, where environmental administration has changed dramatically since the 1990s as a series of new laws have been enacted. These include the Basic Environment Law (1993), the Act on Conservation of Endangered Species of Wild Animals and Plants (1993), Environmental Impact Assessment Act (1997), the Revised River Law (1997), the Act on Promotion of Global Warming Countermeasures (1998), the Act on Promotion of Nature

Restoration (2002), and the Basic Act on Biodiversity (2008). Through implementation of these environmental laws, increasing budgets have been allocated to adaptive governance of biodiversity conservation, nature restoration, and ecosystem management, and collaborations between citizens and administration have been developed. For example, the Revised River Law promoted adaptive comanagement of rivers by considering not only water control and water use but also biodiversity conservation and environmental sustainability (Shimatani 2005; Nakamura et al. 2006). These new environmental laws have been successful in developing adaptive comanagement systems for wetlands, grasslands, forests, and socioecological production landscapes and seascapes in local Japanese communities.

While external knowledge and institutions are provided to local communities by outsiders, these communities have their own knowledge systems and institutions. The problem-solving ability of a local community is determined by how well these knowledge and institutions are utilized, and it is the social ties that determine the level of this utilization. Social ties are strengthened by historical accumulation of social capital and social memory. According to Folke et al. (2005), social capital is the capital built by investing in social relationships, including trust, leadership, and networks of horizontal or vertical collaboration. Similarly, Pretty and Ward (2001) define social capital as relations of trust, reciprocity, common rules, norms, sanctions, and connectedness in institutions. Folke et al. (2005) emphasize that governance systems for ecosystem management require a civil society with a certain level of social capital. In addition to social capital, they argue that social memory is also key to adaptability in local societies because local governance systems must continuously learn and generate knowledge about ecosystem dynamics.

Compared to our deeper understanding of the evolution of knowledge (e.g., Berkes 2009) and institutions (e.g., North 2005), our understanding of the evolution of social ties still remains rather vague. To describe the complex structure of social ties more quantitatively, analytical approaches, and quantifiable models such as the network analysis may be helpful. While Lubell et al. (2014, 2017) applied non-modular network analyses to describe the coordinating roles of actors and institutions in comanagement, it would be beneficial to add a modular structure to the network analysis, considering the tendency of ingroup favoritism. Using this structure commonly used in the analysis of biological communities (e.g., Olesen et al. 2007), actors can be classified into network hubs, module hubs, connectors, and peripherals based on connectivity within and between modules. Community members who belong to one of the modules and interact more closely within the module tend to show goodwill and loyalty to ingroup members but often have doubts and hostility about external members (Greene 2013). To develop cooperation not only within an ingroup (“us”; Greene 2013) but also with an outgroup (“them”), a leader who can work as a connector plays a critical role. A connector is a person who can connect an ingroup with outgroups and play an important role in coordinating conflicts between an ingroup and an outgroup. The development of social ties can be seen as the evolution of connectivity in social networks supported by activities of connectors. To promote collaboration through the community, it is considered effective to increase numbers of connectors by providing opportunities for members to interact with members of different modules in an organization or community. To enhance this interaction, leaders in a community can play major roles.

The role of the leaders has been emphasized in literature on adaptive governance (Folke et al. 2005). According to Gladwell (2000), the leaders are often mavens (altruistic individuals with social skills) or connectors (individuals who know many people with a diversity of acquaintances). Bodin (2017) argued that appointing a specifically designated coordinator with some authoritative capacities can be effective for mediating risky relationships. However, there is insufficient common understanding regarding what a leader is and properties that define a leader. Recently, evolutionary biology was taken into account (Bastardoz and van Vugt 2019), and the relationship between the Big Five personalities and leadership was discussed (Judge et al. 2009). The big five personalities including openness, conscientiousness, agreeableness, extroversion, and neuroticism are associated with the following qualities needed in leaders: vision, self-management, devotion, passion, and risk management. Humans are diverse in their personalities, both genetically and empirically (Vukasovic and Bratko 2015). For this reason, human resources with outstanding capabilities in perception, self-management, devotion, passion, and risk management are rare. From an evolutionary viewpoint, it is considered advantageous to follow the leader's decision as a follower, when decision-making as a leader is more costly than following a leader (King and Cowlishaw 2009; Bastardoz and van Vugt 2019). In many cases, a leader pays a larger cost (time, effort, and other resources) in organizing and sustaining a cooperative team by managing noncooperative activities in a collective action. Consequently, leaders who are willing to devote to building and maintaining a team required for social transformation are always a limited resource. Then, how can we find good leaders who are needed to transform our society toward a sustainable future? In the following section, we distinguish two types of leaders, game changers and mediators, and argue that scientists can play a significant role as game changers.

4.3 *Lessons from Transdisciplinary Projects at the Institute of Decision Science for a Sustainable Society (IDS3)*

In this section, based on our experience in transdisciplinary studies at the Institute of Decision Science for a Sustainable Society (IDS3), we consider the roles of scientists in adaptive governance as the leaders on social problem-solving processes and social transformation for sustainability. While scientists are major participants in the knowledge generation processes, it has been found that they also play leading roles in adaptive governance in communities. Here, we consider the roles of scientists in adaptive governance as "game changers" and "mediators" (Fig. 1.4).

As emphasized by Folke et al. (2005), collaboration in governance networks by a community in need of change requires entrepreneurial leaders. Entrepreneurial leaders can provide innovative visions and options for decision-making toward

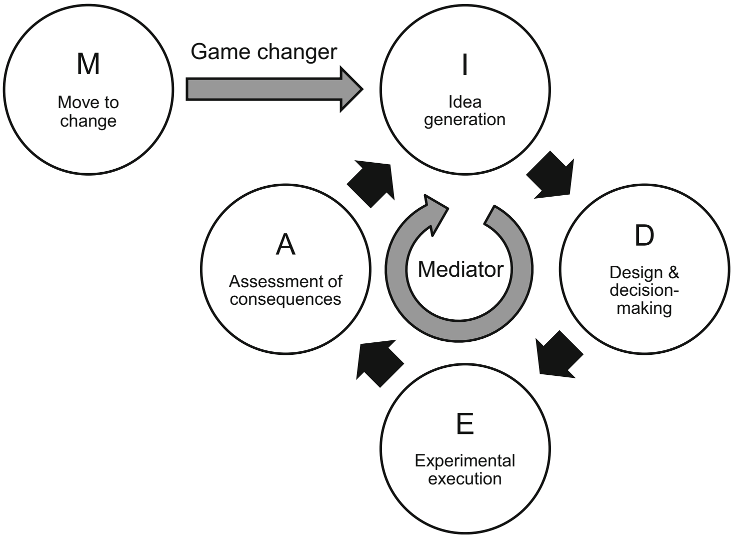

Fig. 1.4 A modified scheme of the IDEA cycle incorporating the roles of game changers and mediators

change and reorganization, and coordinate collaboration between stakeholders by initiating partnerships among actors, building trust, managing conflict, and mobilizing available resources for change. We define an entrepreneurial leader who initiates and catalyzes collaboration for change as a "game changer." A community in need of change is often trapped by social dilemma (Axelrod 1984; van Lange et al. 2013) that can be modeled as a public goods game (Isaac and Walker 1988; Bowles and Gintis 2011); action for change is costly to each actor, even if change is beneficial for all community members. Additionally, expected outcomes of change are often uncertain and complicated. Under these circumstances, it is not easy to initiate collaboration for change. A game changer is an altruistic person who is willing to do the heavy lifting to resolve dilemma and start a rotation of the IDEA cycle that involves idea generation, design and decision-making, experimental executions, and assessments of consequences (Fig. 1.4). While people other than scientists can play the role of a game changer, scientists who are employed by public institutions, rather independent of various economic interests, and have scientific knowledge required for both short-term and long-term decisions are more likely to act as game changers.

After activation of change, social adaptation to new environments and transformation to a desirable state often requires long-term effort and collaboration between stakeholders. In this process, stakeholders are required to make continuous efforts for rotating the IDEA cycle (Fig. 1.4). Bodin (2017) suggests that specific actors are required to act as "risk mediators" to maintain collaborative endeavors under tight bonding structures. In our experience, scientists can serve as mediators not only in managing risks of unstable cooperation but also evolve knowledge, institutions, and social ties under intimate interactions. Below, we introduce five successful cases where scientists played critical roles as game changers and then as mediators of the evolution of knowledge, institutions, and social ties. In these examples, scientists developed various mediation mechanisms including a science committee, academic societies for area studies, and social businesses. The first three case studies are from Japan, followed by Cambodia and India. In the three Japanese cases, local communities faced difficulties associated with deer overdominance, an aging society, and devastation by floods. In Cambodia, people coped with the loss of forests by developing community forestry. In India, people have developed social businesses for medical support in villages. While some of these projects have long histories of collaboration between stakeholders, others have developed more recently. By comparing these heterogeneous cases, we demonstrate how scientists can perform as game changers and mediators.

4.3.1 Ecosystem Comanagement in Yakushima, Japan

The island of Yakushima, Kagoshima Prefecture, spans an area of 504.9 km^2 and is located 60 km south of Kyushu Island. Yakushima harbors pristine forest vegetation from its sea level to its highest peak (1936 m), including lowland broad-leaved forests and highland coniferous forests, where over 40 endemic plant species have been discovered (Yahara et al. 1987). Most forested areas are protected and managed as national parks by the Ministry of Environment or national forests by the Forestry Agency. Additionally, the continuous landscape from Yakushima's seashore to its highest peak is registered as a UNESCO World Natural Heritage Site as well as a UNESCO Biosphere Reserve.

As reviewed by Yahara (2006), population declines of threatened plant species due to deer browsing was first reported by scientists in the Red Data Book published by Environment Agency in 1997. Scientists organized an assessment project between 2004 and 2006 to measure the increase in deer population and declines in plant species. While conducting assessments, project teams developed collaborations with the island's citizens as well as administrations of the Ministry of Environments, the Forestry Agency, Kagoshima Prefecture, and Yakushima Town. The assessment project provided convincing evidence of deer population increases and declines in threatened plant species to citizens and administrations (Yahara 2006). In 2009, the Ministry of Environment and the Forestry Agency established the World Natural Heritage Regional Science Committee by inviting both citizen scientists living on the island and external professional scientists to participate in the management of the World Heritage Site area (Okano and Matsuda 2013). The administrations of Kagoshima Prefecture and Yakushima Town joined the administration team and this alliance enabled the four largely isolated governments to discuss the ecosystem of Yakushima at the same table. Since 2009, the science committee has played a key role in planning ecosystem management in Yakushima and worked for monitoring and management of deer, developing common understanding based on data, and building consensus among stakeholders on measures against undesirable ecosystem changes. Activities of the science committee further evolved with the invitation of social scientists to discuss other issues including the overuse of tourism. The 2009 foundation of the science committee was a successful turning point in the adaptive governance of Yakushima driven by significant contributions of scientists, who in this case, served, as game changers.

Since 2009, scientists contributed significantly to the processes of adaptive governance by not only providing scientific knowledge (e.g., providing a mathematical model for zone-based management of the deer population; Fujimaki et al. 2016), but also by mediating the evolution of knowledge, institutions, and social ties. Notably, the Society for Yakushimaology, an academic society of area research on Yakushima, was founded in 2013 in a collaboration between 200 members including professional scientists and citizen scientists (Matsuda et al. 2015). A group of scientists who have achievements in on-site research in Yakushima, including primatologists, botanists, and hydrologists, made efforts negotiating with the mayor, administrators, and citizens of Yakushima Town. As a result, the Society for Yakushimaology was founded in 2013 as a collaboration with the municipal administration, and until 2019 it organized six annual meetings providing platforms for mutual learning among participants including hunters, ecotourism guides, and citizens, on both natural and social sciences and basic and solution-oriented research on Yakushima.

4.3.2 Citizenship Education in an Aging Society of Tsushima, Japan

Tsushima, an island 132 km north of Kyushu Island, Japan and 50 km south of Busan, Korea, has a population of 32,000. Tsushima's society is facing the threat of a rapidly aging and declining population (Kawaguchi and Araki 2016). The aging of farmers has made it difficult to continue paddy cultivation. Consequently, large areas of rice paddy fields were abandoned and changed to wastelands. The increase in abandoned paddies has not only decreased agricultural productivity but also negatively impacted biodiversity. Many aquatic organisms lived in these paddy fields, which served as alternative habitats for wetlands. The decrease in aquatic animals, especially frogs, may threaten an endemic subspecies of wildcat (*Prionailurus bengalensis euptilurus*) due to food limitation (Kawaguchi and Araki 2016). Other consequences of abandoned paddies are increases in populations of boar and deer, which are damaging to both agricultural produce and natural vegetation.

Adaptive comanagement of social-ecological systems in Tsushima has been developed by the city government since 2011, when it received a subsidy from the Ministry of Internal Affairs to hire external personnel for local community development. This subsidy system was founded in 2009 by the Japanese government to support community development in areas facing rapid aging and population decline. Using this subsidy, the city government hired graduates, including PhD holders, who worked as game changers by promoting a "Field Campus" project. Field Campus was aimed at inviting external researchers and graduate students to carry out on-site research in Tsushima. As Tsushima does not have any universities, high school students who wish to pursue higher education leave Tsushima and seldom return. "Field Campus" is an effort to overcome the issue of the lack of universities in Tsushima, and scientists of some universities including Kyushu University, Nippon University, Rikkyo University, and Yokohama National University have responded to this project (see Itonaga 2014; Maeda 2014). To support Field Campus, in 2014, the city government established a plan for community development by promoting cooperation between the Tsushima area and universities. Starting in 2015, the city government began hosting an academic meeting called the "Tsushimaology Forum." Our IDS3 team from Kyushu University joined the Field Campus project in 2014 and initiated some transdisciplinary projects in Tsushima (Tokunaga and Akiho 2018).

A project named "Treasures of the Island Project" was developed in cooperation with Tsushima City Administration, Kami Tsushima High School, Tsushima Chamber of Commerce, and Kyushu University, aiming at providing high school students with the opportunity to discover and learn about local attractions. After twenty meetings to discuss and co-design the project, six groups of high school students made field reports on questions including "How can we increase jobs in Tsushima?", "What is the attractiveness of local foods in Tsushima," and "What are needs of Korean tourists?" Scientists and graduate students of Kyushu University supervised and facilitated group projects of high school students, who then presented their findings in meetings open to citizens. After joining this project, high school students' scores for willingness to participate in local community development were found to have significantly increased (Tokunaga and Akiho 2018). As the activity of Kyushu University is supported by a time-bounded grant from JSPS, Kami-Tsushima High School plans to continue this education using their own budget. This is another successful example of the evolution of knowledge, institutions, and social ties mediated by scientists.

4.3.3 Recovery from Flood Damage in Asakura and Toho, Japan

Asakura City, Toho Village and the adjacent region located in northern Kyushu Island suffered serious floods caused by torrential rainfall on July 5, 2017 (Kawano and Kawamura 2020). At least 40 people were killed as hilly slopes collapsed causing landslides and bringing down large numbers of trees. Due to severe sediment run off, infrastructure including roads, bridges, and buildings were destroyed. In response to this disaster, Kyushu University organized Support Team for Recovery, Rehabilitation, and Reconstruction that was joined by 52 professors from various faculties including technology, agriculture, science, and arts, and initiated activities including surveys and support for those who had been evacuated (Mitani 2018). Support Team was intended to continue supporting a long-term process needed for immediate response to the disaster, repairing from the disaster, and restoration of ordinary lives, where urgent, short-term, and long-term decision makings must be integrated (Fig. 1.5; Shimatani 2016). Professors at Kyushu University's Disaster Risk Reduction Research Center took leadership organizing

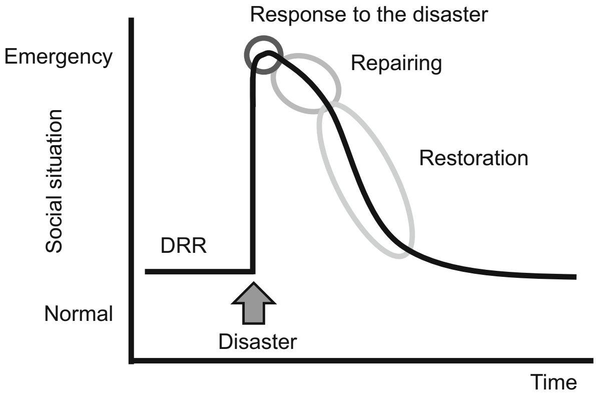

Fig. 1.5 Scheme of urgent, short-term, and long-term decision-making after a disaster (Shimatani 2016)

Support Team and worked as game changers. After the emergency response phase, Support Team joined meetings of affected people in 17 villages, provided them with aerial photographs of villages depicting where and how severely landscape and infrastructure were damaged, and asked them to write their requests on post-its and stick them on particular damaged sections on aerial photographs (Shimatani et al. 2020). Notably, experts of various disciplines including civil engineering, forestry, and ecology joined meetings and facilitated citizen discussion. Administrators of municipalities and the Ministry of Land, Infrastructure, Transport, and Tourism also participated. Village meetings proved to be extraordinary opportunities for bridging fragmentation of both academia and administration, and mediating collaborative interactions among citizens, administrators, and scientists (Shimatani et al. 2020). On September 13, 2017, Support Team held an open meeting for citizens to introduce early findings from surveys, summarize progress in various activities including volunteers and cultural support, and discuss challenges and needs for recovery. On December 17, 2018, Kyushu University, Asakura City, and Toho Village had a joint open meeting to share knowledge and experiences during the recovery process and visions for future reconstruction. The role of scientists here shifted from game changers to mediators of a long-term reconstruction process. Continued support for this process still remains a challenge.

4.3.4 Supporting Community Forestry in Cambodia

Collaboration between Kyushu University and the Forest Administration of Cambodia began in the 2000s when Dr. Heng Sokh studied at the graduate course of Kyushu University. Since then, many staff members of the Forest Administration have enrolled and earned PhDs at Kyushu University and returned to jobs at the Forest Administration. In his pioneering paper, Sokh and Iida (2001) reviewed practices of community forestry in Thailand, Vietnam, Laos, the Philippines, and Indonesia and concluded that most practices had five key factors: (1) a well-defined community organization, (2) security of rights on land and trees, (3) economic benefits to local communities, (4) evaluation and monitoring, and (5) strong support from NGOs and central and local governments. On the other hand, they argued that some projects of community forestry in Cambodia are underway without evaluation and monitoring, and more efforts for monitoring are needed to improve project implementation. Since then, increasing efforts for monitoring community forestry achievements have been made as a result of collaborations between the Forestry Administration and Kyushu University. Most recently, Lonn et al. (2018) made a country-scale analysis of biophysical factors affecting forest coverage changes in community forestry areas from 2005 to 2016 using a dataset of 197 projects and high-resolution maps of forest coverage. Results showed that probability of forest loss increased with community forestry size and decreased with elevation and slope, suggesting that smaller areas are more effective for community forest management at lower elevations with gentle slopes. Results also showed that the probability of forest loss was lower if a community forest was located closer to villages and markets but further from the main roads, suggesting that cooperation is more stable under situations that many people can observe. In the development of community forestry under the collaboration between the Forestry Administration and Kyushu University, Dr. Sokh functioned as a game changer. Since his initiation of the collaboration, various projects have developed as collaborations between the Forestry Administration and Kyushu University, including assessments of wood fuel consumption patterns (Top et al. 2004), forest biomass estimation (Kajisa et al. 2009), tree water use in a community forestry site (Miyazawa et al. 2014), monitoring plant species and phylogenetic diversity (Toyama et al. 2015), and studies on flora and vegetation of a national park (Zhang et al. 2016). In these projects, scientists worked as mediators of the evolution of knowledge and social ties.

4.3.5 Development of Portable Health Clinic as Social Business in India

The Portable Health Clinic (PHC) is a remote health service system using a set of medical sensor devices in a briefcase and software enabling telecommunications on medical examinations (Ahmed et al. 2013). A set of devices in a briefcase is designed to determine essential indicators for physical examination including body temperature, blood pressure, blood tests, and urine tests. PHC was developed by a collaboration of Kyushu University (KU) and the Grameen's social business (Yunus 2007, 2010), and has been used to develop a remote health services in Bangladesh (Nakashima et al. 2013; Hossain et al. 2019). In India, the Portable Health Clinic (PHC) research project started in March 2016 as a community-based health check-up services in a collaboration of KU, Grameen Communications (GC) company of the Grameen Organizations in Bangladesh, and Biyani Group of Colleges (BGC) in India. This collaboration was developed since the 6th Asia Telemedicine Symposium held in Fukuoka, Japan in 2012 where a research director of BGC expressed interest in PHC. More details of this project and its lessons are provided in Sect. 2.2 (Yokota et al. 2018).

Noncommunicable diseases such as hypertension, diabetes, and kidney diseases have been an increasing social issue in India as in other developing countries. To address these problems, the primary objectives of the PHC project in India were:

- To increase access to basic health check-ups and telemedicine services.
- To increase community health awareness, knowledge, attitude, and behaviors for prevention of noncommunicable diseases.
- To reduce incidents of disease complications and comorbidities such as hypertension, diabetes, dyslipidemia, and anemia.

To achieve these objectives, the PHC project in India aimed to provide sustainable mobile health check-up services in collaboration with local government agencies, industries, and communities in the state of Rajasthan, India.

During the initial phase from March 2016 to April 2017, these objectives were shared and agreed upon among KU, GC, and BGC. In this pilot phase, development of the research plan, training workshops, implementation of research, data analysis, and data feedback workshops were conducted in collaboration with KU, GC, and BGC. The game changer who enabled the launch of these pilot activities was the BGC research director. In the following phases described in Sect. 2.2 (Yokota et al. 2018), a coordinating staff of BGC acted as a mediator of these activities under the leadership of the BGC research director, and researchers of KU also acted as mediators of the evolution of knowledge and social ties by improving the PHC system and incorporating community needs.

In the processes of co-design and co-implementation of the PHC project in India (Yokota et al. 2018), the following lessons from the success of Grameen’s social business (Yunus et al. 2010) have been consulted:

1. Challenging conventional wisdom and basic assumptions: This lesson encourages changes to the current rules of public games.
2. Finding complementary partners: This lesson emphasizes the importance of cooperation as a major success of social businesses.
3. Undertaking a continuous experimentation process: This lesson is similar to the idea of the adaptive management (Holling 1978; Walters 1986) in that it facilitates knowledge acquisition through experimental execution.
4. Favoring social profit-oriented shareholders: This is a vision unique to Grameen’s social business that pursues positive links between all stakeholders, including shareholders.
5. Clearly specifying the social profit objective: This is another vision unique to Grameen’s social business, which aims to generate social profit rather than financial profit.

Compared to the four transdisciplinary projects above, the PHC project in India is unique in having the above visions of social business development shared by the Grameen Organizations. Currently, a PHC service is being designed as a health insurance system for employees of a private company in Rajasthan, India. The new proposal, drafted by KU and BGC, was shared with the company manager to discuss the feasibility of continuing the PHC project as a company's health insurance. The development of PHC projects as social businesses is in progress not only in India but also in Bangladesh, Pakistan, and Thailand (Grameen Comunitations 2020).

4.4 The Roles of Scientists to Drive the Evolution of Knowledge, Institutions, and Social Ties

In this chapter, we reviewed successful cases of adaptive governance and social transformation. Collaboration between scientists and society has developed since the 1970s, long before 2013 Future Earth initiative. UNESCO's Biosphere Reserve is the root of adaptive co-management of natural resources, and the Grameen's social business that began in 1976 can be regarded as another pioneering effort to promote adaptive governance on poverty alleviation. These efforts consist of three key elements: knowledge production and social learning, improvement of institutions including laws and business, and strengthening social ties. In addition, these processes proceed due to interaction.

The important lesson from various successful examples of adaptive governance and social transformation is that the role of scientists in starting and mediating the evolution of knowledge, institutions, and social ties within a community is often very large. Scientists can work as game changers by specifying a problem, organizing stakeholders, and promoting a project that will initiate social change. Scientists can also act as mediators and as continuous catalysts for social transformation. While scientists are now one among many actors involved in knowledge generation (Folke et al. 2005), they can also play significant roles as game changers and mediators of social transformation. To be successful in fulfilling these roles, scientists must follow the co-design guidelines we developed in Sect. 1.2. In order to strengthen the role of such scientists, it is necessary to establish a framework for evaluating and supporting not only research achievements but also activities that contribute to social transformation. Moreover, a new knowledge system is needed to support activities of scientists in transdisciplinary sciences, and this chapter addresses this need.

5 How can We Transform Our Society Toward a Sustainable Future?

In this section, we will further integrate lessons learned from past failures (Sect. 3) and successes (Sect. 4) to provide a more general discussion of how we can promote social transformation toward a sustainable future. As shown in Sect. 4, adaptive comanagement on natural resources has had many successful examples, at least locally. There are also many successful examples of local efforts for poverty alleviation, public health assistance, and community education. On the other hand, it is more difficult to solve global problems where the stakes are more complex and conflicts are larger. Then, how can we connect local success to global problem-solving?

There are two major factors behind the difficulty of the problem. First, human cooperation is unstable in large groups, and given this nature, global cooperation is the most difficult task. Secondly, there are often complex and serious conflicts among countries and ethnic groups over trade, territory, religion, culture, and history. Providing a comprehensive perspective to solve these difficulties is beyond the scope of this chapter. However, based on lessons we have gained so far from the local success and failure, we could expect the following directions to be key clues to global problem-solving: (1) facilitating the participatory process, (2) mediating conflicts among groups with different views, (3) improving institutions represented by subsidies and legal regulation, (4) enhancing education and adaptive learning, and (5) promoting behavior based on hope rather than fear.

5.1 Promoting Participatory Process

Let us start by considering international cooperation that has been developed through participatory processes in biodiversity issues. Many biodiversity issues are local, but the ecosystem itself has no border, and there are various linkages between ecosystems. First, as represented by migratory birds and fish, many animals live across borders, and multilateral cooperation is necessary for the conservation of these animals (Barkin and DeSombre 2000; Runge et al. 2015). Secondly, the local environmental burden is linked globally by trade (Lenzen et al. 2012). For example, the decline in tropical forests in Southeast Asia is closely related to timber consumption in countries of other areas, including Japan, China, and the United States (Nishijima et al. 2016). Changes in consumer consumption behaviors and corporate decision-making in these major countries are needed to conserve tropical forests. Third, as represented by UNESCO Biosphere Reserves and World Heritage, there are international mechanisms that contribute to regional development. By strengthening these linkages, it is possible to increase opportunities for local citizens to recognize that global issues are their problems. In Yakushima and Tsushima, academic societies on area studies involving citizen scientists have been developed through collaboration between citizens and experts. These attempts can provide a good opportunity for citizens to become aware of the link between local issues and global issues. Organizing collaboration between citizens and experts in regional projects such as UNESCO Biosphere Reserves and networking them internationally would be a hopeful option for developing participatory processes that connect local and global scales (Sato et al. 2018).

Another possibility to connect the local scale with the global scale is the biodiversity observation network. Unlike climate change observation, the cooperation of many citizens is particularly effective for biodiversity observation (Chandler et al. 2017). Citizen participation platforms such as iNaturalist (Cobb et al. 2019) and international cooperation on specific organisms such as migratory birds (Kirby et al.

2008) have already been well developed. Recently, citizen participatory monitoring utilizing advanced technologies such as environmental DNA has been developed (Miya et al. 2015; Valentini et al. 2015). In order to link such local biodiversity observations to global observations such as GEO BON, both national level observation networks and regional level observation networks such as APBON (Nakano et al. 2014) are important (Navarro et al. 2018).

A variety of international cooperation has been developed through participatory processes in issues other than biodiversity. According to the comprehensive review of Charnovitz (1997), history of NGO participation in national and global governance dates back to 1775 when the Pennsylvania Society for Promoting the Abolition of Slavery was founded. Since then, participation of NGOs pursuing peace, worker solidarity, and new international regimes gradually emerged until 1919 when the Paris Peace Conference was held and the League of Nations was organized. After the disengaged stage under World War II, participations of NGOs were formalized in 1945 under the United Nations, and activated even under the Cold War from 1950 to 1971. Since the end of the Cold War, NGO participation in international governance have been intensified through its growth in number, size, and diversity. Both UN Economic and Social Council (ECOSOC) and the UN General Assembly have developed and strengthened relationships with NGOs in the planning process of international conferences.

While participatory processes in national and global governance have been successfully developed as summarized above (Charnovitz 1997), such national and international cooperation often faces difficulties due to conflicts among various groups including nationalist groups, ethnic groups, and political groups. In the following section, we will consider the ingroup favoritism behind various conflicts in human society, and how we can avoid conflicts and develop cooperation between groups.

5.2 *Reducing Conflicts Among Groups with Different Value Systems*

The phenomenon of human cooperation becoming unstable in large groups has been widely recognized through research on the tragedy of the commons (Hardin 1968), collective action problems (Olson 1965; Sanders 1992), free-rider problem (Grossman and Hart 1980), and social dilemmas (Axelrod 1984; van Lange et al. 2013). On the other hand, it is also true that humans have developed cooperation in large-scale societies and achieved civilization. Cooperation in such large-scale societies have been developed through the self-organization of communities (Ostrom et al. 1999; Ostrom 2000, 2009) and the implementation of various institutions, including markets and laws (North 2005; Cosens et al. 2018). The biological foundation of the community self-organization and institutional development is human moral behavior that evolved with human ability of planning and self-control,

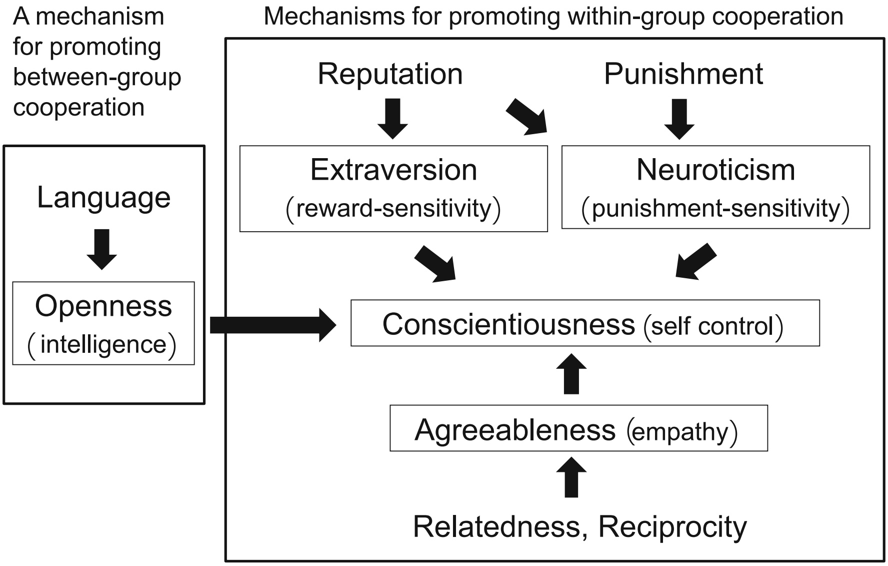

Fig. 1.6 Big five personalities as mechanisms for promoting human cooperation

associated with advanced language ability and two personality traits: openness and conscientiousness (Fig. 1.6). With this development of planning ability, humans have acquired the ability to carry out planned violence. Greene (2013) argued that the "action plan monitoring module" associated with the moral emotion evolved as a device to suppress this violence. This idea is consistent with Boehm's (2008) study that morality against violence is widespread in hunting and gathering societies. The research on hunter-gatherer societies reviewed by Boehm (2008) showed that direct punishments for those who broke the rules and indirect pressure through reputation are widespread, suggesting that those are major social factors to maintain moral behavior.

Punishment and reputation are widely incorporated into the model of the evolution of human cooperative behavior, but these studies suggested that cooperation in large groups is difficult to be maintained only by these factors (Bowles and Gintis 2011). Selection mechanisms that prompted the evolution of human cooperative behavior in large groups have yet to be established. Recently, however, there have been increasing agreements on the role of culture in the evolution of large-scale cooperation. First, Bowles and Gintis (2011) argued that the evolution of human cognitive capacities allowed the formulation of social norms, and the emergence of social institutions regulating these norms, and consequently these institutions facilitated human cooperation within groups. Second, Boyd and Richerson (2009) discussed that the evolution of learning ability favored by ordinary natural selection resulted in culturally evolved cooperative social environments, and social selection within groups favored genes that enhanced pro-social behaviors. Third, Henrich and McElreath (2003) formulated how a process of cultural group selection under the interaction between cultural and genetic transmission can promote the evolution of enhanced pro-social behaviors in a large community. More recently, Henrich (2017) comprehensively reviewed empirical evidence showing how cultural evolution promoted human cooperation in the process of human civilization. In all of these discussions, researchers suggested that the evolution of human cooperation was promoted within groups under escalating human conflicts among groups.

One of the human characteristics that promote cooperation in a large group is pro-social punishment behavior (behavior that attempts to punish noncooperators even if they are costly to the punisher). Greene (2013) thought that the pro-social punishment behavior is associated with moral emotion supported by the action plan monitoring module, and that this nature has evolved as a means of solving within-group cooperation problems represented by the tragedy of commons. Like the above researchers, he argued that this property is not a mechanism that promotes collaboration among groups, but rather a mechanism that favors competition among groups. Different groups often have different moral systems shared within each group. For this reason, competition between groups with different morality (moral tribes) tends to create emotional conflicts over morality. Here, the moral emotion that evolved as a means of solving the cooperation problems within the group itself is the source of conflict between groups. Greene (2013) named this situation "the tragedy of common morality." According to Greene (2013), in order to solve this situation, it is necessary to switch from intuition-based decisions (like the automatic mode of a camera) linked to moral emotion to reason-based decisions (like the manual mode).

The moral emotions that bring about "the tragedy of common morality" as described by Greene (2013) are considered to be associated with the four of big five personality factors: extroversion, neuroticism, conscientiousness, and agreeableness (Fig. 1.6). Extraversion is a sensitivity to positive reputation and is associated with positive emotions when praised. Neuroticism is a sensitivity to punishment and negative reputation, and is associated with negative emotions with a sense of shame and guilt. These sensitivities allow humans to monitor how their actions are evaluated by others, and based on these sensitivities, humans can control their actions with conscientiousness. In addition, agreeableness is a personality factor that promotes cooperation among ingroup members and is associated with empathy.

As Haidt (2006) explained using a metaphor of elephants (intuition) and elephant riders (reasons), the power of elephants (intuitions) is often too strong to be controlled by elephant riders (reasons). For this reason, Haidt emphasized that efforts to improve the relationship between elephants (intuition), such as trust, are more important in mediating social conflicts, rather than the rational argument between elephant riders. Greene (2013), however, argues that resolution by rational argument is effective in mediating conflicts among groups with different moral views. Like Structured Decision Making proposed by Gregory et al. (2012), Greene (2013) encourages stakeholders to share a specific understanding of trade-offs and pursue reasonable compromises. While Haidt (2006) recommended to use intuition related to extroversion, neuroticism, conscientiousness, and agreeableness, Greene (2013) relied on openness-based reason to resolve social conflicts between groups.

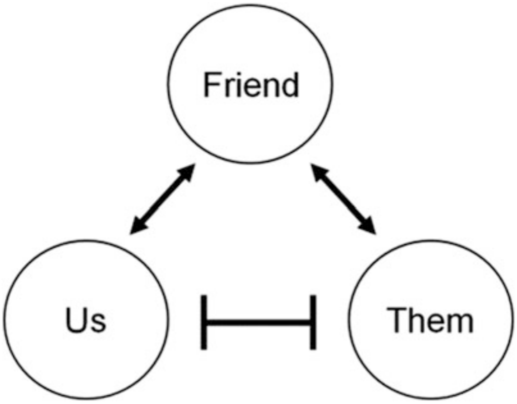

Fig. 1.7 A trichotomous model of human group relationship

Greene's argument on "Moral tribes" (Greene 2013) is based on the dichotomy of ingroup ("us") and outgroup ("them"). In human hunter-gatherer societies, however, tribes were connected by various interactions including knowledge exchange, mating, and trades, and the mode and strength of interactions (cooperation and competition) varied between groups (Bowles and Gintis 2011). In historical societies, presence or absence of support from friendly states greatly affected the survival of civilization (Diamond 2005). Thus, the dichotomy of ingroup ("us") and outgroup ("them") may oversimplify the relationships among human groups or "moral tribes." Even in modern human societies, relationships between groups are not limited to those between two parties, but interactions between groups of three or more parties are common (Tooby et al. 2006). In an interaction between three parties, for example, the third group may be friendly with both "us" and "them" (Fig. 1.7). Under this interaction, we manifest a distaste for exploitation or unfairness by others not only to ingroup members (us) but also to the third group valued by us, and this emotion may alleviate conflicts with the second group. Under such an interaction between multiple groups, we use "theory of group mind" (Tooby et al. 2006) by considering a group as a person. This is a conceptual extension of "theory of mind," a specialized set of cognitive mechanisms that enable us to interpret mental states of others behind their behaviors (Baron-Cohen et al. 1985). In fact, we tend to consider as if a group (e.g., a company and a university) has a favor or some hostility toward us, assuming that a group has mind. According to Tooby et al. (2006), a theory of group mind is a mind system that evolved as an adaption to engage in complex n-party interactions. Using this system, the moral emotion that originally evolved as a means of solving cooperation problems between groups may be extended to solve the cooperation problems between groups. Thus, not only our reasoning abilities but our moral emotion may also help us resolve conflicts between "moral tribes."

5.3 Improvement of Institutions

As a lesson from local successes of adaptive comanagement, it has been confirmed that the improvement of institutions greatly contributes to its success. For example, in the ecosystem management on Yakushima, the establishment of the Yakushima World Natural Heritage Regional Science Committee has brought about significant ongoing progress. Institutional improvement is also important for improving sustainability at the national level, and the development of a series of environmental laws in Japan since the 1990s is a good example. Needless to say, institutional improvements have greatly contributed to solving global problems. The IPCC plays a major role in consensus building on international measures against climate change and the development of international cooperation. Similarly, IPBES has announced regional and global assessments, as an international mechanism that contributes to the sustainability of biodiversity and ecosystem services.

In this way, the importance of institutional improvement is empirically clear, but basic issues such as how the institution changes and evolves and what social mechanisms are behind the institutional evolution are still not fully understood. North (2005) published a book “Understanding the Process of Economic Change” that considered these issues and proposed a pioneering theoretical framework. North (2005) regarded an institution as a deliberate effort to control the environment around us. This environment includes a natural environment and an artificial environment that we have created. The artificial environment is the legal and normative system itself, which defines the framework for human interaction. Natural science has developed various technologies to deal with the natural environment and reduced its uncertainty by deepening our understanding of the natural environment. However, North (2005) argued that the introduction of new institutions often increased the uncertainty of artificial environments and forced humans to constantly adapt to the new environment. This argument of North (2005) can be seen as applying the Red Queen model on the coevolution of organisms in ecosystems (Ridley 1993; Benton 2009) to institutional evolution. Antagonistic coevolution between a host and its parasite causes an escalation of trait evolution through adaptive evolution that enhances attack and defense. This process is called “Red Queen Model” after the episode of the fable by Louis Carroll, “Alice in the Looking Glass,” where the Red Queen said by pulling the hands of Alice, “Now, here, you see, it takes all the running you can do, to keep in the same place.” North (2005) thought that there is the evolution of human belief in the background of institutional evolution, and that the coevolution of institution and belief created a red queen-like permanent change.

There remains, however, a significant problem with the discussion in North (2005). His economic considerations are based on the assumption that selfish incentives in competitive markets will result in institutional change. Contrary to this assumption, even in seemingly competitive markets, not only selfish competition but also altruistic cooperation will motivate changes in institutions, as represented by the Grameen’s social business (Yunus 2010; Yunus et al. 2010).

Required is not only institutional changes that reduce transaction costs under selfish competition, but also institutional changes that promote cooperation between stakeholders to achieve widely agreed goals such as the SDGs. Through institutional changes that promote such altruistic cooperation, we have realized cooperation in a large-scale society that far exceeds the Dunbar's number (Dunbar 1993). Such efforts have been expanded from the local/national scale to the international scale, and the United Nations organization, treaties represented by UNFCC and CBD, and the international assessment organizations (IPCC and IPBES) have been established. Expanding a participatory approach from the local/national scale to international mechanisms is considered to be one of the goals of future institutional changes.

5.4 Strengthening Education and Adaptive Learning

The environmental uncertainty surrounding us can be reduced not only by institutions but also by the accumulation of knowledge (North 2005). In this regard, strengthening education and adaptive learning is an effective approach for building the capacity of various actors to solve various social problems. On the other hand, the knowledge we have accumulated so far exceeds the amount that one person can learn in a lifetime. Also, the division and specialization of knowledge generating scientists have created a division of knowledge, often making it difficult to integrate and use diverse knowledge for problem-solving (Hayek 1979; North 2005). Thus, it is important not only to create new knowledge, but also to integrate available knowledge and to provide a comprehensive overview of the knowledge necessary to solve a problem. As an effort in this direction, we wrote this chapter and tried to systematize the understanding of human decision-making that should be shared among stakeholders struggling with solving various social problems. Through deepening the understanding of the natural environment by natural science, we have developed various technologies to deal with the natural environment and reduced uncertainty. Similarly, by deepening our understanding of human decision-making and behavior, we can develop ways to better coordinate human relationships and human social actions and reduce uncertainty about the human environment (Gigerenzer 2007).

The whole body of knowledge we have accumulated throughout human history is called the collective brain (Henrich 2017). Cognitive abilities of a human individual are not always superior to an individual chimpanzee, but owing to our ability of using language and the collective brain, we have built prosperity through civilization and solved various problems throughout human history. Then, how can we enhance individuals' learning abilities and better use the collective brain to create a sustainable society?

In the process of education and learning, we accumulate knowledge as various memories. This memory includes declarative memory and non-declarative memory. The former can be shared as written knowledge and used for rational judgment. On the other hand, the latter serves as an intuitive toolbox available to individuals when faced with challenges (Gigerenzer and Selten 2002; Gigerenzer 2007). Experts experienced in specific fields have a wealth of non-declarative memory in this toolbox. While opinions are divided among experts on which of our cognitive skills, intuition, and reason, is more useful for solving problems (Gigerenzer and Gaissmaier 2011; Haidt 2012; Greene 2013; Marewski et al. 2013), the usual but obvious answer is that both are important. As emphasized by Bazerman and Watkins (2004), decisions that rely only on intuition tend to result in failures due to various cognitive biases. On the other hand, the reason is thought to be the main driver of reducing violence throughout human history (Pinker 2011) and improving our societies in many other aspects (Pinker 2018). Greene (2013) suggested that switching between intuition (auto mode) and reason (manual mode) depending on the situation, maybe a useful way of mediating social conflicts, by combining the advantages of the two cognitive systems. However, recent advances in neuroscience showed that fast response by intuition and slow response associated with attention and cognition are sequential and highly integrated (Schultz 2016).

As an evolved organism, we are adaptive learners always pursuing positive rewards. A reward is broadly defined as "an object, event, stimulus, situation, or activity that generates positive learning, induces approach behavior, is maximized in economic decisions, and evokes positive emotions such as pleasure and desire" (Schultz 2017). In our reward-pursuing behavior, we have a prediction on a reward level, and often face an error that means a discrepancy between what is happening and what is predicted to happen. If an error is more beneficial than a prediction, we are motivated to pursue a signal associated with more rewards. This is a process of reinforcement learning based on a positive reward prediction error signaling that is driven by fast and slow dopamine responses in our brain (Schultz 2016). To advance citizens' adaptive learning for sustainability, therefore, we need to provide adequate rewards, and a goal is one of the most hopeful rewards because our human actions are mostly goal directed (Snyder 2015). SDGs are examples of such goals. To make those goals more effective for motivating citizen's interest and goal-directed behavior, we need to show that those goals are achievable.

5.5 Acting Based on Hope Rather than Fear for a Sustainable Future

A positively motivated state for a particular goal is called hope. According to the hope theory (Snyder 2015), hope is based on an interactive sense of goal-directed energy and successful pathways. When people face difficulties to achieve a goal, high-hope people can find plausible alternate pathways and have positive emotions stemming from perceptions of successful goal pursuit. On the other hand, low-hope people fail to find alternate pathways and are trapped with negative emotions as a product of unsuccessful goal pursuit. An important role of scientists is to identify the pathway to success and to give the public high-hope.

We have solved some problems and made better societies at least in part although we are still certainly facing many difficult problems. Yunus et al. (2010) pointed out this fact in his seminal book "Social Business Revolution" and emphasized the importance to make a wish list for a better society and make efforts to realize those goals, rather than worrying about pessimistic predictions. His wish list is similar to SDGs that are now globally agreed. Another perspective for a positive change of the world has been repeatedly emphasized by Hans Rosling, a creator of Gapminder (https://www.gapminder.org/), through his influential TED talks (see also Rosling et al. 2018). Gapminder is an attractive tool for visualizing changes in the world's population and various statistics related to it. Rosling used Gapminder to point out that with the development of the economy, child survival increased in many countries, the number of children per woman decreased, and the human population is turning from increasing to decreasing. Countries that have contributed significantly to global population growth are poor African countries with low child survival and high numbers of children per woman. However, many countries in Africa are getting out of this situation and are following the trajectory of many other countries toward higher child survival and fewer children per woman. Gapminder convincingly shows that the crisis of population growth and the food crisis are solvable issues. The modern food problem stems from the fact that the product is not delivered to those who need it, rather than a lack of productivity. Following Rosling, Max Roser visualized on the website "Our World in Data" (https://ourworldindata.org/) that various positive changes are taking place in the global community. Ridley (2010), see also 2015) argued that humanity has achieved prosperity through the evolution of social systems that enabled continuous innovations through non-zero sum games of exchanging knowledge and trading goods. According to him, the modern time is the most flourished in human history and is even getting better.

In parallel with these claims, many scientists have gathered evidence supporting that the world is getting better, and argued that our society can be transformed toward a sustainable future by making further efforts. Among them are Banerjee, Duflo, and Kremer who won the 2019 Nobel Memorial Prize in Economic Sciences "for their experimental approach to alleviating global poverty." Reviewing their research findings, Banerjee and Duflo (2011) published a book entitled "Poor Economics," and clarified that there is no general method for effectively supporting developing countries, but by devising effective methods according to individual conditions, various subsidies certainly contribute to development. In particular, the psychological status and the various difficulties in daily life of poverty people are beyond the imagination of people without poverty in developed countries. This knowledge of understanding their specific circumstances is a clue to solution and our decision science has a similar principle to them on a hands-on approach.

In 2011, two other scholars argued that the world is getting better. First, Pinker (2011) gave numerous evidence that violence is decreasing throughout human history, demonstrating that modern society is in an era of expanding human rights that should be called a "rights revolution." Second, Kenny (2011) gave evidence on further social issues and claimed that the world is "Getting better." Following these books published in 2011, further publications including "The Big Ratchet" on agricultural production (DeFries 2014), "How Science Makes Us Better" (Shermer 2015), "Progress" in globalization (Norberg 2016), and "Enlightenment Now" (Pinker 2018) have provided more convincing evidence that the world is improving.

Of course, these achievements are the result of continuous efforts, and further stronger efforts are needed to make the world more sustainable. However, rather than a message that appeals to the negative emotion such as fear and threat that the world is facing a crisis, it is better to convey a positive and hopeful message that we can improve the world based on lessons learned from past successes. Negative messages can be effective for the purpose of drawing more attention to an issue, but may have the opposite effect for the purpose of persuading or changing behavior (Lang 2006). This is because the fear response arises from the negative messages leading to fight–flight or freeze reactions, which are useless in solving problems (Moser and Dilling 2004). Further, negative messages may diminish the beneficial effects of positive emotions associated with hope and consequently keep people away from the problem or even increase skepticism about the existence of the problem (Fischer et al. 2012; O'Neill and Nicholson-Cole 2009). Thus, negative messages may strengthen status quo bias (Samuelson and Zeckhauser 1988) or normalcy bias (Omer and Alon 1994). Moreover, when a negative message arouses fear, the neural signal may skip the cortex, which is linked to cognitive processes associated with creativity (McDonald 2018). This means that negative messages may prevent coming up with creative solutions for the problem.

We scientists need to avoid excessive fear messages, but that does not mean ignoring global issues. We instead believe education and hopeful messages are two effective factors in shaping public awareness and changing human behavior for solving the global issues such as climate change. Education can promote the rational thinking (Gigerenzer 2014, 2015), and can also debias positive illusions (Taylor and Brown 1994). Lee et al. (2015) showed that "educational attainment is the single strongest predictor of climate change awareness." However, in the top 100 universities and liberal arts colleges in the United States, the probability that a student takes at least one climate change course via the core curriculum is as low as 0.17. On the other hand, the public knows too little about the science of climate change, and political affiliation and political ideology had a large effect for climate change beliefs (Kahn et al. 2012; Hornsey et al. 2016). Thus, we need to advance education to change some conservative skepticism students and citizens about climate change. In this education, it is important to show hopeful pathways to mitigate and adapt to climate change because hopeful message with a concrete countermeasure is effective for leading behavior change (Fischer et al. 2012; O'Neill and Nicholson-Cole 2009). The hope for a better future not only plays as an important role for motivating people to participate in actions that contribute to solutions (Moser and Dilling 2004), but also affects the self-efficacy of people who believe that their actions affect the resolution of global issues such as the climate change (Armstrong et al. 2018). The same goes for solving many other issues presented in SDGs.

5.6 Evolution of Institutions and Knowledge Toward a Sustainable Future

We humans are the only species that developed sophisticated civilization on earth. Through this civilization process, humans have changed the global environment significantly. However, humans have not only continued to destroy nature, but have also made efforts to use it wisely and make it sustainable. Agriculture, first started in the fertile crescent, can be seen as the first attempt to use natural resources sustainably (Yahara 2011). In the fertile crescent, a balance between agricultural production and the natural ecosystems had been maintained until it was broken under the rapid population growth under modernization (Jaradat 1998). Agricultural production has enabled the establishment of a state with various institutions (Diamond 1997), and those institutions contributed to decrease violence (Pinker 2011). Also, the accumulation of knowledge associated with agriculture prompted the development of early scientific efforts including biology, humanity, mathematics, physics, and metaphysics. For example, Aristotle's Historia Animalium and Theophrastus's Historia Plantarum written in the fourth century BC were the first systematization of Zoology and Botany, respectively. In the latter, Theophrastus described the techniques of ancient Greeks to regenerate olives and other plants in a sustainable manner. Since the first civilization in the fertile crescent, humans have continually improved institutions and knowledge and this process can be viewed as cultural evolution (Henrich and McElreath 2003; Ridley 2016; Henrich 2017; Wilson 1975).

One of the most influential human-generated knowledge is Darwin's theory of evolution. It has enabled a unified understanding of the whole world of biodiversity, as well as an understanding of how the human body and mind are designed by natural selection. Furthermore, evolutionary theory has proved useful in understanding social transformation as cultural evolution. Biological evolution and cultural evolution consist of five comparable phases (Fig. 1.8). In the first phase, an individual in a biological population acquires a new mutation, and an individual in a society conceives a new idea. In the second phase, a new mutation is combined with existing mutations in the process of recombination, and a new idea is combined with existing ideas in the process of ideation, i.e., creation of an advanced idea by combination. In the third phase, recombination produces phenotypic changes of an individual, while creation of an advanced idea results in changes of various social elements including institutions, knowledge, technology, goods, arts, and language. These elements can be regarded as "social phenotypes." In the fourth phase, a particular phenotype increases in a biological population by natural selection, and a particular social phenotype spreads in a society by social selection. In the fifth phase, adaptive evolution takes place in a biological population and social transformation proceeds in a human community.

Adaptive evolution and social transformation have two important similarities. First, there is no ultimate goal in either process. Second, which phenotype is advantageous varies with time and space. On the other hand, social evolution is unique in that it is driven by human's ability to predict, design, and change the

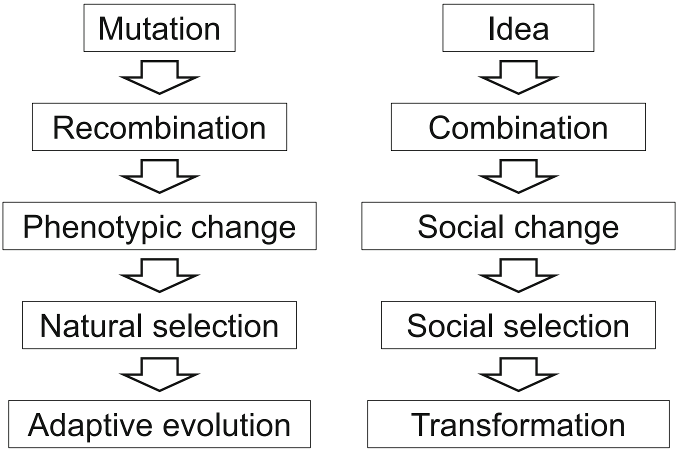

Fig. 1.8 Comparison of biological evolution and cultural evolution

future. Therefore, human societies are capable of realizing not only short-term adaptation to the current environment, but also long-term adaptation to future environmental changes. Social evolution is unique also in that it is driven not only by competition but also by the high degree of human cooperation. Consequently, social elements beneficial not only to individuals but also to society as a whole have been selected. These two uniquenesses have driven the process of continuous improvement in human society.

In this conceptual chapter, we argued that decision-making and adaptive learning through the IDEA cycle is effective to accumulate new knowledge and improve institutions under the cooperation of various stakeholders. We also argued that evolutionary biology or Darwin's idea is helpful to develop solution-oriented transdisciplinary science by integrating natural and social sciences. Based on a review of cognitive nature behind human conflicts and cooperation, we proposed a guideline for co-design in transdisciplinary projects. Further, we reviewed past successes in adaptive comanagement of natural resources and demonstrated that institutions, knowledge, and social ties are the keys to transforming our society toward a sustainable future. Finally, we proposed five strategies for transforming our society by connecting local and global efforts toward a sustainable future. We are surely facing global environmental problems, the global threats of emergent disease, the global risk of stagnation, and many other issues that are embedded in SDGs. At first glance, these problems seem difficult to solve. However, all of these problems are resolvable by improving social elements including institutions and knowledge and strengthening social ties. The key role of scientists in this resolution process is to integrate the various disciplines needed to solve problems, show potential solutions, and present specific options and pathways to a solution. Our efforts to systematize Decision Science by integrating natural, social, and humanity sciences using evolutionary theory as an integrator will contribute to this resolution process. We believe this is one of the most promising ways to support global efforts for transforming our society into a sustainable future.

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