博士論文

Trade-off mechanisms between forest ecosystem services and economic activities based on quantitative value assessment

——A case study in Wuyishan City, China

（定量的価値評価に基づく森林生態系サービスと経済活動の均衡メカニズム研究

——中国ウイ山市を事例として）

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Abstract

With a growing body of evidence confirming that ecosystem services support human well-being, trade-offs between ecosystem protection and economic decision-making have become popular topics. Currently, most countries and regions seek ecological and economic win-win situations instead of sacrificing ecology, as has been commonly done in the past. However, achieving a balance between the economy and ecology requires a robust quantitative assessment of various comprehensive indicators, such as ecological benefits, costs, and effects. Because of the difficulties of quantifying the economic contribution of ecosystems and their services, the trade-off mechanisms between ecology and the economy remain poorly understood. Uncertainty of these mechanisms causes unsatisfactory performance in ecological and economic decision-making and precludes the achievement of eco-protection despite the investment of sufficient funds. In this dissertation, we propose an innovative Management-Stakeholder-Investment (MSI) framework for key issues that are often difficult to quantify in ecological and economic trade-offs.

We comprehensively verified the effectiveness and applicability of the MSI framework by considering a typical ecological and economic conflict in southern China: the conflict between local eco-protection and tea cultivation in the Wuyishan area. We applied the MSI framework to quantify the effect of local ecological policies, the conflicts and needs of stakeholders, and the total economic contribution of the local ecosystems. First, using a variety of methods to quantify public feedback, combined with changes in land-use patterns, we developed a Public Feedback Method (PFM), confirmed the effectiveness of local eco-protection policies, and quantified the economic benefits of the polices, which were equivalent to $140 million. Second, by developing Subjective-Objective Combination Assessment (SOCA) methods for conducting the willingness analysis of stakeholder wishes, we calculated a compensation range for tea farmers from \$443/ha to \$2114/ha per year in the tea-removing area for ecological afforestation. Third, we developed the Public Appraisal Method (PAM) to account for the value of ecosystem services. In the Wuyishan area, the value of 28 types of ecosystem services was calculated, and the total value of ecosystem services provided by the local forests was calculated as approximately \$25.7 billion/year.

The MSI framework provides practical guidance for the trade-off process and is of great significance for exploring multi-dimensional trade-off mechanisms. A typical conflict between economic activities and ecological protection in the Wuyishan area permitted the practical verification of the MSI framework. We solved key difficulties in the local trade-off process between ecological protection and economic activity. Under the guidance of the MSI framework, this doctoral study has developed PFM, SOCA, and PAM—three new methods for separately quantifying policy effectiveness, stakeholder needs, and ecological value—to characterize the trade-off mechanisms between ecosystem services and economic activities. This study is thus of great significance for understanding the future coupling relationship between ecosystems and human well-being.

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Appreciate the love that supports me to harvest all my growth these years. Half of my achievements today are from this love, which brings me independence, courage, ability and diligence. My deepest gratitude is for the person:

Thank you for comforting me when I'm sad

Loving me when I'm mad

Picking me up when I'm down

Thank you for being my best friend and being around

Encouraging me when I need a shove

But most of all

Thank you for loving me for who I am

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List of Papers

Published:

1. **Chang, Y.X***., Yoshino, K., 2017. Theory of willingness to sell (WTS) to valuate ecosystem services in the contingent valuation method. Journal of Environmental Informatics. 29 (1), 53–60. **Impact Factor: 4.604**

2. **Chang, Y.X**., Zou, T.H., Yoshino, K*., Luo, S.Z., Zhou, S.G., 2019. Ecological policy benefit valuation based on public feedback: forest ecosystem services in Wuyishan nature reserve, China. Science of the Total Environment. 673, 622–630. **Impact Factor: 6.551**

3. **Chang, Y.X**., Zhang, Z.Y., Yoshino, K*., Zhou, S.G., 2020. Farmers' tea and nation's trees: A framework for eco-compensation assessment based on a subjective-objective combination analysis. Journal of Environmental Management. 269, 110775. **Impact Factor: 5.647**

4. **Chang, Y.X**., Zou, T.H., Yoshino, K*., 2020. A new public appraisal method for valuating ecosystem services: a case study in the Wuyishan area, China. Journal of Cleaner Production. 286, 124973. **Impact Factor: 7.246**

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5. **Chang, Y.X**., Zou, T.H., Zhang, Z.Y., Yoshino, K*., Zhou, S.G. A review on the quantitative value assessment in the trade-offs between ecosystem services and economic activities. To Ecosystem Services.

List of Abbreviations

CVM: Contingent Valuation Method

ERP: Environmental Risk Perception

MEA: Millennium Ecosystem Assessment

MSI: Management Stakeholder Investment

PAM: Public Appraisal Method

PEC: Public Expenditure Cost

RTTF: Returning Tea to Forest

SOCA: Subjective & Objective Combination Assessment

TCM: Traditional Comprehensive Method

TEEB: The Economics of Ecosystems and Biodiversity

WNNR: Wuyishan National Nature Reserve

WTA: Willingness to Accept

WTD: Willingness to depreciate

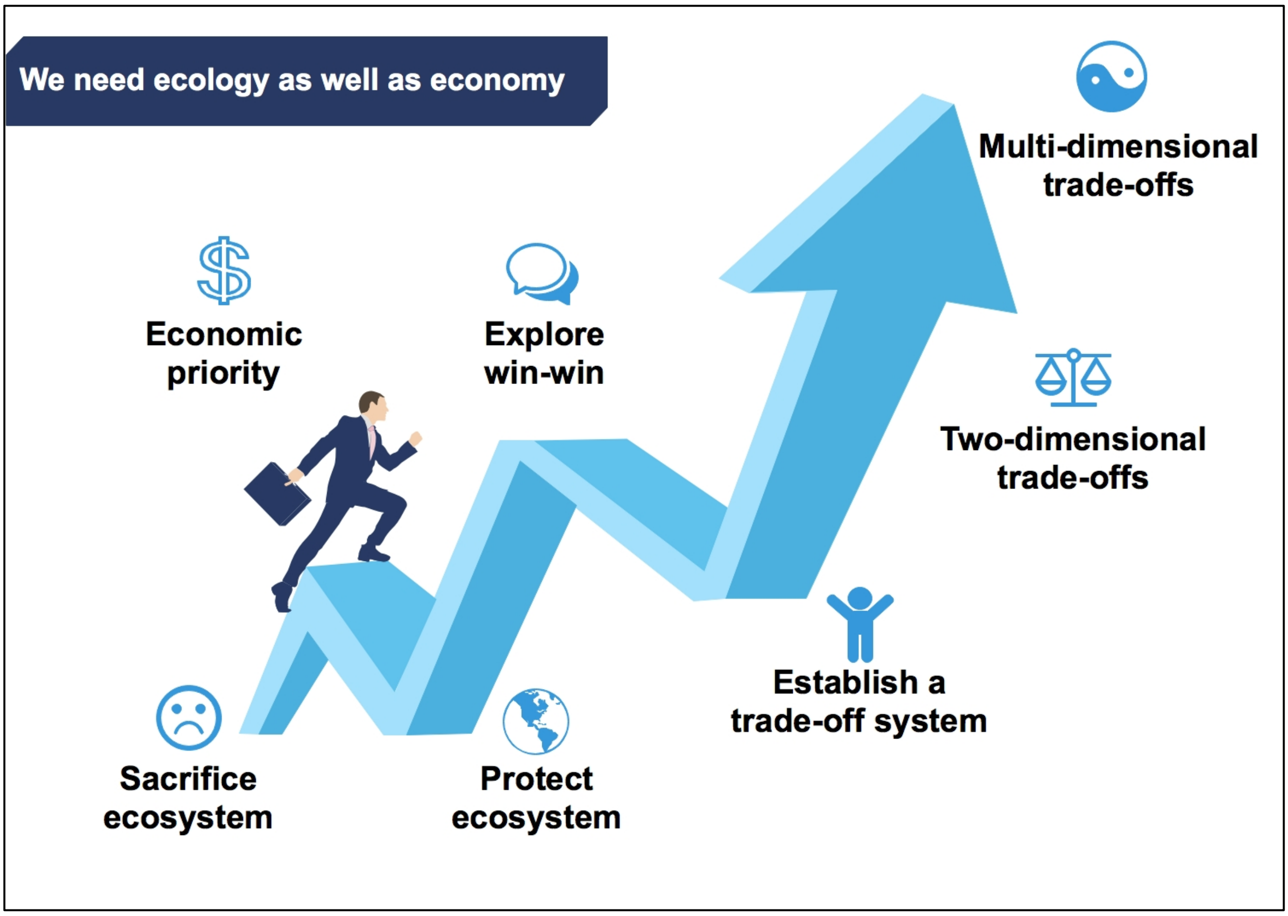
WTP: Willingness to Pay

WTS: Willingness to Sell

WTV: Willingness to Vote

Chapter 1 Introduction - A review on the quantitative value assessment in the trade-offs between ecosystem services and economic activities

Graphical Abstract 1



1.1 Abstract

Ecosystem services have been shown to support human survival and well-being. However, the demand for economic development often conflicts with the protection of ecosystems. Economic development produces direct visual benefits, while the benefits of ecosystem services are difficult to quantify intuitively. Consequently, the contributions of ecosystems to the trade-offs between ecology and economy are often underestimated. Humans tend to choose short-term intuitive benefits rather than potential long-term benefits. As a result, humans will need to pay more for reversing ecosystem damage in the future.

The trade-offs between ecology and economy via diverse quantitative assessments is key for maximizing benefits under limited conditions and resources. Therefore, the quantitative assessment of ecosystems and their services has become a hot topic. Furthermore, the trade-off process often involves more specific issues, such as policy decision-making, stakeholder conflicts, and eco-investment management. These specific issues are at the intersection of trade-offs between ecology and the economy, resulting in a more serious shortage of quantitative assessment methods.

This study reviews the development of the field of ecosystem services assessment, the methods and tools for the quantitative assessment of ecosystem services for trade-offs, and common cases of quantitative assessment in the trade-off process. Moreover, specific issues relating to policy decision-making, stakeholder conflicts, and eco-investment management in the trade-off process were summarized. Finally, Management-Stakeholder-Investment, a trade-off framework between ecology and the economy, was proposed. This study provides a critical summary of the quantitative assessment process related to ecosystem services in the trade-off process and explores future economic and ecological trade-off mechanisms.

1.2: Definitions and classifications of ecosystem services

It has been over 20 years since the publication of two seminal publications on ecosystem services: an edited book by Gretchen Daily (Daily, 1997) and an article in Nature (Costanza *et al*., 1997) by a group of ecologists and economists on the value of the world's ecosystem services. These two publications have been highly cited and have galvanized an explosion of research, policy, and applications of the idea (Costanza *et al*., 2017). Ecosystem services assessment is a growing field of research that focuses on the relationship between ecosystems and human well-being, and the literature on "ecosystem services" has grown exponentially since the 1990s (Costanza *et al*., 2017; Costanza and Kubiszewski, 2012; Droste *et al.*, 2018; McDonough *et al.*, 2017).

This field primarily focuses on understanding the functions and mechanisms of ecosystems, evaluating the benefits provided by ecosystems for human beings, and exploring the sustainable and long-term utilization of ecosystems. Since the late 1960s, numerous studies have discussed the dependence of human society on nature and have emphasized the ability of healthy ecosystems to provide important services for the economy and human well-being (Helliwell, 1969; de Groot, 1987; Odum, 1971; Westman, 1977). Socio-economic systems are highly dependent on the ecological systems in which they are embedded and from which they can derive several goods and services, including food, fibers, freshwater, clean air, pollination, and climate regulation (Daily, 1997). The number of scientific peer-reviewed articles containing the words "ecosystem service" in their titles has grown from less than 30 in the 1990s to over 6000 until 2020 (statistics by web of science). This rapidly growing body of literature includes analyses of all types of ecosystems and a wide range of topics, such as ecological analysis, valuation, biodiversity conservation, and management (Abson *et al*., 2014; Droste *et al*., 2018; Laura *et al.*, 2019).

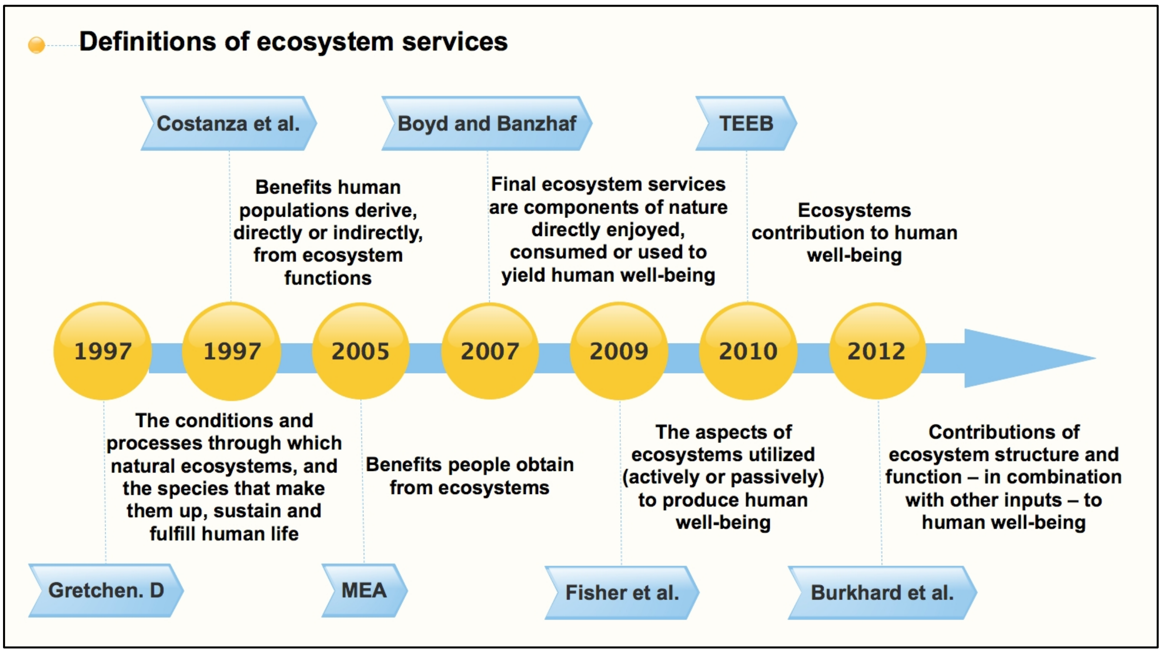


Figure 1.1 Definitions of ecosystem services

The definition of ecosystem services has also evolved in recent decades (**Figure 1.1**). The entire human economy is supplied (and is also constrained) by the availability of stocks of natural capital and flows of ecosystem services (Häyhä *et al*., 2011). The definition of natural capital derives from the notion of capital used in economics, in which capital refers to manufactured assets (e.g., machinery) used to produce flows of valuable goods and services (Costanza and Daly, 1992). Ecologists have further developed theoretical frameworks to explore the interaction between the environment and economy based on the concepts of stock and flow. Odum (1971, 1996) studied natural and human-dominated ecosystems composed of interconnected stocks and flows of both natural and human-driven resources. Costanza and Daly (1992) also proposed a distinction between stocks and flows by stating that stocks of natural capital generate a "natural income" in terms of flows of ecosystem services. Accordingly, natural capital can be defined as stocks of natural resources generating valuable flows of different types of ecosystem goods and services (Häyhä *et al*., 2011). The popularity of the concept has grown further through publication of the seminal Millennium Ecosystem Assessment (MEA, 2005) and research platforms, such as The Economics of Ecosystems and Biodiversity (TEEB, 2010), which have sought to mainstream ecosystem service valuation into decision-making (Laura *et al*., 2019).

The assessment of stocks and flows has also been developed to quantify how much stock humans have and how humans benefit from different flows; however, assessment ultimately depends on the classification and definition of these stocks and flows. The diversity of existing classifications of ecosystem services has led to difficulties and inconsistencies in comparisons between assessments (Fletcher *et al*., 2011; Camino *et al*., 2013). However, a single classification scheme is not applicable for all habitats or assessments (Costanza, 1997; Fisher *et al*., 2009). **Table 1.1** presents some of the international and Chinese mainstream ecosystem service classifications from the Millennium Ecosystem Assessment (MEA) (MEA, 2005), TEEB (TEEB, 2010), CICES (Haines-Young and Potschin, 2011), and EEA (EEA, 1998) as well as from studies by Ouyang *et al.* (1999), Fu *et al*. (2017), and Xie *et al*. (2015). Diverse ecosystems result in different service classifications; thus, maintaining the structure and diversity of ecosystems is critically important for the sustainable management of human activities (de Groot *et al*., 2003; Ekins *et al*., 2003; Folke *et al*., 2011).

Table 1.1 Classifications of ecosystem services

	MEA	**TEEB**	**CICES**	**EEA**	**Ouyang, Z.Y.**	**Fu,B.J.**	**Xie,G.D**
Provisioning	Food	Food	Terrestrial plant and animal	Fresh water	Agricultural products	Food	Food production
	Fresh water	Water	Freshwater plant and animal Potable water	Materials supply	Water resources	Freshwater	Water resources
	Fiber	Raw materials	Marine plant and animal	Energy	Forestry products	Wood and fiber	Raw material production
	Ornamental resources	Ornamental resources		Others	Animal husbandry products		
	Biochemicals	Medicinal resources			Fishery products		
	Genetic resources	Genetic resources			Ecological energy	Genes and biological resources	
					Others		
Regulating	Climate regulation	Climate regulation	Atmospheric regulation	Biophysical regulation	Climate regulation	Climate change mitigation Regional microclimate regulation	Climate regulation
	Water regulation	Regulation of water flows	Mass flow regulation Water flow regulation	Flow regulation	Water conservation Water purification	Flood control	Hydrological regulation
	Water purification and waste treatment	Waste treatment	Bioremediation Water quality regulation Dilution and sequestration of wastes	Physical and chemical regulation	Flood regulation	Water quality regulation	Purification function
	Air quality regulation	Air quality regulation	Air flow regulation	Abiotic regulation	Air purification Oxygen release	Air quality regulation	Gas regulation
	Disease regulation	Biological control	Pest and disease control				
	Pollination	Pollination	Gene pool protection				
	Erosion regulation	Erosion prevention	Lifecycle maintenance and habitat protection		Windbreak and sand fixation Soil conservation Carbon sequestration	Erosion regulation	
	Natural hazard regulation	Moderation of extreme events				Natural hazard regulation	
	Pest regulation	Maintenance of soil fertility	Pedogenesis and soil quality regulation			Pest control	
Supporting	Soil formation	Maintenance of genetic diversity					Soil conservation
	Nutrient cycling	Maintenance of life cycles of migratory species					Maintenance of nutrient cycling
	Primary productivity						Maintenance of biodiversity
Cultural	Spiritual and religious values	Spiritual experience	Spiritual	Spiritual values	Natural landscape	Leisure and entertainment	Aesthetic landscape
	Cultural heritage values					Cultural heritage	
	Cultural diversity					Cultural diversity	
	Sense of place						
	Aesthetic values	Aesthetic	Aesthetic, heritage	Aesthetic values			
	Recreation and ecotourism	Opportunities for recreation and tourism	Recreation and community activities				
	Social relations						
	Inspiration	Inspiration for art	Information and knowledge				
	Knowledge systems	Information for cognitive development					
	Educational values						

1.3 Developments in the quantitative assessment of ecosystem services

A large and rapidly growing body of research seeks to identify, characterize, and value ecosystem goods and services—that is, the benefits that ecosystems provide for people (MEA, 2005). The development of decision-support tools that integrate ecology, economics, and geography to support decision-making is a recent technique that has been used to achieve these goals (Ruhl *et al*., 2007; Daily *et al*., 2009). Current tools range from simple spreadsheet models to complex software packages. Through literature reviews and discussions with 77 colleagues across the academic, public, private, and NGO sectors (Kenneth *et al*., 2013), 17 tools that assess, quantify, model, value, and/or Ep ecosystem services have been developed (**Figure 1.2**). This list of tools excluded 1) mapping of ecosystem services (Egoh *et al*., 2012; Martinez and Balvanera, 2012), 2) conservation planning or optimization tools (e.g., C-Plan, Pressey *et al*., 2005; Nature Serve Vista, Natureserve, 2013), 3) integrated models that are not directly linked to ecosystem services (e.g., Landscape Toolkit, LsT, Bohnet *et al*., 2011) and hydrological process models (e.g., Soil and Water Assessment Tools (SWAT, Arnold and Fowler, 2005), 4) one-time applications (e.g., Maes *et al*., 2012, Advanced Terrestrial Ecosystem Analysis and Modeling, ATEAM, Schroter *et al*., 2005), 5) tools for single landscape types (e.g., CITYGreen, American forest, 2002), and 6) databases for users to assess non-market valuation studies.

Among these assessment tools, ESR (Ecosystem Servicces Review) and Co$ting Nature are used for ecosystem services impact screening; ARIES (ARtificial Intelligence for Ecosystem Services), EcoAIM (Ecological Asset Inventory and Management), EcoServ, Envision, EPM (Ecosystem Portfolio Model), ESValue (Ecosystem Service Value), InFOREST, InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), LUCI (Land Utilization and Capability Indicator), MIMES (Multi-scale Integrated Models of Ecosystem Services), and SolVES (Social Values for Ecosystem Services) are used for landscape-scale modeling and mapping; EcoMetrix and LUCI are used for site-scale modeling; EcoAIM, ESValue, and SolVES are used for nonmonetary valuation; and NAIS (Natural Assets Information System), Ecosystem Valuation Toolkit, and Benefit Transfer and Use Estimation Model Toolkit are used for monetary valuation (Kenneth *et al*., 2013).

Ecosystem Services Review
http://www. wri.org/ (World Resources Institute (WRI), 2012)
Publicly available, spreadsheet-based process to qualitatively assess ecosystem services impacts
ESR
Qualitative

Integrated Valuation of Ecosystem Services and Tradeoffs
http://www. naturalcapitalproject.org, (Kareiva et al., 2011; Tallis et al., 2013)
Open source ecosystem service mapping and valuation models accessed through ArcGIS
InVEST
Quantitative, uncertainty through varying inputs

Artificial Intelligence for Ecosystem Services
http://www.ariesonline.org (Bagstad et al., 2011; Villa et al., 2011)
Open source modeling framework to map ecosystem service flows; online interface and stand-alone web tools under development
ARIES
Quantitative, uncertainty through Bayesian networks and Monte Carlo simulation

Polyscape
(formerly Polyscape), http://www. polyscape.org (Jackson et al., 2013)
Open source GIS toolbox to map areas providing services and potential gain or loss of services under management scenarios
LUCI
Quantitative, currently does not report uncertainty

Multiscale Integrated Models of Ecosystem Services
http://www. afordablefutures.org
Open source dynamic modeling system for mapping and valuing ecosystem services
MIMES
Quantitative, uncertainty through varying inputs (automated)

EcoServ
(Feng et al., 2011)
Web-accessible tool to model ecosystem services
EcoServ
Quantitative, uncertainty through varying inputs

Co$ting Naure
http://www1.policysupport.org/cgi-bin/ecoengine/start.cgi?project=costingnature
Web-accessible tool to map ecosystem services and conservation priority areas
Co$ting
Quantitative

Social Values for Ecosystem Service
http://solves.cr.usgs.gov (Sherrouse et al., 2011)
ArcGIS toolbar for mapping social values for ecosystem services based on survey data or value transfer
SolVES
Quantitative, no explicit handling of uncertainty

Envision
http://envision.bioe.orst.edu (Guzy et al., 2008)
Integrated urban growth-ecosystem services modeling system; has used external models, including InVEST, or created new ecosystem service models as appropriate
Envision
Quantitative

Ecosystem Portfolio Model
http:// geography.wr.usgs.gov (Labiosa et al., 2013)
Web-accessible tool to model economic, environmental, and quality of life impacts of alternative land-use choices
EPM
Quantitative

InFOREST
http://inforest.frec.vt.edu/
Web-accessible tool to quantify ecosystem services in Virginia
InFOREST
Quantitative

EcoAIM
(Waage et al., 2011)
Proprietary tool for mapping ecosystem services and stakeholder preferences
EcoAIM
Quantitative

ESValue
(Waage et al., 2011)
Proprietary tool for mapping stakeholder preferences for ecosystem services
ESValue
Quantitative, uncertainty through Monte Carlo simulation

EcoMetrix
http://www.parametrix.com (Parametrix, 2010)
Proprietary tool for measuring ecosystem services at site scales using field surveys
EcoMetrix
Quantitative

Natural Assets Information System
http:// www.sig-gis.com (Troy and Wilson, 2006)
Proprietary valuation database paired with GIS mapping of land-cover types for point transfer
NAIS
Quantitative, reports range of values

Ecosystem Valuation Toolkit
http://www. esvaluation.org (Ecosystem Valuation Toolkit, 2012)
Subscription-based valuation database paired with GIS mapping of land-cover types for point transfer
EVT
Quantitative, reports range of values

Benefit Transfer and Use Estimating Model Toolkit
http://www.defenders.org (Loomis et al., 2008)
Publicly available spreadsheets, use function transfer to value changes in ecosystem services in the U.S.
BT&UEMT
Quantitative, uncertainty through varying inputs

Figure 1.2 Ecosystem service assessment tools

1.4 Diversified quantitative assessment in the trade-off process

The trade-off process must be established based on quantitative assessment, and the trade-off scheme can be obtained by comparing various quantitative results. Current quantitative assessments of ecosystem services are divided into two categories: physical quantity assessment and monetary quantity assessment. Physical quantity assessment primarily refers to quantifying the actual physical flows of ecosystem goods and services (e.g., tons of food and timber produced or tons of CO_2 absorbed) (Burkhard *et al*., 2012; Kandziora *et al*., 2013; Vihervaara *et al*., 2010ab). Monetary quantity assessment primarily refers to the amount of monetary value; that is, how much monetary value an ecosystem provides (e.g., monetary value of food production in an area or tourism resources). Physical quantity assessment is important for the determination of ecological risk and sustainability, while monetary value is generally considered an important prerequisite for environmental management, economic decision-making, and ecological trade-offs. In addition, as a complement to market-based valuation approaches, other types of comprehensive indicators have been used for quantitative analysis (Brown and Ulgiati, 1999; Jørgensen, 2010; Müller, 2005; Müller and Burkhard, 2012; Odum, 1996; Ulgiati *et al*., 2011ab; Wackernagel *et al*., 1999).

The ISI Web of Science databases on June 22, 2020 were searched, and all peer-reviewed journal articles written in English were considered. Search string words were “ecosystem service* OR ecosystem services” AND (trade-off* OR trade off* OR tradeoff* OR trade-offs* OR trade offs* OR tradeoffs*). The operation was set to include keywords in the title to refine the most relevant articles more accurately. In total, 198 articles were screened from 2010 to 2020. I first read titles and abstracts to identify trade-off and mitigation approaches for discussions and then select appropriate papers. I then read the full text of each article and documented: (1) the purpose of the ecosystem service trade-offs; (2) the object of the ecosystem service trade-offs; and (3) hot topics of ecosystem service trade-offs. These articles were organized into **Figure 1.3**.

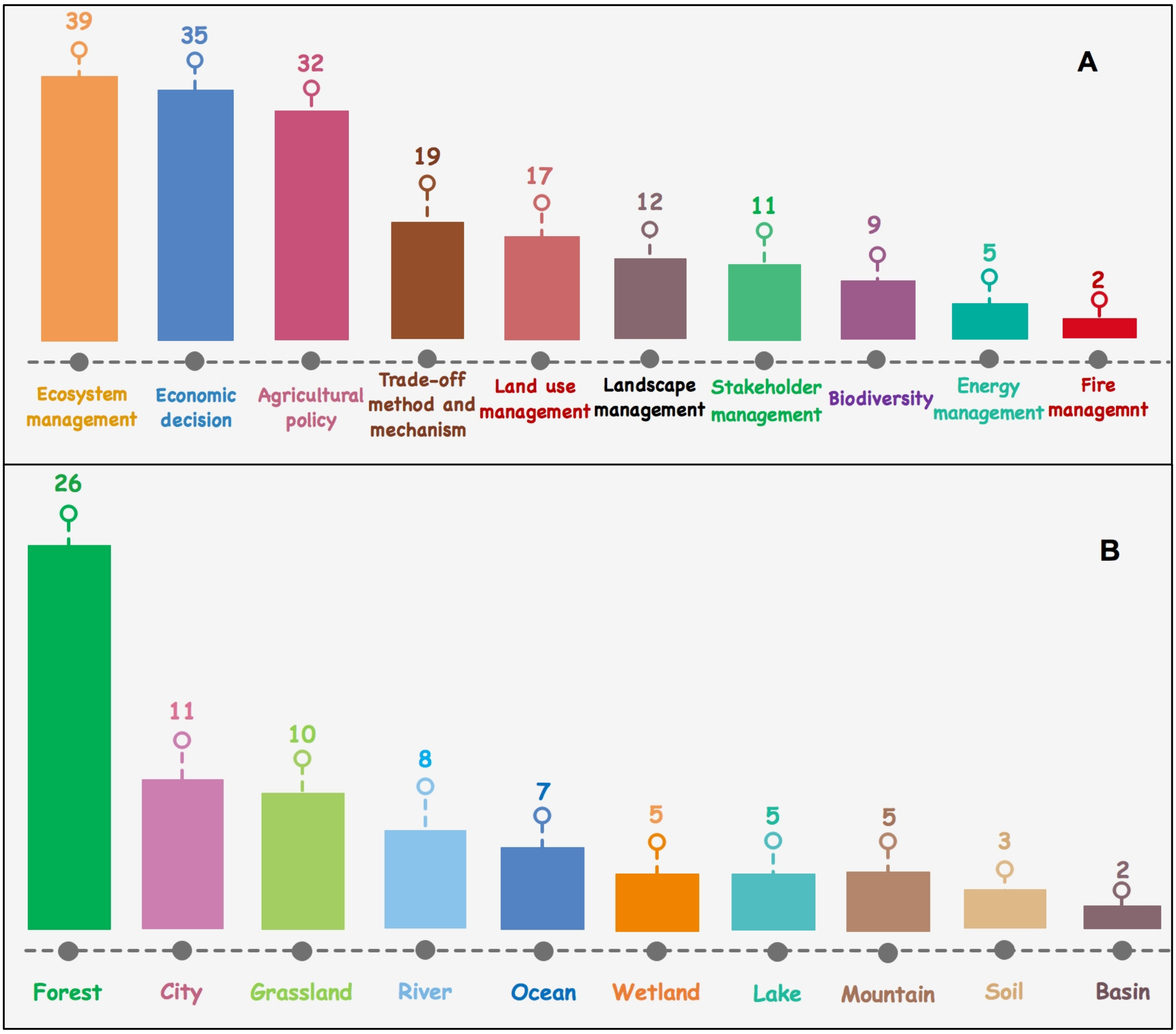


Figure 1.3 Classification and statistics of previous studies. Article classification. **A** is classified according to the research content. **B** is the specific research object (ecosystems).

1.4.1 Management - Ecological policy and decision making

In ecosystem service trade-offs, the most studied subject over the past ten years was related to management, which we defined as ecological management in this study. These studies usually focused on examining ecosystem trade-offs for management decision-making. Subjects related to ecological management primarily included ecosystem management (Villasante *et al*., 2016), economic decision-making (Carpentier *et al*., 2017), agricultural policy (Verhagen *et al*., 2018), land-use management (Sun and Li., 2017), landscape management (Dennis and James, 2017; Plieninger *et al*., 2019), stakeholder management (Maass *et al*., 2016), energy management (Hanes *et al*., 2017), and fire management (Mavsar *et al*., 2013) (**Figure 1.3 A**). Ecological management may be the hottest research topic in the trade-off studies over the past decade. More countries and regions have begun to manage ecosystems consciously and have considered ecosystem services in the process of economic decision-making. Additional trade-off studies focusing on ecological management are likely to be more conducted in the future. To achieve good ecological management is an important channel of the balance between ecology and economy. A reasonable decision on the trade-offs will be conducive to the sustainable development of ecological management. With the emergence of some new infectious diseases, the coupling between ecosystems and human society will become more complex. Therefore, the subjects related to ecological management may receive increased attention in more countries and regions in the future.

1.4.2 Stakeholder - Conflict of demand differences

In **Figure 1.3 A**, there were 11 articles directly related to stakeholders (Butler *et al*., 2013; King *et al*., 2015; Maass *et al*., 2016; Wam *et al*., 2016; Hossu *et al*., 2019), and we also found that a large number of trade-off studies were indirectly related to the subject of stakeholders (Turkelboom *et al*., 2018; Soto *et al*., 2018). Especially in the 32 agricultural policy-related studies, most were related to local farmers (Vaast and Somarriba, 2014). These studies included protective agricultural models, agricultural subsidies, agricultural intensification, farmland protection, agricultural land use, agricultural ecosystem, orchard economy, agricultural production, food security, rural communities, and agricultural water use (Vidal-Legaz *et al*., 2013; Rabotyagov *et al*., 2016; Verhagen *et al*., 2018; Samnegård *et al*., 2019). The trade-offs between agricultural policy and ecosystem services have been a hot research topic over the past decade. The main reason for this interest is that agricultural development generates a direct demand for land use, and agriculture can have substantial impacts on ecosystems by affecting soil conditions, water quality, and flood regulation capacity. Farmers are not only the backbone of agriculture but they are also direct stakeholders of agricultural policies. Any adjustment and change of agricultural policies will produce major changes in the income—and even lifestyle—of local farmers. Research on stakeholders may continue to grow and deepen in the field of ecosystem service trade-offs related to agriculture in the future. Many unresolved issues remain on how to coordinate stakeholders and eco-protection trade-offs.

1.4.3 Investment - Ecological value accounting

Financial support is important for maintaining ecosystem health, which is defined as ecological investment in this study. The concept of ecological investment broadly includes the state, organization, and individual's expenditure on all ecological management policies, ecological restoration and maintenance, and investment in ecological products. Ecological investment is directly related to the realization of ecosystem service trade-offs (Duke *et al*., 2014; Chen *et al*., 2017), and the results of ecosystem trade-offs will simultaneously determine the usage of ecological investment. The ecological investment value of ecosystems can be reflected by the general attention that ecosystems receive, excluding the impact of special disasters on specific ecosystems. The number of studies of different ecosystems relating to ecosystem services trade-offs is shown in **Figure 1.3 B**. We found that the number of forest-related studies was the highest among all ecosystems over the past decade, which reflects the importance of forests (Duncker *et al*., 2012; Lafond *et al*., 2017; Albrich *et al*., 2018). Forest is an effective source of ecosystem services (Pang *et al*., 2017). The stable and diverse economic value of forest itself makes it a hotspot for international eco-protection research. However, the determination and distribution of ecological investment remain uncertain. One of the key difficulties is that the investment value of different ecosystems is not clear. We consider that the value accounting of ecosystem services may be an effective way of providing an investment value for trade-offs. We predict that the assessment of ecosystem investment value and the method of distribution will become a new research issue, especially problems related to forest protection, and will remain a focus of the international community.

1.5 MSI framework integrating quantitative assessment and trade-offs

The substantial contributions of ecosystem services to the sustainable well-being of humans and nature should feature prominently in economic theory and practice (Costanza *et al*., 2017). We propose a trade-off framework between ecosystem services and economic activities, which we call the "Management-Stakeholder-Investment" (MSI) trade-off framework (**Figure 1.4**). The MSI trade-off framework takes the most concerning management, stakeholder, and ecological investment issues as the core. MSI integrates quantitative assessment and provides an operational framework for balancing ecological protection and economic activities. Investment supports management and stakeholder activities simultaneously. Management makes instructions for stakeholders and decisions on the distribution of ecological investment. Stakeholders then provide feedback on the management effect and contribute to ecological investment. Thus, the complete coupling cycle among the three elements of MSI determines the whole trade-off system.

Different quantitative assessment metrics are required for different positions of the MSI framework. First, indicators between management and stakeholder are needed to quantify the management effect through the analysis of instructions and feedback. Second, the financial support and the contribution of stakeholders between stakeholders and investments need to be analyzed; in addition, stakeholder issues need to be assessed. Furthermore, indicators need to be established to quantify the economic costs and benefits of local eco-protection. Third, analysis of the financial support and its allocation between investment and management are needed. Quantitative evaluation of the investment value of eco-protection targets can be used to determine the ecological costs and benefits of local eco-protection. Finally, the trade-off scheme can be established by comparing economic costs with ecological costs and economic benefits with ecological benefits.

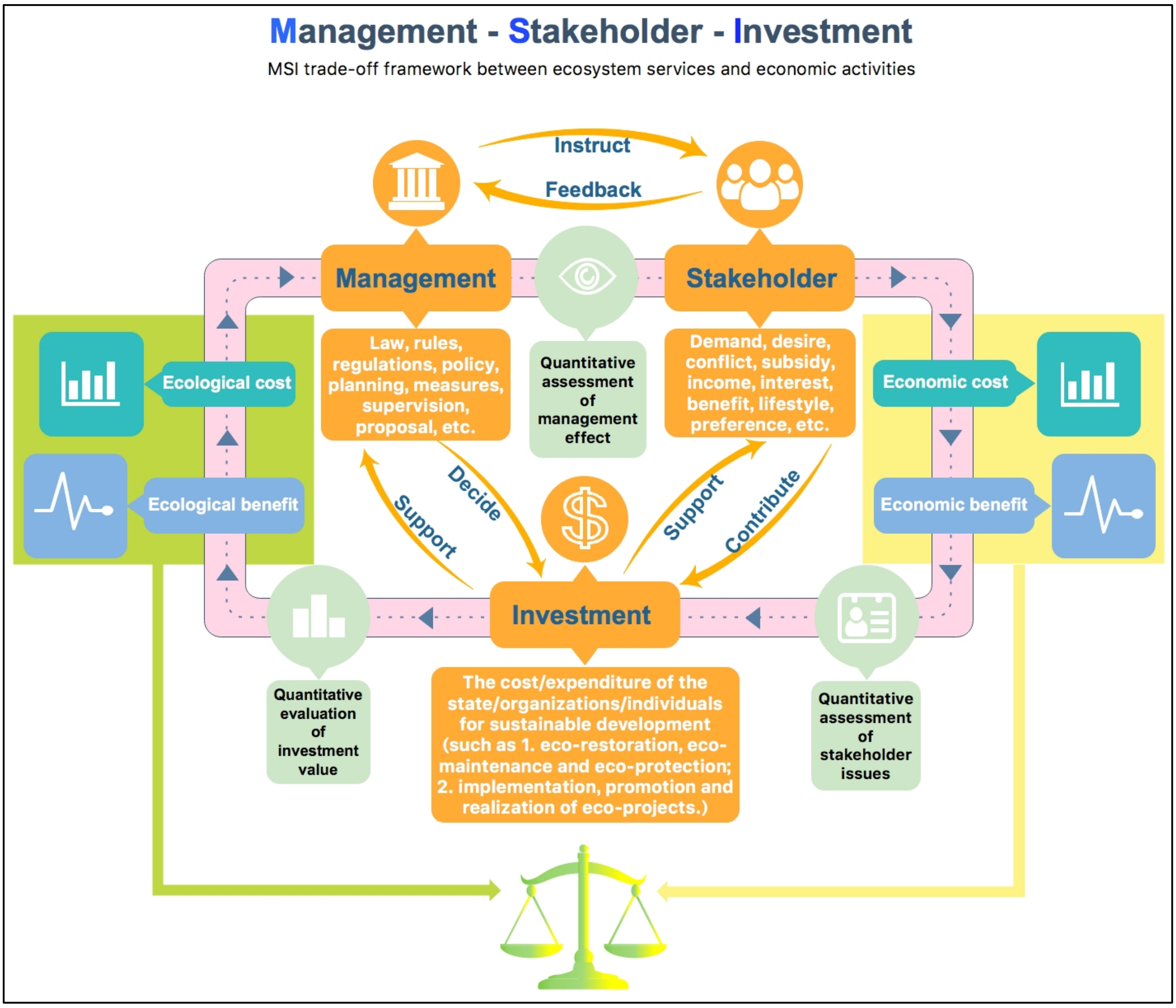


Figure 1.4 Management-Stakeholder-Investment (MSI) trade-off framework

1.6 Summary of doctoral research works

This doctoral project aims to verify the MSI framework and further explain the MSI mechanisms by studying a practical case of trade-off between ecological protection and economic activities. Taking Wuyishan City in China as a case, this study focuses on the impact of the local eco-protection policy "Returning Tea to Forest" (RTTF) started from 2008, analyzes the trade-off process from three perspectives of management, stakeholders and investment. Under the MSI framework, we quantitatively evaluate the management issues, stakeholder issues and investment issues respectively, to completely implement and verify the MSI evaluation process. Finally, we explain the MSI trade-off mechanisms through Wuyishan practical experiences.

1.6.1 Core issues to be solved

Three core issues need to be solved regarding the trade-offs between local ecological protection and economic activities (**Figure 1.5**):

1) Management. As for any typical eco-compensation policy, the RTTF in the Wuyishan area presents a series of unresolved conflicts. The RTTF ecological policy has been implemented since 2008. What has been the impact of this policy over the past decade? What do local people think of RTTF? Is RTTF effective? Is the local forest effectively protected? Does this policy need to be adjusted in the future? How should adjustments be made? This issue is related to the effectiveness of local ecosystem protection.

2) Stakeholder. Tea farmers primarily affected by the RTTF ecological policy were generally not enthusiastic about participating because of the uncertain and unsatisfactory eco-compensation. RTTF did not provide a detailed eco-compensation scheme for tea farmers, and decisions on the eco-compensation scheme were ultimately made by the local government by considering the requirements of both the markets and local needs. How should an ecological compensation scheme be designed so that it meets both the needs of farmers and follows the rules of the market? This issue is related to the fairness of local ecosystem protection.

3) Investment. A fundamental issue of all management activities, including both ecological protection and economic development, is financial support. How should the supply capacity of local ecosystem services from both the perspectives of ecology and economics be quantitatively valuated? How much economic value can the ecosystem provide locally? How much investment is reasonable for local ecological protection and maintenance? This issue is related to the sustainability of local ecosystem protection.

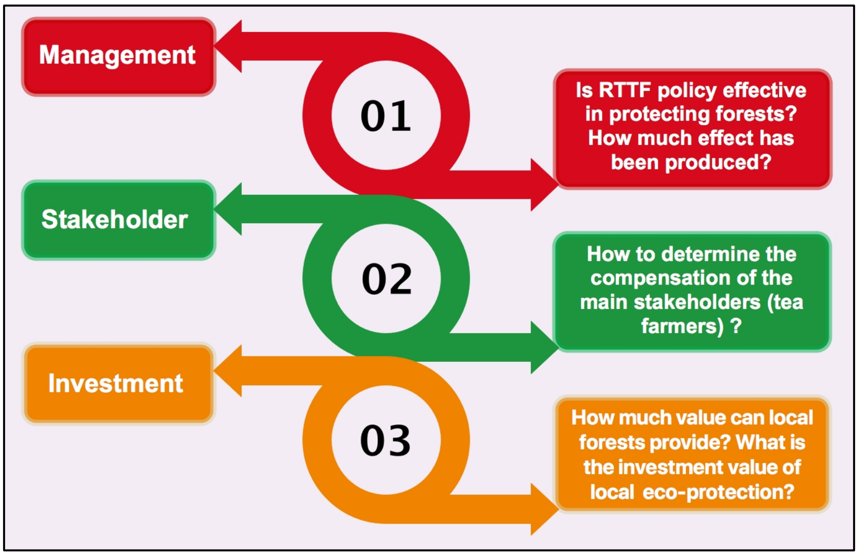


Figure 1.5 Core issues of trade-off between ecology and economy in the Wuyishan City

1.6.2 Research objectives

The purpose of this study is to explore the trade-off mechanism between ecological protection and economic activities through various forms of quantitative assessment. We propose the Management-Stakeholder-Investment (MSI) trade-off framework to aid the resolution of conflicts between ecological protection and economic activities based on the quantitative assessment of items under management, stakeholder, and investment. Taking the conflict of the agricultural economy and ecological protection in Wuyishan area as a case study, this study focuses on: 1) quantification of the effectiveness of local management policies; 2) quantification of the needs of stakeholders; and 3) quantification of the total economic value provided by local ecosystems. This study generated creative solutions for many problems that were difficult to quantify, provided a detailed example for how specific problems in the process of balancing eco-protection and tea cultivation could be solved, and greatly contributed to our understanding of the mechanisms underlying trade-offs between ecological protection and economic activities.

1.6.3 Research contents

This study proposes a complete trade-off framework and summarizes the trade-off mechanisms between ecosystem services and economic activities. The most concerning problems of forest ecosystems and agricultural development in the trade-off studies are selected as case studies, and these problems are solved by addressing the most urgent practical difficulties in local ecosystem protection.

The structure of this doctoral project is divided into six chapters. Chapter 1 reviews the progress, methods and challenges of the trade-off studies between ecological protection and economic activities, and puts forward the MSI trade-off framework of this study. Chapter 2 introduces the local information of the study site Wuyishan area. Chapter 3 focuses on the management issues in MSI framework, which quantitatively evaluates the actual effect of RTTF policy. Chapter 4 focuses on the stakeholder problem in MSI framework, which quantitatively evaluates the eco-compensation standards for tea farmers. Chapter 5 focuses on the investment issues in MSI framework, which quantitatively evaluates the huge value provided by local ecosystems and reveals the potential investment value of this area in the future. Chapter 6 summaries and explains the MSI trade-off mechanisms and extends future works. The research framework and technical route flowchart are summarized in **Figure 1.6**.

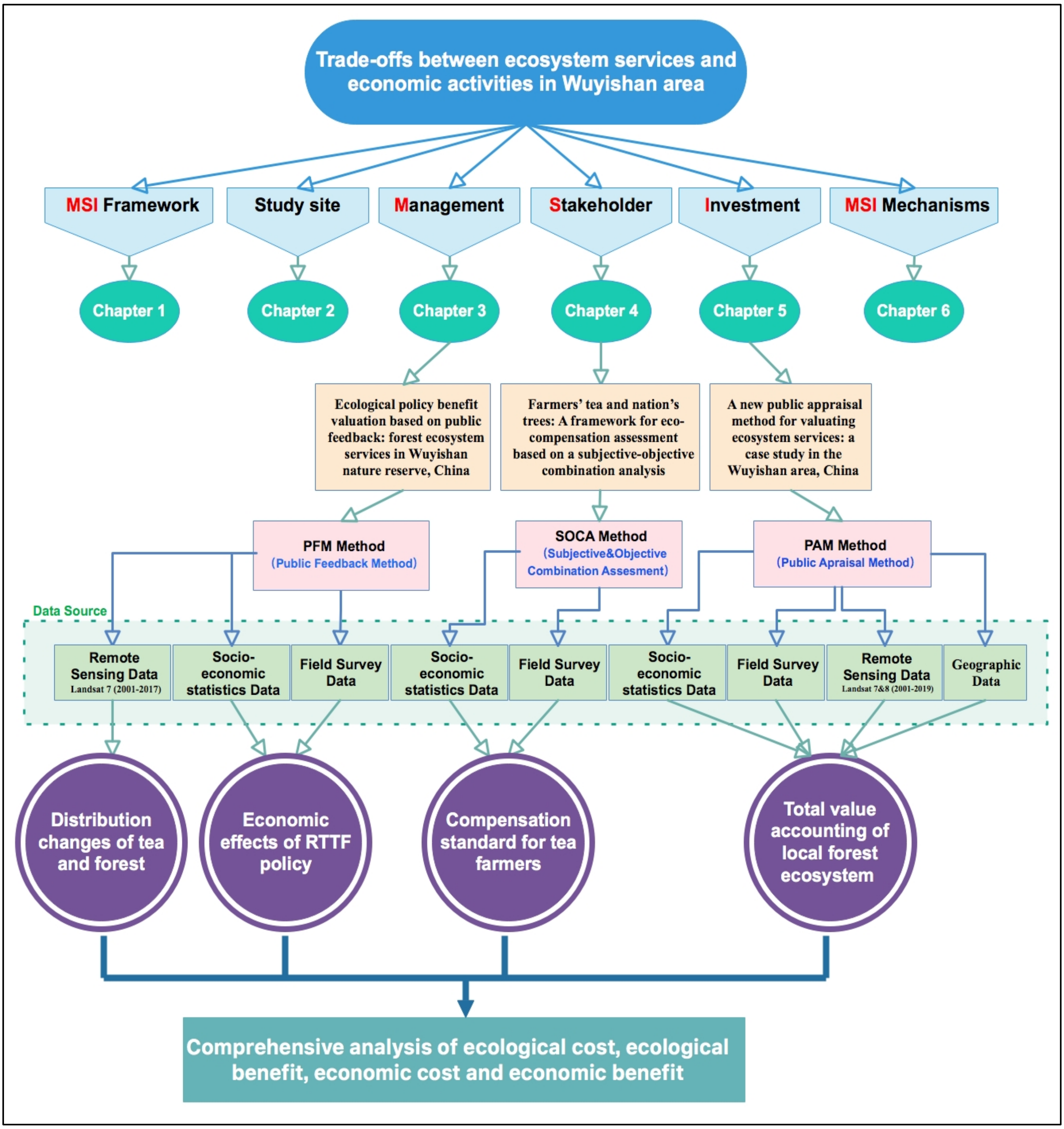


Figure 1.6 Research framework and technical route

1.7.4 Research methodology

It is a common practice for researchers to select an assessment method to quantify the status, function or value of ecosystem services. However, single method and limited data often weaken the generality of the assessment results. Ecosystem services involve many fields, and the relationship between ecosystem services and human well-being is more complex, which leads to the need for multi angle analysis in the research process. In this study, we conducted multidimensional comprehensive analysis to flexibly design the combination of different data and methods according to the evaluation purpose (**Figure 1.7**), and expect to get the results as multi-dimensional as possible.

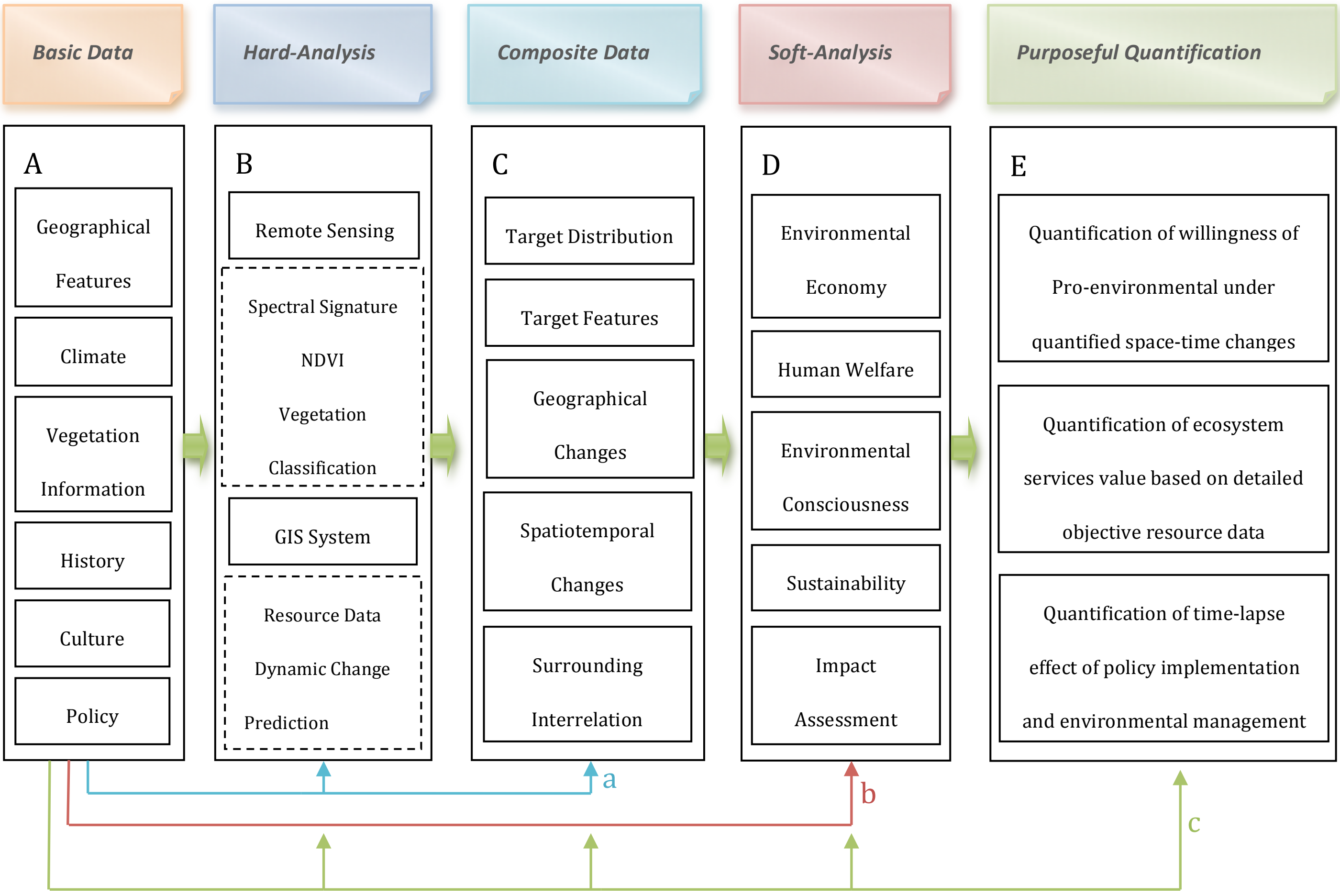


Figure 1.7 Methodological framework. This framework integrated basic database and analysis paths. Path a is the common process using hard techniques and path b is the research process based on soft

techniques. Path c is a complete chain from A to E including hard and soft processes which fused all objective and subjective evaluating factors. Composite results shown in E could be deduced.

This doctoral project adopted the concept of comprehensive analysis methodology. Three different quantitative evaluation methods were designed separately by combining multiple data analysis: 1) Public Feedback Method (PFM); 2) Subjective & Objective Combination Assessment (SOCA); and 3) Public Appraisal Method (PAM). The PFM was designed to evaluate the effect of ecological policy, and quantitative effect was evaluated based on different perspectives of the public. The SOCA was designed for the compensation of stakeholders, and the reasonable compensation interval was calculated through the double quantitative process of subjective willingness and objective correction. The PAM was designed for the total value of ecosystem services, and the total economic value was calculated through the multi-dimensional evaluation of the public.

Chapter 2 Study site – Wuyishan City: a typical case of trade-off between ecology and economy

2.1 Regional information

Wuyishan, a famous mountain is located at the junction of Jiangxi and Fujian provinces in Southeast China. With a variety of wild animals and beautiful natural environment, Wuyishan area is a famous scenic spot in China and one of the first batches of national key scenic spots. Wuyishan area has a typical, large-scale and well-preserved subtropical forest system in the same latitude zone of the world. Evergreen broad-leaved forest is the main vegetation type in this area and a large number of rare tree species have been preserved, such as *Pseudotaxus chienii*, *Ginkgo biloba* and *Taxus chinensis*. With 3,728 known plant species and 5,110 known animal species, Wuyishan area is often referred to as a rare and endemic wildlife gene pool (Han and Li, 2019).

Due to the abundant natural resources in Wuyishan area, a national nature reserve has been set up inside the Wuyishan area. Wuyishan National Nature Reserve (WNNR) is an essential global biodiversity conservation area, with a total area of 565 km^2 (He *et al*., 2018a). As the first national key nature reserve in China, the WNNR is also highly valuable in terms of biodiversity (Liu *et al*., 2015). In 1987, UNESCO listed WNNR as a member of the World Conservation Network (He *et al*., 2018b), which is the only Chinese site designated as a UNESCO biosphere reserve, as well as a World Mixed Natural and Cultural Heritage Site (Chen *et al*., 2017).

In terms of the administrative division, Wuyishan area is mainly located in Fujian Province, under the jurisdiction of Wuyishan City. Wuyishan City mainly governs the whole Wuyishan ecosystem including the WNNR. Wuyishan City is located in northern Fujian Province, with a humid climate in the middle subtropical monsoon region (**Figure 2.1**). The total area is 2,813 km^2, with a total population of 241,641 and 71,686 households (2019). Wuyishan City has 79.2% forest coverage, 2,120 km^2 of commercial forestry land, and over 50 rare tree species. The total timber volume is 11.6 million m^3 and the annual timber output is 100,000 m^3. Also, Wuyishan City is famous for tea production, being home to over 100 km^2 of tea gardens, with an annual output of 19,200 tons and an economic output of $312 million. Wuyishan City is home to nearly 80,000 tea producers and more than 710 tea factories. In 2018, the city's GDP was approximately $2.6 billion; it is also famous for tourism, with over 15 million visiting tourists and total tourism revenue of approximately $4.6 billion. The main types of local industries are listed in the **Table 2.1**.

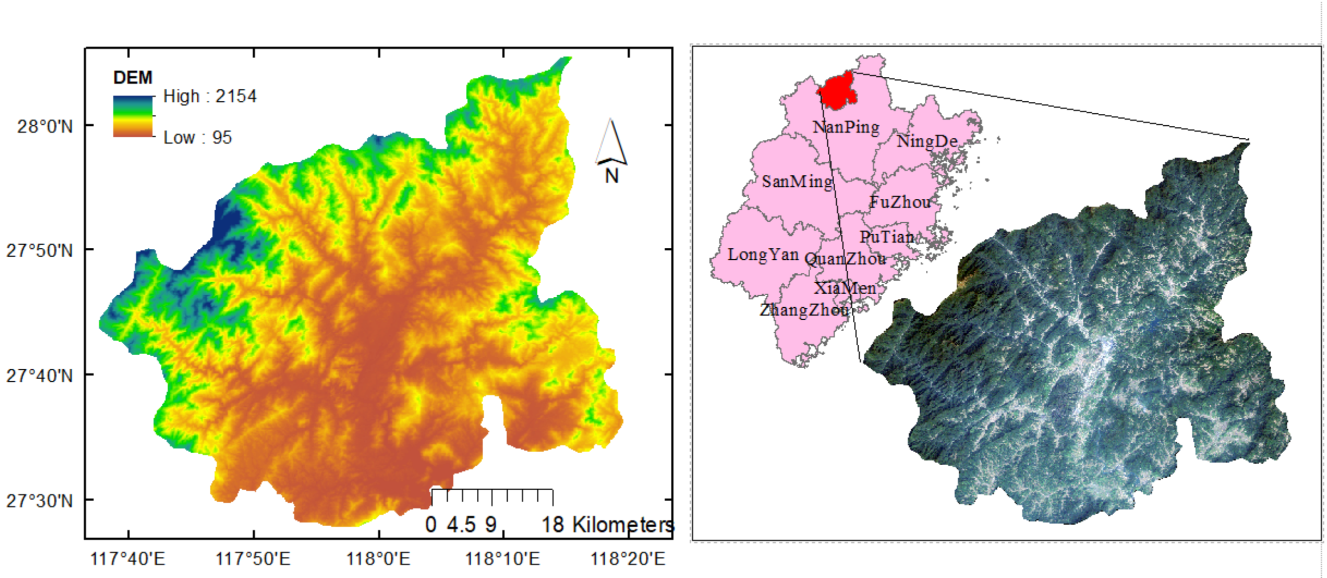


Figure 2.1 Study site map: Wuyishan City. (Left: The digital elevation model with spatial resolution of 90m; Right: A true color composite image of Landsat 8 acquired on October 25, 2017)

Table 2.1 Industry information in Wuyishan City

Industry type	**Primary industry**	**Secondary industry**	**Tertiary industry**
Industry content	Grain and tea planting	Wine, beverage and tea industry, food processing industry, textile and clothing, wood processing	Tourism
Industrial proportion (2019)	13.4%	39.6%	47%

2.2 Local issues between eco-protection and economic activities

The most recent and central regional issue in the Wuyishan area is the conflict between ecological protection, tea cultivation, and ecotourism. The Wuyishan area, which has extremely precious and abundant biodiversity resources, but a culture of tea cultivation in this area is nearly one thousand years old. The soil and climate of this area are very suitable for tea cultivation, thus commodity tea from the Wuyishan area is a popular product in the market. Driven by enormous economic interests, tea farmers began expanding by planting in areas illegally, turning many ecological forests into tea gardens. The spontaneous expansion of tea cultivation has gradually led to the degradation of forest ecosystem services in the area. Moreover, erosion control and water flow regulation declined with the destruction of the original forests. Frequent floods made the local community realize that excessive tea-cultivation expansion has overdrawn local sustainable long-term development costs.

Since 2008, the government began implementing the RTTF policy, requiring the removal of tea from eco-functional areas and planting trees for afforestation in the case of eco-compensation. However, there is still no clear conclusion on how to balance tea cultivation and forest protection (Su *et al*., 2017). Tea cultivation was one of the key productions for the local economy, and the economic benefits of protecting the forest ecosystem services is not clear (He *et al.*, 2018a), making it difficult for tea farmers to understand the benefits of RTTF policy. Moreover, the current single, unified compensation standard makes meeting the farmer expectations difficult. Also, the gap between the actual economic losses suffered by farmers and the compensation standards cannot be quantified. If the existence of non-commercial forests cause the economic losses of some farmers, then it does not conform to the principle of ensuring equitable social benefits for non-commercial forests (He *et al.*, 2018b). Especially in areas where a combination of ecosystem services, tourism, and multiple economic activities exists, local institutions should consider regional stakeholder's willingness as part of the decision-making process (Areti *et al.*, 2001; Stephenson and Shabman, 2019). Some images of local tea cultivation situations are shown in **Figure 2.2**.

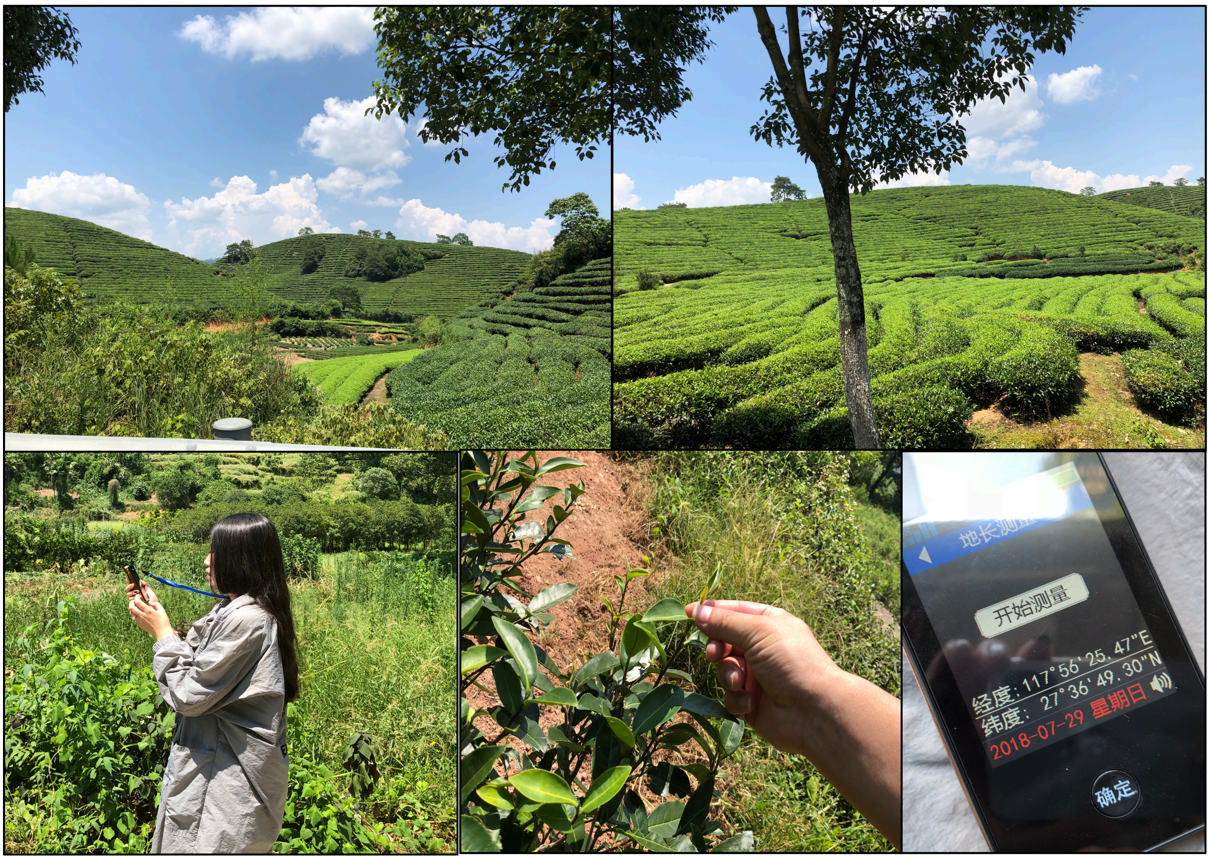
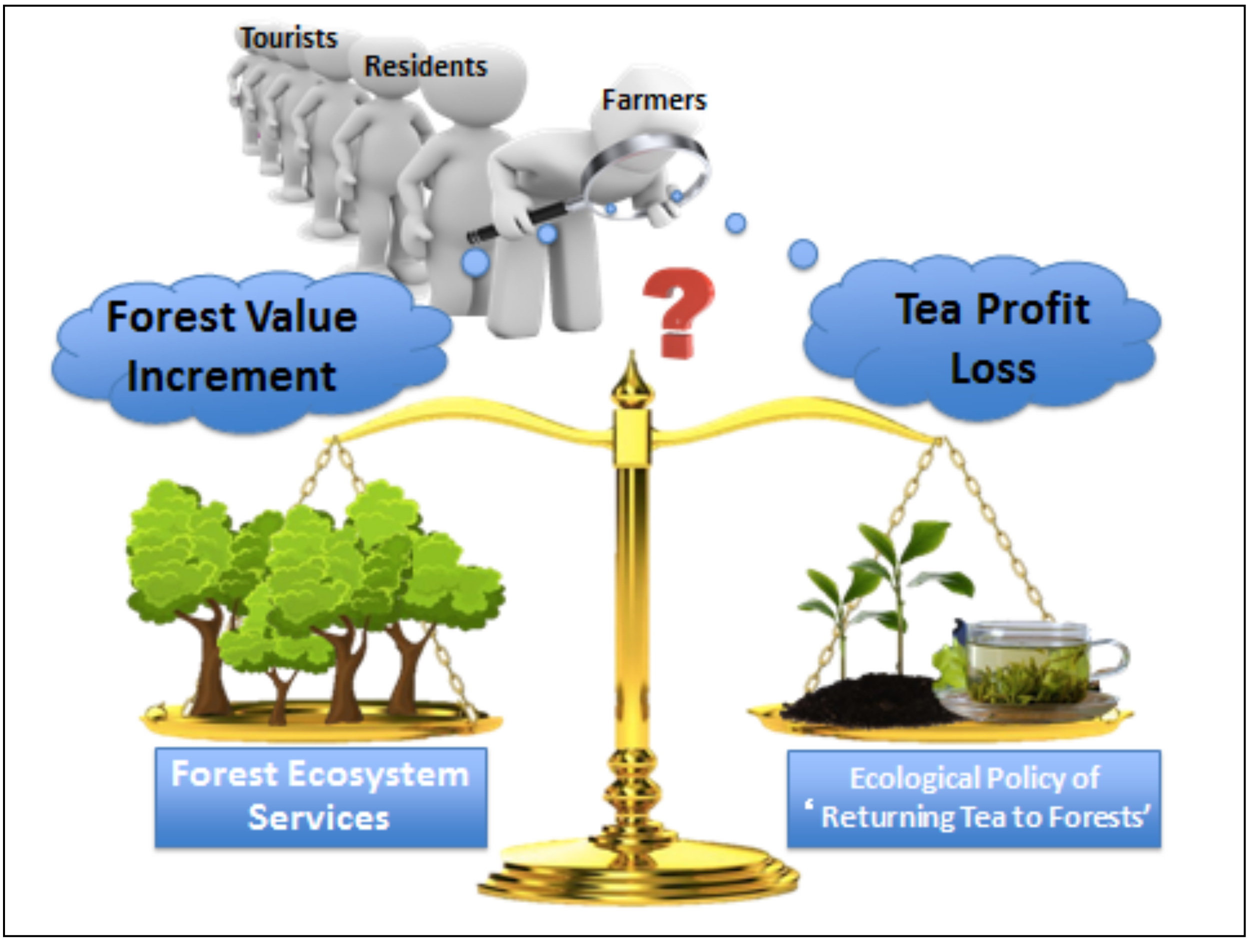


Figure 2.2 Field survey (Wuyishan area, July-September, 2018).

Chapter 3 Ecological policy benefit valuation based on public feedback: forest ecosystem services in Wuyishan City, China

Graphical Abstract 2



3.1 Abstract

The spontaneous expansion of tea cultivation has led to the degradation of forest ecosystem services in the Wuyishan area. In 2008, the local government put forward the RTTF policy to protect the forest ecosystem. However, in order to measure its effects over the past ten years, it is necessary to accurately quantify the economic benefits of this ecological policy. This study tracked the land use changes in Wuyishan City during the last 17 years and estimated the ecosystem service value caused by the RTTF policy. We used virtual market methods to convert different types of public feedback into a unified monetary value, and estimated the economic benefits of RTTF by combining the land use changes. Results showed that the added value of forest ecosystem services not only compensated for the loss of tea profits, but also brought about remarkable economic benefits (approximately US$140 million). Through the combination of ecological changes and economic benefits, we proposed a future direction of the RTTF policy adjustment. More broadly, we provided a method to quantify economic effects (or economic losses) from the perspective of public feedback on the basis of ecological changes. This attempt has contributed to the solving of econometric problems related to ecological policy by combining bioinformatics with ecological economics.

3.2 Introduction

The forest ecosystem provides important services to the environment, including water purification, soil conservation, hydrological regulation, biodiversity support, carbon sequestration, raw material production, food provision, and scenic spots (Augustynczik *et al*., 2019; Janke *et al*., 2017; Lu *et al*., 2013; Rodrigues *et al*., 2019; Schaubroeck *et al*., 2012). The degradation of forest ecosystem services will lead to complex changes, both economically and culturally (Caputo *et al*., 2017; Qiao *et al*., 2019). Although national policies have shown prominent effects in mitigating ecosystem degradation (Yin *et al*., 2010), different policy choices have varied benefits for ecosystem changes (Banzhaf *et al*., 2016; Wu *et al*., 2019). Chinese policy has the advantage of strong action due to the nature of administrative instructions during decision-making process. Based on the beneficial characteristics of eco-investment to the public, the government formulates ecological policies for long-term development rather than using simple cost-benefit analysis. Following the implementation of these ecological policies, their "ex post" evaluation is a hot topic in China. Public feedback as a comprehensive perception of policy effects reflects the public's evaluation of the ecological and economic cost-benefit of these policies. Leveraging citizen science-based data may support the integrated valuation and also reflects the public's understanding of policy (Pandeya *et al*., 2016).

With rich natural resources and biodiversity, the Wuyishan area is highly valuable in terms of its ecosystems. However, the enlarging commodity tea cultivation has rapidly occupied forestland in this area and impairs the delivery of forest ecosystem services, with a risk of threat to sustainability and human wellbeing (Bai *et al*., 2012). Since 2008, the local government had implemented a RTTF policy. Despite the positive ecological effects, tea farmers express low levels of enthusiasm for adopting RTTF as the potential contribution of forests to the local income is still unclear. In addition, the economic benefits of forests to the regional long-term development are often underestimated due to the fact that the profit from forests is much slower than that of commodity tea cultivation. Tea cultivation in forest ecosystems reflects conflicts between different stakeholders, including tourists, residents and farmers (Chen and Ota, 2017), thus it is urgent to evaluate RTTF feedback among different stakeholders by using comparable economic indicators. Therefore, in order to clarify the value of forests and further improve the public's understanding of ecological policies, quantifying the benefits of the policies into monetary units is conducive to the trade-off between the forest value increment and tea profit loss.

There are two main difficulties in quantifying the cost-benefit of the RTTF policy. On the one hand, it takes a long time to protect and restore forests (Bullock *et al*., 2011; Dorren *et al*., 2004), requiring many years to track the process of forest restoration (Putz and Redford, 2010). On the other hand, due to inconsistencies in the calculation units (Keith *et al*., 2017), even if ecological changes are determined (Chazdon, 2008), it is still difficult to compare the effects of these ecological policies with other economic indicators (Balmford *et al*., 2002). In order to evaluate the effectiveness of these policies, it is necessary to observe land use change first (Kapos, 2017; Rasmussen *et al*., 2018), and then establish an appropriate model to translate these changes into economic indicators. Therefore, in order to clarify the economic contribution of ecological policy, we proposed a method to combine ecological changes with economic value assessment.

There are three specific scientific contributions in this study, as described below. First, a new valuation technique denoted the public appraisal method is developed. By inviting the public to speculate on a reasonable market price of diversified services provided by forest ecosystem per unit area, different types of public feedback are quantified as a unified monetary value. Second, changes in tea plantation and forests over the past 17 years were tracked using satellite remote sensing images. The distribution of forest and tea trees before and after the implementation of the RTTF policy in the whole Wuyishan City was extracted. Finally, an eco-economic calculation model combining land use classification information with economic indicators was established. By quantifying the value of ecosystem services per unit area, combined with the changing areas, the economic effect of the RTTF policy was estimated. This provides a valuable case for evaluating the effect of ecological policy.

3.3 Methods

3.3.1 Public feedback survey using composite CVM

Various frameworks and methods have been developed for the purpose of ecological assessment (Saarikoski *et al*., 2016). Among them, the Contingent Valuation Method (CVM) is an important comprehensive method for assessing the value of ecosystem services (Tien *et al*., 2018), and it is a common practice used to determine the public's willingness to protect the target (Stefania, 2018). CVM can not only quantify public feedback (Jeff *et al*., 2018), but also covers the non-use value of ecosystem services (Ståle and Jon, 2018). Thus, it is an effective method of determining the forest ecosystem service value based on public feedback. However, traditional CVM models are susceptible to interference by investigators' descriptive preferences and respondents' income levels (Clive, 2000；Kim *et al*., 2018; Peter *et al*., 1996). In addition，the assumptions of egoism, altruism or harmfulness have a significant impact on the evaluation results (Elizabeth and Francisico, 2018). In order to reduce the bias of CVM, we designed a composite CVM based on public appraisal.

Composite CVM consists of four groups of valuations: the traditional Willingness to Pay (WTP) and Willingness to Accept (WTA) are used in order to quantify the Payment for Ecosystem Services (PES), while the Willingness to Sell (WTS) and Willingness to Depreciate (WTD) are added as a composite CVM (Chang and Yoshino, 2017). The surveys of WTP and WTA set the public as subjective positions, while surveys of WTS and WTD set the public as objective positions. Key definitions in this study are provided below：

- Willingness to Pay (WTP): Willingness to pay for positive behavior (protecting ecosystem services or preventing ecological destruction).

- Willingness to Accept (WTA): Willingness to accept compensation for negative actions (ecological destruction or termination of ecological protection).

- Willingness to Sell (WTS): Reasonably speculative price of ecosystem services or ecological products circulated in the market.

- Willingness to Depreciate (WTD): Amount that may be depreciated on the basis of the original WTS if negative consequences occur (ecosystem damage).

The main valuation index used in this study was WTS. The survey was based on a process of public appraisal on the third-party speculative value, rather than the owner's willingness to sell. First, the area was delimited as the valuation unit. Since unit of area is used as a measurement of forest restoration in the RTTF policy, and the value of forest ecosystem services is affected by forest area (Hidemichi *et al*., 2017). Thus, we grouped the diversified ecosystem services provided by forests per unit area in this study. Second, alternative costs of forest conservation were assessed. Since the conservation cost is assumed to reflect the direct value gained from human usage of forest services (Amani, 2015), the cost of forest maintenance per unit area was taken as a reflection of forest value using the cost substitution method. A total of 1,500 questionnaires were distributed in the Wuyishan area, and a description of the survey questions is provided in **Table 3.1**.

Table 3.1 Indicators and valuation results for forest ecosystem service (FES) assessment

Primary indicators	Index description	Investigatory question	Method classification	Average value (US$)	Intermediate indicators	Index descriptio	Calculating method	Total value [a] (Million $)	(%)
P_1	Value of precious trees	The possible circulation price of precious tree species as ornamental trees in the market	WTS	52,725	**I_1**	Total value of trees	$P_1 \times \text{Number}_{(\text{Rare})} + P_2 \times \text{Number}_{(\text{General})}$	-	-
P_2	Value of general trees	How much is a reasonable penalty for a third party to destroy an ordinary tree	WTS	922					
P_3	Costs of maintaining FES	How much is a reasonable monthly salary for a worker who manages 1,000m^2 of tree health and environmental hygiene	WTS	888	**I_2**	Eco-efficiency rate of FES per m^2	$\frac{P_3}{1000}$	-	0.9
P_4	Economic losses caused by FES damage	According to the set benchmark, how much is the average devaluation of forests when trees are 50% destroyed [b]	WTD	581	**I_3**	Devaluation rate caused by FES damage	$\frac{P_4}{1460}$	-	39.8
P_5	Payment for FES protection	Willingness to contribute to FES conservation	WTP	41	**I_4**	Total willingness to pay for FES	$P_5 \times$population size	1,144.7	-
P_6	Compensation for FES damage	According to the set benchmark, how much compensation is required when trees are 50% destroyed [c]	WTA	13,980	**I_5**	Compensation rate for FES destruction	$\frac{P_6}{60{,}000}$	-	23.3
P_7	Payment for tea product	Willingness to buy the local commodity tea	WTP	80	**I_6**	Market potential of tea purchase	$P^7 \times$population size	2,234.6	-

[a] Calculations based on 2017 data.

[b] Assume a price of $ 60 /m^2 for high-quality forest land in the Wuyishan area.

[c] Based on $60,000 /1,000m^2 according to the results of the pre-survey.

3.3.2 Monitoring land use changes using remote sensing techniques

Based on the distribution and transformation of land use (Zou and Yoshino, 2017), satellite remote sensing images of the Wuyishan area over a period of 17 years were analyzed. With 2008 as the demarcation point, we analyzed vegetation cover changes from 2001 to 2007, from 2007 to 2013 and from 2013 to 2017. In this study, geo-referenced Landsat 7 (ETM+) images acquired on October 21 2001 and November 7 2007, and Landsat 8 OLI images acquired on December 1 2013 and October 25 2017 were used. These images can be freely obtained from the Global Land Cover Facility (http://www.landcover.org/data/landsat/). The spatial resolution of the Landsat images is 30 meters, and with a cloud cover for each satellite image as less than 10%, no significant spectral differences from clouds are expected (Chen and Wang, 2002). The path number used for each image is 120 and the row number is 41. In this study, the band 6 of the images was not used since it is a thermal band, and not required for our analysis. Bands 1-5 and band 7 were stacked into a single BIL format image and used as primary data in order to classify land use type of the study area.

Image processing was performed using ENVI 5.0. Supervised maximum likelihood classification, which calculated the likelihood that a given pixel belonged to a specific class, was employed to classify the study area into six land use types: urban, cropland, water, tea trees, forests and bare land (Rozenstein and Karnieli, 2011). Training and test data for the associated types were delineated based on the field survey and prior knowledge of the study area. As most of the vegetation in Wuyishan is evergreen all year round and the climate is wet and rainy in the mountainous areas, some difficulties have arisen in vegetation classification since the spatial resolution required to distinguish general crops and tea trees is higher than that of Landsat images (Li and Han, 2001). After field investigation and manual correction, the separation accuracy was greatly improved. The confusion matrix combined with ground samples was used to analyze the data of 2001, 2007, 2013 and 2017 (Serra *et al*, 2003). The overall accuracy of the classification image was derived 93.76%, 92.39%, 88.28% and 91.43% for 2001, 2007, 2013 and 2017 respectively. The kappa coefficient was given as 90.95%, 90.04%, 85.51%, 86.99% in the year of 2001, 2007, 2013 and 2017, respectively. These results indicate that the classification accuracy (**Table 3.2**) in the present study is acceptable. In addition, we separately compared the images from 2001 with 2007, 2007 with 2013, 2013 with 2017, and extracted distribution changes of tea cultivation and forests on the basis of comprehensive land use change. In order to determine the area change as a result of these vegetation increases and decreases, an index was derived by pixel counting. Thus, we obtained a way to quantify vegetation change since 2001.

Table 3.2 Accuracy assessment of land use classification

Land type	2001		2007		2013		2017	
	Producer	User	Producer	User	Producer	User	Producer	User
	Accuracy (%)							
Urban	84.95	88.76	76.15	92.76	91.08	92.35	75.86	86.10
Forest	97.66	99.75	98.15	99.24	96.43	91.38	97.83	98.83
Tea field	90.78	83.61	89.33	86.38	74.19	78.80	84.87	85.17
Bare land	86.07	71.79	89.45	79.51	91.18	87.69	69.87	73.56
Water	94.75	99.34	96.75	99.67	97.31	98.92	96.90	99.25
Cropland	91.27	88.96	95.74	86.49	84.13	85.22	88.70	79.46

3.3.3 “Ecological-Economic” benefits transformation model

3.3.3.1 Forest Value

First, the total reasonable circulation calculation value (WTS_{total}) was calculated according to Formula (3-1),

$$WTS_{total} = \frac{S_{total}}{S_{unit}} WTS_{unit1} \qquad \text{Formula (3-1)}$$

where the forest value per unit area (WTS_{unit1}) was obtained through investigation surveys, the total forest cover area (S_{total}) over different years was obtained by land use analysis, and the area unit (S_{unit}) is that used in the survey. Second, the loss corresponding to forest destruction is calculated. In order to facilitate the calculation and understanding of the respondents, this study uses a 50% loss rate as the calculation objective, as shown in Formula (3-2). The average value given by the public was obtained through the pre-survey as the virtual unit area forest price (WTS_{unit2}), and then we determine the unit amount of depreciation (WTD_{unit}) when the forest was destroyed to half. The devaluation ratio is obtained by dividing these two values, and multiplying by the total price (WTS_{total}) to obtain the amount of economic value ($V_{Tree\ reduction}$) when the forest damage reaches 50%.

$$V_{Tree\ reduction} = \frac{WTD_{unit}}{WTS_{unit2}} WTS_{total} \qquad \text{Formula (3-2)}$$

Finally, the total value of forest (V_{total}) was calculated, as shown in Formula (3-3),

$$V_{total} = V_{Trees\ reduction} \frac{S_1}{S_2 - S_1} \quad (S2 \neq S1) \qquad \text{Formula (3-3)}$$

where the total area of forest distribution (S_1) before change and the total area of forest distribution (S_2) after change were extracted by land use analysis. For S_1 greater than S_2, a loss of forest is implied, the actual change rate calculated will be negative, and the calculated V_{total} is the loss of forest value. For S_1 less than S_2, the forest is increasing or restoring. The calculated actual change rate will be positive, and the calculated V_{total}

is the profit of forest value.

3.3.3.2 Tea Value

First, the increase in the profit accounting ($P_{(ayby)total}$) of tea between year a and year b was estimated using Formula (3-4),

$$P_{(ayby)total} = (S_{by} - S_{ay})p_{unit\ average} \qquad \text{Formula (3-4)}$$

where S_{ay} and S_{by} are the distribution areas of tea for year a and year b, respectively, extracted by tea distribution detection. The average price profit per unit area ($p_{unit\ average}$) can be obtained from the survey of tea growers. When the distribution of tea in year b is greater than that in year a, the total amount of tea cultivation is increasing. The result is positive and the profit of tea is calculated. When the distribution of tea in year b is less than that in year a, the total amount of tea cultivation is decreasing, the result is negative, and the loss of tea is calculated.

Second, we calculated the government subsidy compensation (SU_{total}) for the RTTF policy using Formula (3-5),

$$SU_{total} = \frac{S_{tea-forest}}{S_{per\ plant}} \times SU_{unit} \qquad \text{Formula (3-5)}$$

The area from tea to forest ($S_{tea-forest}$) was extracted by statistical distribution analysis, and is also denoted as the policy effective area. Since the government subsidizes the amount of green tea saplings, the total number of returned tea saplings was estimated by dividing the total area of the policy effective area ($S_{tea-forest}$) by the average area of per tea sapling ($S_{per\ plant}$). This was then multiplied by the subsidy compensation of each sapling (SU_{unit}) to get the total subsidy compensation amount.

Finally, the profit deficit of the removed part of the tea trees from year a to year b ($D_{(ayby)total}$) was calculated from Formula (3-6),

$$D_{(ayby)total} = P_{(ayby)total} - SU_{(ayby)total} \qquad \text{Formula (3-6)}$$

Where $SU_{(ayby)total}$ is the subsidy and $P_{(ayby)total}$ is the profit of year a to year b ($P_{(ayby)total}$). The difference between the hypothetical profits from tea cultivation and the subsidy compensation in this region represents the rough economic loss estimates of tea farmers.

3.4 Results and Discussion

3.4.1 Public ecological feedback quantified into a unified monetary value

On the basis of an in-depth understanding of public feedback, we find that the combined alternative valuation method has achieved remarkable results. Previous experiences of "one-to-one" economic valuation (quantifying the overall objective through a single assessment technique) often leads to unrealistic amounts of funds, which has been criticized by economists (Shabman and Stephenson, 2000). In this study, by using WTS and WTD valuation technology, we were able to obtain valuation results that were in line with the market experience, and fully verified the validity of the composite CVM for the quantification of public feedback. This study explored the public feedback mechanism using eco-economic analysis. The reasonable price in individuals' consciousness represents their actual market experience, which has a reference value.

As shown in **Table 3.1**, the final statistics of the economic indicators of public feedback in Wuyishan City were concluded after the unified conversion of units. The feedback types commonly seen in forest systems were covered. Among them, the feedback value of trees was reflected in the index of P_1, P_2 and I_1.

Therefore, when ecological loss or land use form changes in a certain area in the future, the total value of damaged trees can be calculated using the index, and the loss amount of forest ES (amount of ecological compensation) can thus be obtained. In this study, the primary indicators were counted, while the intermediate indicators were briefly discussed.

The indices P_3, I_2, P_5, I_4, P_7 and I_6 reflected the feedback value of ES and tea cultivation activities. The public evaluated that the value of forest ecosystem maintenance per 1,000m^2 was approximately \$888 per month. The replacement cost reflected the value of the ecological effect that healthy trees (per 1,000m^2) provided. As we expected, the high average WTP on tea production represented the recognition of the external public for the high quality tea in Wuyishan City, and also reflected that the public desired to retain a certain area of tea cultivation land in Wuyishan City. According to the results, we suggest that it is necessary to adjust the cultivation structure of tea, as more refined with a high quality rather than expanding the cultivation area. Moreover, it is more appropriate for a tea output close to \$80 per person, and for the government to invest a gross value of \$41 per person in protecting forests.

From the results of indices P_4, I_3, P_6 and I_5, as the initial value base per 1,000m^2 was assumed, we did not directly use specific amounts as a reference, but rather calculated the proportionality coefficient of forest ES loss. Every 50% of the damage to the forest ecosystem was likely to be close to 23.3% of the compensation demanded by local residents, while the external public thought that the environment would depreciate by approximately 39.8%. In addition, as shown in **Figure 3.1**, through the correlation analysis of the purpose of the visit and the impression of Wuyishan area, we also found that the average value of the forest value assessment of visitors for tourism purposes was higher. Visitors who thought the natural environment of Wuyishan area was beautiful gave a higher average value for different types of forest ecosystem services. The socio-economic characteristics of the sample are shown in **Table 3.3**.

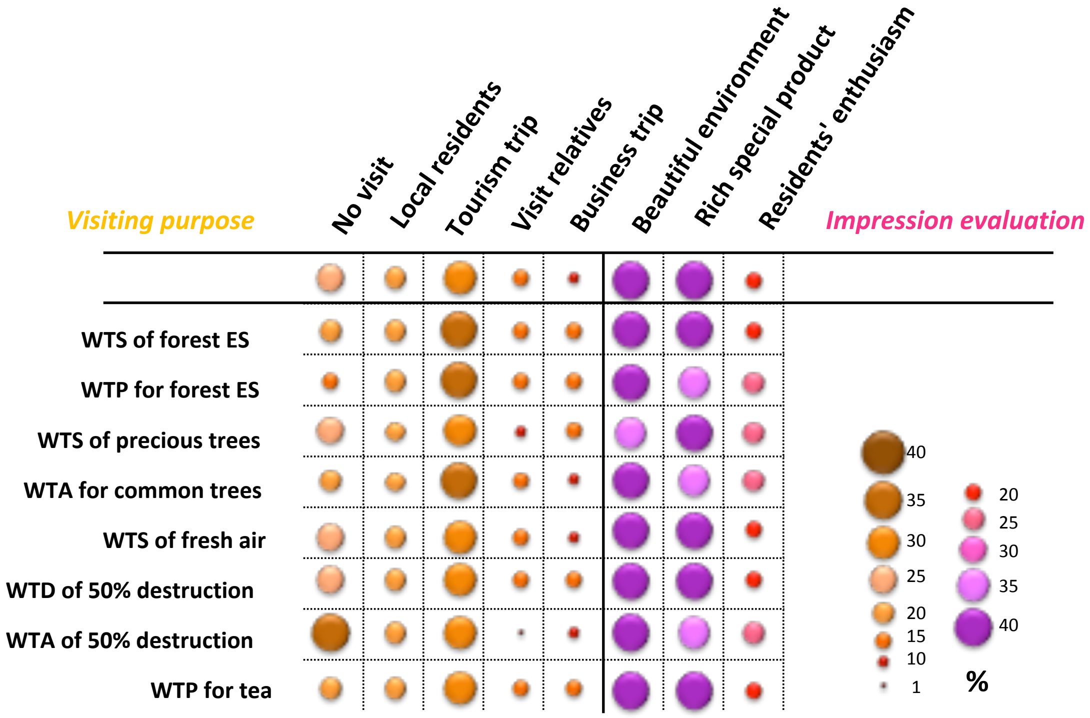


Figure 3.1 Relevant factors affecting assessment value. This figure shows the impact of visit purpose and impression evaluation on several assessment results. The larger the percentage, the more people who give a high valuation value under this factor. Tourists clearly reflect the tendency of a high valuation of different kinds of forest ecosystem services. Respondents who were impressed by the beautiful environment of Wuyishan area gave a high valuation of forest ecosystem services.

Table 3.3 Demographic features of the people under survey

Demographic Characteristic	*Grouping*	*Number*	*Proportion %*	*Demographic Characteristic*	*Grouping*	*Number*	*Proportion %*
Visit Purpose	Tourism	435	44.4	Gender	Male	547	55.8
	Business trip	212	21.6		Female	433	44.2
	Visiting friends	134	13.7	Occupation	Students	211	21.5
	Local Resident	199	20.3		Agricultural	54	5.5
Age	10-20	46	4.7		Individual	155	15.8
	20-30	294	30.0		Civil institutions	179	18.3
	30-40	341	34.8		Employees	302	30.8
	40-50	182	18.6		No occupation	79	8.1
	50-60	89	9.1	Income monthly ($)	0-447	348	35.6
	Over 60	28	2.8		447-745	314	32.0
Education	High school	432	44.1		745-1490	203	20.7
	Technical School	176	17.9		1490-2980	45	4.6
	Undergraduate	297	30.3		Over 2980	70	7.1
	Master / PhD	75	7.7				

3.4.2 Changes of tea and forest distribution in different stage

Previous studies generally focus on the regional monitoring of tea distribution. In this study, we paid more attention to the changes of forest cover and tea cultivation. Through a more in-depth analysis of the regional changes of tea and forest transformation, these changes were used as indicators to evaluate the effectiveness of policies. Moreover, we obtained the changes of forest, tea, urban buildings, bare land, cropland and water system coverage (**Figure 3.2** and **Table 3.4**) through the analysis of satellite images in four key years of 2001, 2007, 2013 and 2017. The land use change matrix for different years is shown in **Table 3.5**, **Table 3.6** and **Table 3.7**. Among them, both forests and bare land showed a dramatic declining trend, with the area of bare land falling by 65% from 2001 to 2017. However, from 2007 to 2013, the distribution of forests increased on a large scale. Although the overall situation is still in decline, the sharp decline slowed down significantly. The water system and cropland classes tended to decrease slightly, while urban land and tea land tended to increase. Although the obvious slowdown of forest decline can be regarded as direct evidence of the effectiveness of the RTTF policy, we cannot obtain specific change information between tea and forests using only the total distribution of different land types, thus further analysis was performed.

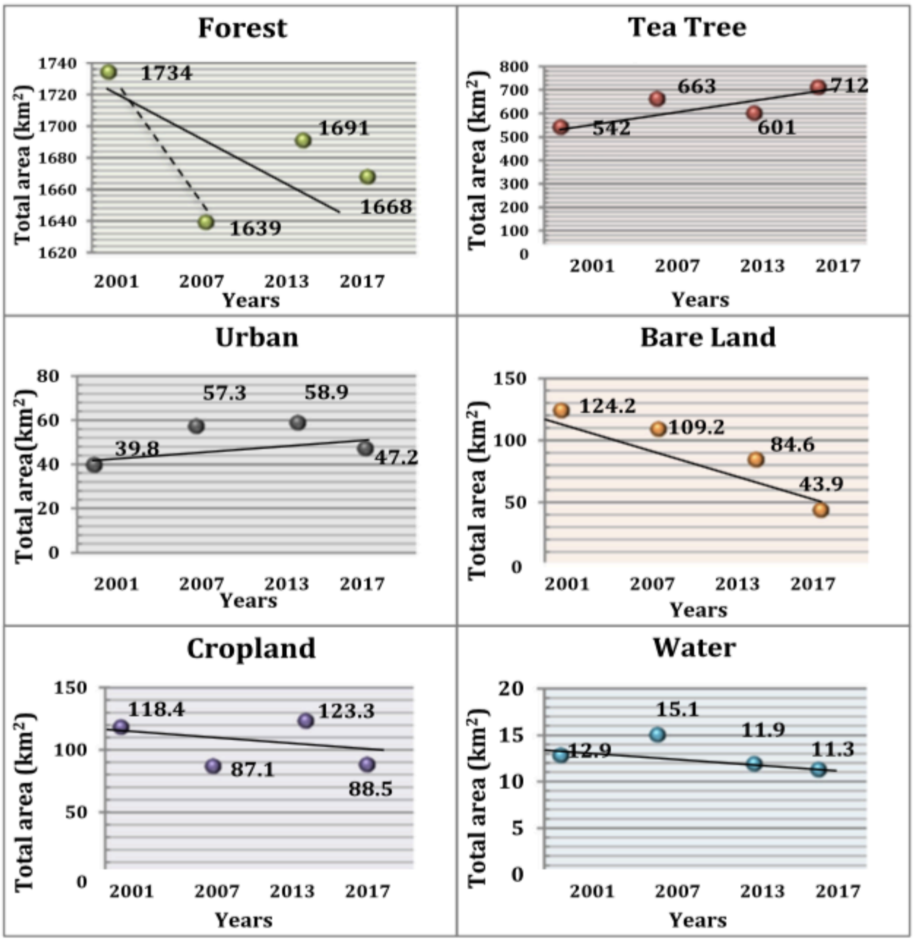


Figure 3.2 Land use changes. Twenty-year trends of major land use patterns in Wuyishan area, including forests, tea tree, bare land, urban area, cropland and water space.

Table 3.4 Extent of different land types in Wuyishan City

Land types	Area	2001	2007	2013	2017	Change rate 2001 – 2017 (%)
Urban land	Km^2	39.8	57.32	68.89	57.24	+0.43
	%	1.55	2.23	2.68	2.23	
Cropland	Km^2	118.41	87.1	113.35	93.51	-0.21
	%	4.6	3.39	4.41	3.64	
Water	Km^2	12.85	15.03	11.94	11.31	-0.11
	%	0.5	0.58	0.4	0.4	
Tea tree	Km^2	541.72	663.39	601.43	681.41	+0.26
	%	21.07	25.8	23.39	26.5	
Bare land	Km^2	124.21	109.2	84.62	43.13	-0.65
	%	4.83	4.25	3.29	1.71	
Forest	Km^2	1734.32	1639.27	1691.17	1684.76	-0.03
	%	67.45	63.75	65.78	65.52	
Total		2571.31	2571.31	2571.4	2571.36	

Table 3.5 Land use change matrix for Wuyishan City from 2001 to 2007

2001	2007	Urban Land	Cropland	Water	Tea tree	Bare land	Forest	Total
Urban Land	Km^2	11.2	4.89	2.97	9.29	10.12	1.33	39.8
	%	28.14	12.29	7.46	23.34	25.43	3.34	100
Cropland	Km^2	14.73	55.14	0.72	41.89	5.75	0.18	118.41
	%	12.44	46.56	0.61	35.38	4.86	0.15	100
Water	Km^2	0.93	0.27	8.44	1.25	1.37	0.59	12.85
	%	7.23	2.1	65.68	9.73	10.66	12.5	100
Tea tree	Km^2	9.49	9.16	1.68	428.63	25.01	67.75	541.72
	%	1.75	1.69	0.31	79.12	4.62	12.51	100
Bare land	Km^2	19.54	16.92	0.7	37.21	36.8	13.04	124.21
	%	15.73	13.62	0.56	29.96	29.63	10.5	100
Forest	Km^2	1.43	0.72	0.52	145.12	30.15	1556.38	1734.32
	%	0.08	0.04	0.03	8.37	1.74	89.74	100
Total		57.32	87.1	15.03	663.39	109.2	1639.27	2571.31

Table 3.6 Land use change matrix for Wuyishan City from 2007 to 2013

	2013	Urban Land	Cropland	Water	Tea tree	Bare land	Forest	Total
2007								
Urban Land	Km^2	30.37	7.82	0.84	11.63	4.85	1.81	57.32
	%	52.98	13.64	1.47	20.29	8.46	3.16	100
Cropland	Km^2	8.52	55.09	0.33	18.85	3.32	0.98	87.09
	%	9.78	63.26	0.38	21.64	3.81	1.13	100
Water	Km^2	3.09	1.14	7.29	2.16	0.3	1.05	15.03
	%	20.56	7.58	48.50	14.37	2	6.99	100
Tea tree	Km^2	15.21	37.3	1.87	366.1	40.53	202.4	663.41
	%	7.82	10.05	0.92	39.52	16.18	25.52	100
Bare land	Km^2	8.55	10.98	1.01	43.19	17.68	27.89	109.3
	%	0.19	0.06	0.04	9.73	1.09	88.88	100
Forest	Km^2	3.15	1.02	0.6	159.5	17.94	1457.04	1639.25
	%	2.29	4.8	0.46	23.39	3.29	65.77	100
Total		68.89	113.35	11.94	601.43	84.62	1691.17	2571.4

Table 3.7 Land use change matrix for Wuyishan City from 2013 to 2017

	2017	Urban Land	Cropland	Water	Tea tree	Bare land	Forest	Total
2013								
Urban Land	Km^2	35.89	10.69	1.37	15.49	3.8	1.66	68.9
	%	52.09	15.52	1.99	22.48	5.52	2.41	100
Cropland	Km^2	6.61	65.93	0.29	34.88	5.35	0.3	113.36
	%	5.83	58.16	0.26	30.77	4.72	0.26	100
Water	Km^2	0.62	0.24	7.83	1.83	0.65	0.77	11.94
	%	5.19	2.01	65.58	15.33	5.44	6.45	100
Tea tree	Km^2	6.97	12.58	1.03	435.93	12.02	132.93	601.46
	%	1.16	2.09	0.17	72.48	2	22.1	100
Bare land	Km^2	5.01	3.65	0.24	52.45	16.22	7.06	84.63
	%	5.92	4.31	0.28	61.98	19.17	8.34	100
Forest	Km^2	2.14	0.42	0.55	156.66	5.96	1525.34	1691.07
	%	0.13	0.02	0.03	9.26	0.35	90.21	100
Total		57.24	93.51	11.31	681.41	43.13	1684.76	2571.36

Figure 3.3 presents several change areas of forest and tea land use patterns in different years. In the first stage, from 2001 to 2007, the number of forest resources decreased and tea cultivation increased significantly. Approximately 8.5% of forests were converted to tea cultivation, and large areas of cropland and bare land were also transformed into tea planting areas. Many changes have occurred in forest resources in the whole region, of which the expansion of tea cultivation area is the most significant. At this time, tea cultivation demonstrated a scattered distribution, and there was no obvious trend of a centralized distribution. It can be implied that tea cultivation at this stage was essentially the spontaneous behavior of tea farmers. It is worth noting that during the second stage, after the government put forward the forest protection policy in 2008, the speed of forest area reduction slowed down rapidly. From the green distribution point in the map, we can see that a large number of land originally used for tea cultivation turned to forest distribution. This is the most critical evidence of the effects of the policy. Approximately 28% of tea cultivation was returned to forests. In particular, some areas with serious forest loss (red points) in the first stage have changed into forest distribution in the second stage. This suggested that the afforestation at this stage is a planned and targeted forest restoration action.

However, in the third stage, during 2013-2017, the land where forest resources became tea cultivation rebounded greatly. A large area of tea cultivation was restored, particularly in the southern part. Approximately 70 km^2 of tea planting was turned into forests, and 145 km^2 of forests was converted into tea cultivation. This may be due to the weakening of the policy effects, or the emergence of some partial policy changes in the southern region. From **Figure 3.3(d)** and **3.3(e)**, the transformation of the tea and forest classes in different years is shown. Through the statistics of the changing areas, the specific data of the mutual transformation between forest resources and tea cultivation were extracted, and the monetary value was subsequently calculated.

Fig. 3.3 (a)

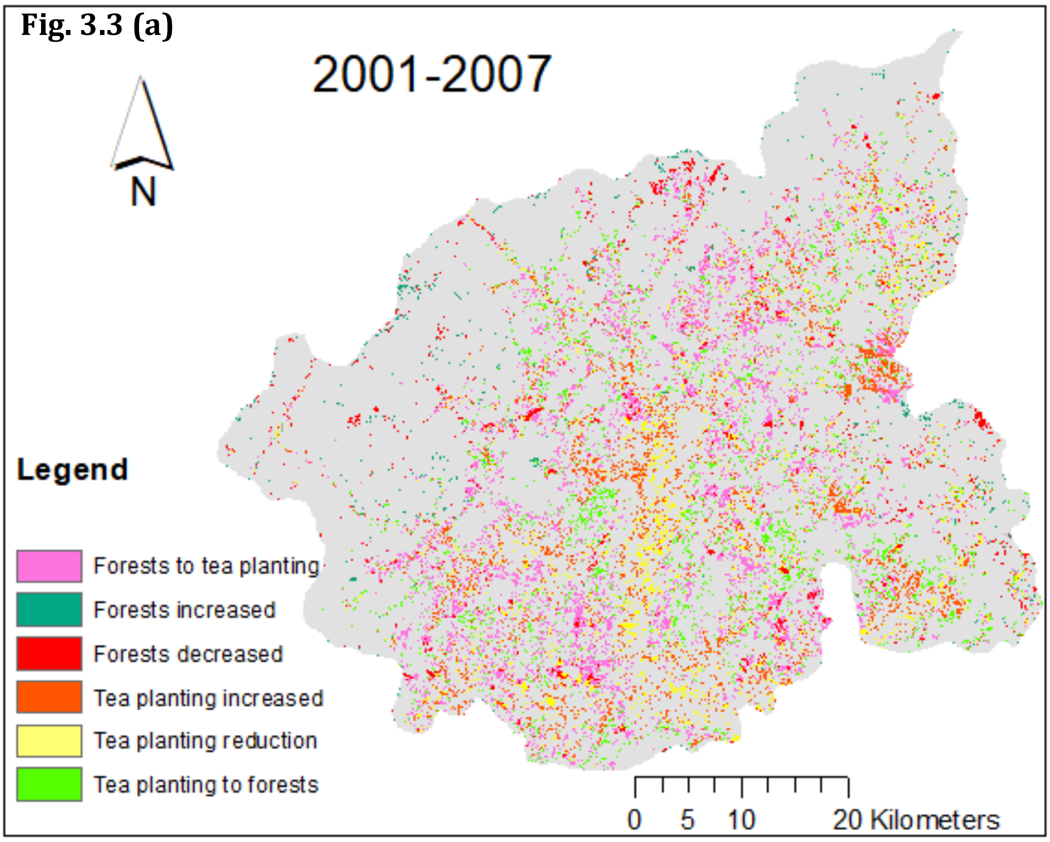
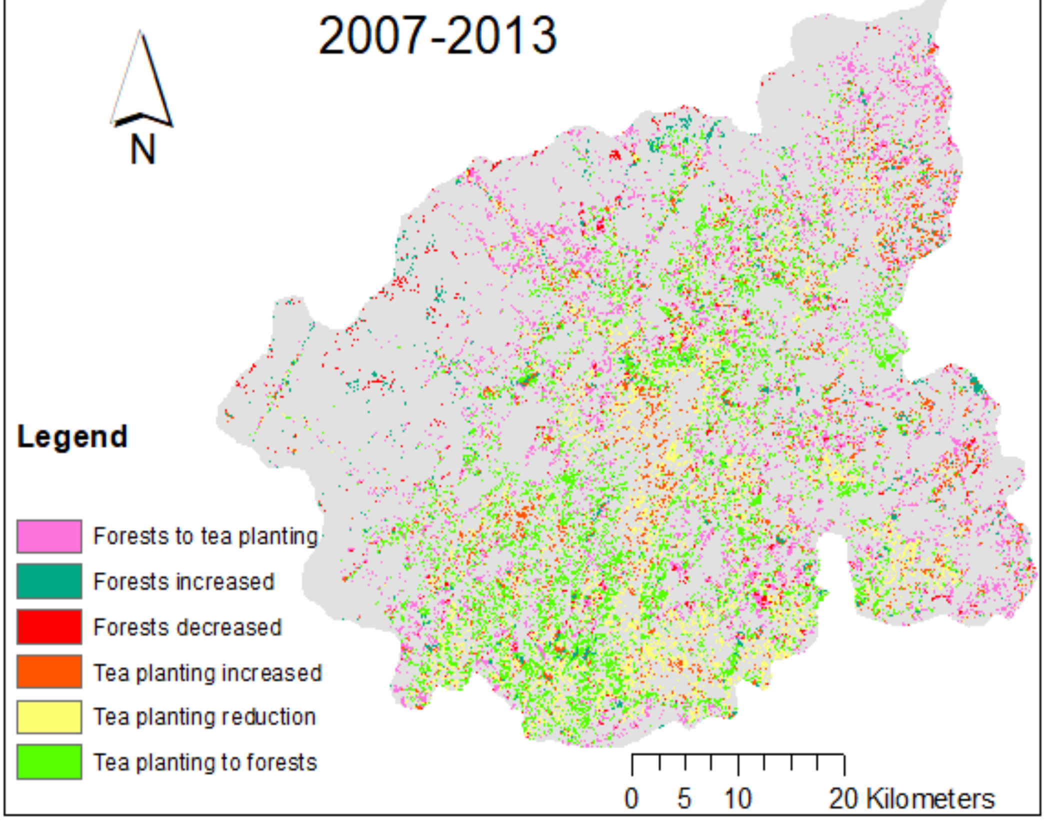


Fig. 3.3 (b)



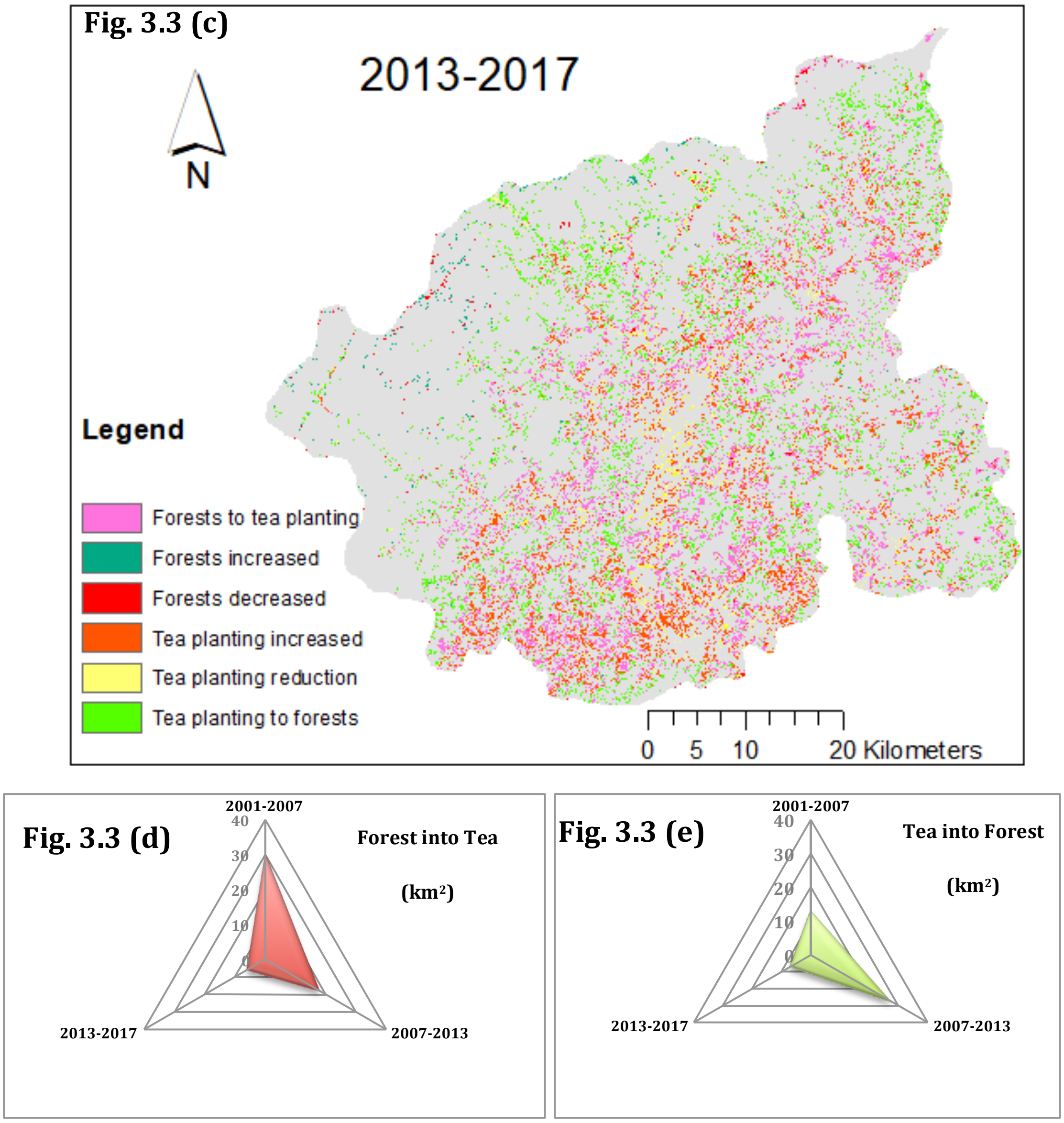


Figure 3.3 Change detection within regions using satellite images. (a) From 2001 to 2007; (b) 2007 to 2013 and (c) 2013 to 2017. Different types of changes in forest and tea fields were extracted. (d) and (e) are the mutual transformation between tea and forest.

3.4.3 Increment of forest value and the loss of tea profits

The economic losses and benefits of forests at different stages were calculated (see **Figure 3.4**) by combining the spatial change of forest area with the economic indicators of forests. From 2001 to 2007, driven by the benefits of commodity tea, wide ranges of public forests were occupied and the economic loss of forests was approximately \$328,522,099 (**Figure 3.4(f)**). After the government started ecological management in 2008, the situation improved. By 2013, the policy effects were remarkable. The ecological policy implemented to protect forests had an ecological profit of approximately \$195,391,405 (**Figure 3.4(f)**). However, after 2013, the effect of the forest protection policy began to slow down, and the situation of forest loss rebounded, with a loss of approximately \$55,329,792 (**Figure 3.4(f)**). However, compared with pre-2007 levels, some economic benefits are still present. We calculated that from 2007 to the present date, this policy has produced an economic benefit of \$140,061,613, locally.

According to the feedback of the quantitative survey, the per capita willingness to buy Wuyishan tea is US\$80, and the total population of the Fujian Province is 39.11 million (2017). According to the proportion of the population in the sixth census (16.6% aged 0-14, 70.14% aged 15-59 and 13.26% aged over 60), we assume that minors and the elderly do not have the purchasing power. The middle-aged population is approximately 27.92 million, and it is estimated that the market demand for tea cultivation is approximately 2233.6 million US dollars. According to statistics, the government's RTTF policy gives local tea farmers a subsidy of US\$0.73 to US\$2.19 per tea saplings. Tea is cleared for afforestation, and the government subsidizes the cost of tree saplings. According to the average output, the subsidy is US\$0.66/m^2. However, before the RTTF policy, the income from the cultivation of commodity tea was US\$4.37/m^2. Although the government has tried its best to select forest species with a strong profitability, and even though the ownership of planted trees belong to the tea growers, a profit gap still remains because of the slow return of forestry. The income of tea in different years was calculated based on the change of the total distribution of tea in different years and the average income per unit land area. During the initial period of the RTTF policy from 2007 to 2013, the loss of tea income was estimated at US$270,728,055 (**Figure 3.4(a)**) due to the rapid decrease of commodity tea. The government's subsidies and profit margins were calculated by extracting the areas converted from tea fields to forests (**Figure 3.4(c)**). From 2007 to 2013, at the beginning of the implementation of the RTTF policy, the decrease in the cultivation of commodity tea resulted in a deficit of $751 million. While, from 2013 to 2017, we found that the deficit fell sharply to $493 million. This is because the area of commodity tea cultivation has rebounded, however, according to land analysis, the area of tea rebound does not coincide with the forest area. Thus, the secondary expansion of tea does not occupy the forest area, but develops more bare land for tea cultivation (**Figure 3.4(b)**).

Since the implementation of the RTTF policy from 2008, the government has subsidized $221 million (**Figure 3.4(c)**) in compensation for tea trees. However, the loss deficit caused by the reduction of commodity tea cultivation was still large, at $1,244 million (Calculated from **Figure 3.4(c)**). By subtracting the profit deficit of tea cultivation from the ecological profit of the policy, we found that the RTTF policy was effective, and after offsetting the deficit, we still had a surplus of $15.6 million. Although the RTTF policy has achieved remarkable results, the loss of forest ecosystem services caused by tea expansion before 2007 is huge, and at present, there still exists a loss of forest value of $188 million. We offer two options to overcome this loss. The first is to improve the quality of commodity tea in order to increase commercial profits in a limited range of tea cultivation areas. After all, the bare land resources available for new development are also limited. The second is to continue to increase forest cover and improve forest quality. At the same time, we remain optimistic about the future, as planted trees may start to generate profits in the future. It is necessary to refer to the two measures we provide for the future implementation of the RTTF policy.

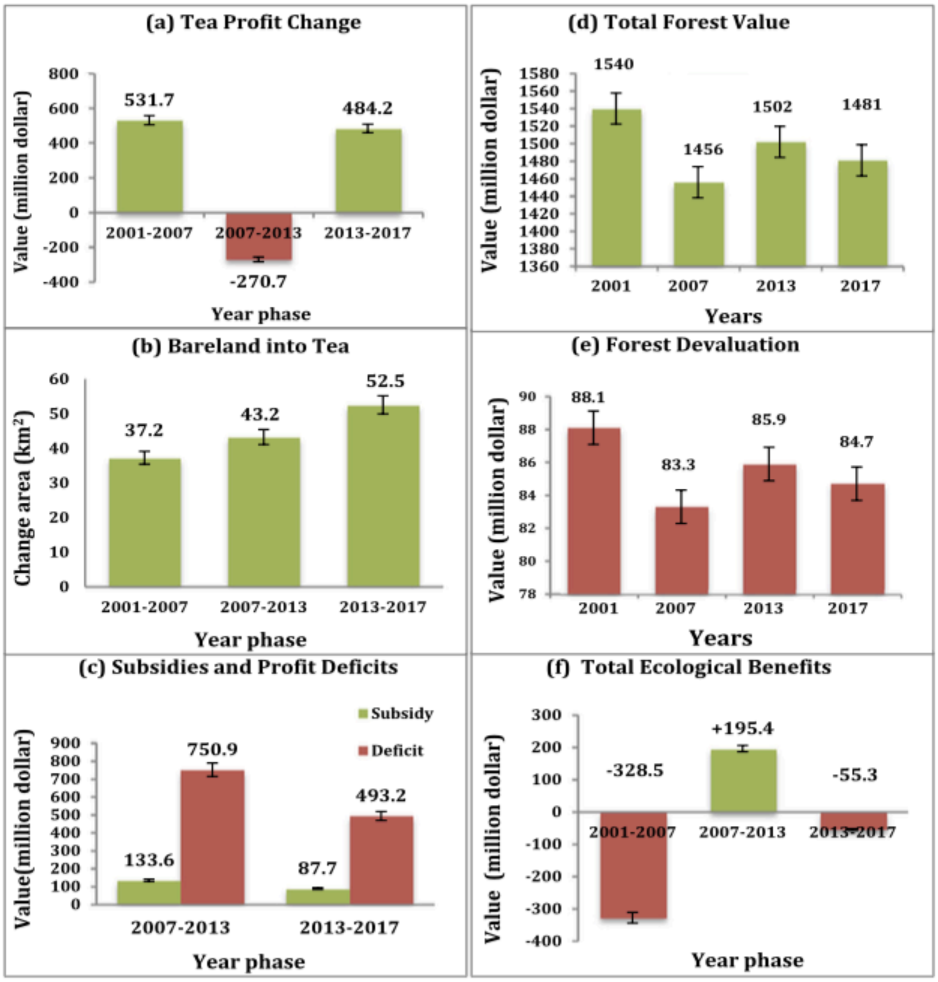


Figure 3.4 Total accounting of forest value and commodity tea value. (a) the profit changes of commodity tea; **(b)** the annual changes of bare land; **(c)** the deficits between profit loss and subsidy; **(d)** the changes of forest value; **(e)** the devaluation amount caused by forest damage; **(f)** the change of total ecological benefits. Forest value and commodity tea value were calculated separately. These were then used to derive the ecological profit and economic loss of the policy of returning tea to forests. As the policy was launched close to 2007, we chose 2007 as the turning point to compare the ecological profits or losses at different stages.

It is not possible to determine the cost of all natural resources, and some emotional values can only be quantified by public feedback. Therefore, we urgently need a method to convert vague emotional perception into the amount of money for comparison. For our method, we first made a general valuation of the research object, obtained the valuation data of small units, and then combined the ecological variables in order to calculate the change trend of value, making the results more objective and effective. In this study, we provided a way to quantify economic benefits or losses from the perspective of public feedback on the basis of ecological changes. The main limitation of this study is that it is difficult to accurately determine all tea farmers directly related to the benefits of the RTTF policy. Therefore, the loss of tea profits in the tea returning action is the average loss of tea farmers interviewed. This may not accurately match the average loss of all tea farmers because the profits of different varieties and plantations are quite different. Although the ecological value of forests can cover the loss of tea profits from the macro-perspective, there are still many problems from the micro-perspective. Complex stakeholder conflicts will be needed for further investigation.

3.5 Conclusions

In summary, the core issue of ecosystem services valuation is determining how to combine ecological and economic indicators. The RTTF policy is one of the most famous ecological compensation policies in China, whose economic benefits are often underestimated because the potential contribution of forest ecosystem services to the regional sustainable development is unclear. Through a variety of public feedback quantification, combined with changes of land use patterns, the monetary value of forest ecosystem services can be calculated. The effects of these ecological policies can be transformed into economic benefits or losses, which will provide an important reference for the trade-off for policy implications in the future. In this study, the added value of forest ecosystem services could not only compromise the short-term loss of tea profits, but also brought about remarkable economic benefits (approximately US$140 million). However, the added value of ecosystem services is invisible and of common attribute, thus the short-term profit losses of tea farmers should be compensated by a financial subsidy for forest restoration practice that supports ecosystem service protection. Similarly, to compensate for the revenue loss associated with the RTTF policy, payments for ecosystem services and special national funds to the local government are potential solutions. The win-win possibilities between economic gain and ecological conservation should be explored further based on the multi-stakeholder conflicts.

Acknowledgments

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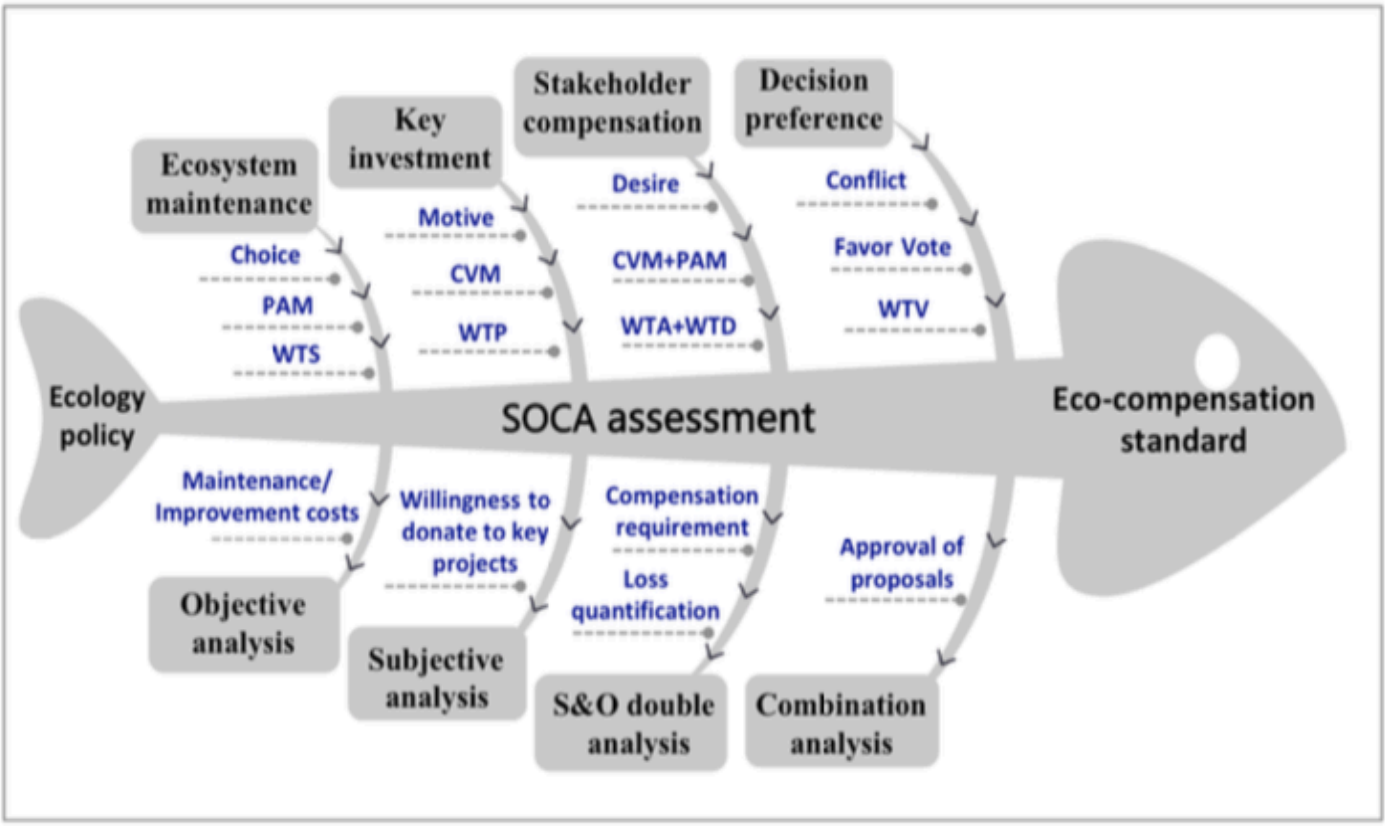
Chapter 4 Farmers' tea and nation's trees: A framework for eco-compensation assessment based on a subjective-objective combination analysis

Graphical Abstract 3



4.1 Abstract

The effectiveness and sustainability of eco-compensation policy implementation are essential to ecosystem service protection. However, a purely subjective standpoint causes deviations from the compensation benchmark, while decision-making based solely on an objective standpoint fails to offer a profound understanding of local stakeholder conflicts. Therefore, local authorities find it difficult to set reasonable and effective eco-compensation implementation standards. An assessment framework for eco-compensation, defined as the subjective-objective combination analysis (SOCA), which considers both the subjective and objective positions of stakeholders is proposed. Focusing on a typical eco-compensation case, "Returning Tea to Forest", a compensation range is finally quantified from \$443/ha to \$2114/ha per year using the SOCA framework. SOCA quantification from multiple perspectives optimized the eco-compensation benchmark determinations and the eco-protection decision-making process.

4.2 Introduction

Ecosystem services are defined as the benefits that humans obtain from ecosystems (MEA, 2005). Services provided by ecosystems and the natural capital stocks that generate these services are critical to the sustainable functioning of the life support systems of Earth (Seidl *et al*., 2019), and they contribute directly or indirectly to human welfare (Zheng *et al*., 2019a). Forests are proven to be an effective and sustainable ecosystem services supply source (Elena *et al*., 2012; Kibria *et al*., 2017). Forests, through their essential role in biogeochemical and hydrological cycles, support life, maintain biodiversity, and balance and stabilize atmospheric chemistry (Campbell and Tilley, 2014; Sannigrahi *et al*., 2019).

However, from an economic perspective, forest ecosystem services have the same economic externalities and characteristics as public goods (Deng *et al*., 2011): services provided by forests are consumed by all of society without any consideration of the maintenance costs. If corresponding protective measures are not taken, the ecological resources of forests will continue to be recklessly consumed and overdrawn. Forest eco-compensation is a transfer mechanism that internalizes forest ecosystem service externalities by compensating individuals and/or organizations for losses and/or costs incurred by forest ecosystem service maintenance (Deng *et al*., 2011; Shang *et al*., 2017). The primary measures are charging for destructive activities and compensating for individual and local conservation investments. In China, activities aimed at protecting natural or non-commercial forests and reconverting farmland into forests or pastures all receive direct government compensation. Setting a superior compensation standard is the core of forest eco-compensation policy (Sheng *et al*., 2017).

China attempts to protect ecosystem services by exploring eco-compensation policies that conform to its economic and social characteristics (Hu *et al*., 2019). In 1998, the forest eco-compensation funding system of China was first listed in the Forest Law of the People's Republic of China. Then, in 2004, the Central Government Financial Compensation Fund (CGFCF) was formally established (Deng *et al*., 2011). CGFCF has paid over 3 billion RMB Yuan per year toward forest eco-compensation, totaling an area over 44 million hm^2 (Dai *et al*., 2008). Forest eco-compensation establishment provides a forest protection funding source, but the forest eco-compensation mechanism still presents complex problems in need of solutions (Sheng *et al*., 2017; Liu *et al*., 2018). The forest eco-compensation standard is a fixed and state-stipulated value, and a single compensation funding source is not adequate for maintaining non-commercial forests (Pan *et al*., 2017) located in zones with key ecological functions that can only be preserved at a high cost (Deng *et al*., 2011). A central government macro-perspective is important to consider, such as regional coordination and central finance (Ling *et al*., 2019), while allocation and administration are the specific functions of the local governments (Zhou *et al.*, 2019). Providing detailed and specific guidance for regionally implementing eco-compensation policy is difficult for the national macro policy to accomplish. Further micro-internal analysis is required to determine how to distribute and use eco-compensation reasonably at the local scale (Singh *et al*., 2014). Having not only a thorough understanding of the current situation and conflicts of local stakeholders but also a better understanding of their wishes and needs (Lars *et al*., 2006; Zheng *et al*., 2019b) is necessary to optimizing the rational allocation of local compensation funds and achieving sustainable management and development (Ninan and Inoue, 2013).

Since the establishment of a reasonable standard is the key to maximize the eco-compensation effect, this study aims to provide an innovative assessment framework for eco-compensation policy, the core of which is subjective-objective combination analysis (SOCA). The subjective perspective provides stakeholder willingness, and the objective perspective provides a relatively reasonable market price. Based on objective valuation theory (Chang and Yoshino, 2017), the valuation system combining subjective and objective has been further developed. The SOCA framework is designed both to account for subjective compensation demand, and simultaneously correct exaggerated objective demand (Chang *et al*., 2019). This framework can greatly reduce bias that incorporating the subjective willingness of stakeholders into the decision-making process might cause, thereby making the evaluation results relatively consistent with objective market conditions. Based on the SOCA framework presentation, this study proposes the following hypothesis: combining subjective requirements and objective correction allows the eco-compensation standard, including both loss compensation and new afforestation maintenance costs, to be quantified. A multi-angle analysis of stakeholder perspectives based on the SOCA framework will provide important public feedback for setting rational eco-compensation allocation standards.

4.3 Methods

Utilizing the SOCA framework (**Figure 4.1**), the target eco-policy was made the object, and objective and subjective analyses were conducted for four key issues: ecosystem maintenance cost, key investment, stakeholder compensation, and decision preference. Finally, the compensation standard was calculated based on the subjective opinions of stakeholders and broad public objective judgment. CVM directly reflects the subjective willingness of stakeholders, which is suitable for obtaining data regarding investment and compensation willingness. The PAM relatively reflects the objective market value judgments by people, which is suitable for obtaining data regarding ecological maintenance costs. In addition to the traditional variables of WTP and WTA (Del *et al*., 2009; Zhen *et al*., 2014), this study contributed PAM as a special measure of the willingness survey, classifying the different positions of stakeholders as objective and irrelevant interests to obtain indicators of WTS and WTD (Chang and Yoshino, 2017). In the combined analysis of decision preference, willingness to vote (WTV) was utilized to evaluate stakeholder favor. Investigators set up subjective and objective scenarios to obtain stakeholder willingness via scenario simulation. The application survey in the Wuyishan area was carried out from July to September 2018, involving four groups of 32 investigators. The sampling method required a combination of random and cluster sampling. Tourists were selected randomly in several scenic locations, and farmers and residents were selected in villages and towns. Questionnaires and interviews were utilized to conduct 900 surveys and collect 865 effective questionnaires (**Table 4.1** and **4.2**).

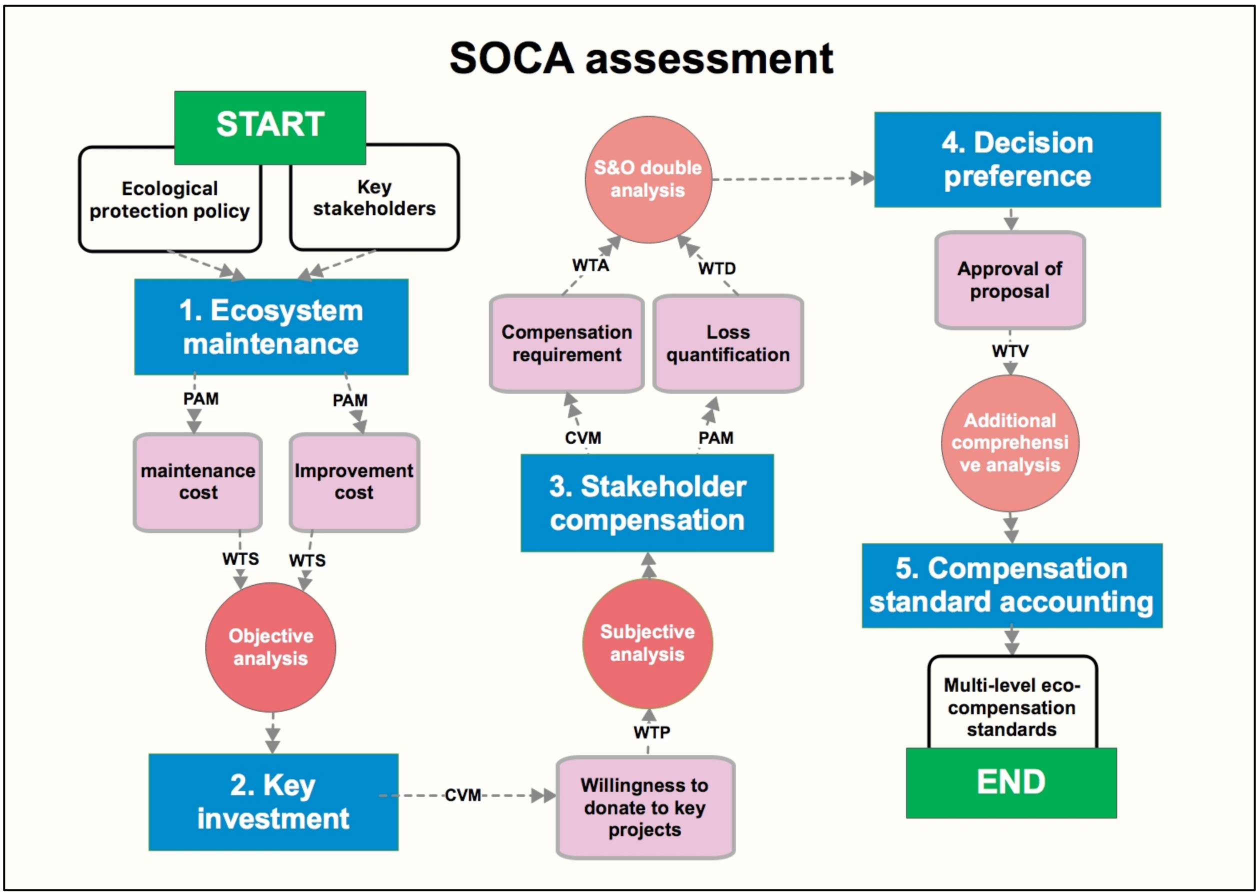
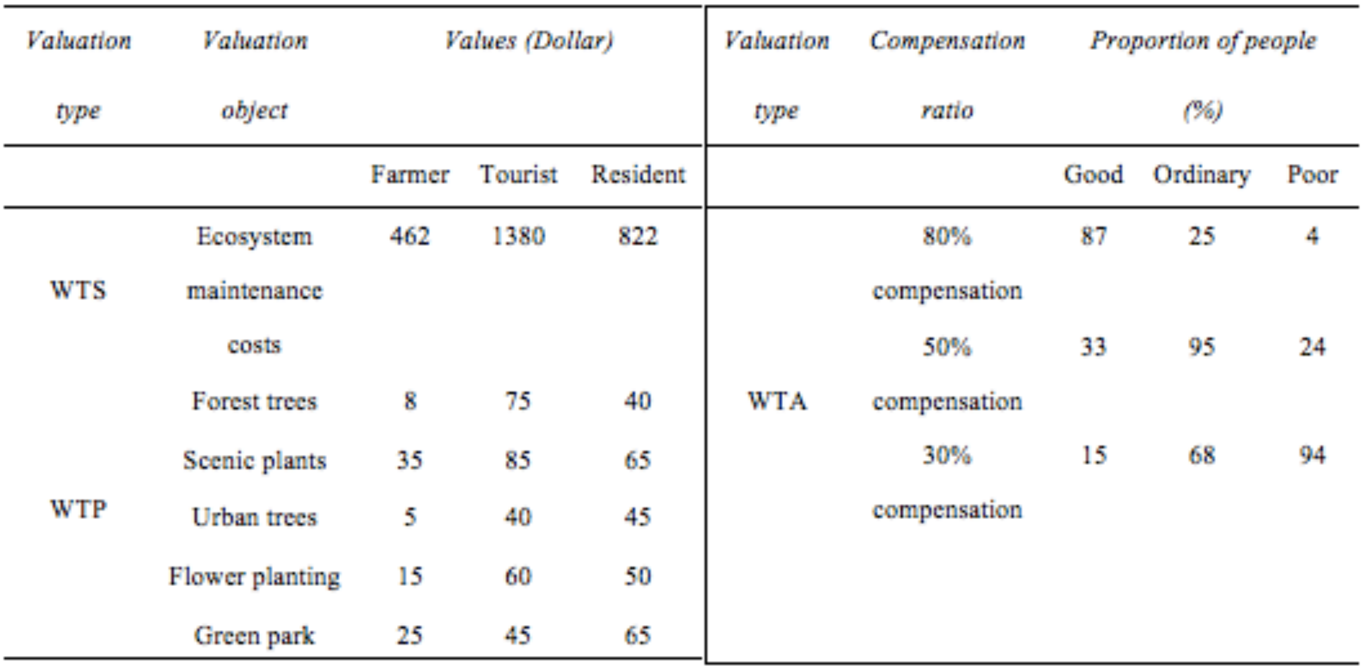


Figure 4.1 SOCA eco-compensation assessment framework. The SOCA assessment process is performed in five steps. Local eco-protection policy and key stakeholders need to be defined at the beginning, and the multi-level eco-compensation standards will be output in the end.

Table 4.1 Demographic features of the people under survey

Demographic Characteristics	*Grouping*	*Number*	*Proportion %*	*Demographic Characteristics*	*Grouping*	*Number*	*Proportion %*
Characteristics	Tourist	362	41.8	Gender	Male	496	57.3
	Famer	101	11.7		Female	369	42.7
	Resident	402	46.5	Occupation	Agricultural practitioners	133	15.4
Age	10-20	39	4.5		Individual management	205	23.7
	20-30	292	33.7		Civil servants and	244	28.2
	30-40	369	42.6		Employees	199	23.0
	40-50	95	11.1		No occupation	84	9.7
	Over 50	70	8.1				

Table 4.2 Summary of valuation results



Valuation type	*Valuation object*	*Values (Dollar)*			*Valuation type*	*Compensation ratio*	*Proportion of people (%)*		
		Farmer	Tourist	Resident			Good	Ordinary	Poor
WTS	Ecosystem maintenance costs	462	1380	822	WTA	80% compensation	87	25	4
WTP	Forest trees	8	75	40		50% compensation	33	95	24
	Scenic plants	35	85	65		30% compensation	15	68	94
	Urban trees	5	40	45					
	Flower planting	15	60	50					
	Green park	25	45	65					

4.3.1 Ecosystem maintenance costs

PAM was utilized as the main valuation method in this study to quantify the reasonable amount of sustained investment in ecosystem protection. The PAM investigation scenario simulation is to make the respondents base themselves on the third party with irrelevant interests, then speculate about the reasonable market price for each corresponding service by utilizing their respective market experience and common sense.

4.3.1.1 Objective scenario 1: general ecosystem maintenance costs

The WTS method in PAM was used to valuate ecosystem maintenance costs (Chang *et al*., 2019). The reasonable income of employees identified by stakeholders was considered as the ecosystem services maintenance cost. The question was stated as "How much monthly income would employees deserve if they were employed to maintain the ecological health of the forests in the region (per hectare) and performed their tasks perfectly?" In reference to the local income level, the semi-open option was set to a \$285 minimum and a \$1425 maximum, which could also be freely filled in the forms by the recipients. Results were averaged after filtering out extreme amounts; values 200% over the sample mode value were filtered out, and the remaining values were averaged.

4.3.1.2 Objective scenario 2: losses from ecosystem destruction

The WTD method in PAM was utilized to assess the ecosystem services depreciation amount. When varying degrees of tree damage occurred, the amount of land value depreciation of the local forest identified by the stakeholders was considered to be the ecosystem damage loss (Chang and Yoshino, 2017). Since this study only considered the depreciation ratio rather than the actual depreciation amount, a virtual WTS value was established to calculate the depreciation ratio. The question was stated as "Suppose forest land is priced at $6000/ha. When forest trees in this area are destroyed by 0%-50%, do you think the local land price should be depreciated accordingly? How much does it depreciate separately?" The semi-closed option set the minimum to non-depreciation, the maximum to worthless, and the depreciation amount could be freely filled in the forms. Results were averaged after filtering out extreme amounts.

WTD_j ($/ha) represents the depreciation ratio when ecosystem j is destroyed, as shown in Formula (4-1) (Chang and Yoshino, 2017).

$$WTD_j = \frac{D_{(a,b,c,d,e)}}{WTS} \qquad \text{Formula (4-1)}$$

$D_{(a,b,c,d,e)}$($/ha) represents the depreciation amount under damage degrees $a, b, c, d,$ and e (a, b, c, d, and e each represents 10%, 20%, 30%, 40%, and 50% trees reduction). WTS= $6000/ha in the experiment. In this study, the amount of loss due to environmental damage was considered as the cost of restoring the environment to its original state, thereby reversing the damage.

4.3.2 Nature reserve investment

The WTP method in CVM was utilized to evaluate key ecosystem services investment intentions, and nature reserves were selected as key investment objects in the Wuyishan case (He *et al.*, 2018a). U is the utility function of the respondents in WTP ($), Y is the independent variable income, and S is the condition, as shown in Formula (4-2).

$$U\ (Y; S) \qquad \text{Formula (4-2)}$$

Each person helps maintain the nature preserve by paying a certain amount of money. In Formula (4-3), Y ($/year) represents income and A represents bid. S represents the influence of socioeconomic characteristics on the preferences of people (Grilli *et al.*, 2015), and it is a WTP value condition, meaning that the influence of personal preference S generates some payment willingness. $\varepsilon_0, \varepsilon_1$ represents independent random variables with the same distribution.

$$U\ (1, Y - A; S) + \varepsilon_1 \geq U\ (0, Y; S) + \varepsilon_0 \qquad \text{Formula (4-3)}$$

The utility function difference can be expressed by Formula (4-4).

$$\Delta U = U\ (1, Y - A; S) - U\ (0, Y; S) + (\varepsilon_1 - \varepsilon_0) \qquad \text{Formula (4-4)}$$

The differential approximation of utility can be utilized in empirical analysis, as shown in Formula (4-5).

$$\Delta U = \alpha + \beta A + \gamma Y + \theta S \qquad \text{Formula (4-5)}$$

WTP is estimated by formula (4-6). $E\ (WTP)$ is the expected value of WTP, and α' is an adjusted intercept, which is appended to the initial intercept of α, shown as $[\alpha' = (\alpha + \gamma Y + \theta S)]$.

$$E(WTP) = \int_0^{Max\ A} F_\eta(\Delta U) dA = \int_0^{Max\ A} \left(\frac{1}{1 + exp\{-(\alpha' \beta A)\}}\right) dA \qquad \text{Formula (4-6)}$$

Payments for the ecological protection of forests, wetlands, and croplands were investigated through

WTP. Also, for a variety of green space resources, the willingness to bid for forest trees, scenic plants, urban trees, flower planting, and green parks was investigated. Open options were set based on pre-experimental results, and average values were obtained after filtering out extreme values.

4.3.3 Tea farmer compensation

The compensation assessment for tea farmer includes two parts: First, WTA in CVM was utilized in the experimental phase to obtain the willingness of farmers to accept compensation (Ronaldo and Ramon, 2018). This experiment only aimed at tea farmers and sought their subjective willingness to accept compensation via scenario simulation. Second, based on subjective willingness, WTD in PAM was utilized in the accounting phase as an objective correction.

4.3.3.1 Tea profit and compensation

To avoid over-pricing deviations (Patrick and Wiktor, 2018), a survey scheme was designed to avoid specific compensation amounts, and a closed option was set to compensate 30%, 50%, 70%, and 100% of the average annual farmer income. This study considered the annual income percentage that respondents chose to receive compensation as representative of tea profit losses they had suffered resulting from RTTF.

4.3.3.2 Tea quality and compensation

Since tea quality significantly affects tea revenue, further scenario simulation experiments were designed to clarify the extent of the willingness to accept compensation that was affected by tea quality.

Assuming that tea in a certain area owned by farmers must be removed, under condition 1: tea quality is good. Under condition 2: tea quality is ordinary. Under condition 3: tea quality is poor. The closed option was made to compensate in majority (80%), in half (50%), and in small quantities (30%).

4.3.4 Ecological decision-making preference

Based on previous expert and literature surveys, local proposals concerning different stakeholders were selected and designed with four closed options: very willing, generally willing, unwilling, and opposing. The experiment utilized a stakeholder indifference survey (Elizabeth *et al.*, 2019). Tea cultivation and compensation-related proposals only counted tea farmers, while the local employment problem avoided tourists. Support proportions for different projects were counted as the degree of support, which will be utilized to consider comprehensively the implementation of compensation schemes.

4.3.5 Eco-compensation standard accounting

Assuming that the compensation standard is M(\$/ha), i is the individual annual income, and M_i is the compensation for the i income level group. Tea planting is T, quality evaluation is a, b, c (a represents good, b ordinary, and c poor), and a certain level of tea can be expressed as $T_{(a,b,c)}$. C_i (\$/ha) represents forest ecosystem services maintenance costs given by group i. Since the government stipulates that ownership and income of afforested trees still belong to the original tea farmers, forest ecology maintenance cost should be calculated as an added value and compensated for as shown in Formula (4-7).

$$M_i = WTA_i \, T_{(a,b,c)} + C_i \qquad \text{Formula (4-7)}$$

C_i(\$) should be revised both subjectively and objectively based on SOCA results. Assuming that I(\$) is an ecosystem services investment and I_j(\$) is a j ecosystem services investment, the maintenance cost C_i(\$) is obtained by multiplying the proportion of $WTPj$(\$) to the total WTP(\$) and the $WTS_{(i;j)}$(\$) of the ecosystem services.

$$C_i = WTS_{(i;j)} \frac{I_{WTPj}}{I_{WTP}} \qquad \text{Formula (4-8)}$$

When the ecosystem is upgraded, C_i(\$) is the usual maintenance cost, which is calculated using Formula (4-8). When ecosystem damage occurs, $C_i{}'$(\$) will include environmental restoration costs, which are calculated by Formula (4-9).

$$C_i' = WTS_j \, WTD_j \qquad \text{Formula (4-9)}$$

M_i(\$) is revised via subjective and objective data, including both stakeholder preferences and objective cost identification. If the final M_i meets current compensation criteria, then it represents a relatively balanced eco-compensation assessment. If M_i is larger than current compensation criteria, then the resulting eco-compensation assessment does not meet compensation needs.

4.4 Results

4.4.1 Forest ecosystem maintenance costs based on a public objective appraisal

Different stakeholder interests are reflected in **Figure 4.2**, which indicates that tourists generally gave the highest level of agreement. Maintenance costs given by different stakeholders are significantly different, as shown in **Figure 4.2(a)**: tourists gave the highest value, followed by residents, and finally tea farmers. In this study, local ecosystem services are divided into three categories: provision, regulation, and culture. **Figure 4.2(b)** shows the judgments of different stakeholders on the importance of service functions. Different stakeholders perceived the importance of different functions in varying ways. Both farmers and residents valued the provision function most, but farmers emphasized it more, while tourists were more concerned about the cultural function. Also, the depreciation ratio was further analyzed via two virtual identities: stakeholders and non-stakeholders. **Figure 4.2(c)** shows that when forest trees were reduced by half, non-stakeholders considered 23% depreciation of the total value, while stakeholders believed that the forest value loss had nearly reached 40%. Therefore, stakeholders generally believed that forest trees are precious and have a high value.

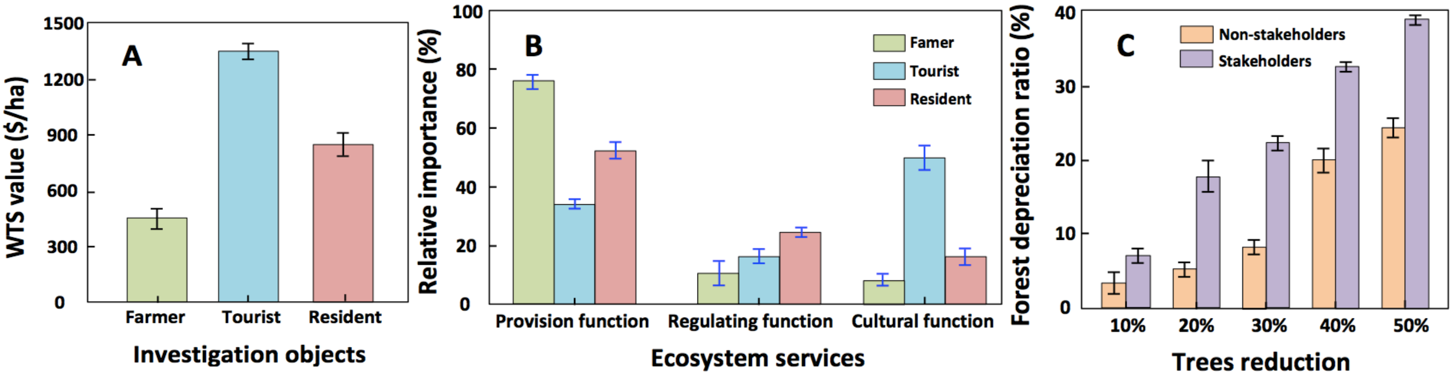


Figure 4.2 Public appraisal value of maintenance cost: **(a)** Ecosystem Maintenance costs: the estimated maintenance cost of the entire forest ecosystem service as judged by different stakeholder members; **(b)** Relative importance evaluation: the public judgment of the relative importance of different service functions; **(c)** Forest depreciation ratio: refers to the depreciation percentage of forest land price caused by the decrease of forest trees.

4.4.2 Willingness to make key investments based on public subjective consideration

Figure 4.3 shows the willingness to contribute to forest and greening ecosystem services, as based on the WTP survey. Different protection objectives revealed that the WTP of stakeholders showed a distinct trend, with **Figure 4.3(a)** showing the WTP for three major ecosystem types in the region. Stakeholders were most willing to protect forests, followed by croplands, and finally wetlands. Furthermore, **Figure 4.3(b)** shows how different stakeholders also showed differences in the WTP of various types of green space. Although different groups showed different levels of investment willingness, they generally preferred investments for plants in scenic spots. Among them, tourists showed the highest level of investment willingness. The desire of residents showed a more average trend, which reflected their hope that all types of green space could be well managed.

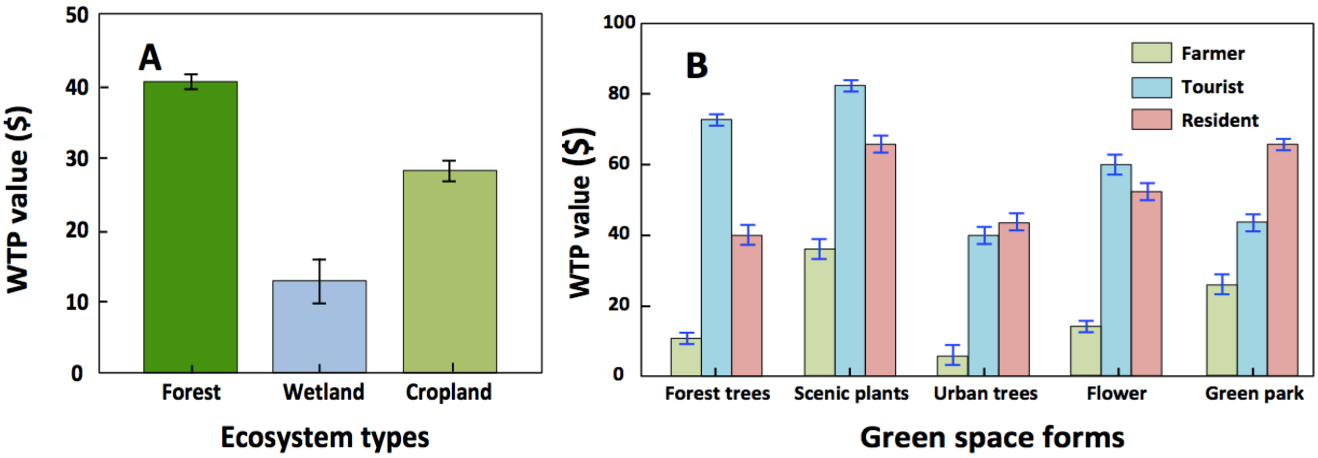


Figure 4.3 Willingness to pay for different ecosystem services: (a) Willingness to pay for different ecosystems: the WTP for the three main local ecosystems; **(b)** Willingness to pay for different green spaces: the WTP for several typical forms of local green spaces.

4.4.3 Compensation for stakeholders based on subjective claims and objective judgment

Figure 4.4 shows the analysis of tea farmer compensation requirements. In comparison to the single compensation standard for removing tea, tea farmers were more inclined to accept compensation corresponding to their economic losses. **Figure 4.4(a)** shows how the WTA/annual income ratio reflected the subjective compensation demand of tea farmers: when the ratio was too high or too low, tea farmers tended to require relatively low compensation; when the ratio was between 50% and 70%, tea farmers required relatively high compensation. Farmers with heavy losses probably had given up tea cultivation completely and turned to other businesses, while the general loss farmers preferred to wait continuously for opportunities. **Figure 4.4(b)** shows the relationship between the compensation requirement and tea quality. Tea farmer compensation requirements were greatly influenced by the tea quality that they originally planted. When tea quality was good, the majority of farmers claimed to compensate 80% of their losses. On the contrary, when the tea quality was poor, the majority claimed to compensate only 30% of their losses.

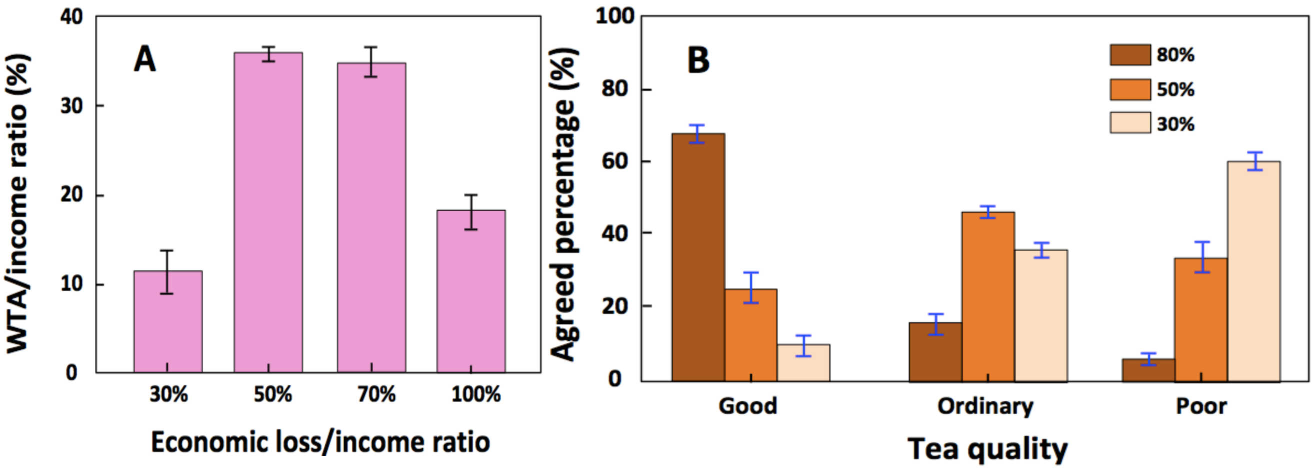


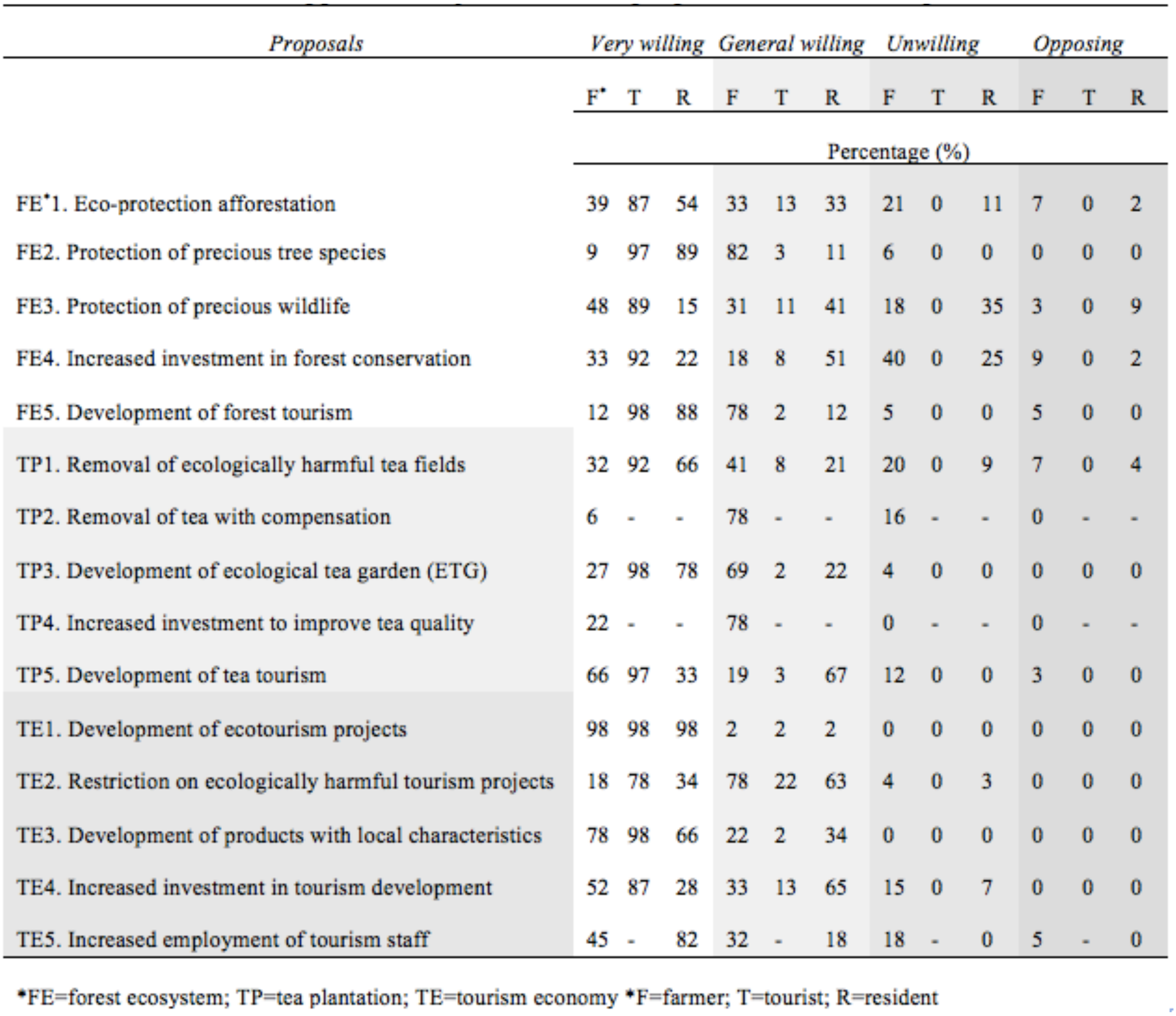
Figure 4.4 Analysis of compensation requirements: (a) The relationship between WTA/income ratio and loss/income ratio. The WTA/income ratio represents the proportion of

WTA value required by tea farmers to their annual income. The loss/income ratio represents the proportion of economic losses caused by the RTTF policy to their annual income; **(b)** The relationship between WTA/income ratio and tea quality. In the legend, the 80%, 50%, 30% represent that the compensation losses required by tea farmers are at least 80%, 50%, 30% of their economic loss due to the RTTF policy, respectively.

4.4.4 Subjective preference voting for external internalization proposals

After expert visiting and information gathering, some popular proposals were listed to figure out the attitudes of different stakeholders, as shown in **Table 4.3**. These proposals mainly focused on the forest ecosystem (FE), tea planting (TP), and the tourism economy (TE). Investigating the attitudes of tea farmers, tourists, and residents revealed significant differences among different stakeholders in these eco-related proposals. Tourists showed the greatest support for all pro-environment proposals, while local people were more hesitant. Most tea farmers were willing to remove tea if they could be compensated, although the compensation satisfaction criteria were still unclear. Residents and tourists shared similar opinions of most of the ecological protection options, but opinions of residents were consistent with those of tea farmers regarding options closely related to the local area. Most notably, proposals to protect local wildlife received a low level of agreement from tea farmers and residents. Despite considerable perspective differences, a consistent trend existed among different stakeholders in ecotourism projects. All stakeholders had the same expectation for ecotourism, especially local people who were more eager for decision-making and ecotourism development to solve their current problems.

Table 4.3 Approval analysis of various proposals related to eco-protection

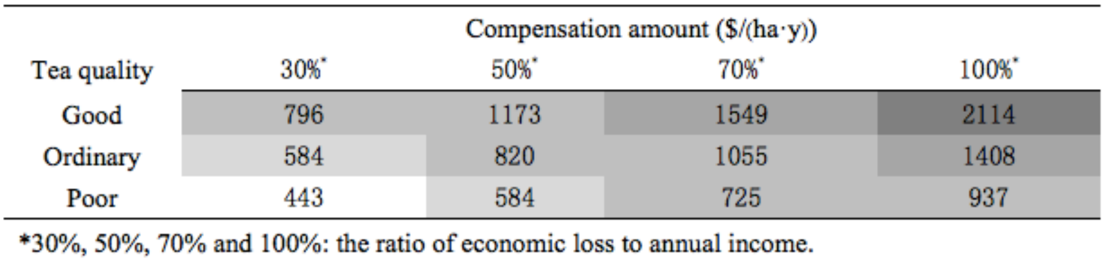


Proposals	*Very willing*			*General willing*			*Unwilling*			*Opposing*		
	F*	T	R	F	T	R	F	T	R	F	T	R
	Percentage (%)											
FE*1. Eco-protection afforestation	39	87	54	33	13	33	21	0	11	7	0	2
FE2. Protection of precious tree species	9	97	89	82	3	11	6	0	0	0	0	0
FE3. Protection of precious wildlife	48	89	15	31	11	41	18	0	35	3	0	9
FE4. Increased investment in forest conservation	33	92	22	18	8	51	40	0	25	9	0	2
FE5. Development of forest tourism	12	98	88	78	2	12	5	0	0	5	0	0
TP1. Removal of ecologically harmful tea fields	32	92	66	41	8	21	20	0	9	7	0	4
TP2. Removal of tea with compensation	6	-	-	78	-	-	16	-	-	0	-	-
TP3. Development of ecological tea garden (ETG)	27	98	78	69	2	22	4	0	0	0	0	0
TP4. Increased investment to improve tea quality	22	-	-	78	-	-	0	-	-	0	-	-
TP5. Development of tea tourism	66	97	33	19	3	67	12	0	0	3	0	0
TE1. Development of ecotourism projects	98	98	98	2	2	2	0	0	0	0	0	0
TE2. Restriction on ecologically harmful tourism projects	18	78	34	78	22	63	4	0	3	0	0	0
TE3. Development of products with local characteristics	78	98	66	22	2	34	0	0	0	0	0	0
TE4. Increased investment in tourism development	52	87	28	33	13	65	15	0	7	0	0	0
TE5. Increased employment of tourism staff	45	-	82	32	-	18	18	-	0	5	-	0

*FE=forest ecosystem; TP=tea plantation; TE=tourism economy *F=farmer; T=tourist; R=resident

The SOCA model can be utilized to calculate compensation criteria under different scenarios and conditions. In this study, local forest ecological environment improvements meant that the added value is calculated according to C_i. Take the local per capita annual income of $2,354 (2017) of rural areas, where a total of 12 compensation standards under different conditions were calculated in **Table 4.4**. When economic losses caused by tea removal account for 30%, 50%, 70%, and 100% of the annual income of farmers, in combination with their tea quality, a compensation range from $443/ha to $2114/ha per year was finally obtained. The general suggestion is to compensate for 3-5 years according to the time needed for new afforestation trees to survive. The compensation period should be adjusted by local institutions according to national standards and the growing needs of different trees. The SOCA model includes the tea compensation costs and ecological maintenance of new afforestation. Therefore, tea farmers need to ensure new afforestation health if they accept SOCA standards. Compensation for the following year can be increased or decreased according to the health condition of the trees in the previous year.

Table 4.4 SOCA eco-compensation standard



	Compensation amount ($/(ha·y))			
Tea quality	30%*	50%*	70%*	100%*
Good	796	1173	1549	2114
Ordinary	584	820	1055	1408
Poor	443	584	725	937

*30%, 50%, 70% and 100%: the ratio of economic loss to annual income.

4.5 Discussion

Eco-compensation criteria based on ecosystem service value assessments can contribute to more sustainable ecological management (Zhang *et al*., 2010). In this case, tea farmers are the key to the RTTF policy, and the compensation standard for tea farmers is connected to successful local ecological protection implementation. Most farmers agreed to be compensated to support ecological protection, but the unified national eco-compensation standard had difficulty in satisfying them. The single willingness to compensate the survey often made farmers overstate their losses. Utilizing the SOCA achieves a proportion of subjective compensation willingness. Then the objective ecosystem maintenance cost was used as the calculation base, which could greatly improve the reference significance of the evaluation results.

The SOCA model result synthesizes the subjective compensation requirements of tea farmers and the objective judgment of forest ecological protection value by all stakeholders. The perceptions of stakeholders mean that it can be considered a reasonable compensation standard. If the total compensation amount exceeds the government budget, then further consideration is needed to determine other ways to internalize these revenue losses. In the case of insufficient subsidies, farmer enthusiasm can be maintained through other forms of contracts (Bennett *et al*., 2018); eco-tourism may be a choice for transforming losses and achieving long-term sustainable compensation for tea farmers (Chen and Qiu, 2017). However, the potential environmental pressure from tourism in the local area could mean that optimizing the tourism industry may be more recommended than simply expanding tourist numbers. These policies may be reflected in increasing eco-tourism labor employment for environmental maintenance and encouraging eco-tourism product development (Han and Li, 2019).

In this study, the SOCA assessment was conducted in Wuyishan City for 6 months. It included two expert interviews, one questionnaire pre-experiment (determining question rationality and setting the answer options range), and one formal questionnaire survey. According to the SOCA framework, the detailed compensation standards for different tea farmers and different tea qualities could be specifically calculated. Institutions only need to count the loss caused by tea removal as a proportion of the original annual income of the farmers, then identify their tea quality via professionals. Finally, corresponding compensation standards could be calculated. The SOCA framework can be applied to other cases utilizing eco-compensation tools to conduct ecological protections. In terms of the operation process, the concept of "loss" suggested to be used instead of the concept of "compensation" when conducting the survey. While the aim is determining the compensation standard, emphasizing the concept of "compensation" in the survey process will lead to exaggeration bias.

Utilization of the SOCA framework to calculate eco-compensation standards can be applied to both positive and negative impact scenarios. Under positive scenarios, the protection policy improves the environment, and contributor compensation can be calculated. In this scenario, the SOCA framework covers the general maintenance costs of the environment in an improved state. Also, under the negative scenario, victim compensation can be calculated when environmental damage occurs due to inappropriate development decisions. In this scenario, SOCA covers the repair costs of those environmental damages. The advantage of the SOCA framework is its general applicability to eco-compensation cases and how it introduces an objective perspective into correct subjective deviation. While the disadvantage lies in needing a large sample size, it is otherwise difficult to reflect the general objective cognition of stakeholders. The limitation of this study is that SOCA focuses on providing a new approach to allow multiple compensation standards to be evaluated, rather than providing a detailed compensation scheme. The detailed compensation scheme must pay attention to regional differences and should be evaluated according to local tea quality, output, number of farmers, financial details, and other factors.

4.6 Conclusions

Establishing non-commercial forest compensation standards is essential to improve the forest eco-compensation system, which should be based on quantitative ecosystem services valuations. In China, determining reasonable compensation standards is difficult due to the lack of market-based pricing conditions for public ownership. This study proposed an eco-compensation assessment framework: the subjective-objective combination analysis (SOCA). Studying the willingness analysis of subjective and objective perspectives allows this framework to balance stakeholder wishes while correcting subjective bias. This study calculated a compensation range from \$443/ha to \$2114/ha per year in the tea-removing area for ecological afforestation. The greatest advantage of SOCA is that it can calculate non-uniform compensation standards according to different loss conditions of tea farmers, including both loss compensation and ecological maintenance costs, as well as providing stakeholder compensation accounting for the complete environmental protection process.

Acknowledgments

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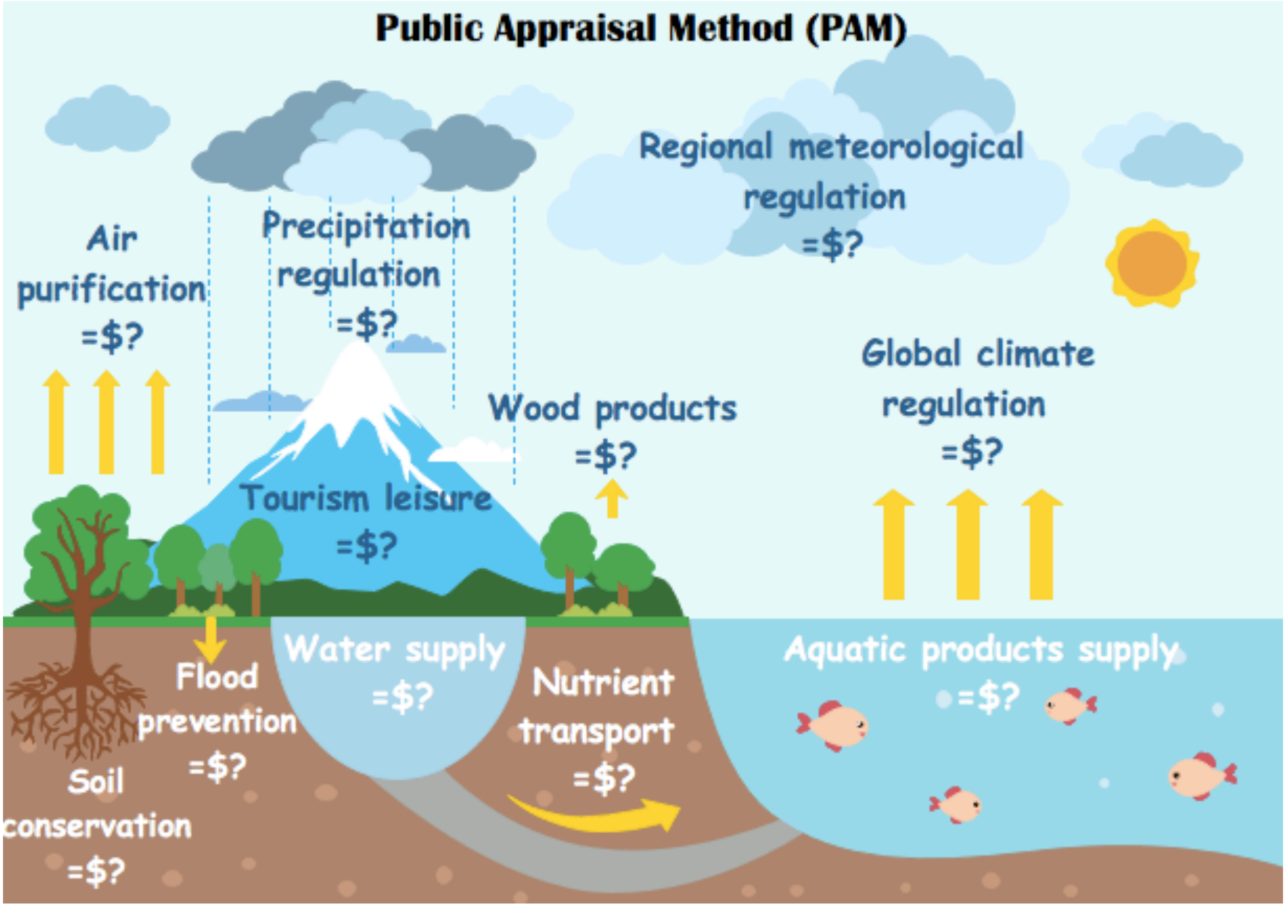
Chapter 5 A new public appraisal method for valuating ecosystem services: a case study in the Wuyishan City, China

Graphical Abstract 4



5.1 Abstract

Revealing the value of ecosystem services is a prerequisite for economic decision-making to maintain life-support functions, yet how to make the valuating process more universally and extensively applicable remains poorly defined. Herein, we developed a public appraisal method (PAM) to let ecosystem services be appraised by the public directly. Inspired by cultural relic identification, the PAM included four steps: categorize real services, build a virtual market, conduct the public appraisal, and produce a valuation list. Taking the Wuyishan forest ecosystem as a study case, we verified the effectiveness of PAM by comparing it with the traditional comprehensive method (TCM). The total value of ecosystem services assessed by PAM was ¥181.6 billion/year, compared with ¥222.3 billion/year for TCM. A new index, called environmental risk perception (ERP), was introduced. The ERP model was used to analyze the differences in the valuation results, as well as to improve the accuracy of PAM valuation. By building a virtual market for real services, we provide a simple valuation method that can be widely applied for value assessment and importance ranking of multiple ecosystem services.

5.2 Introduction

Economic analysis with ecosystem services assessment has proved to be an effective contribution for linking natural systems and human well-being (Bateman *et al*., 2014; Rebecca *et al*., 2019). The ecological modernization movement strongly advocates an integration of ecology and economy, which results in the economic connotation of ecology as broadly important (Young, 2018). Economic decision-making analysis from an ecological perspective has become a priority area of global policy and academic research (Ruckelshaus *et al*., 2015; Jonathan *et al*., 2018), which is related to ecological protection (Amber *et al*., 2018), regional planning (David *et al*., 2018), sustainable development (Stephen *et al*., 2019), biodiversity (Teixeira *et al*., 2019), and human well-being (Gregory *et al*., 2019).

Valuation is a process of translating ecosystem services into money that decision-makers and the general public can readily understand (NRC, 2004). The significance of ecosystem service valuation lies in the fact that all environmental problems and conflicts originate from trade-offs among values (Sander *et al*., 2016). The lack of explicit pricing of ecological value directly drives the neglect of ecological cost in the process of value trade-offs. Valuation is the linchpin that helps decision-makers realize the necessity of eco-investment (Mandle *et al*., 2019; Chen, 2020;). However, the pricing process is extremely difficult because ecosystem services lack price information reflecting social value (Stephen *et al*., 2006), as well as other hard-to-define values. Due to the public nature of ecological goods, there is no market for most ecosystem services at present.

Existing valuation technologies comprise two types: real market and non-market. For those services/goods that circulate in a real market, the common practice is to calculate their economically measurable values based on market transactions (Strand *et al*., 2018). Thus, it is relatively simple for economists to build models for this type of forecasting (Mengist *et al*., 2020). The dilemma is greater for valuing non-market services, which is particularly acute for “regulating services,” such as disease resistance, flood regulation, or climate control. (Stephen *et al*., 2006). Virtual markets are usually established to solve the problem of non-markets, putting the public in the buyer's position and asking their willingness to pay to maintain these services (Sigríður Rós *et al*., 2019). This kind of preference-based approach is often criticized for its uncertainty (Stephenson and Shabman, 2019).

The simplification of valuation methods is a challenge to obtain the valuation results quickly and effectively (Fonseca and Rodrigues, 2017). We propose a simple and universal valuation method that originated from an expert appraisal of cultural relic value. We noticed that bringing ecosystem services into market value judgment is analogous to bringing cultural relics into markets (Chang and Yoshino, 2017). This method augments expert appraisal with public appraisal and sets the public in a position without a direct interest. Therefore, the public can give a reasonable value judgment based on their respective market experience. This contributes to reducing preference differences (Stephenson and Shabman, 2019) because consumers' unwillingness to pay does not affect their perception that the products do have value (which is common in markets). We termed this approach the public appraisal method (PAM), the core of which is based on the objective description of ecosystem services.

The PAM was tested for the Wuyishan forest ecosystem. Compared with the traditional comprehensive method (TCM), we provided an ecosystem service value for economic decision-making with a detailed PAM operation manual. Furthermore, by comparing the valuation results of PAM and TCM, we introduced a new index revealing the constraints of the result differences, which was called the environmental risk perception (ERP) (Alexander and Laurie, 2007). We use the ERP model to explain trends and critical points of value changes in the system. As economic situation may be influenced by external shocks, global environmental events or changes will also affect public judgment on valuation. We believe that the PAM based on public judgment may be more sensitive to changes in recognition and reflect the value changes with the development of the times.

5.3 Methods

5.3.1 Verification case selection

To verify the applicability of PAM, the verification system would best be a large-scale ecosystem with varied categories of services. Wuyishan City is in the northern area of Fujian Province, which is a key area for global biodiversity conservation (Chang *et al*., 2019). With 3,728 known plant species and 5,110 known animal species, Wuyishan area contains a critical gene pool for rare and endemic species (Chang *et al*., 2019). The Wuyishan ecosystem represents a typical case of China's implementation of eco-protection policies, but an unclear contribution of ecosystem services to the economy is hindering eco-protection implementation. Considering the complexity of the ecosystem and the necessity of revealing its economic value, it is an excellent system in which to explore the valuation method. This study involved a wide range of data statistics, mainly using the following data sources (**Table 5.1**): the regional statistical yearbook from 2003 to 2018 (including Wuyishan City and Nanping city), city statistical data of the government, satellite remote sensing data of Landsat 7 and Landsat 8 from 2001-2019, meteorological data published by China meteorological data network (CMDN), and geographic data from geographic information system (GIS).

Table 5.1 Data sources of traditional comprehensive method (TCM)

Data Category	*Data name*	*Data source*	*Data period*	*Data acquisition*
Agricultural data	Agricultural output data	City statistical yearbook	2003-2007, 2010-2018	Wuyishan Statistics Bureau (WSB); Nanping Statistic Bureau (NSB)
Livestock and poultry data	Livestock quantity data	City statistical yearbook	2013-2018	Wuyishan Statistics Bureau (WSB)
Water data	Water consumption data	City statistical data of government	2009-2019	Nanping Water Resources Bulletin (NWRB); Wuyishan Commission of Housing and Construction (WCHC)
Water conservancy data	Hydroelectric generation data	City statistical data of government	2005-2019	Wuyishan Agricultural Bureau (WAB)
Seed resource data	Crop seed data	City statistical yearbook; Public data of government	2015-2018	Wuyishan Statistics Bureau (WSB); Wuyishan Agricultural Bureau (WAB)
Energy data	Biogas utilization data	City statistical yearbook	2010-2019	Wuyishan Agricultural Bureau (WAB); Nanping Statistic Bureau (NSB)
Meteorological and climatic data	Meteorological data	China Meteorological Data Network (CMDN)	2005-2019	National Meteorological Science Data Center (NMSDC)
Forest data	Geographic data; Land use data	Geographic information; Satellite remote sensing image	2001-2019	Geographic Information System (GIS); Landsat 7 and Landsat 8
City data	Demographic data; Tourism data	City statistical of government	2005-2010; 2013-2019	Wuyishan Statistics Bureau (WSB); Nanping Culture and Tourism Bureau (NCTB)

5.3.2 Ecosystem service value accounting: TCM

The traditional comprehensive method (TCM) is used to classify ecosystem functions according to different ecosystem service categories (Strand *et al*., 2018; Marshall *et al*., 2019; Mengist *et al*., 2020), then calculate the physical quantity of functional supply capacity, and finally convert the physical quantity into monetary value (Kenneth *et al*., 2013). The evaluation methods of physical quantity are divided into three categories: (1) statistical investigation method (Terhi *et al*., 2019); (2) valuation method based on a physical model (Grizzetti *et al*., 2019); and (3) energy valuation theory based on material and energy equivalents (Shah *et al*., 2019). Based on defining the physical quantity of each function, there are three primary methods to further convert it into monetary value: (1) market value method (Robinson *et al*., 2019); (2) alternative value method (Lovett, 2019); and (3) contingent valuation method (Venkatachalam, 2004). In this study, the TCM divided ecosystem services into four categories according to the MEA standards (MEA, 2005): provisioning, supporting, regulating, and cultural. The detailed classification and valuation methods are in **Table 5.2**. Statistical data of the provisioning function are in **Table 5.3** according to the local Yearbook. The monetary value of the regulating function is calculated based on the physical quantity data shown in **Table A-1** in the Appendix. All the physical quantity data come from Wuyishan Ecosystem Accounting Report, (Wuyishan Municipal Government, 2018). The accounting methods for supporting and cultural functions are shown in **Figure 5.1** and **Figure 5.2**. The overall total monetary value calculation is carried out after the calculations for each category. All the TCM methods and techniques are based on Specifications for Assessment of Forest Ecosystem Services in China (LY/T1721-2008) and Norm of Techniques for Valuation of Forest Resources Assets (LY/T2735-2016).

Table 5.2 Classification and accounting method of traditional comprehensive method (TCM)

Categories	*Ecosystem services*	*Valuating indicator*	*Data sources*	*Physical quantity methods*	*Monetary quantity methods*
Provisioning	Agriculture products	Grain, oil, vegetables, fruits, tea, et al	Statistical yearbook	SSM	OVM
	Livestock and poultry products	Meat, egg and milk			
	Forest products	Log output			
	Fresh water products	Fish and shrimp			
	Water resources (surface)	Water for agriculture, industry, life			
	Seed resources	Trees and flowers			MVM
	Food and medicine	Herbal medicine and tea			
	Energy (biomass)	Water energy and biogas			
Regulating	Climate regulation	Climate mitigation	Remote sensing data; Meteorological data; Basic geographic data	MM	AVM
		Microclimate regulation		MM	
	Environmental quality regulation	Air purification		SSM	
		Water purification		SSM	
		Noise control		PMM	
		Air conditioning		MM	
	Hydrologic regulation	Runoff regulation		MM	
		Flood regulation		MM	
	Soil conservation	Soil conservation		MM	
Supporting	Biodiversity	Habitat and gene bank	Survey data	SSM	AVM
Cultural	Aesthetic value	Number of tourists	Statistical yearbook	SSM	TCM

SSM: Statistical survey method; MM: Modeling method; PMM: Practical monitoring method; OVM: Output value method; MVM：Market value method; AVM: Alternative value method; TCM: Travel cost method

Table 5.3 Accounting content of provisioning services

Categories	*Valuation*	*Statistical item*	*Categories*	*Valuatio*	*Statistical item*
Agriculture products	Grain	Rice	**Agriculture products**	Characteristic	Cassava
		Wheat			Lotus seed
	Coarse cereals	Corn			Taro
		Sorghum	**Livestock products**	Meat	Pork
		Millet			Beef
	Tubers	Sweet potato			Mutton
		Potato			Poultry
	Beans	Soybean			Rabbit
		Mung bean		Egg	Egg
		Jumby bean		Hunt	Wild animal
	Edible oil	Peanut		Others	Beeswax
		Sesame			Honey
		Sunflower seed	**Wood and forest byproducts**	Forest products	Tung tree seed
	Cotton	Cotton			Litsea cubeba
	Hemp	Hemp			Camellia oleifera seed
	Sugarcane	Sugarcane			Palm
	Tobacco	Tobacco			Pine resin
	Vegetables	Vegetables			Bamboo shoots
	Medicine	Medicine			Thatch grass
	Wild plant	Wild	**Aquatic products**	Fresh water	Fish
	Tea	Black tea			Shrimps and crabs
		Green tea			Shellfish
		Oolong tea	**Water resource**	Water consumption	Agricultural water
	Edible fungi	Edible fungi			Domestic water
	Fruits	Apple			Industrial water
		Citrus			Ecological water
		Pear	**Seed**	Agricult	Rice seed
		Loquat	**Energy**	Methane	Biogas utilization
		Waxberry		Water	Water power
		Peach			

Table 5.3 Accounting content of provisioning services

Categories	*Valuation*	*Statistical item*	*Categories*	*Valuatio*	*Statistical item*
		Persimmon	*Data sources: City statistical yearbook from		
		Grape	Wuyishan Statistics Bureau (WSB) and Nanping		

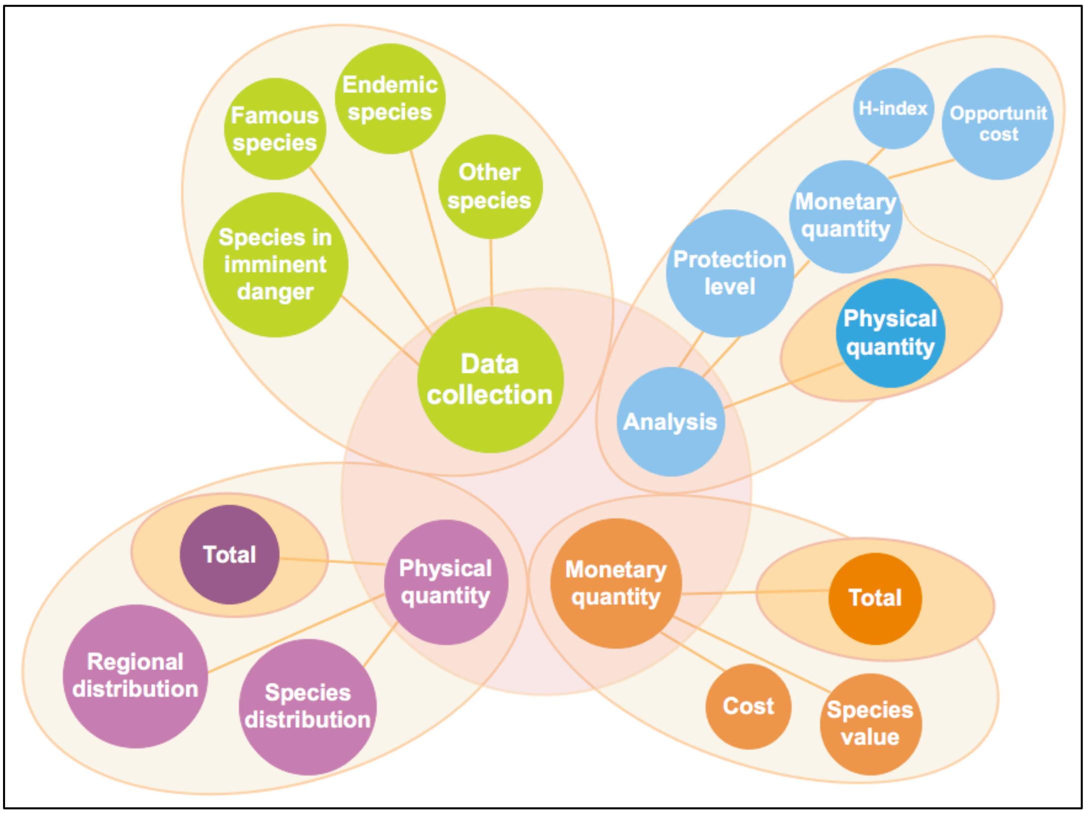


Figure 5.1 Accounting methods of species conservation services. Firstly, obtain species information by data collection. Secondly, analyze the protection level and opportunity cost. Thirdly, determine the physical quantity through species distribution and regional distribution, and finally evaluate the economic value.

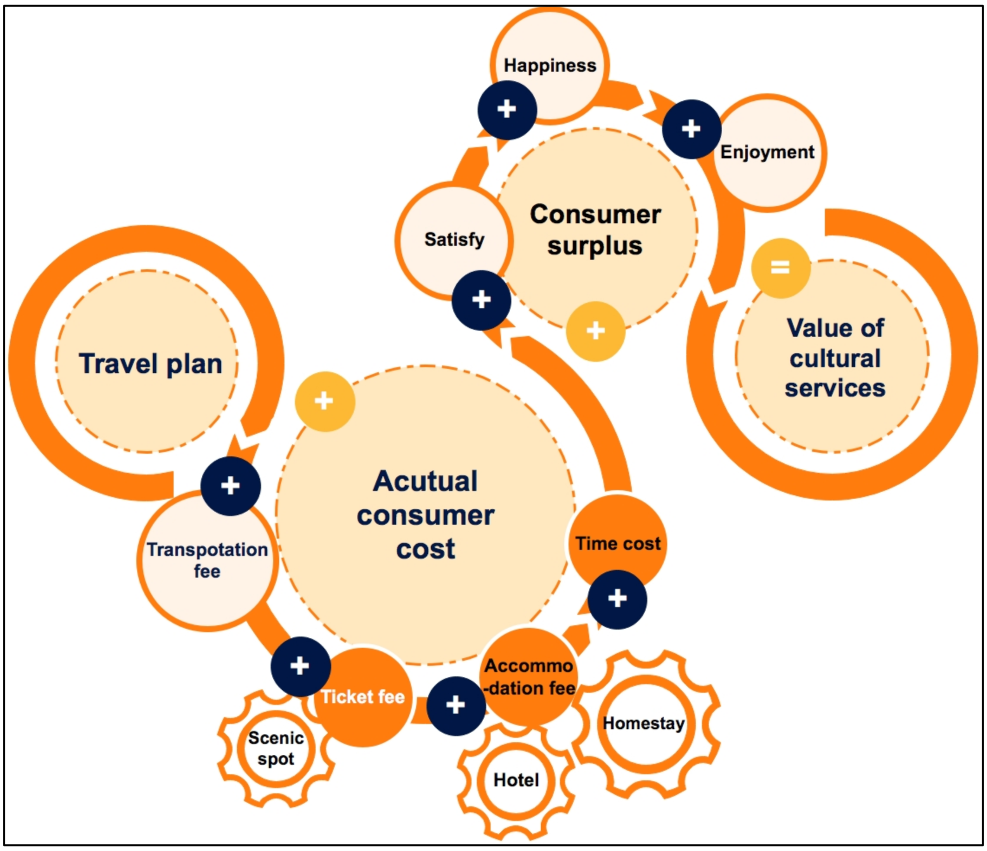


Figure 5.2 Accounting methods of cultural services. The cultural value of ecosystem services is valuated by using the travel cost method. Firstly, compute all the actual consumer cost. Secondly, add up with the consumer surplus. Cultural value is the combination of the actual consumer cost and the consumer surplus of travel.

5.3.3 Ecosystem service value accounting: PAM

In this study, we formally define PAM as appraising the market circulation value of ecosystem services from the standpoint of the third party whose interests are not related. The main feature of PAM is the objective position. Although the survey that involved people is generally influenced by subjective factors, we found that respondents also have relatively objective positions (Chang and Yoshino, 2017). The objective position can be realized through the design of investigation methods, which ignore the interference of ownership loss and ownership benefit, so as to reduce the deviation of subjective factors as much as possible. Although the deviation of subjective cognition usually exists, the interference of subjective interests can be avoided to a certain extent by setting a relatively objective position for the respondents (Chang and Yoshino, 2017).

The PAM implementation needs to objectively introduce the functions of each ecosystem service to be valuated, and then ask the respondents to judge the value of all services from an objective standpoint. All the questions need to be set by objective questions, avoiding subjective preferences. The survey adopted the principle of psychological equidistance, and did not emphasize subjective benefits or losses. All the respondents came from the scope inside ecological function area to ensure that they may have a certain understanding and interest in the ecosystems. The operation of the PAM experiment was designed specifically for this study (**Figure 5.3**), and we divided the PAM valuation process into four steps: 1) categorize real services, 2) build a virtual market, 3) conduct a public appraisal, and 4) output a pricing list. This study outlines the method design and implementation process of PAM in detail through the Wuyishan case.

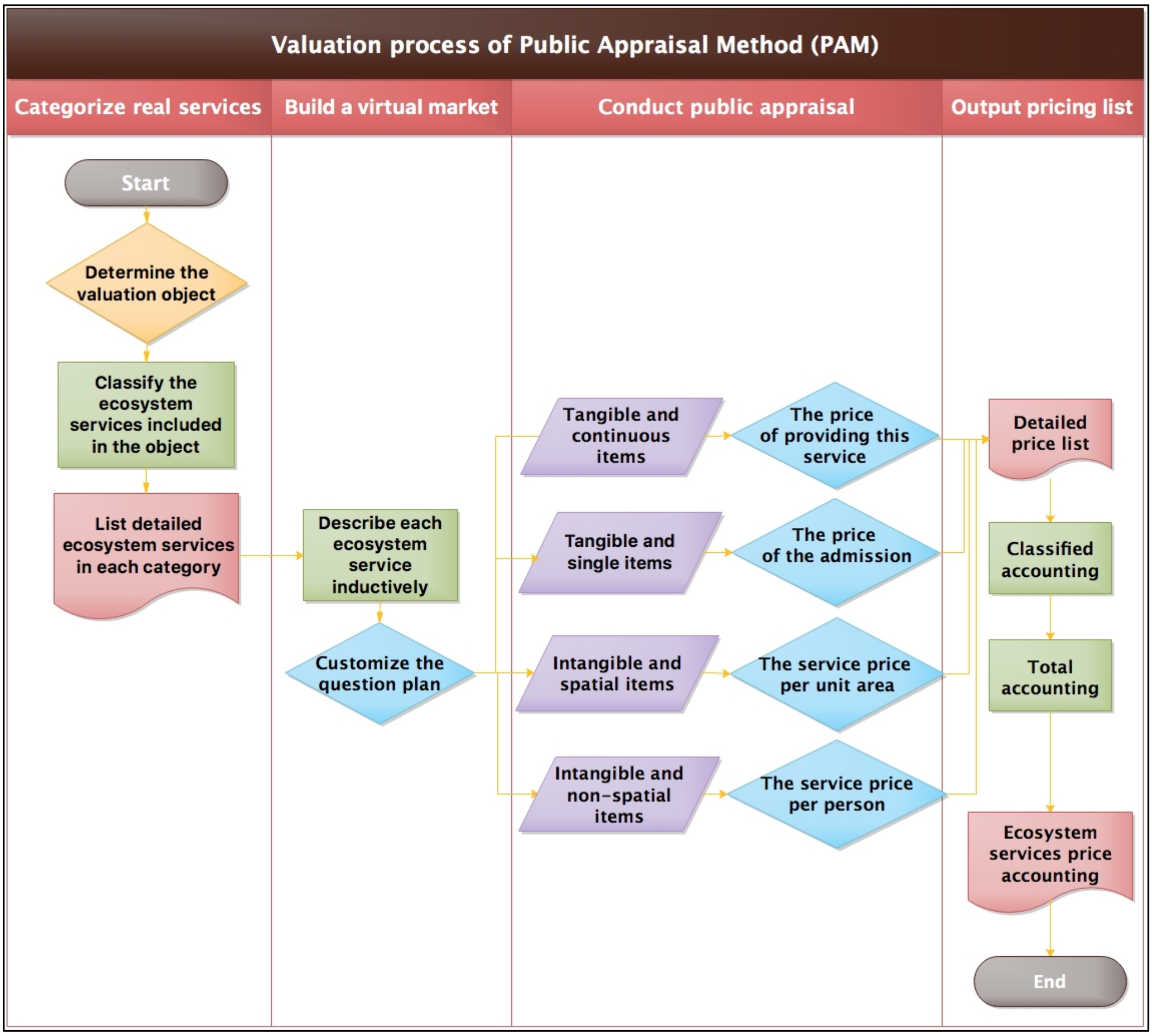


Figure 5.3 Technical flowchart of the PAM implementation process

5.3.3.1 First step of PAM design: categorize real services

In the first step of categorizing real services, it is necessary to determine the valuation object first, then classify the types of ecosystem services contained in the object, and finally list the detailed ecosystem services contained in each type. In categorizing of ecosystem services in Wuyishan, we integrated the ecosystem services classification system of the MEA (MEA, 2005) and the Environmental-Economic

Accounting (EEA) (UN, 2014), and determined 4 categories and 28 items of ecosystem services (**Figure 5.4**). We integrated different classification systems and adopted common description to explain various services, which mainly included definition introduction and function description. Before the virtual market pricing started, we first explained these services to the respondents, including objective functions and some daily examples to help them understand, especially those with less public contact.

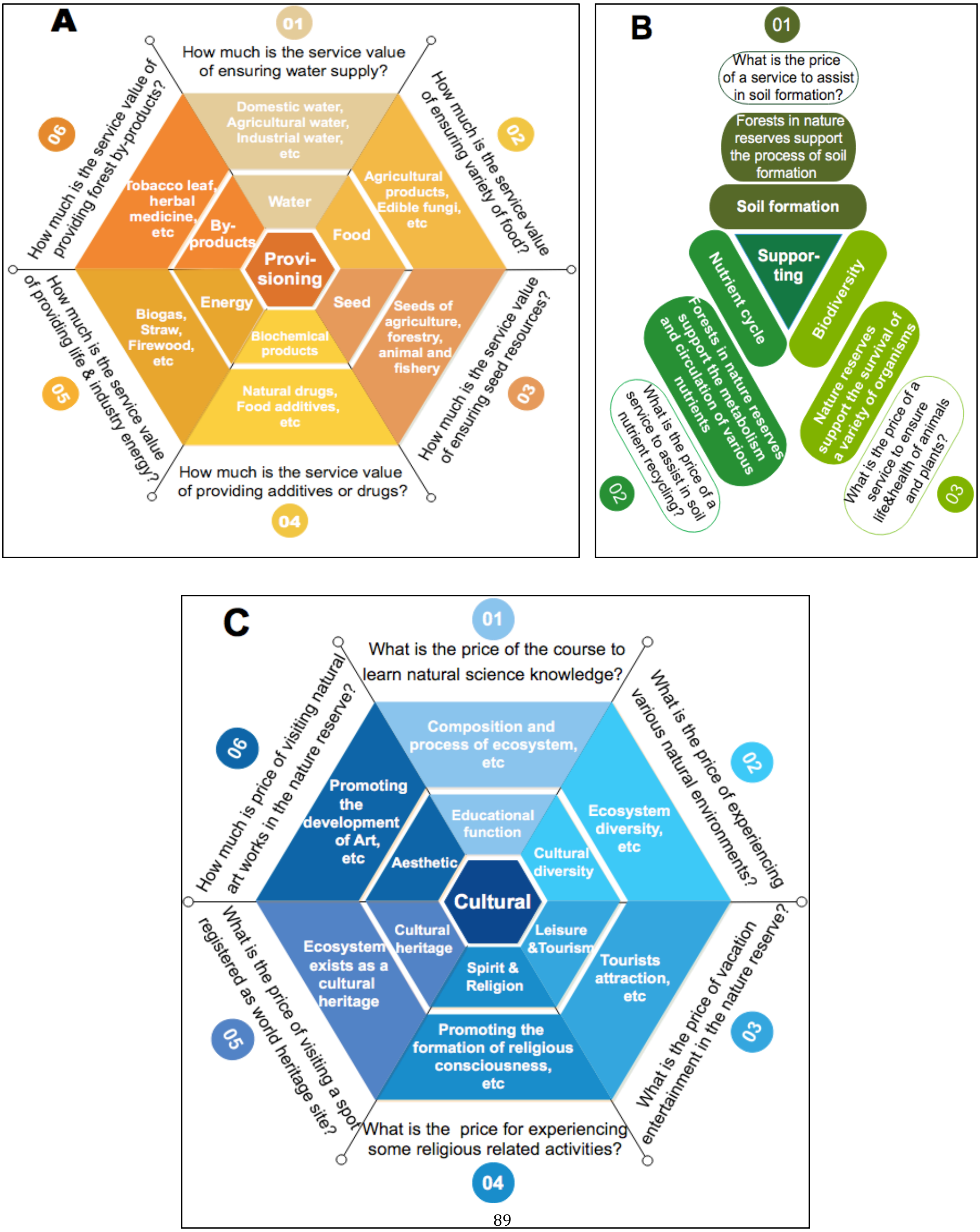
Figure 5.4 PAM Classification systems of ecosystem services

5.3.3.2 Second step of PAM design: build a virtual market

With a list of real services in place, the next step is to build a virtual market. As with the general process of auction or cultural relic appraisal, a detailed description of the object to be appraised is crucial. In this step, ecosystem service categories beyond common knowledge need to be translated into specific descriptions that are easy for the public to understand. Next, according to the description, a way must be determined to ask questions. This study roughly divided the description into four categories. First, tangible and continuous items (such as provisioning function), for which the public appraised the price of the services. Second, tangible and single time items (such as tourism and leisure function), using the publics' appraisal of the admission price. Third, intangible and spatially definable items (such as soil purification), with the publics' appraisal of price per unit area. Fourth, intangible and difficult to define space items (such as air purification), with the public's appraisal of the service price for each person's usage.

5.3.3.3 Third step of PAM design: conduct the public appraisal

Since public value appraisal depends on their understanding of the service, the detailed question description is critical to conducting PAM (**Figure 5.5)**. Item A is provisioning function, which is divided into six categories from A1-A6, item B is supporting, which is divided into three categories from B1-B3, item C is cultural function, which is divided into six categories from C1-C6, and item D is regulating function, which is divided into 13 categories from D1-D13. The first layer is the classification, the second layer is the definition, and the outermost layer is the main inquiry mode of the survey. Focus group experiments, centralized interviews, and questionnaire surveys can be utilized in the appraisal process. In this study, the questionnaire survey was selected based on a pre-experiment of centralized interviews. The total number of surveys included 100 for the pre-experiment, 5000 for the formal experiment, and 4875 for effective recovery.



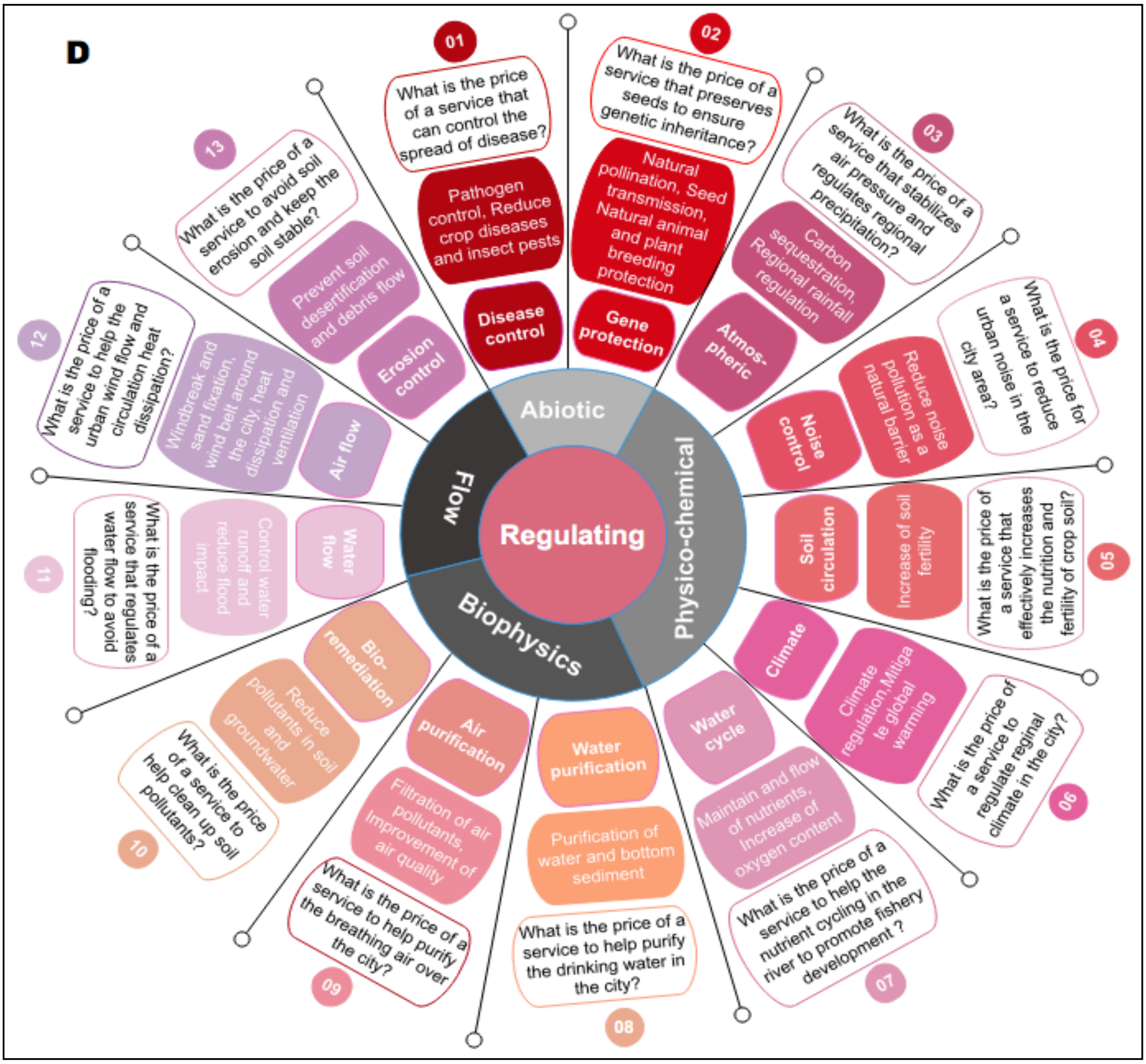


Figure 5.5 Description and investigation questions during PAM implementation process. **A**: **Provisioning**. In A1-A6 items, each person's monthly usage of different items was taken as the unit and appraisal of the economic value of different types of services were applied (per person/month). **B**: **Supporting**. B1 and B2 surveys were set per 1km^2/month, and the calculated area was the total area of forest; The B3 survey contained three categories: plant species, animal species, and precious species, and appraisal was the economic value that forests provide for survival and reproduction of each species (per

species/month). **C**: **Cultural**. C1-C6 survey appraisal was based on a single visit per person (visit/year). **D**: **Regulating**. D1, D8, and D9 surveys were based on per person monthly usage (per person/month); D2-D6, D10, D12, and D13 surveys were based on 1km^2 forest/month, and calculated area was the total area of forest; D7 and D11 surveys were based on 1km^2 area/month, and area was based on the river basin.

5.3.3.4 Fourth step of PAM design: output a pricing list

In the final step, all sub-items were totaled. A total of 28 ecosystem services were classified as A (Providing), B (Supporting), C (Cultural), and D (Regulating) according to their attributes (**Figure 5.5)**. There are 6 items in category A, 3 items in category B, 6 items in category C and 13 items in category D. The unit prices of different items were calculated into the total price within the different categories. The appraisal values of 28 services from item A-D were obtained through investigation, and the average value was taken for statistical calculation. According to the small units divided, multiply by population, forest area, river basin area, biodiversity types, etc. The calculation method was as follows:

In the **A** term, the person's per month usage of different items were expressed as A_1, A_2, A_3, A_4, A_5, and A_6, and the sum of items **A** was the sum of all items from A_1 to A_6 as shown in Formula (5-1).

$$P_A = (A1 + A2 + A3 + A4 + A5 + A6)T^{Population} \qquad \text{Formula (5-1)}$$

$\mathrm{P_A}$ represents the total price of item **A**, $\mathrm{T^{population}}$ represents the total population in the area. Six items in **A** and the total value $\mathrm{P_A}$ were calculated.

In the **B** term, services provided per unit area were expressed as B_1, B_2, and B_3, and the sum of items **B** is the sum of all items from B_1 to B_3 as shown in Formula (5-2).

$$P_B = (B1 + B2)S^{forest} + B3_a \times N^a + B3_p \times N^p + B3_v \times N^v \qquad \text{Formula (5-2)}$$

P_B represents the total price of item **B**, and three items in **B** and the total value P_B were calculated. S^{forest} represents the total forest area. $B3_a$, $B3_p$, and $B3_v$ represent animal species, plant species, and valuable species, respectively, whereas N^a, N^p, and, N^v represent the number of animals, plants, and valuable species, respectively.

In the **C** term, the service value per single visit of different items was expressed as C_1, C_2, C_3, C_4, C_5, and C_6, and the sum of items **C** was the sum of all items from C_1 to C_6 as shown in Formula (5-3).

$$P_C = (C1 + C2 + C3 + C4 + C5 + C6)T^{Tourist} \qquad \text{Formula (5-3)}$$

P_C represents the total price of item **C**, $T^{tourist}$ represents the total tourists in a year to the area. Since item **C** was appraised by the consumption per visit, the total number of tourists was used to calculate the six items of item **C** and the total value P_C.

In the **D** term, D_1, D_8, and D_9 were the usage per person; D_7 and D_{11} used 1km^2 of the river basin as the service providing unit, and D_2, D_3, D_4, D_5, D_6, D_{10}, D_{12}, and D_{13} used 1km^2 of forest area. The sum of item **D** is the sum of all items from D_1 to D_{13} as shown in Formula (5-4).

$$P_D = (D1 + D8 + D9)T^{population} + (D7 + D11)S^{river}$$

$$+(D2 + D3 + D4 + D5 + D6 + D10 + D12 + D13)S^{forest} \qquad \text{Formula (5-4)}$$

P_D represents the total price of item **D**, S^{river} represents the area of the river basin. The 13 items in **D** and the total value P_D were calculated separately.

Finally, because appraisal units were all monthly except item **C** (visit/year), the total value of P_A, P_B, and P_D were multiplied by 12 and then added P_C to get the annual total monetary value of all ecosystem services provided.

5.3.4 Constraints of PAM values: ERP

In this study, a new index, environmental risk perception (ERP), was introduced to reveal the constraints of the valuation results (Carmen *et al*., 2012). In comparing the differences of PAM and TCM results, we realize that various types of money perception may be subject to a deeper and more systematic constraint—perceived degree of environmental risk (Luiza and Erik, 2007). To verify whether and how EPR restricts the valuation results, we designed an additional virtual market experiment: "virtual decision-maker." Each person was given 100 units of virtual currency, which had to be used for ecological costs. The environmental risk was divided into five levels, ranging from good to serious damage, and four kinds of money perception were tested: market value by a public appraisal, individual willingness to pay, individual willingness to claim compensation, and reasonable public expenditure cost on eco-protection.

Scenario 1: Very good environmental quality (the air is fresh, the rivers are clear, the vegetation is luxuriant, and the climate is comfortable). Scenario 2: Good environmental quality (no pollution of air and rivers, healthy vegetation and normal climate). Scenario 3: Slightly damaged environmental quality (slight pollutants in air and rivers, vegetation damaged in some area, and occasionally abnormal climate). Scenario 4: Moderately damaged environmental quality (the air and rivers are polluted and produced pathogenic bacteria, serious damage to vegetation, abnormal climate). Scenario 5: Seriously damaged environmental quality (serious pollution of air and rivers which causes human death, no vegetation, extreme climate). In these scenarios, the appraised local ecological value was marked as PAV_1 to PAV_5, the willingness to pay to maintain/ restore the ecology were marked as WTP_1 to WTP_5, the compensation requirement due to poor ecology were marked as WTA_1 to WTA_5, and the public expenditure cost (PEC) for maintaining/restoring the ecosystem was marked as PEC_1 to PEC_5. All scenarios initially set respondents as local stakeholders. When there is no intention of eco-protection, it is possible to choose to move out of the area. Finally, the average values of PAV, WTP, WTA, and PEC under all scenarios were calculated.

5.4 Results and Discussion

5.4.1 Total value accounting: comparison of PAM and TCM results

The accounting results of the total monetary value of Wuyishan ecosystem services are shown in **Figure 5.6**. The total PAM result was ¥181.6 billion/year and the TCM result was ¥222.3 billion/year, a difference of ~18%. The primary reason for the difference was in supporting and provisioning services. PAM supporting function was ¥35.7 billion/year (19.7% of the total value) and provisioning was ¥21.9 billion/year (12% of the total value). TCM supporting function was the largest at ¥95.9 billion/year (total's 43.1%) and only ¥5.4 billion/year (total's 2.4%) for provisioning function. The decisive component of supporting function mainly reflected in item B3-biodiversity. Compared with TCM, PAM underestimated the value of biodiversity function with a difference of 270%. For the provisioning function, PAM was 4.1 times higher than TCM. The value differences between the two categories directly affected the final overall accounting results of all ecosystem services.

The value difference depends directly on the methods. Taking biodiversity as an example, TCM compiles detailed statistics on the types and quantities of species and then converts them into possible market values (Clément *et al*., 2018). The more species and numbers there are, the higher the value accounting results will be. PAM enables the public to identify the survival and maintenance costs of species categories. The more detailed the classification, the higher the value accounting results. In this study, PAM simply divides species into three categories: general plants, general animals, and precious species, resulting in the underestimation of biodiversity value. In terms of provisioning, TCM calculates the local physical output, whereas PAM counts the supply value of products needed by human society, and the urgency of human demand for daily necessities may be the reason why PAM overestimates the value of provisioning.

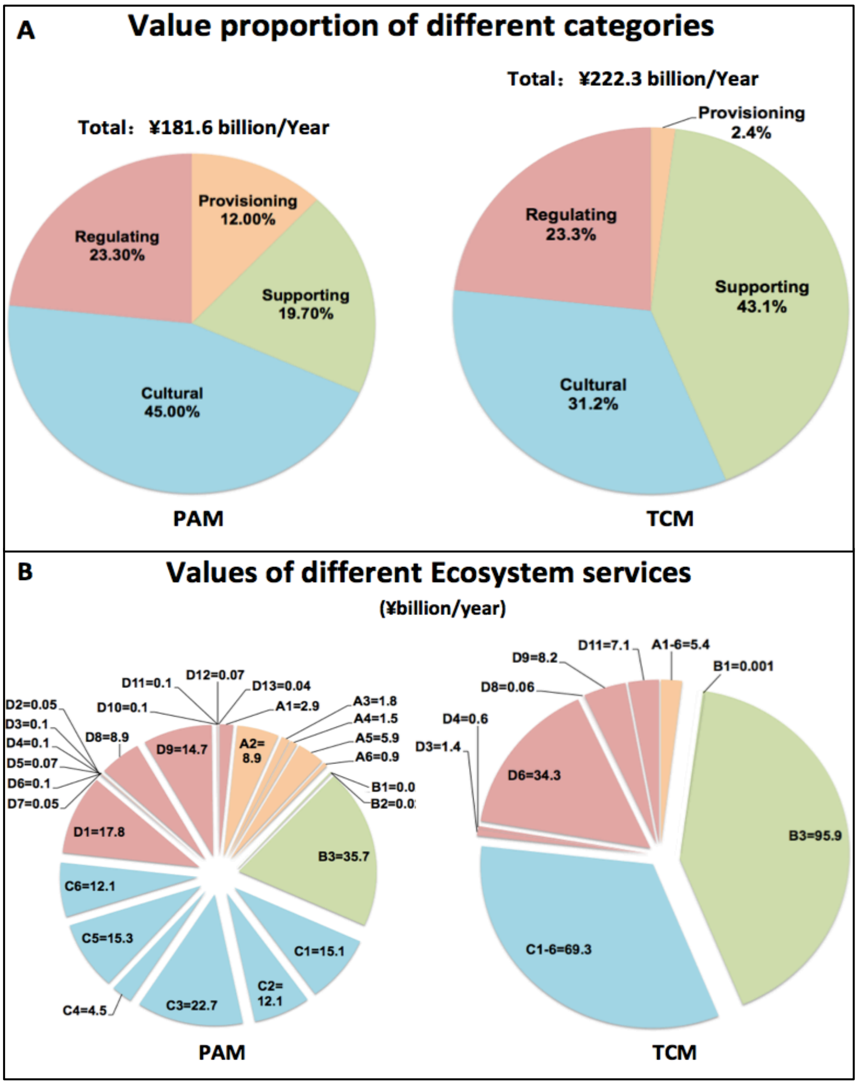


Figure 5.6 Economic values of Wuyishan ecosystem services

5.4.2 PAM or TCM selection based on valuation purpose

A comparison of PAM and TCM is shown in **Table 5.4** and **Table 5.5**. We divided the valuation process into four stages: preparation, implementation, results, and applicability. The advantages of TCM are primarily the data itself since it is a monetary value conversion based on detailed quantification of the functional physical quantity. Disadvantages included: 1) long implementation time, 2) the complex calculation method, and 3) the extensive needs for data. The advantages of PAM included simplicity and rapid application time, as well as objectively and accurately valuing ecosystem services. The primary disadvantage of PAM is that the investigation necessitates many personnel and requires them to have experience. Also, question descriptions can affect the valuation results.

The choice between PAM and TCM mainly depends on the valuation purpose and valuation objects. From the viewpoint of valuation purpose, TCM is recommended if the need is to precisely verify the supply capacity of all local ecosystem functions. However, if there is a need to determine a conceptual monetary value for eco-protection or cultural tourism publicity, we recommend the use of PAM, which will greatly reduce workload and cost. From the perspective of the valuation object, both methods apply to an individual object. When making a horizontal comparison of the economic value of multiple objects, PAM is more recommended, because the operation methods of PAM are highly standardized and can be used in different regions in a reproducible way.

Table 5.4 Comparison of characteristics of TCM and PAM

Stage	*Category*	*TCM*	*PAM*
Preparation in advance	Theoretical foundations	Monetary value quantity based on the physical quantity of ecosystem service function	Monetary value based on public's sense and experience of the market
	Preparation of data materials	Extremely diverse and complex	Simple and convenient
Implementation process	Difficulty of investigation	Complex data measurement, simple public investigation	Complex public survey, simple data measurement
	Unity of operations	Select different methods according to different categories	Standardized approach
	Period and time	Long and time-consuming	Short and less time commitment
	Economic cost	High	Low
	Data calculation	High	Low
Assessment results	Comparability of results	Difficult to compare because different methods are adopted for individual cases in different regions	Relatively easy to compare because the same method can be applied in different regions
Applicability	Recommended application scope	Scientific value: single cases that require quantification of ecosystem services	Conceptual value: multiple cases of value comparison requiring extensive feedback from the public

Table 5.5. Comparison of advantages and disadvantages of TCM and PAM

	Advantages	*Disadvantages*
TCM	1. The workload of social survey is small 2. Physical quantity of ecosystem services can be quantified 3. The results can reflect the actual ecosystem service capacity	1. Data calculation is huge and large number of data sources are required 2. Diverse approaches lead to the complexity of operation 3. Long time consuming 4. Economic cost high (a variety of equipment is needed) 5. Difficult to valuate multiple objects simultaneously
PAM	1.Data calculation is less and fewer data sources are needed 2. Unified approaches make operation easier 3. Short time consuming 4. Economic cost low (no equipment required) 5. Multiple objects can be valuated simultaneously and compared conveniently	1. The workload of social survey is heavy 2. Physical quantity of ecosystem services cannot be quantified 3. The results cannot reflect the actual ecosystem service capacity

5.4.3 Environmental risk perception (ERP) as a key constraint factor for PAM

According to the valuation results in **Figure 5.7(A)**, we built the ERP model, shown in **Figure 5.7(B-1, B-2, B-3)**. In the ERP model, the public's appraisal of ecological economic value would depreciate with the increased environmental risk; conversely, expenditures for ecological maintenance would increase with environmental risk. The willingness to pay and the demand for compensation would increase first and then decrease, with the deterioration of the environment up to a certain point. We found that when the environment was in a good state, respondents showed tendency to pay to maintain the good state. The willingness to pay gradually became stronger when environmental problems occurred, but would suddenly decreased even to zero if the environmental damage became extremely serious, indicating that they might have given up their efforts if the consequences were irreversible. L_1 is the highest amount of enforceable compensation; L_2 is the critical point of reasonable compensation demand and undeserving compensation demand; L_3 is the perfect balance between ecological value and eco-expenditure; L_4 is the "critical point of rescue and abandonment" from the view of ecological victims; L_5 is the "maximum utility of public expenditure"; L_6 is the "complete abandonment" of the stakeholders. Different critical points in the ERP model are expected to be further simulated and predicted in the future through the combination of different valuation methods.

ERP constraints are the underlying driver of the value differences between PAM and TCM results. Fundamentally, the opposite trend in biodiversity and provisioning assessments between PAM and TCM are due to ERP differences. The public ERP for the provisioning function is stronger, whereas the ERP for the biodiversity function is weaker. In short, the risk perception of extinction of a species (such as butterfly) is far weaker than the loss of a daily food (such as rice). In terms of money behavior, psychological perception is often the key constraint factor rather than the real environmental loss (Gao *et al*., 2019). Even if the environmental loss has been serious, the public would not indicate significant changes in monetary control until they perceive the threat (Liobikiene and Juknys, 2016). Therefore, an in-depth understanding of ERP is the key to improve the accuracy of the PAM result. In the categories that public ERP is weak, classification needs to be increased to achieve more effective results.

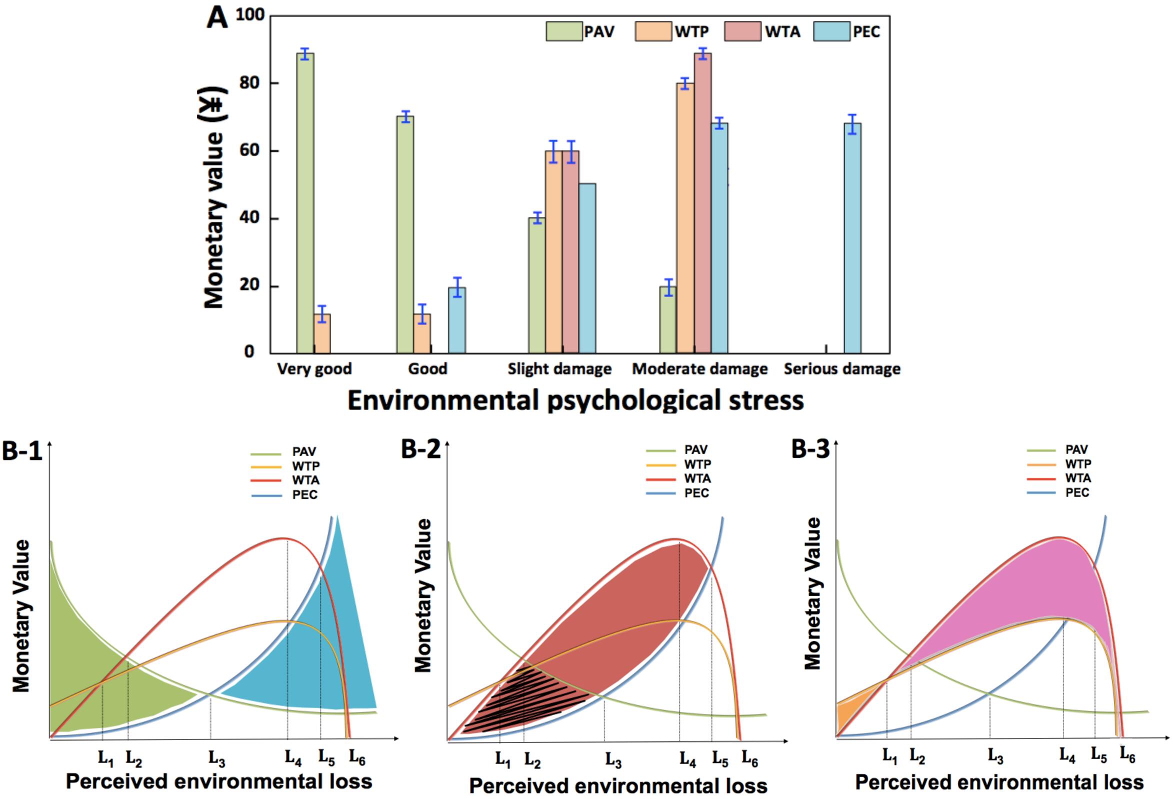


Figure 5.7 Monetary value model under environmental risk perception (ERP). A: Monetary value under ERP constraints. PAV: public appraisal value; WTP: willingness to pay; WTA: willingness to accept compensation; PEC: public expenditure cost. **B: ERP model.** Relationship between four monetary value types and ERP in the face of environmental damage. (**B-1**, **B-2** and **B-3** are the same graphs, used to show different critical areas). In **B-1**, the green area is the “undesirable area lacking in eco-investment”, represents the value of ecological goods recognized by the public is greater than the expenditure for its maintenance. Blue area is the “waste area of public spending”, represents the public

expenditure for ecology has exceeded the actual value of the public's perception of the ecological goods. In **B-2**, the red area is the "extra compensation expenditure", represents the demand for eco-compensation has exceeded the actual amount available for eco-expenditure. The black-striped region is the "Enforceable compensation range", represents the public's value judgment is higher than the current eco-expenditure. This suggests it belongs to the reasonable compensation demand, and the eco-expenditure shall be forcibly increased for compensation or maintenance. In **B-3**, the yellow area is the "effective area of fund-raising payment", represents the compensation requirement is less than the public's willingness to pay. The pink area is the "weak area of fund-raising payment", represents the requirement has exceeded the public's willingness to pay.

5.4.4 Limitations and uncertainties of PAM

Concerning the fundamental uncertainty origins of ecosystem service valuation, the act of defining ecosystems through human economic concepts drives inevitable biases. Human society is the product of the natural system, which means that the valuation process itself is an operation within the limits of human cognition. The complexity of natural systems and the lack of well-developed methods are challenges (Hou *et al.*, 2013). It is not just the respondents who cannot imagine the services being valuated—even the investigators cannot accurately define these services. If it is difficult to form a unified knowledge base, then individual differences will become obvious. Therefore, when the valuation process involves public concepts, it will be inevitably restricted by personal factors such as respondents' preference biases and investigators' statement biases (Chee, 2004). The experts of ecosystem service valuation should pay more attention to how to minimize such biases.

There are several limitations to applying PAM to evaluate ecosystem services. 1) PAM is only suitable for quantifying the monetary value of ecosystem services, and it cannot evaluate the supply capacity and risk of ecosystem service. 2) PAM is more suitable for the evaluation of large-scale composite ecosystems, and the evaluation of a single ecosystem service function is limited. 3) PAM concludes with a conceptual value based on public feedback, which reflects the public's awareness of importance ranking, but it is not a physical reflection of ecosystem services. 4) PAM is suitable for the assessment of the ecosystems with abundant information, but it has a limited effect on those assessment objects lacking complete human understanding.

The valuation results of PAM have several uncertainties. 1) PAM largely depends on the classification of ecosystem services, and researchers from different backgrounds hold a different understanding of the classification principles. Coarse classifications lead to undervalued results and fine classification leads to double-counting. 2) The PAM results are restricted by public ERP, which is difficult to control because it is difficult to know the public's initial knowledge or feeling changes during the survey process. Especially for those ecosystem functions (supporting and regulating) that are not familiar to the public, the public's ERP will come directly from the description of the investigators. 3) The statement preference of investigators and social propaganda affects the public's understanding and ultimately the accuracy of results. 4) PAM accuracy may be affected by the selection of different respondents; expanding the type and number of samples may be a way to reduce the bias.

5.5 Conclusions

In this study, the public appraisal method (PAM) is defined as a simple and standardized ecosystem service valuation system. It provides a solution to the challenge that the valuation methods and indicators of ecosystem services are difficult to be unified. Through application in the Wuyishan area, the value of 28 ecosystem services was calculated, and the total value of ecosystem services provided by the Wuyishan area was calculated as approximately ¥181.6 billion/year. The value list and total value accounting of ecosystem services can directly contribute to the local trade-offs of various ecological investment policies. The establishment of the ERP model revealed the key factors that restrict the PAM results and provided theoretical guidance for the extensive implementation of PAM. Due to its versatility and replicability, PAM may be widely applied to large-scale and multi-objective ecosystem service valuation in other areas.

Acknowledgments

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Chapter 6 Summary and conclusions

6.1 Dissertation summary

6.1.1 The complete MSI trade-off framework

Due to the lack of unified quantitative methods, ecological cost is often ignored in the trade-off analysis between eco-protection and economic development. In order to solve the conflicts between eco-protection and economic development, this study focused on the three key dimensions: managers, stakeholders and investors. For the first time, we proposed a three-dimensional framework, which was defined as MSI framework. Under MSI framework, quantitative analysis was carried out from the three dimensions to separately determine the management effect, stakeholder needs and investment values. MSI was proposed as a trade-off framework based on quantitative evaluation, which quantified both structured costs and intangible emotions into monetary value, so as to facilitate the comprehensive comparison of decision-makers.

Taking Wuyishan natural ecosystem in China as a study case, this study verified MSI framework with the complete trade-off process in the actual conflict between eco-protection and economic development. In different cases, the issues of management, stakeholder and investment usually manifest in different forms, but their quantitative assessment is crucial to the whole trade-off process. MSI reflects the relationship among managers, stakeholders and investors. Each branch of MSI was based on quantitative evaluation and provided comparable results for comprehensive analysis on trade-offs. The conclusion of this study showed that emotional factors could also be quantitatively evaluated and combined with economic indicators. We have proved that the process of trade-off can be presented/expressed visually and intuitively, and the decision-making organization can design a complete trade-off process by designing different emphasis points with MSI to clarify the direction of the solution.

6.1.2 Three quantitative methods to evaluate the MSI items

We solved key problems in the local ecological and economic trade-off process through application of the MSI framework in the Wuyishan area. Specifically, we quantitatively evaluated the effect of the local ecological policy of Returning Tea to Forest (RTTF), which has been implemented since 2008. The ecological benefits of the RTTF policy were quantified based on the analysis of changes in the distribution of forest and tea over the past ten years, and the total economic contribution of RTTF policy was determined to be equivalent to \$140 million. This study was the first attempt to quantify the actual effect of the local RTTF eco-protection policy, which is of great significance for the direction of future decision-making and policy adjustment.

However, the quantified ecological benefits were based on the economic losses of a part of tea farmers. Therefore, we conducted an in-depth stakeholder analysis by developing Subjective & Objective Combination Assessment (SOCA) methods. We quantified the economic compensation for local tea farmers as \$443/ha to \$2114/ha per year. The formulation of SOCA compensation standards was important for solving conflicts among local stakeholders and improving the effectiveness of future eco-protection activities. Since the compensation implantation, eco-tourism and local ecological integration projects have required additional financial support. Thus, clarifying the value provided by local ecosystems for local investment decisions is critically important.

Finally, we proposed the public appraisal method and calculated the total value of the Wuyishan forest ecosystem. We found that the local rich ecosystems provided major ecological benefits, equivalent to an annual economic contribution of $25.7 billion. Definition of the total ecological value is important for increasing future financial investment in eco-protection, including investments from organizations, enterprises, and all sectors of society.

In sum, the forest ecosystem in the Wuyishan area provides substantial ecological benefits. Even if setbacks associated with some tea farmers lead to decreases in local incomes and burdens of compensation payment, the ecological benefits of the Wuyishan area are still large enough to cover any losses sustained by the tea economy over the long-term. Future policies should continue to invest in eco-protection and develop other economic modes that are innocuous to local ecosystems. Developing eco-tourism projects and new specialty commodities within the scope of the environmental carrying capacity and under the premise of ecological management might be worth considering.

6.1.3 MSI trade-off mechanisms

The trade-off mechanisms between ecosystem services and economic activities were summarized in **Figure 6.1** by applying the MSI framework to the Wuyishan area. We found that the operation of the actual trade-off process was highly consistent with the mechanisms; consequently, the MSI framework could be used to solve most of the major problems relating to the economic and ecological trade-offs.

The management link primarily includes laws, rules, regulations, policies, planning, measures, supervision, and proposals; the stakeholder link primarily includes demand, desire, conflict, subsidy, income, interest, benefit, lifestyle, and preference; the investment link primarily includes the cost or expenditure paid by the states, organizations, and individuals for sustainable development as well as the implementation, promotion, and realization of eco-protection projects. Specifically, investment supports management and stakeholder activities simultaneously; management makes instructions for stakeholders and allocates ecological investment. Stakeholders then give feedback on the management effect and contribute to ecological investment. This complete coupling cycle among the three elements determines the entire trade-off system.

Quantitative assessment (green outer ring) runs through the entire process of the three elements in the trade-off process. Between management and stakeholders, indicators for analyzing management feasibility (to be implemented) and management effect (implemented) are necessary. Between stakeholders and investment, indicators for quantifying the losses of stakeholders (the economic compromises for eco-protection) and benefits (ecology creates income for the economy) are needed. Between investment and management, indicators for quantifying the investment value (the investment object is not clear) and the investment ability (the investment object is clear) are required. Finally, the results of the aforementioned quantitative assessments need to be integrated, and comparisons of the overall ecological and economic benefits/costs need to be made, followed by final decision-making and trade-off suggestions. Characterization of the trade-off mechanisms in this doctoral study is important for finding the future balance between ecology and the economy and aids our understanding of the coupling relationship between ecosystems and human well-being.

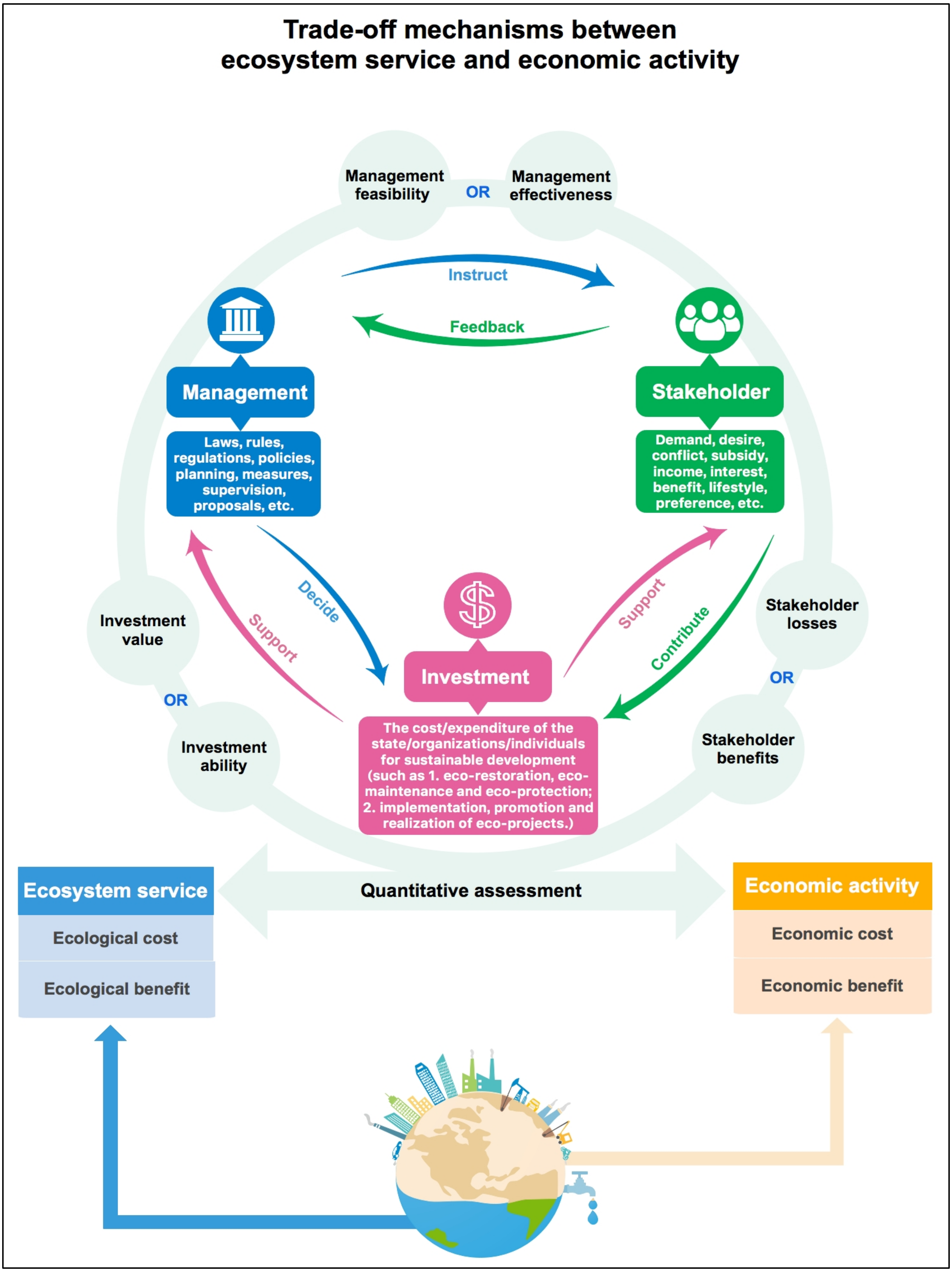

Figure 6.1 Trade-off mechanisms between ecology and economy

6.2 Novelty statement

In this dissertation, aiming at solving the trade-off issues between eco-protection and economic development, for the first time, we established a complete quantitative trade-off framework defined as MSI from the three dimensions of managers, stakeholders and investors.

Three quantitative assessment methods were originally developed to evaluate the management effectiveness, stakeholder needs and ecosystem service value. We contributed three repeatable quantitative methods for the issues that were difficult to quantitatively evaluate.

This study revealed the mechanisms in the actual trade-off process and summarized the internal links among management, stakeholder and investment, which greatly contributed to the deeper understanding of the coupling relationship between ecosystem and human well-being.

6.3 Limitations and future challenges

6.3.1 Limitations

Trade-off is a complex process, because it attempts to maintain a state of dynamic balance. In addition to the comparison of benefits and costs commonly used in economics, the trade-off also needs to consider more about willingness and preference. In the trade-off process, not all gains and losses are based on economic benefits. There are also many invisible emotional effects. Therefore, a quantitative method integrating environmental psychology and environmental economics may be able to better reflect the conflicts in trade-offs. Under the MSI framework, this doctoral project further contributes three independent quantitative methods, which are combined with subjective willingness and objective perception to quantitatively evaluate the items in the process.

Actually, there are various indicators in the broad sense of quantification. This doctoral research takes the monetary value as the general quantitative index. Since the purpose of this study is to focus on the trade-off between economic development and ecological protection, we turn the gains and losses from both the aspects of economic and psychological into monetary value, so as easy to compare. We considers that the use of monetary value indicators may be more intuitive response to conflicts, and also more intuitive to tell the general public what are the interests of ecological protection. We believe that the fundamental basis of trade-offs lies in quantitative analysis, but the quantitative analysis should not only limited to the monetary value. There may be a better indicator system to be established in future trade-offs works.

6.3.2 Future challenges

Previously, most studies of trade-offs have focused on the two-dimensional trade-off between ecology and the economy; this doctoral research also considered these types of trade-offs. However, the need to face multi-dimensional trade-offs may increase in the future. Indeed, an increasing number of trade-offs between ecology and the economy have emerged and continue to emerge, such as those involving global emergencies, human survival, social development, human well-being, and international cooperation. The increase of zoonosis or emerging infectious disease (such as COVID-19) makes world focus more on the balance between ecosystem and human society than in the past (Gibb *et al.*, 2020). Currently, however, we have little knowledge of such multi-dimensional trade-offs involving ecology, society, economy, management, and well-being. The future exploration and application of more complex multi-dimensional trade-off mechanisms will require the development of interdisciplinary methodologies and joint effort among scientists worldwide.

Multi-dimensional trade-offs are complex and are based on different, complex types of quantitative assessment. The quantitative assessment needs to be based on the exploration of new evaluation indicators. Multi-dimensional trade-offs require the support of many interdisciplinary methodologies as well as the establishment of an effective time response mechanism to facilitate their adjustment over time. The most urgent future global challenge will be the exploration of the methods for and the mechanisms underlying multi-dimensional trade-offs. Ecosystem protection may receive more attention in the future, because contradictions between human system and ecosystem may cause some new diseases. Since disease control is also one of the most important functions associated with the regulation of ecosystem services, incorporating the maintenance of ecosystem health into the trade-off system of human society will help maintain the long-term health of human society.

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Appendix

Table A-1 Monetary value accounting of regulating services based on physical quantity data

Category	***Ecosystem service***	***Physical quantity data****	***Monetary valuation methods****
Climate regulating	Carbon sequestration	1. Calculation basis: Specifications for Assessment of Forest Ecosystem Services in China (LY/T1721-2008) and Norm of Techniques for Valuation of Forest Resources Assets (LY/T2735-2016) 2. Data sources: Remote sensing data, meteorological data and geographic data. 3. Calculation results (2015): Total carbon sequestration (T_{CO_2}) = 3.3×10^6 t	The value of carbon sequestration is calculated by multiplying the physical quantity and price: $V_{CO_2}=T_{CO_2}\times P_{CO_2}$ (A-1) V_{CO_2}: The value of oxygen supply (¥); P_{CO_2}: Price (¥).
	Oxygen release	1. Calculation basis: Specifications for Assessment of Forest Ecosystem Services in China (LY/T1721-2008) The mass of O_2 released from ecosystem was calculated from the mass of net primary productivity. (For every 1g CO_2 fixed, plants release 0.73g O_2) 2. Calculation results (2015): Total oxygen release (T_{O_2}) =2.4×10^6 t	The value of oxygen supply is calculated by multiplying the physical quantity and price: $V_{O_2}=T_{O_2}\times P_{O_2}$ (A-2) V_{O_2}: The value of oxygen supply (¥); P_{O_2}: Price (¥).

	Microclimate regulation	1. Calculation basis: The Penman Monteith (P-M) model recommended by FAO was used to calculate the potential evapotranspiration (FAO, 2006), and the solar energy absorbed by the ecosystem was used as the physical quantity of climate regulation. 2. Calculation results (2015): Solar energy absorbed by forest ecosystem (S_{ea})=2.1×10^{11} kWh	The cooling value is calculated as: $V_{tf}=(S_{ea}/n)\times P_R$ (A-3) V_{tf}: Total value of regulating temperature (¥); n: air conditioning energy efficiency ratio; P_R: electricity price (¥).
Environmental quality regulation	Atmospheric purification	1. Calculation basis: Specifications for Assessment of Forest Ecosystem Services in China (LY/T1721-2008) According to the pollutant emissions and atmospheric environmental capacity, the ability of the ecosystem to purify sulfur dioxide, nitrogen oxides and block dust was evaluated. 2. Data sources: Fixed point observation. 3. Calculation results (2015): Sulfur dioxide=216.5t; Nitrogen oxides=55.1t; Smoke and dust=107.4t	Value of air purification are calculated through the cost of industrial treatment of 3 kinds of the local air pollutants: $V_a=\sum_{i=1}^{3} c_i\times Q_i$ (A-4) V_a: Total value of atmospheric purification ($10^4\cdot$¥); C_i: Cost of air pollutant treatment (¥/t); Q_i: Annual amount of pollutants ($10^4\cdot$t).

	Water purification	1. Calculation basis: Water GAP model in MEA an emergy analysis method. 2. Data sources: Fixed point observation. 3. Calculation results (2015): COD=2599.5t; Ammonia nitrogen emissions=417.8t	Value of water purification are calculated through the cost of industrial treatment of water pollutants: $V_w=\sum_{i=1}^{2} c_i \times Q_i$ (A-5) V_w: Total value of water purification (10^4·¥); C_i: Cost of water pollutant treatment (¥/t); Q_i: Annual amount of pollutants (10^4·t).
	Noise control	1. Calculation basis: Norm of Techniques for Valuation of Forest Resources Assets (LY/T2735-2016) 2. Data sources: Fixed point observation 3. Calculation results: Data shown in Wuyishan Ecosystem Accounting Report (2018)	Calculation based on the cost of noise reduction is: $U_a=K\times A$ (A-6) K: Cost of noise reduction (¥); A: The kilometer of sound insulation wall converted from forest area (km). Noise reduction value (forest) is calculated by afforestation cost: $V_a=R\times C\times V\times S$ (A-7) R: Proportion of reducing noise value by forest (%); C: Cost of afforestation (¥/m^3), V: Volume per unit area of mature forest (m^3/hm^2); S: Area of forest land (hm^2).
	Air anion provision	1. Calculation basis: Norm of Techniques for Valuation of Forest Resources Assets (LY/T2735-2016) 2. Data sources: Fixed point observation 3. Calculation results (2015): The total number of air anion is 7.98×10^{27}.	The air anion value is computed as: $U_{anion}=5.256\times10^{15}(Q_{anion}-600)\times K_{anion}AH/L$ (A-8) U_{anion}: Value of anion provide by forest (¥·a^{-1}); K_{anion}: Production cost of air anion (¥·per^{-1}); A: Forest area; H: Forest height; L: air anion lifetime. $K_{anion}=5.8\times10^{-18}\cdot per^{-1}$ (The national recommended value).
Hydrologic	Runoff	1. Calculation basis:	Value of water flow conditions in

regulation	regulation	Distributed Time Variant Gain Model, DTVGM** (Xia et al., 2003). DTVGM mainly includes runoff generation model and confluence model. The runoff generation model includes rainfall evapotranspiration module, surface water flow module, soil water flow module and underground water flow module. The confluence model was calculated by Muskingum method. 2. Data sources: Hydrological data, meteorological data and spatial geographical distribution and Wuyishan Ecosystem Accounting Report 2018. 3. Calculation results (2015): The annual runoff regulation (W)=8.7×10^8 m^3.	ecosystem based on the construction cost of reservoir: $V=W\times c$ (A-9) W : Annual runoff regulation (m^3); c: engineering cost of construction unit capacity (¥/m^3).
	Flood regulation	1. Calculation basis: Evaluation model for flood control capacity in China*** (Rao et al., 2014). Based on the empirical equation established by the quantitative relationship between the existing flood control capacity and the total storage capacity of reservoirs, the flood control capacity (C_f) of reservoirs at all levels in Wuyishan City was calculated. 2. Data sources: Wuyishan	Value of flood control capacity based on the construction cost of reservoir: $V=C_f\times c$ (A-10) C_f: Annual flood control capacity (m^3); c: engineering cost of construction unit capacity (¥/m^3).

		Ecosystem Accounting Report 2018. 3. Calculation results (2015): The annual flood control capacity (C_f) is 0.14×10^8 m^3.	
Soil conservation	Soil conservation	1. Calculation basis: The Universal Soil Loss Equation (USLE) and Chinese Soil Loss Equation (CSLE). 2. Data sources: Geographic data and Wuyishan Ecosystem Accounting Report 2018. 3. Calculation results: Data shown in Wuyishan Ecosystem Accounting Report (2018)	The economic value of reducing sediment deposition disaster is computed as: $V_{1n}=(24\%\times SC\times C/\rho)/10000$ (A-11) V_{1n}: Economic benefit of soil conservation (10^4·¥); SC: Amount of soil conservation (t); C: Engineering cost of construction unit capacity (¥/m^3); ρ: the soil bulk density (t/m^3).

*The data, methods and calculation results of physical quantity and the monetary valuation methods come from:

1. Wuyishan Ecosystem Accounting Report (2018, Wuyishan Municipal Government)
2. Specifications for Assessment of Forest Ecosystem Services in China (LY/T1721-2008)
3. Norm of Techniques for Valuation of Forest Resources Assets (LY/T2735-2016)

** DTVGM model for Runoff regulation evaluation: Xia, J., Wang, G., Lv, A.F., Tan, G., 2003. A research on distributed time variant gain modeling. Acta Geographica Sinica. 58, (5), 789-796. (In Chinese)

*** Model for flood regulation and storage evaluation: Rao, E.M., Xiao, Y., Ouyang, Z.Y., 2014. Assessment of flood regulation service of lakes and reservoirs in China. Journal of Natural Resources. 29, (08), 1356-1365. (In Chinese)