REVIEW

Assessment of ecosystem services in restoration programs in China: A systematic review

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Abstract We examined the use of ecosystem service (ES) approaches at the landscape scale to assess two major ecological restoration programs (ERPs) in China. We found 68 papers highlighting four aspects: (1) most papers considered only one ES, and all ES categories were not covered equally; (2) regional-scale and short-term assessments dominated the reviewed papers, and few papers evaluated the impacts of ERPs on ESs at multiple spatial scales; (3) the majority of datasets were from global and national databases; and (4) 40% of studies used mostly proxy models and did not report model validation. Finally, we identify four needs: (1) for a deeper understanding of the interactions between multiple ESs; (2) to establish multiple temporal and spatial scales on ERP assessments including future scenarios and balanced efforts of ERP assessments over the entire territory; (3) to establish multiple data scales; and (4) to develop robust modeling approaches.

Keywords China · Ecological restoration program · Ecosystem services · Systematic review

INTRODUCTION

After the Chinese economic reform, the rapid economic growth in China caused changes in ecosystem structures and processes, which led to the loss of biodiversity and a decline in ecosystem services (ESs) (Li 2004). More particularly, natural disasters (flooding and drought) caused by ecosystem degradation have occurred more frequently in

the recent decades, and these disasters have posed a threat on sustainable socioeconomic development (Lü et al. 2012). In response, the Chinese government has implemented several large-scale ecological restoration programs (ERPs), starting in 2000, including the Natural Forest Protection Program (NFPP, also known as the Natural Forest Conversion Program, NFPP), and the Grain for Green Program (GGP, also known as the Sloping Land Conversion Program, SLCP). The NFPP and the GGP are two of the biggest ERP programs worldwide in terms of their operating geographic scales (territory covered: 6.3 million km², accounting for almost two-thirds of China's territory), public investment (total budget of NFPP: \$164.86 billion¹, and total budget of GGP: \$319.07 billion¹), and potential environmental implications (Liu et al. 2008; Yin et al. 2010). In 2011, the central government decided to launch the second phase of the NFPP from 2011 to 2020. By the end of 2015, the central government also announced the extension of the GGP. Therefore, it is important to monitor the efficiency and impacts of these ERPs. A review of previous ERP assessments could provide insights for future ecological restoration.

ESs are widely defined as “the benefits people obtain from ecosystems” (MEA 2005). Based on this definition, the core purpose of ES approaches is to link ecosystems with human well-being. MEA (2005) classified ESs into four categories: provisioning services, regulating services, supporting services, and cultural services. Efforts to develop ES approaches began in the late 1990s, and have recently rapidly increased (Crossman et al. 2013). Today, the concept of ESs has become an important tool for linking the functioning of ecosystems to human welfare (Fisher et al. 2009; De Groot et al. 2010), and it is a

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¹ Budget in American dollars (based on 2017 currency).

significant research topic with diverse scopes supporting ecosystem management at different spatial and temporal scales (Maes et al. 2012).

Evaluating ERPs is currently gaining further momentum (Zhang et al. 2000; Xu 2011). Different scopes and methods have been widely used to assess ERPs at different temporal and spatial scales in China, such as remote sensing (Brandt et al. 2012; Zhou et al. 2012), ecological indicator frameworks (Fu et al. 2011; Jia et al. 2014), or economic valuation (Wang et al. 2007). Previous review papers generally focused on the evaluation of environmental and socioeconomic effects of the ERPs rather than on the methods themselves used to assess the ERPs (Liu et al. 2008; Yin et al. 2010). D'Amato et al. (2016) made a review of studies dealing with the monetary valuation of forest ESs in China. However, this review partially included ERP assessments using ES approaches, specifically focusing on the economic assessment of the value per unit of ES. To our knowledge, no review studies have provided an overall description of the use of ES approaches to assess the impacts of ERPs in China.

In this context, this paper presents a systematic review of the literature related to the use of ES approaches at the landscape scale for ERP (including the GGP and the NFPP) assessments in China. This paper addressed one key question: how and to what extent have ES approaches been used to assess ERPs in China? First, we provided an overview of the NFPP and the GGP. Second, we described the assessment framework to answer the research question. Third, reviewed papers are analyzed and described based on three dimensions: (1) the ESs analyzed in relation to the ERPs, (2) the temporal–spatial scales used, and (3) the data sources and models used to assess the ERPs, to answer the research question. Lastly, we discussed limitations and challenges related to ERP assessments using ES approaches.

OVERVIEW OF THE NFPP AND GGP PROGRAMS

The NFPP covered 18 provinces and was officially launched in 2000. The NFPP aimed to (i) conserve and restore natural forests in damaged regions, (ii) plant forests for soil and water protection, (iii) reduce timber harvest in natural forests from 32 million m³ in 1997 to 12 million m³ in 2003, and (iv) increase forest cover to 19% of total land area by 2010 (Li 2004). For the second phase (2011–2020), the NFPP aims to increase forest cover by 5.2 million ha, to reduce soil erosion, and to enhance biodiversity (Liu et al. 2013). Key policy included the provision of subsidies for forest companies and forest workers (e.g., mountain closures received a subsidy of \$152.35/ha and aerial seeding received \$108.82/ha).

Another important driving force behind soil erosion is farming on sloping terrain (Liu et al. 2013). In order to convert sloping farmland, the central government implemented the GGP in 2000, following successful tests in Sichuan, Shaanxi, and Gansu Provinces during 1998 and 1999. The GGP addressed both environmental and rural economic concerns. Key policies included: (1) croplands on a slope of more than 25° were converted into ecological forests (e.g., timber-producing forests) and grassland, whereas croplands located on a slope between 15 and 25° were converted into economic forests (e.g., fruit orchards) or grassland. (2) Farmers received compensations (e.g., \$43.53/ha was provided yearly for living expenses, and \$108.83/ha was provided for seeds in the first year).

MATERIALS AND METHODS

Literature review

We defined three specific criteria to select papers to be reviewed in this study.

Criterion 1: The papers were selected based on 21 commonly quantitated ESs grouped into four categories defined by the Millennium Ecosystem Assessment (MEA 2005). These ESs and related search terms (Table 1) were individually combined with the terms “NFPP”, “GGP” (including “NFCP” and “SLCP”) using the ISI Web of Science database. A complementary selection was done by reviewing systematically the reference lists of selected papers. Only the papers published in English between 2000 and 2017 were selected.

Criterion 2: All the papers needed to assess the ERPs using ES approaches at the landscape scale. In general, ES supplies are temporally and spatially explicit (Fisher et al. 2009). A better understanding of where, when, and what types of ESs are provided by certain pieces of land can improve landscape planning and program efficiency. Thus, studies that did not analyze ES changes at this scale were out of scope and therefore not further considered.

Criterion 3: ES assessment is generally divided into two categories: the economic assessment of the value per unit, and the ecological assessment of the ESs supply (De Groot et al. 2012). The ecological valuation encompasses the health state of the ecosystem (Muller et al. 2000), while the economic valuation attempts to measure diverse benefits and costs associated with ecosystems in monetary units (Farber et al. 2002). Since these two categories include numerous and distinct methodological approaches, this review excluded papers presenting economic valuation of ES to focus only on ecological assessment of ESs. We selected 68 papers in this review.

Table 1 Ecosystem services as categorized by the Millennium Ecosystem Assessment (MEA 2005) and corresponding to the search terms used in the literature review

Category of ES	Ecosystem service (ES)	Related search terms
Regulating services	Air-quality regulation	Air quality, sandstorm
	Climate regulation	Carbon sequestration, climate
	Pollination	Pollination
	Erosion regulation	Water and soil erosion
	Water regulation	Water retention, flood prevention
Provisioning services	Water purification	Water quality, waste water treatment
	Food production	Crop production
	Fresh water production	Water quantity, runoff, water yield
	Fiber and timber	N/A
	Genetic resources	Genetic
	Biochemicals	Medicinal resources
Supporting services	Ornamental resources	N/A
	Nutrient cycling	N/A
	Primary production	Net primary production
	Soil formation	Soil quality, soil moisture, microbial processes
Cultural services	Aesthetic values	Aesthetic and education information
	Cultural diversity	
	Educational values	
	Knowledge systems	
	Recreation and ecotourism	Recreation and tourism
	Spiritual and religious values	Spiritual experience

Assessment framework

This review analyzed three aspects of the reviewed papers:

ES analysis in relation to the ERPs

It is acknowledged in the literature that ERPs induced changes on many ESs (Liu et al. 2008, 2013). Some papers analyzed the impacts of the ERPs on a single service, while others analyzed the impacts of ERPs on multiple ESs (two and more types of ESs). Ecological restoration is a complex process, which involves multiple interactions between the structure, function, and composition of ecosystems. That is why the analysis of multiple ESs is critical to better understand an ERP's efficiency. We systematically reported the number of ESs analyzed and their relationship with the assessed ERP in the reviewed papers.

To maximize the benefits from the ERPs, while maintaining the ecosystem's health, the interactions between ESs should be understood. These relationships between ESs boil down to tradeoffs and synergies across spatial and temporal scales (Bennett et al. 2009). Tradeoffs occur when for one service that is improved, another declines. Synergies occur when for one service that is improved or decreased, another is also improved or decreased. Thus, we systematically reported the amount of ESs analyzed and the presence or the absence of relationship analysis between these ESs in the reviewed papers.

Spatial and temporal distributions of the studies

We reviewed the papers based on the resolution at which the spatial and temporal results were presented. As for spatial scales, we used the following categorization system: (1) the county level assessment refers to the evaluation of ERPs in a specific county, (2) the regional level assessment refers to watershed or catchment, and provincial scales, and (3) the national level assessment refers to the assessment of ERPs across China.

Since GGP and NFPP were officially launched in 2000, many papers analyzed the temporal changes in ESs before and after the programs, while others only analyzed the temporal changes in ESs after the implementation of these programs. We defined two temporal categories: historical and scenario. As for the period covered, we defined two classes: the short-term evaluation, which refers to studies covering less than 20 years; and the long-term evaluation, which refers to studies covering more than 20 years. Scenarios are usually defined as possible future representations of one or more components of a system. In this paper, scenario analysis refers to the analysis of potential future impacts of ERPs. It should be noted that papers which first estimated the impacts of ERPs on ESs during the past and present periods before simulating the impacts and potential future impacts of ERPs on ESs under different scenarios were categorized as “scenario” papers, because the major research objective in these papers was to analyze the potential impacts of ERPs in the future under different scenarios.

ES data and models used to assess the ERPs

The quantifying and mapping of ESs largely relied on existing data, which limited the nature of the ESs that could be mapped. Some types of data often rely on government-maintained monitoring infrastructures (e.g., climate data), while other data layers are produced by government agencies (e.g., LULC maps). This may not be available in every region or to every researcher. Thus, the review focused on the types of data used and their level of

availability. We measured this element based on the availability of free data at multiple spatial–temporal scales for researchers.

We also reviewed data and models used to assess the ERPs. We used a categorization system using three classes based on previous reviews (Andrew et al. 2015): (1) direct mapping methods refer to the use of field observations and laboratory analysis to provide information on ESs, (2) process-based models refer to the incorporation of representations of physical processes underpinning the functioning of the ecosystem, and (3) proxy models refer to the use of a set of indicators to map ESs. Lastly, we also reviewed information about internal correction and the performance of the models based on Rykiel (1996).

Although we selected 68 papers in the review, it should be noted that some papers can be counted several times in the same analysis depending on the parameter analyzed, i.e., the total number of papers can be larger than 68 in some figures and tables. As an example, a paper analyzing ESs in different provinces will be counted in each province covered in the spatial-scale analysis.

RESULTS

Ecosystem services analysis in relation to ERPs

ES approaches have been widely used to analyze the ecological impact of ERPs in China. However, current ERP assessment studies did not evaluate all ESs. As an example,

air-quality services were not evaluated in the review papers, whereas 46% of studies evaluated the impact of ERPs on regulation services. In particular, these studies on regulation services focused on evaluating the impacts of ERPs on erosion regulation (e.g., soil erosion) and climate regulation (e.g., carbon sequestration). 34% of studies assessed the ecological impacts of ERPs on provisioning services. Specifically, these studies focused on assessing food and fresh water production, fiber and timber, and genetic resources. Only 18% of studies estimated the impacts of ERPs on supporting services, including soil formation and primary production. The reviewed papers showed little interest in evaluating the impacts of ERPs on cultural services, with only 2% of the studies related to these topics.

Moreover, results indicated that the two programs were unevenly assessed. 83% of the reviewed papers evaluated the impacts of the GGP, while 17% of them assessed the ecological impacts of the NFPP. Figure 1 shows the percentage of each ES category assessed for the NFPP and the GGP. Supplementary Table S1 provides a full list of reviewed papers for each ES analyzed. 20% of studies evaluated the impact of GGP on climate regulation, while only 4% of studies estimated the impact of NFPP on this ES. 12% of studies evaluated the impact of GGP on food provision, while no papers estimated the impact of NFPP on this service. Conversely, 3% of studies evaluated the impact of NFPP on fiber and timber provision, while this ES was not evaluated for the GGP.

Fig. 1 Percentage of each ecosystem service category assessed for the GGP and the NFPP (total number = 89)

ERPs can have an effect on multiple ESs, simultaneously or not. However, 58 reviewed papers only evaluated the impacts of ERPs on single ES. Only four reviewed papers estimated the impacts of ERPs on two types of ESs, while six reviewed papers assessed the impacts of ERPs on multiple ESs (three and more types of ESs).

Spatial and temporal distributions of the studies

A few of the papers evaluated the impacts of ERPs on ESs at multiple spatial scales. The regional level assessment dominated the published studies, accounting for 53% of the reviewed papers, followed by county-level assessment, taking up 34% of the reviewed papers. Only 13% of studies considered national scales. Provisioning services (e.g., food production, fiber and timber) were commonly mapped across large areas, while other services were commonly mapped across regional or county scales. As the NFPP and the GGP almost covered 25 provinces (two-thirds of China's territory), we further analyzed the spatial coverage of the reviewed papers (Fig. 2). 30 papers chose a case study located in Shaanxi Province, while 14 papers chose a case study located in Gansu Province.

Second, our results indicated that studies covered temporal scales unevenly. 42 papers evaluated the changes in ESs related to the ERPs in the short term (less than 20 years). In particular, 28 papers focused on evaluating less than 10 years of temporal extent. Only 22 papers analyzed more than 20 years of data, while only 4 reviewed papers designed different scenarios to analyze potential impacts of ERPs on ESs in the future. Moreover, scenario analysis focused only on three sub-ES categories: forest products (Zhang and Guan 2007; König et al. 2014), crop production (Sun et al. 2006), and vegetation carbon sequestration (Caldwell et al. 2007).

ES data and models used to assess the ERPs

Data used to assess the ERPs

27% of studies considered LULC data as their main source of data. LULC data can be linked to other variables to produce other spatially distributed biophysical parameter values such as water yield, soil erosion, and vegetation carbon dynamic. 18% of studies used topographic data which provide input to empirical models of water-related services. The climate regulation, erosion, and provision of fresh water services can be indirectly expressed using climate data (18%) and soil data (18%). Survey data (5%) and statistical data (5%) were often linked to LULC data (e.g., Feng et al. 2005) and modeled to estimate the supply of ESs. Moreover, 4% of studies considered biological data as their main source of data. 5% of studies used agricultural

mapping was commonly modeled using the revised universal soil loss equation (RUSLE) and the universal soil loss equation (USLE). Water supply mapping usually estimated the volume of water yield available in a spatial unit. Fiber and timber services were estimated through a quantitative evaluation of harvest timber in a spatial unit. Food production services can be measured with LULC by identifying the net change in potential agricultural productivity. Our results also indicated that the NPP was the most commonly used indicator to evaluate primary production service.

Moreover, 19 reviewed papers used direct mapping methods to assess the ERPs. The collection of information directly from sample plots was a common characteristic to all soil moisture and soil organic carbon (SOC) evaluations. Field observations and laboratory analysis were one of the most commonly used methods in this category, which are essential for determining changes in soil carbon content for different land management treatments at the plot scale. Only five papers used process-based models and the application focused on evaluating soil erosion (e.g., Li et al. 2010) and water regulation (e.g., McVicar et al. 2007).

ES models testing and analysis

41 reviewed papers, accounting for 60% of the reviewed papers, validated their outputs. In particular, 19 papers used direct mapping methods, which consist in using survey data obtained from field sample plots (e.g., soil survey samples) and laboratory analysis to provide validation information on ESs. Moreover, 22 papers validated their modeling results using observation data which are usually obtained from government-maintained monitoring infrastructures (e.g., weather stations). Among these 22 papers, studies which quantitated changes of water yield or runoff usually validated their simulation results. Validation methods included model calibration and comparisons between the simulation results and observation datasets. However, many papers usually used sample data from field experiments to represent changes in their study sites through interpolation or other tools. The validation of simulation results in these papers were essentially partial, although the performance of ES models can be verified by the consistency between observations and calculations. 40% of studies did not report model output validation. For example, the papers using proxy models to assess large-scale impacts of ERPs on ESs (e.g., soil erosion) usually did not report a validation procedure, and validation was not common for papers that quantitate multiple ESs.

DISCUSSION

Ecosystem services analyzed in relation to the ERPs

Although ES approaches have been widely used to analyze the ecological impact of ERPs, reviewed ERP assessment studies showed that all ESs were not studied. Only a few papers assessed the impacts of ERPs on supporting and cultural services. Moreover, many studies investigated the impact of ERPs on single ESs, and only six reviewed papers assessed the impact of ERPs on multiple ESs or analyzed the relationships between multiple ESs. The ecosystem should be considered as a whole, because the changes or impacts on one part of an ecosystem can have consequences for the whole system. Bennett et al. (2009) stressed the importance of understanding direct and indirect relationships between multiple ESs. From a management perspective, targeting the sustainable development of a single service's supply might have a positive or negative impact on the supply of another ES. These interactions are principally determined by the synergies or tradeoffs between ESs. Landscapes differ in their capacity to provide ESs, and the spatial patterns of LULC changes can be linked to the provision capacity of ESs (Burkhard et al. 2009). Thus, appropriately planned and managed land use can support not only single ESs, but also other ESs. As such, the patterns, interactions, and quantitation of multiple ESs need to be further examined in order to minimize tradeoffs among ESs and to maintain ecosystem health.

Likewise, although many studies have already assessed the impact and efficiency of ERPs, ways to enhance the effectiveness of these programs remain unclear. In China, most of the programs were not tailored for the local hydrological, climate, and land conditions of the arid and semi-arid regions covered by the program (Cao et al. 2011). These programs could simultaneously increase the risk of unwanted negative effects. The amount of precipitation can limit the vegetation's potential growth capacity in arid and semi-arid regions. Water is one of the most important factors for large-scale afforestation in these regions. Massively planted trees in the semi-arid Loess Plateau in China altered hydrologic cycles and led to negative impacts on native plants (Cao et al. 2009). In these regions, water availability appears to be unsuitable for afforestation using currently used tree species, because they require huge volumes of water compared to native ones (Feng et al. 2012). The central Chinese government has already launched the second phase of the NFPP, from 2011 to 2020, and announced that, at the end of 2015, it will extend the GGP for a new round, which means that billions of dollars will be invested. A deeper understanding of the interactions between multiple ESs and the

mechanism behind these relationships could help improve the programs' effectiveness.

Spatial and temporal distributions of the program evaluations

The NFPP and the GGP almost cover two-thirds of the Chinese territory, and most regions covered by the programs are both lagging economically and ecologically fragile (Liu et al. 2008). Our results indicated that many studies evaluated the impacts of ERPs on ESs at different spatial and temporal scales in China. The study site selection in the reviewed papers was not evenly distributed throughout China but was in line with major local ecological characteristics or problems. For example, many papers chose northern Shaanxi Province as the case study site, and the program evaluation in this region usually focused on changes of soil erosion (e.g., Fu et al. 2011), water supply (e.g., Feng et al. 2012), and soil formation (e.g., Yang et al. 2012). This is because this region is mainly located in the Loess Plateau which is well known for its severe soil erosion in China. The climate is mainly characterized by cold and very dry winters and dry springs and autumns. Thus, afforestation in this region usually leads to water shortage (Cao et al. 2009). Moreover, natural disasters like drought, sandstorms, and landslides in this region are quite frequent.

However, most of the studies investigated the impacts of ERPs on ESs at a specific scale such as regional scale and administrative districts, and 42 reviewed papers evaluated the change of ES value caused by the ERPs in a short term (less than 20 years). An increasing recognition that different processes operate at different scales and cross-scale dynamics should be considered in the study of ecological systems (Agarwal et al. 2002). Some ecological processes are associated with a particular scale, while other processes may occur across multiple scales. Given that ecosystems are complex, single temporal- and spatial-scale observations may capture, miss, or distort ES interactions (Raudsepp-Hearne and Peterson 2016). Likewise, the complexity of ecosystems and the various temporal dimensions have led to the recognition that ecological research must be conducted at middle- or long-term scales (Lindenmayer et al. 2000).

The growing body of literature regarding LULC change scenario modeling shows its importance and potential role in providing insight and informing landscape planners and policy makers (Nelson et al. 2009). However, based on our analysis, only four reviewed studies evaluated scenarios that could allow for policy evaluations. Thus, it is necessary to establish a temporal scope that covers the past, present, and reasonably foreseeable future for the programs' assessment.

ES models and data used to assess the ERPs

Our results indicated that the ES data were usually derived from global or national datasets, which offered a practical and economic approach to perform spatially continuous observations. However, it is difficult to obtain large spatial-scale data and long-term, consecutive temporal-scale data. Researchers usually use sample data representing changes in large scales and use interpolation or other statistical tools. For example, large spatial precipitation maps are created using point observations, such as weather stations. However, not all the weather stations under the CMDSS framework broadcast a complete set of data, and not all stations broadcast continuously. Moreover, observations at large spatial scales are usually scarce (Martinez-Harms and Balvanera 2012). For example, Landsat images can present an incomplete spatial and temporal coverages due to cloud cover in some images. This can increase uncertainties in large-scale ES modeling (Crossman et al. 2013).

Likewise, using data from different temporal and spatial scales and inconsistent approaches can make integration of comparisons assessment results difficult. For example, many studies and government reports have confirmed that the NFPP and the GGP have greatly increased the forest area. However, several studies found no significant changes in forest cover in some counties. Moreover, several counties showed a forest cover decline due to touristic development (Yin et al. 2010). 27% of studies considered LULC data as the main source of data. Remotely sensed data are the main source of LULC data. Since the information contained in a remotely sensed image is strongly dependent on the spatial resolution, and the spatial resolution of an image affects every stage of the image classification process (Ghassemian 2016), the spatial resolution of the remotely sensed images directly influences ES simulation results. Given that the evaluation of ESs is becoming an important tool to guide decision-making, improving the quality of data and establishing multiple data scales are important in order to be able to provide more accurate information.

An impressive suite of models has already been used to represent and analyze the changes of ESs under these two programs, such as direct mapping, ecological process-based models, and proxy models. However, 40% of studies did not report model output validation, which may limit the accuracy and precision of evaluation results. Thus, it is necessary to develop robust approaches to ES modeling and valuation.

Language of selected papers

We acknowledge that selecting only peer-reviewed papers published in international journals (i.e., English language)

has impacts on the analysis. We made this choice in order to have a systematic and reproducible approach. Integrating local reports and publications could have been interesting to complete the analysis, but this selection would have been incomplete and not systematic. Access to these local studies is variable, and their quality is hard to assess. Moreover, collecting and reviewing these publications all over China for the past decades would have represented a tremendous amount of work which is out of the scope of this review. By using English-published papers, our review provides a systematic analysis of GGP and NFPP using ES and highlights three aspects generalized over the entire country. It allows identifying several issues regarding specific provinces, ES analyzed, or databases. The local literature review could be used at this level and performed by researchers interested in probing deeper into specific questions and issues.

CONCLUSION

This study reviewed 68 papers to evaluate how and to what extent ES approaches have been used to assess the ERP in China. This review examined three aspects: the ESs analyzed in relation to the ERPs, the temporal–spatial scales used, and the data sources and models used. The review revealed that ES approaches are becoming an important tool to assess the ERPs in China. Four major elements were identified to improve future ERPs assessments in China using ES approaches: (1) the need to assess the impacts of ERPs on multiple ESs and to better understand the interactions between multiple ESs; (2) the need to establish multiple temporal and spatial scales for ERP assessments, the need to balance efforts of ERP assessments over the entire territory, and the need to design alternative future scenarios for the analysis of the potential impacts of ERPs on ESs; (3) the need to establish multiple data scales; and (4) the need to develop robust modeling approaches, particularly regarding model validation. These recommendations are highly dependent on the availability of well-distributed and standardized data over the entire territory. A government-funded national monitoring program related to the GGP and NFPP would probably be necessary to provide these data.

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