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A watershed-based adaptive knowledge system for developing ecosystem stakeholder partnerships

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Abstract This study proposes a Watershed-based Adaptive Knowledge System (WAKES) to consistently coordinate multiple stakeholders in developing sustainable partnerships for ecosystem management. WAKES is extended from the institutional mechanism of Payments for Improving Ecosystem Services at the Watershed-scale (PIES-W). PIES-W is designed relating to the governance of ecosystem services flows focused on a lake as a resource stock connecting its inflowing and outflowing rivers within its watershed. It explicitly realizes the values of conservation services provided by private land managers and incorporates their activities into the public organizing framework for ecosystem management. It implicitly extends the “upstream-to-downstream” organizing perspective to a broader vision of viewing the ecosystems as comprised of both “watershed landscapes” and “marine landscapes”. Extended from PIES-W, WAKES specifies two corresponding feedback: Framework I and II. Framework I is a relationship matrix comprised of three input-output structures of primary governance factors intersecting three sub-systems of a watershed with regard to ecosystem services and human stakeholders. Framework II is the Stakeholder-and-Information structure channeling five types of information among four stakeholder groups in order to enable the feedbacks mechanism of Framework I. WAKES identifies the rationales behind three fundamental information transformations, illustrated with the Transboundary Diagnostic Analysis and the Strategic Action Program of the Bermejo River Binational Basin. These include (1) translating scientific knowledge into public information within the Function-and-Service structure corresponding to the ecological subsystem, (2) incorporating public perceptions into political will within the Service-and-Value structure corresponding to the economic subsystem, and (3) integrating scientific knowledge, public perceptions and political will into management options within the Value-and-Stakeholder structure corresponding to the social subsystem. This study seeks to share a vision of social adaptation for a global sustainable future through developing a network to adopt contributions from and forming partnerships among all ecosystem stakeholders.

Keyword: ecosystem services; information transformation; integrated ecosystem management; stakeholder partnerships; transaction costs; watersheds

1 INTRODUCTION

In many parts of the world, human societies are facing the tradeoff between pursuing economic prosperity and maintaining ecosystem integrity. Economic development requires extensive uses of natural resources from both terrestrial and aquatic ecosystems. Without systematic ecosystem preservation, conservation, restoration or

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rehabilitation, such exploitation will reduce ecosystem integrity which allows the different parts of the ecosystems to function coherently. Whereas economic development generates immediate, material wellbeing benefits for human societies, ecosystem integrity sustains the long-term, physical, mental and psychological health of humans. Here, the decision for tradeoff is evident; that some financial resources resulting from economic development must be invested in ecosystem management in order to maintain ecosystem integrity and the wellbeing of human societies.

However, public decision-making for such a tradeoff is difficult for human societies with multiple stakeholders who have different private interests. In order to effectively regulate the behaviors of industries and individual citizens and/or motivate their behavioral changes towards an expected outcome, policy makers are in need of a comprehensive knowledge system for ecosystem management, with the objective of answering the following key questions (Landell-Mills and Porras, 2002; Gutman, 2003; Hartmann and Peterson, 2004; Wunder, 2005; Forest Trends, 2007; USAID, 2007; Bulte et al., 2008; Engel et al., 2008; Ferraro, 2008; Jack et al., 2008; Kosoy et al., 2008; Wunder, 2008; Wunscher et al., 2008; Redford and Adams, 2009; Farley and Costanza, 2010; Kemkes et al., 2010; Kosoy and Cobera, 2010; McAfee and Shapiro, 2010; Cranford and Mourato, 2011; Leimona et al., 2015; Reed et al., 2015):

Question 1: Which parts of the ecosystem should be preserved, conserved, restored or rehabilitated for the overall improvement of ecosystem functions affected by ongoing human activities?

Question 2: How should the performance of these management activities be evaluated, and by whom, in view of the activities of other human stakeholders which are ongoing?

Question 3: How should the evaluation results of these management activities be used, by whom, in view of the activities of other human stakeholders which are ongoing?

Question 4: How many financial resources should be invested in ecosystem management to maintain the ecosystem integrity necessary to support human activities?

Question 5: How should these management activities be implemented, and by whom, in view of the activities of other human stakeholders which are ongoing? In particular, how should practitioners, such as foresters, be identified to initiate and maintain effective management activities?

Question 6: When should these management activities be implemented, in view of the activities of other human stakeholders which are ongoing? In particular, how should other human stakeholders, essentially, citizens and industries, be motivated to coordinate their activities towards the same goal and without intentional and negative impacts on the management activities? In other words, factual and intelligent answers must be communicated to citizens and industries in such a way as to attract their interests and encourage them to cooperate and contribute to ecosystem management.

These questions have been reflected in more than 150 Payments for Ecosystem Services (PES) programs implemented in more than 30 developing countries (Lin and Nakamura, 2012). PES programs are interactive ecosystem management programs designed for multiple stakeholders to cooperate through partnership development in diverse management contexts (CANARI, 2002; Arocena-Francisco, 2003; FAO, 2004; Hartmann and Peterson, 2004; Mayrand and Paguin, 2004; CCICED, 2006; Scurrah-Ehrhart, 2006; Agarwal et al., 2007; Asquith and Vargas, 2007; Bracer et al., 2007; Huang and Upadhyaya, 2007; McIntosh and Leotaud, 2007; Swallow et al., 2007; Blignaut, 2008; Chiotha and Kayambazinthu, 2008; King et al., 2008; Mwangi, 2008; Randimby et al., 2008; Ruhweza et al., 2008; Southgate and Wunder, 2009; Van Noordwijk and Leimona, 2010).

Successful PES partnerships (Lin and Ueta, 2012; Lin et al., 2013a) tend to develop from the following understandings shared among participating stakeholders (Fig.1).

(1) The ecosystem is a functional system which generates ecosystem services;

(2) Human societies depend on ecosystem services to implement activities;

(3) Viewed at a watershed scale, human activities upstream can directly affect ecosystem services received downstream through upstream impacts on ecosystem functions;

(4) With trust, upstream and downstream stakeholders can collectively discover win-win, cost-effective management options to enhance ecosystem functions in providing improved ecosystem services.

In this sense, a more accurate and functional term of PES is Payments for Improving Ecosystem Services at the Watershed-scale (PIES-W) (Lin, 2012; Lin et al., 2013b).

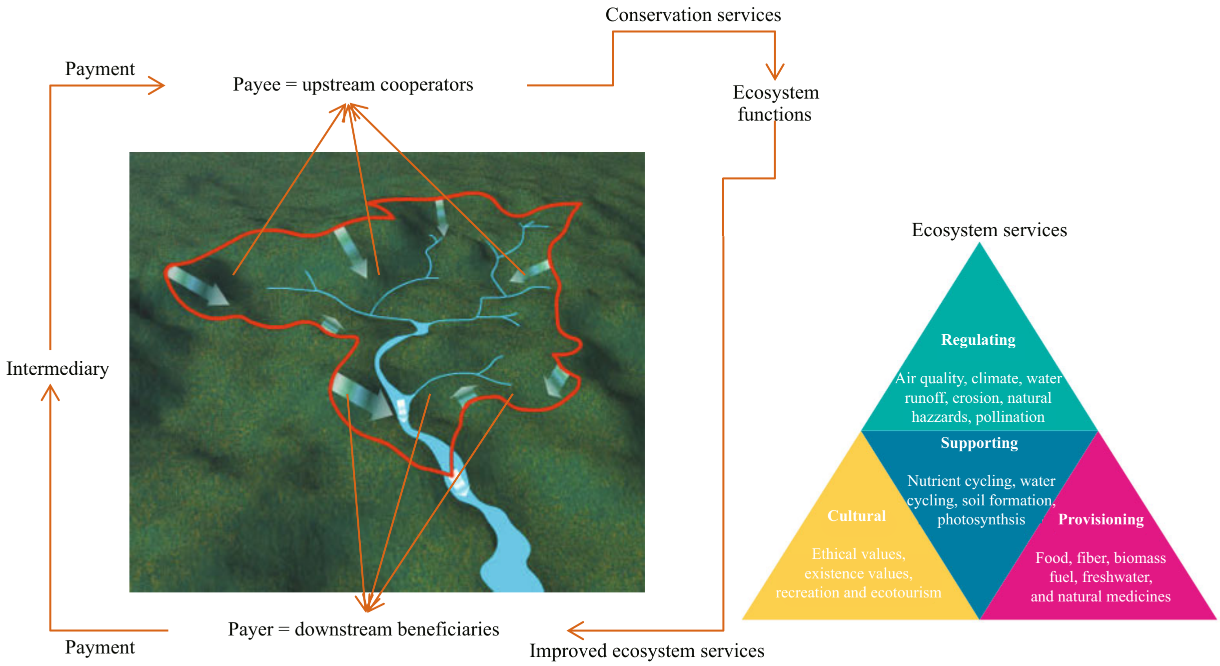

Fig.1 Stakeholder relationships in Payments for Ecosystem Services (PES) programs

Sources of the images for the watershed and ecosystem services are available on the websites: http://www.kidsgeo.com/images/watershed.jpg; https://conceptdraw.com/a1080c3/p1/preview/640/pict--page1-ecosystem-goods-and-services---segmented-pyramid-diagram.png--diagram-flowchart-example.png.

A typical PIES-W program can be implemented in 15 steps (Fig.2). Based on scientific knowledge, some conservation activities upstream are diagnosed as having a potential for enhancing ecosystem functions which, in turn, improves the provision of ecosystem services delivered downstream. For example, conserving cloud forests in the headwaters may improve the availability of water in the river used for irrigation downstream. In order to finance the conservation activities, an organization or leader is identified to act as an intermediary to develop a win-win exchange relationship between upstream and downstream stakeholders, such as foresters and farmers. As beneficiaries, some downstream stakeholders are motivated to provide financial payments as a more cost-effective option compared with other investment alternatives such as constructing water diversion projects. As cooperators, some upstream stakeholders are motivated to provide conservation services in exchange for the financial payments as a more cost-effective option compared with other livelihood alternatives such as slash-and-burn agriculture. Despite other institutional factors, including especially property rights, prices, and transaction costs, the key challenge in sustaining a PIES-W program lies on how to utilize scientific evidence of conservation activities improving ecosystem functions to promote partnerships between upstream cooperators and downstream beneficiaries.

The recent development of national databases on water and land has indicated the technological sophistication of monitoring the hydrological, chemical and biological conditions of waterbodies at the watershed-scale. Some of these databases have been made publicly accessible at specific watershed locations with detailed geographical information. In the United States of America, for example, these interactive databases especially include: the National Hydrography Dataset (Simley and Carswell, 2009), Watershed Boundary Dataset (USGS and USDA, 2012) and National Land Cover Databases (Jin et al., 2013). As scientists have been using watersheds as a physical and logical unit to derive adaptive observations on ecosystems for decades (Holling, 1978; Habron, 2003), these databases indicate a great potential to support analyses of the mutual impacts between ecosystems and human societies as a whole.

Building on these insights, this study proposes a Watershed-based Adaptive Knowledge System (WAKES) to consistently coordinate multiple stakeholders in developing sustainable partnerships for ecosystem management. It seeks to share a vision of social adaptation for a global sustainable future through developing a network to adopt contributions from and forming collaborations among all human stakeholders in our society. This study is focused on

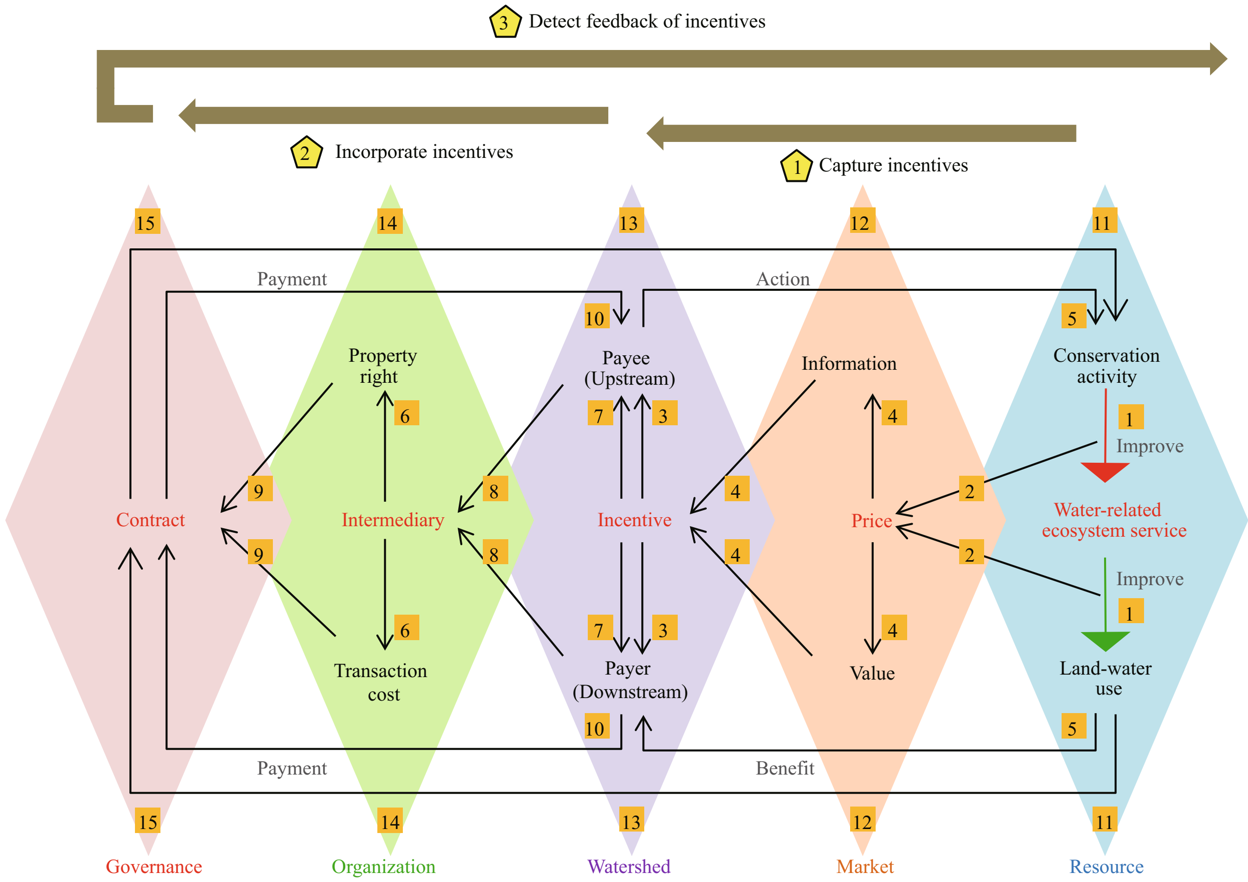

Fig.2 A common procedure of implementing Payments for Improving Ecosystem Services at the Watershed-scale (PIES-W) programs

The fifteen steps in these parts include: (1) preparing publically-available data; (2) formulating preliminary transaction options; (3) facilitating negotiation; (4) obtaining private information; (5) specifying feasible and acceptable transaction options; (6) diagnosing arrangement elements; (7) making contractual proposals; (8) collecting counter proposals; (9) identifying preliminary contractual options; (10) identifying feasible and acceptable contractual options; (11) monitoring outcomes; (12) refining contract proposals; (13) analyzing changed incentives among participants; (14) identifying potential incentive changes among nonparticipants; (15) identifying governance options (Source: Lin and Nakamura, 2012).

elaborating the structure of WAKES and draws on experiences in the Bermejo River Binational Basin in South America to illustrate the fundamental ideas of WAKES and its general applicability to diverse ecosystem management contexts.

2 MATERIALS AND METHODS: THE WATERSHED-BASED ADAPTIVE KNOWLEDGE SYSTEM (WAKES)

2.1 Overview

WAKES is constructed as an extension of the institutional mechanism of PIES-W (Lin, 2012; Lin et al., 2013a; Lin and Thornton, 2013) which is composed of three sub-systems, including ecological, economic and social sub-systems at the same watershed scale (Fig.3a, b, c and d). The three PIES-W sub-systems are positioned in such an order that, compared with a left-hand-side sub-system, a right-hand-side sub-system has a higher degree of complexity in terms of the interactions between the ecosystem and human stakeholders. Specifically, WAKES visualizes an efficient structure of governing ecosystem services and conservation services through revealing and incorporating economic values of the services, and coordinating human stakeholders to exchange their private information (Fig.3e, f and g). Essentially, WAKES presents a feedback structure for facilitating information transformation and enhancing partnership development among multiple stakeholder groups for ecosystem management (Fig.3h).

2.2 Watersheds and subsystems

For the purpose of ecosystem management, a watershed can be viewed as a landscape unit with essential topological components connected from

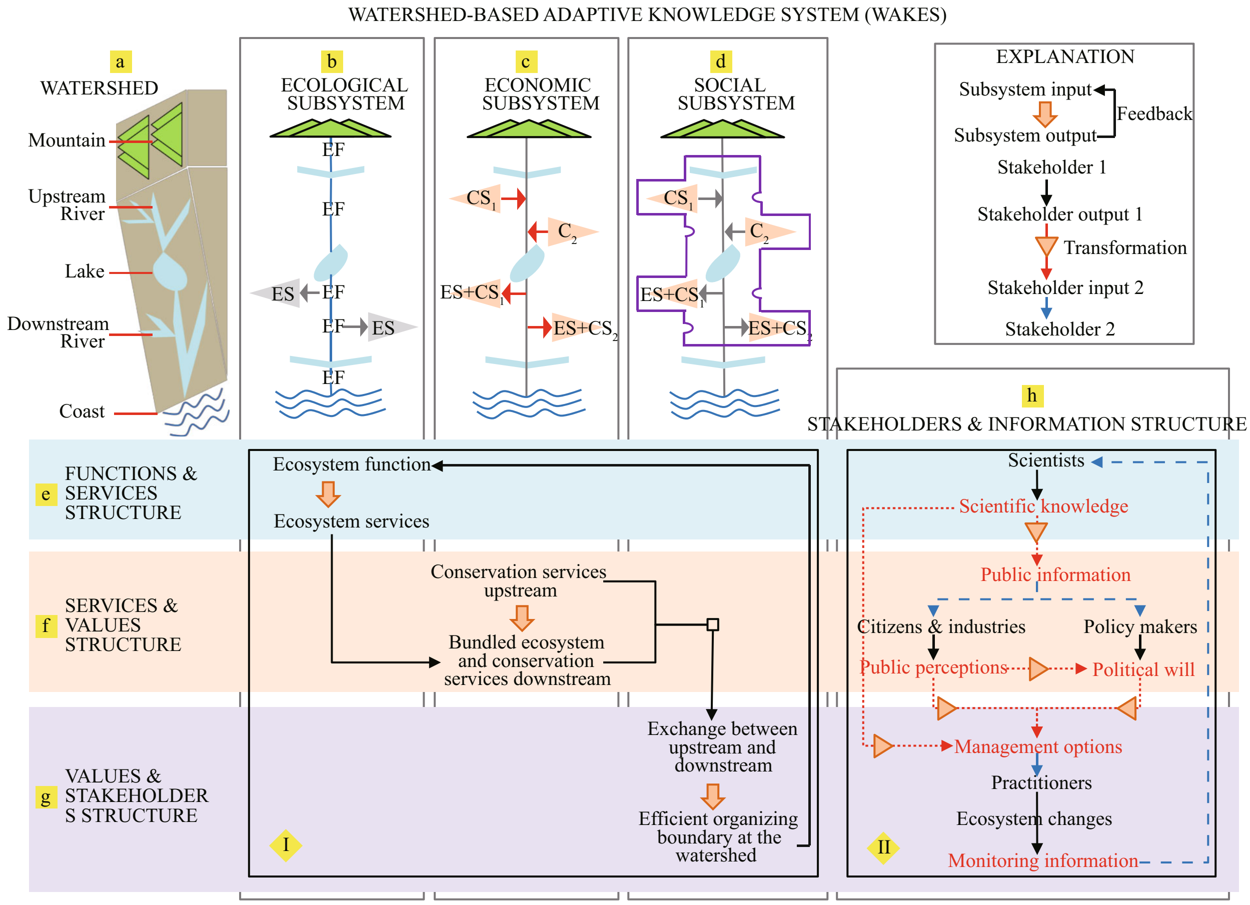

Fig.3 The Watershed-based Adaptive Knowledge System (WAKES)

CS: conservation services; EF: ecosystem function; ES: ecosystem services; ES+CS: bundled ecosystem and conservation services.

upstream to downstream (Fig.3a). These include mountains, upstream rivers, lakes/reservoirs, downstream rivers, and the coast. The overall topology, including elevation, affects the surface section of the hydrological cycle. Based on PIES-W, interactions between humans and the ecosystem at the watershed scale can be observed as three sub-systems. Viewed within the ecological subsystem (Fig.3b), ecosystem functions (EF) connect the topological components and provide ecosystem services (ES) both upstream and downstream. Viewed within the economic subsystem (Fig.3c), conservation services provided by human stakeholders upstream can potentially enhance the ecosystem functions connecting upstream and downstream, such as those of the lakes. In turn, the enhanced ecosystem functions improve the ecosystem services (ES+CS) received downstream. In other words, conservation services provided by humans have added values to ecosystem services provided by the ecosystem. Viewed in the social subsystem (Fig.3d), an effective organizing boundary of watershed partnerships can be formed between upstream cooperators and downstream beneficiaries with the latter providing payments to the former to finance their conservation services upstream.

Together, the three sub-systems form a basis for determining an efficient organizing boundary for a PIES-W framework (Lin, 2012; Lin and Thornton, 2014) (Fig.4). PIES-W is designed relating to the governance of ecosystem services flows focused on a lake as a resource stock connecting its inflowing and outflowing rivers within its watershed. PIES-W mimics the decision making of a manufacturing firm in its production stages in terms of interactions with the market, or the “vertical integration” of internal and external transactions. In manufacturing a product, the firm can choose to make certain components internally or buy similar components externally from the market. Both decisions induce costs. This “make-or-buy” decision is determined by the lower cost. After the product is manufactured, the firm can choose to use it internally or sell it externally to the market. Both decisions generate values. This “use-or-sell”

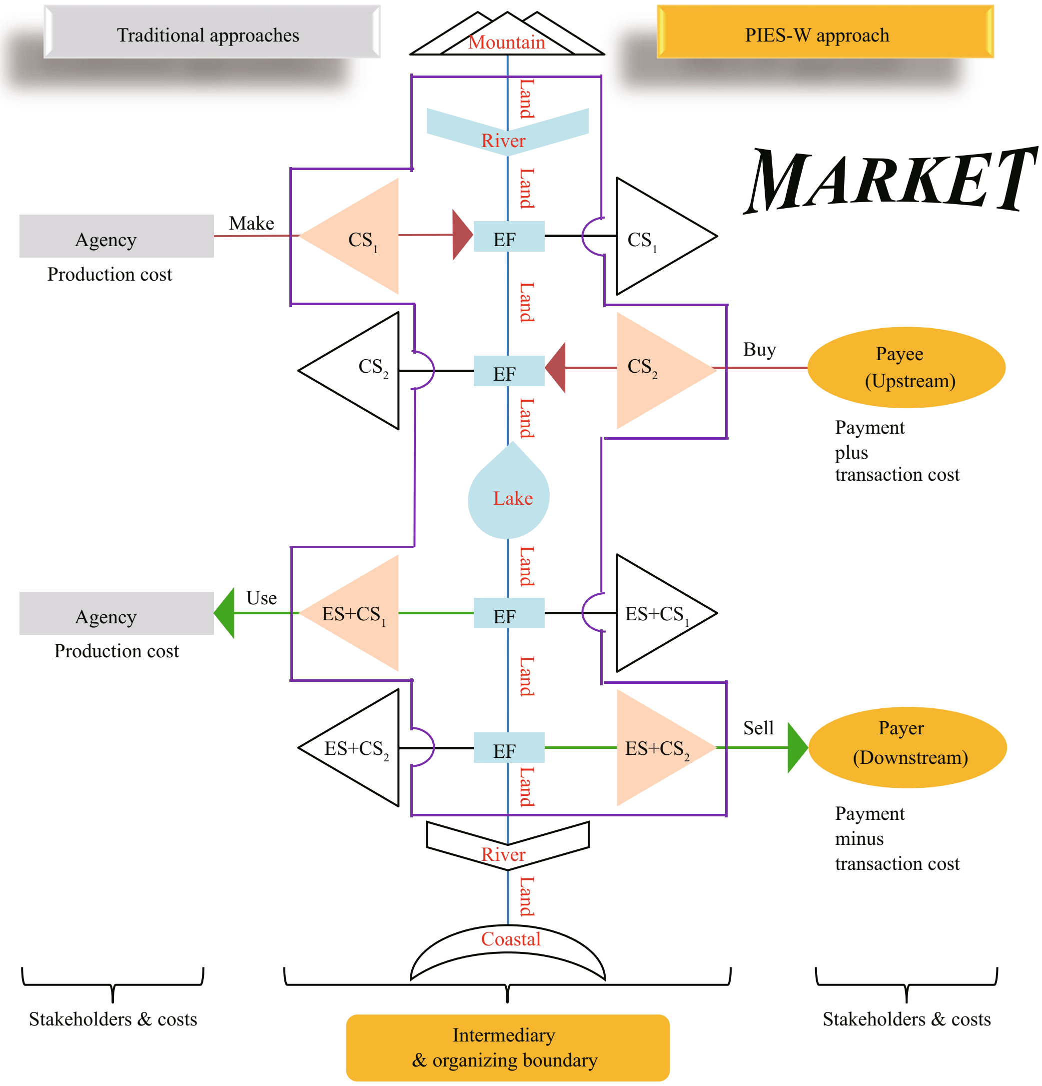

Fig.4 The efficient organizing boundary of PIES-W

CS: conservation services; EF: ecosystem function; ES: ecosystem services; ES+CS: bundled ecosystem and conservation services (Source: adapted from Lin and Thornton, 2014).

decision is determined by the higher value. An efficient organizing boundary is formed by integrating all the "make", "buy", "use", and "sell" decisions into one internal organizing framework. Similarly, the efficient organizing boundary of a PIES-W framework is formed based on specifying the "make-or-buy" integration decision relating to a conservation service (CS) upstream and the "use-or-sell" integration decision relating to a bundled ecosystem service and conservation service (ES+CS) downstream.

Consider governments as the ultimate ecosystem management organizations which represent the interests of human societies to generate conservation services upstream so as to enhance ecosystem functions in generating ecosystem services benefiting the human societies downstream. For upstream, in a traditional "make" option, a conservation service (e.g., CS_1 in Fig.4) is "internally" manufactured by an agency designated by the governments. This option induces a production cost (that is, PC_{CS}). In the PIES-W approach, as a new "buy" option, the conservation service (e.g., CS_2 in Fig.4) could be "externally" supplied by a private land manager, or a PIES-W payee, through the effects of his/her modification of land use activities with specific instructions prescribed in the contract terms negotiated by the PIES-W intermediary. This option induces a cost of PIES-W payment as the market value of the private conservation service (that is, MV_{CS}) and a transaction cost (that is, TC_{CS}) for making the contractual arrangement. If the total cost of externally "buying" the private conservation service from a

PIES-W payee is lower than or equal to the production cost of internally "making" the public conservation service, then a "buy" option is chosen, as in Eq.1; otherwise the "make" option is chosen, as in Eq.2.

$$MV_{CS}+TC_{CS}\leq PC_{CS}, \quad (1)$$

$$MV_{CS}+TC_{CS}>PC_{CS}. \quad (2)$$

For downstream, in a traditional "use" option, the bundled service (e.g., $ES+CS_1$ in Fig.4) is "internally" processed by a user designated by the governments. This option generates a value in terms of saving a production cost (that is, $PC_{(ES+CS)}$) which would otherwise occur when a similar product is manufactured. In the PIES-W approach, as a new "sell" option, the bundled service (e.g., $ES+CS_2$ in Fig.4) could be "externally" supplied to a private resource user, or a PIES-W payer, with specified expectation of the service prescribed in the contract terms negotiated by the PIES-W intermediary. This option generates a value of PIES-W payment as the market value of the bundled service (that is, $MV_{(ES+CS)}$) reduced by a transaction cost (that is, $TV_{(ES+CS)}$) for making the contractual arrangement. If the total value of externally "selling" the bundled service to a PIES-W payer is higher than or equal to the value of internally "using" the bundled service, then a "sell" option is chosen, as in Eq.3; otherwise the "use" option is chosen, as in Eq.4.

$$MV_{(ES+CS)}-TC_{(ES+CS)}\geq PC_{(ES+CS)}, \quad (3)$$

$$MV_{(ES+CS)}-TC_{(ES+CS)}<PC_{(ES+CS)}. \quad (4)$$

In effect, PIES-W explicitly realizes the values of conservation services provided by upstream private land managers and reveals the perceptions of the values of ecosystem services benefiting downstream private resource users. Collectively, PIES-W incorporates both upstream private stakeholders' activities and downstream private stakeholders' perceptions into the public organizing framework for ecosystem management and facilities partnership development among all stakeholder groups.

Furthermore, PIES-W implicitly extends the "upstream-to-downstream" organizing perspective to a broader vision of viewing the ecosystems as an entity comprised of both "watershed landscapes" and "marine landscapes". In particular, distinguished by the coastlines, on the "watershed landscape", the liquid water flows over lands from "upstream mountains" to "downstream coastal areas", whereas on the "marine landscape", the water vapor transports through the atmosphere from "upstream oceans" to "downstream lands" (Lin and Thornton, 2014). Whereas "watershed landscape" is a dominating concept underpinning practices of resources management in the contemporary world, the importance of "marine landscape" is on the new horizon for sustainable development under global environmental change (Das et al., 2014). In this regard, PIES-W provides an important direction towards developing comprehensive architecture for governing the interfaces of water, land, atmosphere, human societies and other biological communities.

2.3 Input and output structures

In order to explicitly present the interactions between the ecosystem and the different human stakeholder groups, three input-and-output structures are constructed for WAKES, including the following:

A Function-and-Service structure;

A Service-and-Value structure; and

A Value-and-Stakeholder structure.

The Function-and-Service structure (Fig.3e) conceptualizes a fundamental input-output relationship in the ecological subsystem. Enhanced ecosystem functions generate improved ecosystem services, as in Eq.5.

$$\text{Change in (ES)/Change in (EF)}\geq 0. \quad (5)$$

Equation 5 supports answers to Question 1 and Question 2 in selecting different types of ecosystem management activities for implementation and in evaluating the impacts of implementation, respectively.

The Service-and-Value structure (Fig.3f) describes a potential input-output relationship in the economic subsystem. Conservation services (CS) add value to ecosystem services (ES) and form higher valued bundled ecosystem and conservation services (ES+CS), as in Eq.6.

$$\text{Value of (ES+CS)}\geq\text{Value of (ES)}. \quad (6)$$

Equation 6 supports answers to Question 3 and Question 4 in utilizing the evaluation results to inform the values of both conservation services supplied upstream and bundled services received downstream and in determining the proportion of economic resources for financing ecosystem management, respectively.

The Value-and-Stakeholder structure (Fig.3g) reveals a promising input-output relationship in the social subsystem. As more and more upstream and downstream stakeholders exchange with each other, their trust in each other increases. The transaction costs (TC) accompanying the exchanges decrease.

More conservation services generated by individual land managers upstream will be demanded by downstream (Williamson, 1985; Lin and Thornton, 2014). Simultaneously, more bundled ecosystem and conservation services will be demanded by the private resource users downstream. Overall, the partnership formed by "enclosing" upstream and downstream participants in the exchanges, as in Eq.7, determines an efficient organizing boundary.

$$\text{Change in (ES+CS)/Negative change in (TC)} \geq 0. \quad (7)$$

Equation 7 supports answers to Question 5 and Question 6 in determining the partners to finance and practitioners to implement management activities and in determining the timetable for the implementation, respectively.

In forming partnerships between upstream and downstream stakeholders, the Function-and-Service, Service-and-Value, and Value-and-Stakeholder structures are interrelated. The output (that is, ecosystem services) in the Function-and-Service structure contributes to the output (that is, bundled ecosystem and conservation services downstream) in the Service-and-Value structure, as indicated in Fig.3e and f. Facilitated by intermediaries (Lin and Nakamura, 2012), both the output and the input (that is, conservation services upstream) in the Service-and-Value structure contribute to the input (that is, exchange between upstream and downstream) in the Value-and-Stakeholder structure, as indicated in Fig.3f and g. The output (that is, an efficient organizing boundary at the watershed) in the Value-and-Stakeholder structure forms a feedback loop to the input (that is, ecosystem functions) in the Function-and-Service structure, as indicated in Fig.3g.

2.4 Stakeholders and information

The connections among Function-and-Service, Service-and-Value, and Value-and-Stakeholder structures can be further observed via a Stakeholder-and-Information structure (Fig.3h). The Stakeholder-and-Information structure describes how information flows for ecosystem management at the watershed scale can be effectively transformed and communicated among stakeholders. Four groups of stakeholders are specified, including scientists, citizens and industries, policy makers, and practitioners.

Within the Function-and-Service structure, scientific knowledge regarding how to enhance ecosystem functions for improved ecosystem services is generated by scientists. Scientific knowledge forms a base for the public information provided to citizens and industries, and policy makers in the Service-and-Value structure. Public information includes the types of conservation activities upstream which could enhance ecosystem functions, and the types of productive activities downstream which may benefit from the improved ecosystem services. In turn, public perspectives are generated by citizens and industries and provided to policy makers; political will is then generated within the policy making community. Public perceptions include the values of conservation services provided by upstream stakeholders and the values of bundled ecosystem and conservation services benefiting downstream stakeholders.

Within the Value-and-Stakeholder structure, management options are generated as a result of combined scientific knowledge, public perceptions and political will, and provided to practitioners. Management options include politically supportive exchanges in which downstream stakeholders provide financial payments to upstream stakeholders for their conservation services. Based on the management activities and the induced ecosystem changes, monitoring information is generated by practitioners and provided to scientists, which completes the circle of information flows. Monitoring information includes verification of whether the implemented management activities have resulted in the expected impacts of enhancing ecosystem functions. It also includes identifying the potential types of services (ES, CS and ES+CS) which are considered in the exchanges, in other words, the scale of efficient organizing boundaries at the watershed scale.

Overall, WAKES reveals three necessary transformations of information for adaptive ecosystem management. First, Scientific Knowledge (SK) needs to be translated into Public Information (PI) within the Function-and-Service structure corresponding to the ecological subsystem, as in Eq.8. Second, based on Public Information (PI), Public Perceptions (PP) need to be incorporated into Political Will (PW) within the Service-and-Value structure corresponding to the economic subsystem, as in Eq.9. Finally, Scientific Knowledge (SK), Public Perception (PP) and Political Will (PW) need to be integrated into Management Options (MO) within the Value-and-Stakeholder structure corresponding to the social subsystem, as in Eq.10.

$$PI_{\text{citizens, industries and policy makers}} = \text{Transformation}\ (SK_{\text{scientists}}), \quad (8)$$

$$PW_{\text{policy makers}}=\text{Transformation}\,(PP_{\text{citizens and industries}}), \quad (9)$$
$$MO_{\text{practitioners}}=\text{Transformation}\,(SK, PP, PW). \quad (10)$$

2.5 Summary

WAKES specifies two corresponding feedback frameworks for adaptive ecosystem management: Frameworks I and II. Framework I is a relationship matrix comprised of three input-output structures (Fig.3e, 3f and 3g) of primary governance factors intersecting three sub-systems (Fig.3b, 3c and 3d) of a watershed (Fig.3a) with regard to ecosystem services and human stakeholders. Framework I consistently identifies collective targets, overcomes gaps, and constructs linkages. The core of the matrix is three fundamental relationships (Eqs.5–7). Their feedback mechanism is governed by four integration decisions (that is, Eqs.1–4) within the institutional mechanism of PIES-W (Fig.4). Framework II is a Stakeholder-and-Information structure (Fig.3h) intersecting three sub-systems (Fig.3b, 3c and 3d) of a watershed with regard to ecosystem services and human stakeholders. Framework II channels five types of information among four stakeholder groups in order to enable the feedback mechanism of Framework I. Framework II effectively facilitates communication and coordination among different stakeholders. Framework I and II are complementary and mutually reinforcing, and indispensable for WAKES. Without Framework II, certain governance factors in Framework I would remain "foreign" concepts to certain stakeholders, and the potential feedback mechanism would be invalid. Without Framework I, certain information inflow/outflow in Framework II may not be generated, and the potential transformation mechanism would be inactive. However, with both Framework I and II, WAKES becomes a promising compass for effective navigation in diverse ecosystem management contexts.

3 RESULTS OF A CASE STUDY: BERMEJO RIVER BINATIONAL BASIN IN SOUTH AMERICA

The Transboundary Diagnostic Analysis and the Strategic Action Program of the Bermejo River Binational Basin reflect the potential uses of WAKES in a transboundary ecosystem management context. The Bermejo River basin is shared by two countries: Argentina and Bolivia (UNEP, 2004). The river flows from Bolivian headwaters to the plains of northern Argentina, where it joins the Parana-Paraguay-La Plata River system (Fig.5). The Basin has a rich diversity of habitats and 1.3 million people reside in it (OAS, 2010). However, it also has very high erosion rates and sediment transportation rates which have imposed negative impacts on aquatic ecosystems, wetland corridors and economic activities (OAS, 2000). In other words, a number of ecosystem services benefiting the residents are reduced. These benefits include not only water quality, water availability, flood regulation with tangible values, but also "cultural services" that provide recreational, aesthetic, and spiritual benefits, and "supporting services" such as soil formation, photosynthesis, and nutrient cycling the values of which are beyond measurement (MEA, 2005).

While both Argentina and Bolivia had some monitoring and management programs in place, there was no overall view/picture of the basin as a whole. In the Transboundary Diagnostic Analysis, initial challenges included different mapping scales used by each country, different national soil names used for various/shared soil groups in each country, and a lack of data and information sharing platforms. A key first step in implementing a Strategic Action Program was developing a common understanding of the river basin and river system. For the first time, a shared Geographic Information System platform was created and basic physical properties of the basin were presented on the basin scale: hydrology, rainfall, soils, vegetation, land uses etc. (OAS, 2000). These were published as technical papers by the project staff and summarised in the Transboundary Diagnostic Analysis and "translated" to share with various stakeholders. In terms of WAKES, an information transformation translating Scientific Knowledge into Public Information was realized (Eq.8). This transformation identified potential land management activities at various locations of the Basin to enhance the ecosystem functions in generating improved ecosystem services (Eq.5).

In the upper portion of the Basin, NGOs were an essential facilitator/intermediary in conveying the need for pasture management to the citizenry. It was *Vida Verde*, or "Green Life", who acted as the "face" of the project in establishing the outreach program that led to fencing, rotation of animals between paddocks, and the vegetable gardening projects which were subsequently adopted by local farmers. With this success, the Tarija municipality was motivated to do the "heavy lifting" associated with the placement of erosion control Best Management Practices: gabion

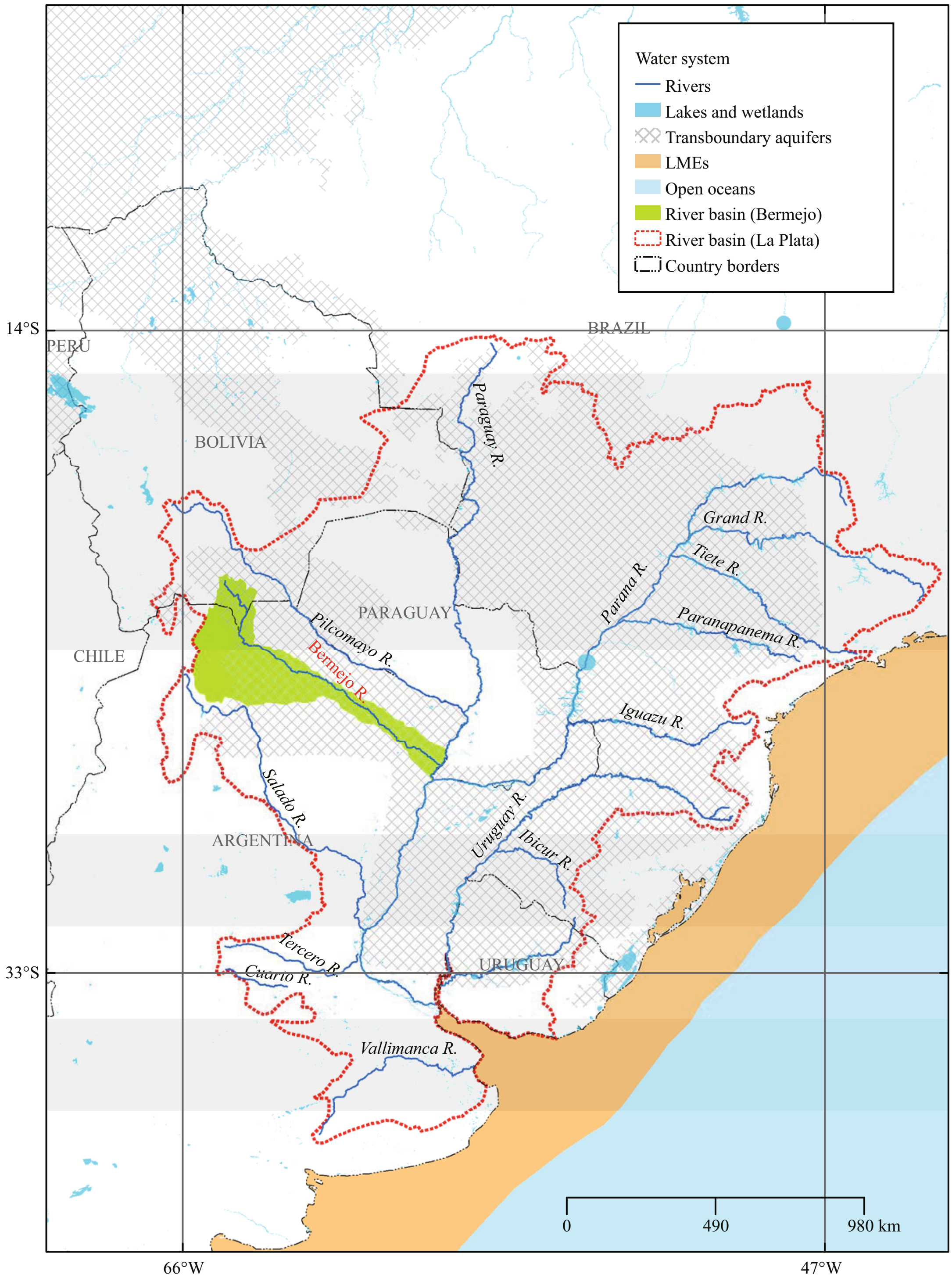

Fig.5 The location of Bermejo River in the La Plata River system

LME: large marine ecosystem.

walls, earth dams, etc. By blending the outcomes of both activities, individual citizens made use of the standing water behind the dams to water vegetable gardens. While the intent of the technical project was to reduce soil loss, the effective communication and coordination among stakeholders has led to broader results including improved public health as a result of the regular addition of vegetables to the community diet, and community income from selling surplus farming products as a result of fencing and vegetable gardening efforts. In terms of WAKES, two information transformations were realized simultaneously which generated a mutually reinforcing effect on each other. Specifically, Public Perception was incorporated into Political Will (Eq.9). In addition, Scientific Knowledge, Public Perception and Political Will were integrated into Management Options (Eq.10). These land management activities provided not only indirect benefits to downstream resource users through enhancing the ecosystem functions of erosion control, flood regulation, and habitat protection, but also direct economic benefits to the land managers upstream (Eq.6).

In the middle portion of the Basin, a university was the principal facilitator/intermediary. Two professors of the university endeavored to change a "slash and burn" subsistence-level community into a new community with more sustainable lifestyles. The professors and the one volunteer built a terrace, historically an agricultural technique utilized by the indigenous community. On these terraces, they planted fruit trees that were specially chosen so as to produce fruit before the onset of the annual floods—this enabled the farmer to produce, transport and sell his products in the town of Bermejo, located on the far side of the river from the project site. The farmer's success, and subsequent affluence, resulted in many copycat projects, limiting the denudation of the steep hillsides and reducing soil loss, which was the desired outcome of the project. However, there were also additional spin-offs: the demand for fruit tree seedlings, for example, resulted in the municipality starting a nursery garden to produce the desired trees and later plants. The province too created a revolving loan fund that allowed participants to obtain 200 pesos for development of allied economic activities. For example, the initial participant used the funds to buy chickens, whose manure together with the leaves shed seasonally from the fruit trees created a compost that allowed the farmer to grow vegetables in between the rows of fruit trees. Ultimately, this individual had made enough money to buy an automobile, which helped him to transport his goods to the market. Other community members followed suit, in terracing, etc., which stabilised the soils, while yet other community members developed aquaculture, handicrafts producing wood products sold in the nearby national park, and other economic activities well beyond the original terracing project. Overall, the professors' efforts have catalyzed a chain of reactions, resulting in active and diverse exchanges, trust building, and partnership development among the farmers, the government, and the local scientists. A more sustainable lifestyle has been established, with reduced transaction costs and formation of local markets. In terms of WAKES, their efforts have succeeded in generating a positive feedback mechanism among Scientific Knowledge, Public Perception, Political Will and Management Options (Fig.3g; Eqs.8–10). Moreover, as more and more upstream and downstream stakeholders (both horizontally and vertically) exchange with each other, their trust in each other increases, and the "invisible organizing boundary" for sustainable ecosystem management is created (Eq.7).

4 CONCLUDING DISCUSSION

The feedback structure of WAKES establishes an adaptive knowledge architecture to catalyze information transformations for developing sustainable partnerships for ecosystem management. WAKES is constructed based on a systematic integration of important findings from previous studies and practices in integrated ecosystem management. It is featured with a central idea of visualizing how institutional arrangements both could be affected by and affect the institutional environment (Davis and North, 1971; Williamson, 1998; Klein, 1999). In WAKES, the institutional arrangements are reflected as management options, whereas the institutional environment is reflected as scientific knowledge, public perceptions, and political will. WAKES is envisioned with a calling to all ecosystem stakeholders in collectively making a crucial step toward global sustainable development – developing sustainable stakeholder partnerships, making a delightful future.

5 ACKNOWLEDGEMENT

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