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# Integrated evaluation of Ecosystem Services in Prawn-Rice rotational crops, Vietnam

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ABSTRACT

The hydrologic condition in Kien Giang province on the west coast of Vietnam's Mekong Delta is unique in the sense that it has extensive saline water intrusion during the dry season every year. Instead of a triple crop scheme like other areas in the Delta, a prawn and rice rotational cultivation scheme was initiated to facilitate agricultural production in Kien Giang. In this paper, the ecosystem services (ES) generated from the agriculture ecosystem under the prawn and rice rotational crops (PRRC) were assessed using an integrated approach. The specific ES identified here include water and nutrition regulation in the soil together with climate regulation in favor of the cultivated crops. A multi-disciplinary approach including remote sensing, GIS, social surveys and statistical analysis was adopted to comprehensively evaluate the geographical, biophysical, economic and social aspects of the ES. Firstly, Landsat 8 images were processed with Normalized Difference Vegetation Index (NVDI) and Modified Normalized Difference Water Index (MNDWI) to identify the areas cultivating PRRC. The accuracy of image classification was assessed by ground truthing and we found an 80% coincidence between the simulated results and the field observations. Then, the social survey was conducted using face to face interviews at 50 local households to collect data related to farming practices. Economic values of ecosystem services were obtained using the revised market methods by annual crop yields per unit area. The mean estimated value of ES provided through the PRRC was 1300 USD/ha/year (standard deviation of 600 USD/ha/year) which accounted for 38.1% and 59.4% of the averaged economic revenue and net benefit, respectively. The analysis of social survey data revealed the factors having the greatest effects on ecosystem services values were selling prices of prawn and farming experiences. Finally, results were synthesized with GIS to describe how ES values vary across the research area which facilitates effective communication of the importance of ES concepts to policy makers regarding land use planning and natural resources management decisions.



## 1. Introduction

A number of definitions for ES can be found in the literature (Hayha et al., 2015) of which three are commonly cited:

- the conditions and processes through which natural ecosystems and the species that make them up, sustain and fulfill human life (Daily, 1997),
- the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al., 1997),
- Or more concisely, the benefits people obtain from ecosystems (MA, 2005).

In spite of different terms and notions, these definitions share a common ground: human well-being depends on the continued provision of ES in many ways. Therefore, these services should bear some economic value. It is the emphasis on welfare and human well-being that sets the need for economic valuation which must be coupled with biophysical analysis (Boyd and Banzhaf, 2007). The ultimate goals of valuation practices must not entirely be putting price tags on goods and services provided by nature. Rather, such efforts also must be done to realize pathways to bring the pedagogical concept of ES from the academic arena to reach the government policy agenda. More explicitly, Liu et al., (2010)

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pointed out at least three specific objectives of ES valuation are to (1) assess and ensure the ecological sustainability of human activities within the biosphere, (2) distribute resources fairly taking into consideration the links between generations, between humankind, and the environment; and (3) efficiently allocate natural resources.

Guided by such goals, a number of valuation frameworks have been developed of which TEEB's *Total Economic Value* (TEV) one of the most is commonly applied. Using standard accounting units (such as money), TEV can facilitate the comparison between ES and conventional services. There are three clearly differentiated valuation approaches in this framework: (1) revealed preference; (2) cost-based; and (3) stated preference. These different economic techniques are adopted to handle ES with contrasting characteristics. For instance, the *market price method*, which is an example of the revealed preference approach, is widely used for those services with real markets such as crops, livestock or forestry products. Conversely, for others without well established markets such as cultural or spiritual values of landscapes, stated preference methods such as contingent valuation methods are more appropriate. These two techniques as well as related methods have strengths, weaknesses as well as their specific validity. Nevertheless, yet another methodological review is not the intent of this paper because such reviews are readily available (*e.g.* Farber et al., 2002; Freeman et al., 2003; Hadley et al., 2011; Atkinson et al., 2012). Rather, this paper looks at how to overcome some of the challenges faced in applying ES through the use of an integrated socio-economic/biophysical visualization and statistical approach.

Along with the dramatic increase in the number of ecosystem valuation publications such as Environment Valuation Reference Inventory (Liu et al., 2010), mapping of ES values also constitutes a fast growing body of literature, especially with the advancement of GIS and other earth observation techniques. How natural benefits vary across a geographical area has become one of the most active topics in the environmental research agenda (Troy and Wilson, 2006). Attempts have been made to map the use values of timber production, carbon sequestration and natural hazard protection (Seidl et al., 2007; Teich and Bebi, 2009) as well as non-use values such as cultural, educational or spiritual services (Fagerholm and Kayhko, 2009; Fagerholm et al., 2012; van Berkel and Verburg, 2014). The additional geographical dimension of *where* has the potential of improving the comprehensibility of ES values in supporting land use decisions (Nahuelhual et al., 2015).

The objectives of this article are to analyze how economic values of ES can be calculated and mapped at the district scale, focusing on the PRRC areas of the An Minh district, Vietnam and to examine how applying ES valuation framework can improve land use planning decisions. The PRRC scheme includes rice and prawn crops periodically cultivated within the course of a year in accordance with the specific hydrologic conditions, in particular saline concentration. The research was initiated with the acquisition and processing of Landsat 8 data to identify the PRRC areas in An Minh District. The validation of land cover classification was controlled by ground truth points. Secondly, within the framed ecosystem of PRRC we consider all the ES contributing to crop yield. The services include, but are not limited to, water and nutrition supply, nutrient cycling, hydrologic regulation, and pest control. Each of these, individually, does not appear in any well-established markets for purchase or exchange. But as a bundle, they contribute to the generation of rice and prawn crops which are marketable. Therefore, a common value for all the associated ES is assigned and reflected partially in the total crop revenues. This is the prerequisite to apply the direct market price methods. Ubiquitously 100% of the crop revenues have been used as the proxy to evaluate agriculture related ES (Sumarga and Hein, 2014; Hayha et al., 2015). However, this assumption is prone to overestimation because it neglects the human participation through capital and labor. Furthermore, in the context of agricultural ecosystem, anthropogenic contributions do not only bear economic significance but social values as well, such as family and communal tillage experience. Clearly, direct market price methods are not originally designed to handle these values. This shortcoming raises questions about the validity of the market approach in valuing ES.

To overcome the challenge, we first subtract the total crop revenues by associated costs to account for the human contributions which, in turn, makes the economic values of ES better estimated (TEEB, 2010; EC, 2013). Information about these costs were collected through face to face interviews. Secondly, these costs were further analyzed to uncover the underlying socio-economic relationships associated with the local context. This analytical framework constitutes a *modified market approach,* in which we strive to integrate new ways to understand and appropriately evaluate ES and thereby make it a more comprehensive, yet practical decision-making tool, particularly for planning practitioners. Our analytical framework highlights both the biophysical performance and social integrity of ES and in this way addresses the nature-social dualism that often is a barrier to effective environment management. Our results were synthesized in thematic maps for better visualization and communication with stakeholders to re-evaluate the current land use planning and to shed useful light on challenges in both natural suitability and social integrity.

## 2. Material and methods

### 2.1. The research area

Kien Giang is a province of Vietnam, located on the southwestern side of the Mekong Delta, with the provincial capital being Rach Gia city. The total area is about 6299 $km^2$ of which 66% of the natural area is agricultural. The population is about 1,634,043, of which 22% live in the urban area. The research area is An Minh district, located on the west coast of the province. The district is bordered by An Bien district in the North, U Minh Thuong district in the East and the West Sea in the west, with 37 km of coast line. The district consists of 11 communes (smaller administration units under districts) with the total area of 59,000 ha. Fig. 1 shows the location of the research area with the identification of Kien Giang within Vietnam's Mekong Delta.

An Minh district was chosen for this research due to its large cultivated area as well as its high productivity of PRRC (BCS, 2015). Historically, rice is the predominant crop of Kien Giang province. However, due to its unique hydrologic conditions with periodic salinity intrusion during dry seasons, the productivity and values of rice crops are heavily affected, especially for coastal areas such as the An Minh district. The situation has become even worse in recent years due to climate change impacts which were mainly storm surges and salinity intrusion (Vietnam National Mekong River Commission, 2011). Recently, the provincial government has initiated several measures to cope with this situation, one of which is the shifting from a rice intense tillage scheme to PRRC.[1] The concept behind this rotation is to combine crops with different water requirements and salinity adaptability to cut down on land idle time and to increase crop yields in the course of a year.

[1] PRRC was discovered by chance in Ca Mau Province when farmers found brackish water prawns in their fields after harvesting the rice crops. The prawns are believed to have followed the irrigation stream to enter the fields.

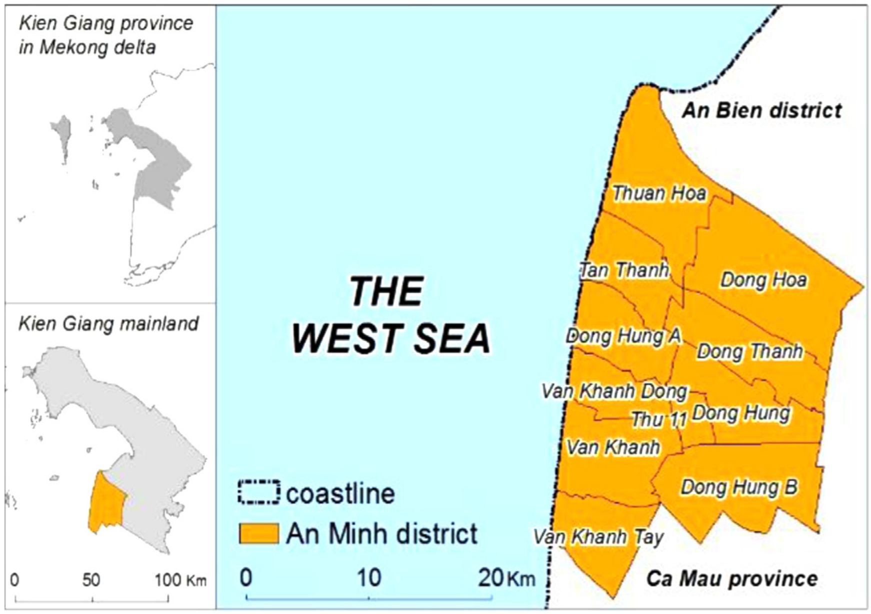


**Fig. 1.** An Minh district location.

### 2.2. Remote sensing and GIS

The first task of this research was to identify the areas of PRRC in An Minh district *via* remote sensing. Landsat 8 images with 30 m × 30 m resolution taken on 25/11/2013, 27/12/2013, 24/08/2014 and 21/04/2015 (cloud ratios: 17.73%, 0.16%, 39.07% and 2.21%, respectively) were acquired from the United States Geographical Science (USGS) website. The chosen dates correspond with the cultivating time of respective crops.[2]

Firstly, we filtered the images using the median method to screen random noise and outliers. Then, pre-processing imagery analysis was conducted by calculating the *Normalized Difference Vegetation Index* (NDVI) and the *Modified Normalized Difference Water Index* (MNDWI) to identify vegetated areas and water bodies in the research area (Farrar and Nicholson, 1994; Xu, 2006).

Next, image supervised classification was conducted using a Maximum Likelihood algorithm with the creation of training sample objects. These sample objects were created based on empirical classification indicators: colors, shapes, patterns, size, location and typical characteristics combined with field survey results. Finally, we overlaid the classified images to produce a comprehensive land cover map of the research area. Image classification results were validated using global accuracy and Kappa indexes (Congalton, 1991).

### 2.3. Field survey and household interviews

The field survey had two objectives: to verify (ground truth) remote sensing analysis results and to gather information regarding farming activities which are related costs, crops selection *etc.* as well as respondents' social and demographic characteristics. A total of 50 households were surveyed *via* face to face interviews using semi-structured questionnaires. The households were purposely chosen based on their tillage practices in recent years. Hence, the surveyed respondents consisted of those with certain experience (at least 5 years) with PRRC which cover all 11 communes throughout the landscape of the An Minh district. The interviews started with an introduction about ecosystem and ecosystem services as well as the purpose of the research. Respondents were then asked about basic demographic characteristics *i.e.* names, genders, age, education *etc.* The next section of the questionnaire examined issues of PRRC such as agricultural calendars, seed selection, and schedule for each crop. Finally, the associated costs (fixed and variable) as well as averaged yields and benefits in recent years were discussed. Each interview took approximately 40–50 min.

### 2.4. Integrated evaluation methods

#### 2.4.1. Biophysical and economic valuation

In this paper, we focus on the ES that are associated with PRRC. These services include but are not limited to provisioning services: water and nutrition; regulating services: nutrition circulation, and climatic regulation. These conditions combined with proper farming activities could generate crop yields which are direct benefits for society. Because of the absence of real markets for these services and the desire to avoid double counting during the calculation processes, we used the proxy of annual crop yields per unit area to represent the biophysical units of incorporated ES mentioned above. Subsequently, we calculated the economic values *via* resource rent method (European Commission, 2013). One recent study also used a similar approach to calculate multiple services in the agriculture ecosystem of Central Kalimantan province, Indonesia (Sumarga et al., 2015). The economic values of ES are calculated using:

$$RR = TR - (FC + VC + OC) \quad (1)$$

where RR=Resource Rent, TR=total revenue from crops, FC=Fixed costs, VC=Variable costs, OC=opportunity costs. These costs are further discussed in Section 3.3.

#### 2.4.2. Data analysis

The novelty of this paper is that we not only calculated the biophysical and economic values and visually display them on GIS maps (Burkhard et al., 2011; Remme et al., 2014; Costanza et al., 1997; de Groot et al., 2012) but also looked at the relationships between these components and the social-demographic

[2] The rice crop usually starts from November until February depending on hydro-meteorological conditions to utilize storm water for irrigation and desalination. The prawn crop starts from February until November to cope with dry weather and salinity intrusion (field survey).

background of respondents. This approach has been applied to investigate cultural and spiritual services of landscape (Chan et al., 2012; Martin-Lopez et al., 2012; Ryan, 2011). Willingness to pay for landscape ES was also explored using a similar approach (Loomis et al., 2000).

At first, the social-demographic characteristics *i.e.* age, gender, education were categorized into absolute values and proportions. Further, we factor analysis methods to detect and represent the underlying pattern of these attributes and associated costs in PRRC.

For better clarification, we first categorized information gathered into two sub-groups of variables: qualitative and quantitative. The first group, which describes the social characteristics of respondents, consists of experience, age, education, location, selected crop seeds and cultivation calendar. This group consists of both continuous and categorical variables, therefore was handled using factor analysis for mixed data (FAMD) (Le et al., 2008; Husson et al., 2015).

The latter which consists of 9 variables (3 different types of costs, productivity of two crops, cultivated area, market prices of crops and extra revenue from bi-products) representing the economic aspects of PRRC, all of which are continuous variables and thus was analyzed using principal component analysis (PCA). The bi-products consist of straw or leftovers of crops that could be used as supplementary food for farm animals. The sample verification of data was conducted *via* significant values in Bartlett's test for Homogeneity of Variances (Bartlett, 1937) and Kaiser-Meyer-Okin Measure of Sampling Adequacy (Tabachnik and Fidell, 2001). In order to confirm the adequacy of the principal components generated, we followed the Kaiser Criterion (Hair et al., 1998).

Finally, to identify possible bundles of individuals sharing similar patterns, we performed hierarchical cluster analysis (HCA) through Euclidean distance and Ward's agglomerative methods using the coordinates of the two most significant principal components respectively. All of the aforementioned analyses were conducted using FactomineR (Le et al., 2008; Husson et al., 2015; R Core Team, 2015).

## 3. Results

### 3.1. Satellite images processing

Landsat 8 images were obtained from the USGS website (http://landsat.usgs.gov/). Fig. 2 shows one image in its primary form. The area of An Minh district was extracted from the original image pre-processed by NDVI and MNDWI. These indicators were acquired by synthesizing the reflectance spectra of different color channels of the satellite images.

In particular, to obtain NDVI values, the integration of reflectance spectra values of near infrared and red channels was conducted. The higher this index, the denser the vegetated area. Similarly, reflectance spectra values of near infrared and green channels were combined to generate MNDWI values. Higher values of MNDWI index signify deeper water (Parida et al., 2008; Xu, 2006). Therefore, NDVI and MNDWI were used to identify vegetated areas such as forests, paddy fields and water bodies such as rivers, canals, and aquaculture fields throughout the landscape.

In the An Minh district, because of the rotation between rice and prawn crops, the corresponding land cover classes would also be periodically shifted between vegetation and waterbodies, which accordingly presents a challenge to distinguish PRRC from other land covers. To work around, NDVI and MNDWI value maps for multi-temporal imagery were generated. Fig. 3(a) and (b) shows results of NDVI and MNDWI on Nov/25/2013 and Aug/24/2014 images respectively.

We noticed there are certain locations on the east side of the research area for which the values of the indices differ between the two periods of each image. More specifically, the NDVI values for these areas are higher in the November image than in the August image and *vice versa* for MNDWI values. This difference is relevant with the changes in land cover of PRRC which gives an essential key to classify PRRC among other vegetation areas such as paddy fields, forests and water bodies such as aquaculture or rivers for which the indices remain unchanged.

Sample objects were then created to train ArcGIS to distinguish between different land cover types. Conducting supervised image classification using the Maximum Likelihood algorithm, the maps of each period in Nov 2013 and August 2014 were created with

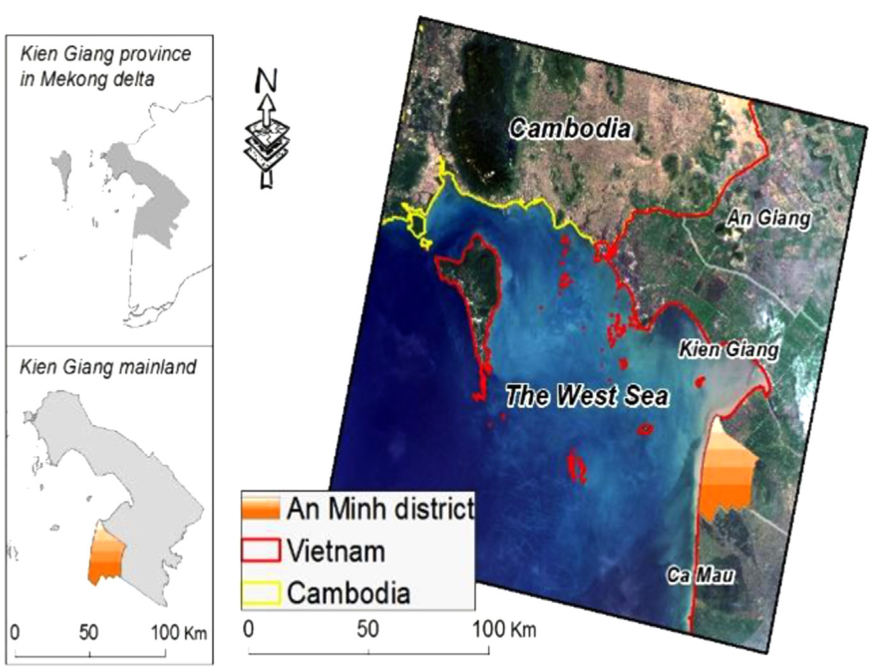


**Fig. 2.** Landsat 8 image from USGS website. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

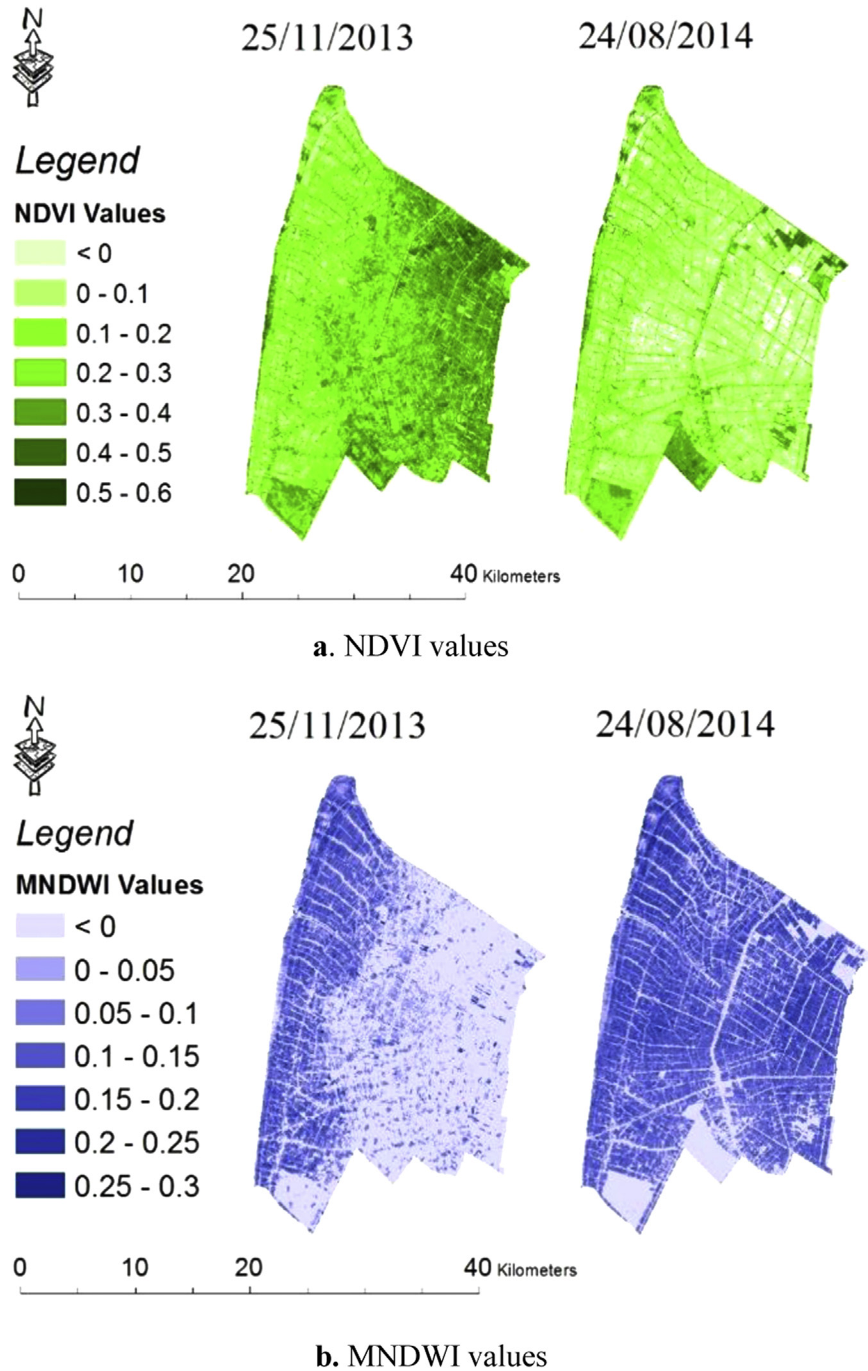


**Fig. 3.** a. NDVI values. b. MNDWI values.

identified land covers throughout the research landscape. Shown in Fig. 4 is the classification results of Nov/25/2013 and Aug/24/2014 images.

PRRC is generally recognized as areas with different land cover types between two images. In the November image, PRRC areas are classified as *Paddy fields* whereas in August they are classified as *Aquaculture*. The four classified images were overlaid to generate the overall land cover map of the An Minh district. Classification validity was confirmed *via* field surveys and observations with GPS handheld devices to accurately geo-reference the sites. This was done alongside interviews with the farmers to collect data for farming practices, the results of which will be discussed in Section 3.2. Shown in Fig. 5 is the final land cover map and the locations of our field observation sites.

In total, we conducted field observation at 50 locations with different land cover types. Global accuracy of this test was 86% with a Kappa index of 0.72. For PRRC, specifically, these values were 92.59% and 0.85, respectively. Shown in Fig. 6 is the map of PRRC areas identified in the An Minh district.

Within the research area, Dong Hoa is the commune with the largest PRRC area with 6667.28 ha which accounts for 26.58% of the total PRRC area of the An Minh district. The second and third largest PRRC areas are located in Dong Thanh and Dong Hung B with 4382.3 and 4369.64 ha, respectively. Each commune accounts for approximately 17% of the total PPRC area. Conversely, the smallest identified area lies in Van Khanh Tay commune with 457.49 ha that accounts for 1.82% of the total PRRC area.

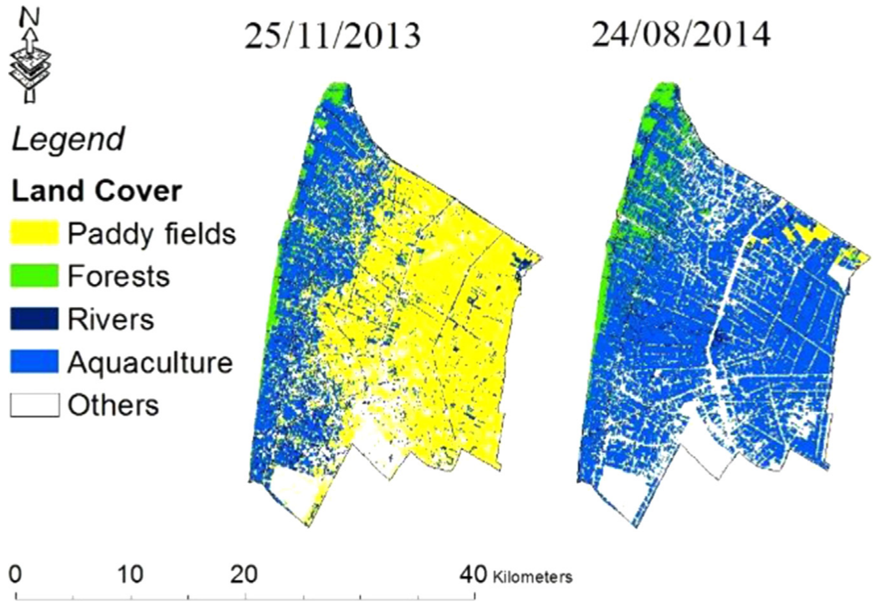


**Fig. 4.** Supervised-classification results.

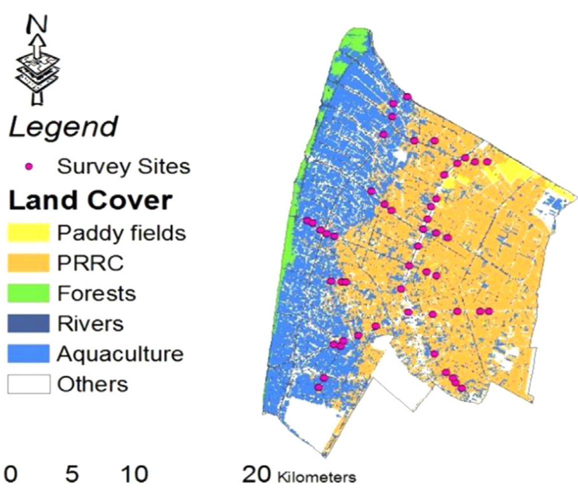


**Fig. 5.** Land cover maps and observation location.

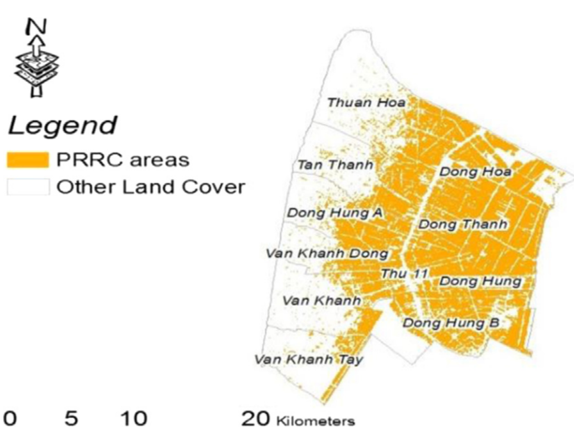


**Fig. 6.** PRRC areas.

### 3.2. Characteristics of respondents

The survey was completed with 50 interviews covering all 11 communes. 7 respondents were female which accounted for 14% of the sample. This is in line with the predominant number of men participating in the agriculture labor force. The average age is 46 and the majority of individuals are from 40 to 49 that accounts for 34%.

In terms of cultivation experience, those living on the west side of An Minh district are likely to be more experienced with PRRC (10–19 years). This group accounted for 36% of the respondents. However, the majority of respondents had less experience (5–10 years) and had just adopted the PRRC model, following the land use policy of the government. Previously, they had been cultivating double rice crops and other kinds of vegetation crops. Regarding educational background, 48% of respondents were either illiterate or had an elementary level education, while 3 respondents had a high school level education, and only one respondent had been professionally trained about aquaculture.

### 3.3. Biophysical and economic indicators

Crop yields were used as appropriate proxies to indicate biophysical units for ES evaluation (Hayha et al., 2015; Sumarga et al., 2015). The data on crop yields were converted into unit productivity per hectare for standardization. The first four columns of Table 1 shows the crop yields as well as averaged selling prices of each crop. The highest productivity of rice crop was 4630 kg/ha in Dong Hoa commune and 4078 kg/ha in Dong Hung. Regarding prawn crops, these figures were 347 kg/ha in Thuan Hoa and 337 kg/ha in Dong Hung B. The values in the table are averaged from the questionnaires and shown according to respective communes. Information regarding yields and costs are collected from the interviews. Comparison with market prices will be difficult for various reasons such as: the type of seed used, the size of the prawn batch and market price fluctuations as well. Moreover, the prices also depend on if farmers sell their crops to state-owned factories or to individual dealers such as restaurants. These factors would call for a much more intensive economic research which is beyond the manuscript scope.

The Fixed Costs (FC) are the long term investments consisting of canals and ponds dredging cost, machines (tractors) purchase, irrigation system installation. The Variable Costs (VC) are associated with seasonal expenses such as crop seeds, labor, fertilizers, and pesticides. The Opportunity Cost (OC) is defined as the

**Table 1**
Economic values of ES in USD.

| Commune | Crop Yields ($10^2$ kg/ha/year) | | Selling Prices (USD/$10^2$ kg) | | Associated Costs (USD/ha/year) | | | | Economic values of ES (USD/ha/year) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rice | Prawn | Rice | Prawn | FC[1] | VC[1] | OC[1] | Total | Min | Max | Mean |
| Dong Hoa | 46.30 | 3.01 | 23.27 | 880.68 | 69.13 | 1164.24 | 887.78 | 2121.16 | 761.13 | 1179.55 | 923.22 |
| Dong Hung | 40.78 | 2.75 | 22.77 | 844.15 | 79.86 | 1483.14 | 776.62 | 2339.62 | 200.08 | 2529.27 | 917.42 |
| Dong Hung A | 20.06 | 2.34 | 22.27 | 800 | 82.92 | 1205.02 | 771.6 | 2059.54 | 412.68 | 1946.94 | 1136.5 |
| Dong Hung B | 35.8 | 3.37 | 21.55 | 781.82 | 73.55 | 1213.66 | 754.07 | 2041.28 | 147.36 | 1432.8 | 1022.23 |
| Dong Thanh | 32.7 | 3.31 | 24.59 | 786.36 | 67.73 | 818.43 | 789.14 | 1675.3 | 269.48 | 1562.84 | 900.99 |
| Tan Thanh | 34.98 | 3.13 | 20.36 | 787.88 | 76.38 | 972.46 | 789.14 | 1837.98 | 1005.1 | 1956.73 | 1490.48 |
| Thu 11 | 38.58 | 2.06 | 23.41 | 988.64 | 91.28 | 1166.34 | 745.3 | 2002.92 | 733.16 | 1210.53 | 971.85 |
| Thuan Hoa | 34.89 | 3.47 | 22.45 | 836.36 | 101.5 | 994.6 | 824.21 | 1920.32 | 749.02 | 2852.07 | 1542.89 |
| Van Khanh | 17.13 | 3.3 | 23.18 | 881.82 | 93.86 | 1006.12 | 736.53 | 1836.52 | 957.82 | 2691.41 | 1487.26 |
| Van Khanh Dong | 30.86 | 2.53 | 24.64 | 893.94 | 79.4 | 909.91 | 818.37 | 1807.68 | 1453.79 | 2883.09 | 2006.7 |
| Van Khanh Tay | 13.89 | 3.32 | 22.73 | 863.63 | 121.71 | 1294.65 | 876.82 | 2293.19 | 193.18 | 1884.3 | 1038.74 |

Values in table have been converted into US dollars (USD) from Vietnam dong (VND).
1 USD∼22,000 VND.
[a] FC=fixed costs, VC=variable costs, OC=opportunity cost.

foregone benefits, which was estimated by the average land rental cost of the respective areas. The introduction of OC was to evaluate the capacity of the ecosystem in supporting a substantial livelihood compared to income from land leasing. Columns 5 through 8 in Table 1 shows the mean values of these costs in each commune. In general, VC accounts the largest portion, followed by OC and FC. Regarding the communes, Dong Hung had the highest total cost (2339.62 USD/ha/year) whereas Dong Thanh had the lowest cost (1675 USD/ha/year).

With respect to FC, Van Khanh Tay had the highest value (121 USD/ha/year) and Dong Thanh had the lowest (67.73 USD/ha/year). Regarding variable costs, Dong Thanh also had the lowest value (818.43 USD/ha/year) whereas Dong Hung respondents spent the most (1483.14 USD /ha/year). Last but not least, Dong Hoa had the highest land rent (887.78 USD/ha/year) whereas Thu 11 was the cheapest location to rent PRRC land (745.3 USD/ha/year).

The total revenues (TR) value in Eq. (1) is the summation of the multiplication of each crop yield by their respective selling prices. Finally, ES economic values are obtained by subtracting total revenues with the total costs. The last 3 columns in Table 1 display the minimum, maximum and mean values of ES economic values of which units were also converted into USD/ha/year.

The averaged economic values of ES reflected by resource rent values (RR) in 11 communes is 1183 USD/ha/year. Among the communes, Van Khanh Dong and Thuan Hoa communes had the highest ES values being 2007 and 1542 USD/ha/year. The lowest value of ES was approximately 901 USD/ha/year found at Dong Thanh commune.

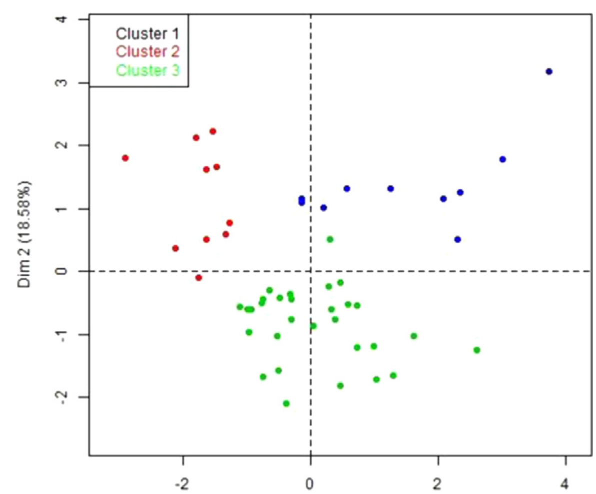

**Fig. 8.** Factor Map for qualitative variables.

### 3.4. Spatial distribution

Rice yields were higher in the east side of the study area and *vice versa* for prawn yields. More specifically, communes with the

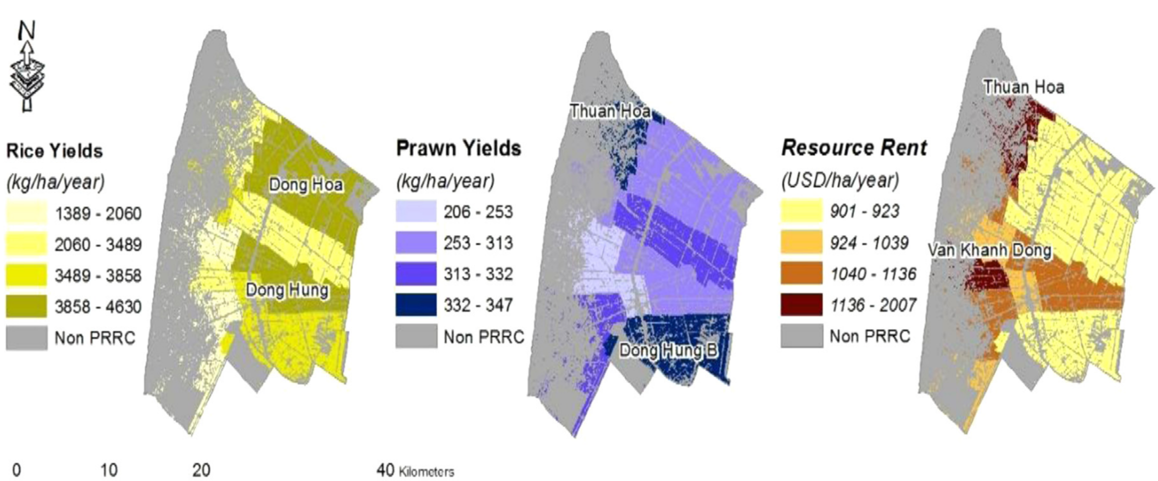

**Fig. 7.** Spatial distribution of crop yields and resource rent.

**Table 2**
Qualitative PCA Representatives.

| Cluster | Age | Edu[a] | Exp[b] | Seed[c] | Calendar[d] | Loc |
|---|---|---|---|---|---|---|
| 1 | 38 | Sec | 15 | MBD | 2nd | Coast |
| 2 | 62 | Pri | 30 | Others | 1st | In-land |
| 3 | 54 | Hig | 20 | MBD | 1st | Coast |

[a] Edu = education level, Pri = Primary, Sec = Secondary, Hig = high school and above.
[b] Exp = cultivation experience.
[c] MBD are codenames of the most popular rice seeds.
[d] The 1st cultivation calendar usually starts from October and the 2nd one starts from November every year. The selection of calendar relies on experience and sowing plan of farmers.

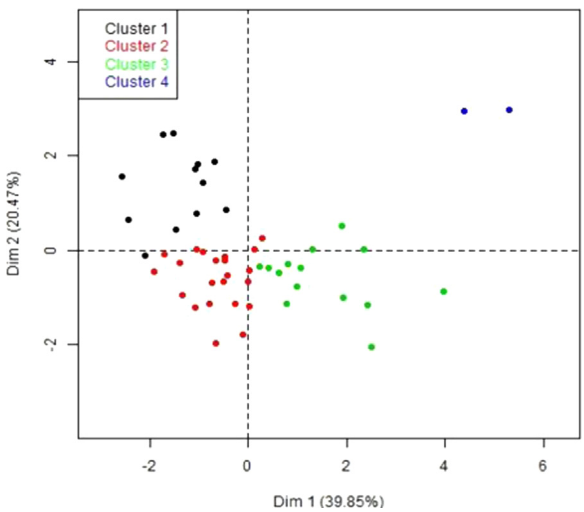


**Fig. 9.** Factor map for quantitative variables.

**Table 3**
Quantitative PCA Representatives.

| Cluster | RY | PY | FC | VC | ER | PP | Area[1] |
|---|---|---|---|---|---|---|---|
| 1 | 46.3 | 2.89 | 119 | 1300 | 0 | 9 | 10,368 |
| 2 | 23.15 | 2.89 | 82 | 1048 | 0 | 8 | 15,552 |
| 3 | 31.72 | 2.74 | 60 | 707 | 0 | 8 | 23,328 |
| 4 | 54.01 | 1.54 | 62 | 1021 | 1500 | 12 | 25,920 |

RY = rice yield, PY = prawn yield, FC = fixed costs, VC = variable costs, ER = extra revenues from bi-products, PP = prawn price.
[1] Area = area under PRRC in square meters.

highest rice yields were Dong Hoa and Dong Hung with 46 and 40 t/ha/year. With respect to prawn production, Thuan Hoa and Dong Hung B had the highest annual yields with 347 and 337 kg/ha. These differences partially reflect the hydrologic conditions variations between sites (Fig. 7).

Regarding the farming expenditures, the highest values were distributed in the southeastern communes, in particular Thu 11 and Dong Hung B had the highest figures for total costs. This trend relates to the cultivation experience dissimilarities, especially with prawn crops throughout the landscape. In fact, one of the respondents shared his thoughts about PRRC application. His family had been cultivating rice for generations but he had shifted to PRRC 10 years ago following the government policies although he had been reluctant. This incident motivated us to explore social attributes of the local community and the relationships with farming practices.

With respect to the resource rent representing economic values of ES, its distribution is more correlated with the prawn yields spatial pattern than that of rice crops. Notwithstanding, Dong Hung B is one exception where despite having high prawn yields the commune can generate relatively low ES economic values. This is because of the highest cost incurred during the cultivation practice. All of these dissimilarities signify the imbalance between rice and crops with respect to associated costs, selling prices, and also the social preferences in the local context of the An Minh district.

### 3.5. *Factors and bundles analyses*

Initially, we considered all the variables from the collected information from the interviews. Following Kaiser's criterion, the number of variables decreased to 6 qualitative variables and 7 quantitative variables. For qualitative variables, the first three factors accounted for 58.59% of the variance. The first factor (23.88% of the variance) was explained by the socio-demographic characteristics of respondents' *i.e.* age, education and years of farming experience. The second factor (18.58% of variance) represents the cultivation practice of respondents through the selection of crops and calendar. The last component which contributes 16.12% of extracted variance is explained by the locations. Then a new coordinate system was sketched using two factors/principal components. All data points/individuals were projected into this new coordinate system constituting the *factor map*. From Fig. 8 data points with similar characteristics are grouped into separate clusters using HCA. The decision on the number of clusters are decided by the Ward's criterion (Husson et al., 2010).

Points (individuals) that are closest to the barycenter of each clusters clouds are chosen as representatives (Table 2).

Among 3 clusters of data in Fig. 8, group 1 was characterized with the youngest age and experience, prefer the 2nd cultivation calendar and MBD rice seed. People with the highest experience, age and lowest education level fall into group 2. This group prefers other seeds and the 1st calendar. Middle aged people with moderate education level that prefer the 2nd cultivation calendar and prefer MBD seed belong to group 3. Cluster 2 represents in-land communes whereas 1 and 3 represent coastline ones.

Regarding PCA for quantitative variables, the first two factors cover 60.32% of data variance. The first factor which accounts for 39.85% of inertia is contributed by cultivated area, prawn productivity, fixed costs, and extra revenue from the selling of bi-products. The second axis which accounted for 20.47% of inertia is explained by the rice productivity, variable costs, and market price of prawn. Shown in Fig. 9 is the factor map for the HCA applied for quantitative variables.

Similar to the qualitative factor map, barycenter closest points (individuals) are chosen as cluster representatives (Table 3).

Cluster 4 was the most outstanding with extra revenue from bi-products. The bi-product for this household is mainly straw for which the amount is relevant with rice crop yields and cultivated areas. This group also had the largest RY, area and PP whereas prawn yield and FC were the lowest.

Clusters 1 through 3 share similar patterns in prawn yield. None of these had extra revenue. Cluster 1 was characterized with higher rice yield and associated costs but also with the smallest area. Cluster 2 had the 2nd smallest figures in fixed costs and areas. Cluster 3 had the smallest figure for variable costs yet the 2nd largest cultivated areas. Of the 3 observations chosen, cluster 1's representative had the highest ES values, followed by group 3's and group 2's. Group 4's had the smallest ES values.

By synthesizing the results of the principal components above, we made an effort to describe the most typical tendencies of high ES values in terms of socio-economic background and tilling practice. More specifically, regarding social attributes, those who are middle age, with 10–19 years of farming experience and have a medium level of education are more likely to have higher ES values. With respect to economic aspects, ES values tend to be higher for those who can meet the following conditions: keeping the costs reasonably low, having higher yields for smaller areas, having higher selling prices for prawn yields.

There are, nevertheless, cases which are not in accordance with our detected pattern because 100% of the data variance cannot be captured and explained by only two principal components. In fact, there are other circumstances such as disease, natural disasters such as floods or droughts (which were not included in the scope of this paper), which could have been responsible for the dissimilarities from the main trend.

## 4. Discussion

### 4.1. Implications of remote sensing applications

Remote sensing, GIS and earth observation techniques have been utilized in ES studies. These techniques are employed from identifying sub-areas of interest using image classification algorithms, and visualizing tools to effectively display the spatial pattern of ES (Hayha et al., 2015; Sumarga and Hein, 2014; Tuan et al., 2015; Plieninger et al., 2013; Kuenzer and Tuan, 2013). In this research, we demonstrated an effective workflow to recognize a rotational crop cultivation areas using remote sensing. First, we applied NDVI and MNDWI to provide a preliminary recognition of the distribution of PRRC in the landscape. Then, image classification using a Maximum Likelihood algorithm with controlled ground points for validation was conducted. The novelty of this approach is the combination of NDVI and MNDWI, each of which, is traditionally used to recognize either vegetation or water bodies, respectively (Thi et al., 2008; Parida et al., 2008; Xu, 2006). We further refined the NDVI/MNDWI classification based on field observations conducted alongside farmer interviews, which enhanced the accuracy and reliability of image classification for areas with seasonal changes in land cover such as the PRRC.

### 4.2. Integrated market price method

This research sought to apply and improve the market price approach for assessing ES which are associated with a typical agricultural cultivation practice. In addition to multiplying the market prices in the final calculation of ES values, we explicitly analyzed their contributions by FAMD and PCA to explore the socio-economic and production factors affecting these values (Helian et al., 2011; Liu et al., 2010; Schagner et al., 2013).

In general, income from prawn accounts for larger proportions of total revenues because of their higher selling prices compared to rice. We intentionally chose to use the term selling price over market price since its magnitude is not entirely decided by the external market. Rather, they covariate with the sizes of the prawns which are related to how long they are grown. Particularly, keeping the prawn longer means farmers have to take higher risks of diseases and mortality. Conversely, selling a smaller sized prawn could reduce the risks but would result in lower income as a tradeoff.

With respect to rice crops, the selling price remains relatively more stable owning to its characteristic as a national commodity and that its production relates to national food security objectives. Hence, the productivity of rice had considerable loading in the construction of the principal component in PCA together with cultivated area and extra revenues from bi-products.

All of the aforementioned findings could not have been discovered if it had not been for the integration of factor analyses into the traditional market price method. This demonstrated the benefits of applying PCA to explore the underlying structure of the data and unfold the relationships between socio-economic, demographic, and production variables.

### 4.3. Benefit transfer support

From our calculations, the biophysical units and economic values of ES associated in PRRC areas were obtained. In recent years, PRRC has been commonly cited as an adaptive cultivation scheme in coping with a climate change impact *i.e.* salinity intrusion for coastal areas. Our findings would then be relevant to inform land use decision makers of the capacity of the associated ES in PRRC in terms of added economic values. Furthermore, these values could serve as transferable benefits to support future studies about ES evaluation in the Mekong Delta (Wilson and Hoehn, 2006; Troy and Wilson, 2006; Richardson et al., 2015).

### 4.4. Social integrity

There has been debate over the cultivation of rice crops and PRRC in the area. The first consideration has been the traditional and predominant tillage activity of the community for generations. However, the yields recently have decreased due to the change in hydrologic conditions. This is more likely to become even worse in the future (Vietnam National Mekong River Commission, 2011). As such, PRRC was initiated as an adaptive measure to climate change impacts. The application of PRRC and other crop rotation schemes started initially in the coastal communes and then spread towards in-land areas 10 years ago. The diffusion in part also seems to be driven by the high economic values of prawn crops. The concept seems promising when the rotational crops not only could adapt to the disadvantageous hydrologic conditions but generate considerably higher income as well. But then is it too good to be true? Indeed, our results have revealed different facets of PRRC. Large variations of incurred costs, crop yields, and crop selling prices for the An Minh district suggest that the PRRC is not necessarily the *golden goose* for everyone. This is also reflected in the large variance of ES economic values. The average value is 1300 USD/ha/year with a standard deviation of 600 USD/ha/year. These numbers disclose different situations of ES utilization efficiency. Besides farmers who have substantially converted ES into high economic values, there are others who have not yet adapted to the new cultivation scheme.

In particular, high yields, regardless of prawn or rice, could not guarantee substantial economic yields, for instance, in the Dong Hung B commune. Effectively managing associated costs and selling products at reasonable prices are of equal importance. These conditions could not be satisfied without sufficient practical experience, which apparently some households in the area are missing. Hence, sharing of practical experience within the community and between different communes should be encouraged to fill these knowledge gaps and to increase the overall values of provided ES (Scheyer et al., 2015). These goals could be achieved through local and regional seminars at which best practices and lessons learned from successful implementation could be presented and shared. For instance, the selection of crop seeds and sowing calendars, water quality and quantity standards, desalination methods, or agrochemical dosages *etc.* are among essential information that could be shared to promote the success of PRRC in the region. Our findings also have showcased the need to integrate social attributes of the local community into land use planning besides natural conditions suitability.

### 4.5. Implications to land valuation

The application of ES evaluation framework could highlight the contribution of the ES to the local economy (Daily et al., 2009; Primmer and Furman, 2012; Hayha et al., 2015). We used Eq. (1) adopted from the European Commission to calculate the economic values of this contribution by subtracting the investments from the human side. Hence, the economic value of ES was expressed as the contribution of the Nature rather than just the marketed values of its end products, in particular crop yields.

The non-negativity of ES values calculated gives the confidence of substantial input from the ecosystem to the local economy. In addition, this would point out that the effective assignment of land prices might have underpriced the value of the area by not accounting for the values of incorporated ES on the land. The current land use policy places PRRC areas in the same category with other annual crops such as rice, vegetables and values them based on geographical attributes (Kien Giang PPC, 2014). The simplification in classification and valuation of the effective land pricing codes would undervalue the roles of typical ES in each land uses, for instance the seasonal hydrological conditions that facilitate PRRC. This bias is prone to underestimating the land values which might open doors to misconducts such as overexploitation of resources or irresponsible land use decisions. It is therefore recommended that the land evaluation code be re-visited to integrate the potential values of ES into the existing pricing criteria and other land use management decisions.

### 4.6. Risks and challenges

A study conducted on the PRRC scheme in Ca Mau, a different province, but one that is also on Vietnam's Mekong Delta pointed to a number of risks and limitations of the PRRC practice. Findings from this study showed the main problems in culturing prawn include water management, disease and breed quality whereas soil salinity, rice seed salinity adaptability, diseases and unfavorable weather conditions are major concerns in rice tillage. These difficulties, in fact, lie within the interrelated nature of the prawn and rice crops. The soil salinity is in fact introduced by the earlier prawn harvests. On the contrary, fertilizers and agrochemicals left in the soil after the rice crops are among major reasons affecting the yields of the following prawn crops (Nguyen et al., 2011). On the other hand, PRRC could also be held responsible for a number of disservices such as the disruption of habitat and nursery function for wild animals or water resource pollution (Ma et al., 2015).

### 4.7. Integrating Ecosystem Service framework into land use planning

The integration of the ES framework has many advantages over the conventional approach. Firstly, it could reduce the conflicts between environmental concerns and economic objectives when the ecosystem is seen as a source of beneficial services that also bears economic values (Hayha et al., 2015). Secondly, it offers a more holistic view of the current management through the benefits per unit land. This, additionally, facilitates the comparison with other development proposals. Moreover, this standardization enables the aggregation to illustrate the spatial distribution of ES values in the area of interest, thereby facilitating communication of technical results to policy makers (Sumarga and Hein, 2014). Thirdly, the ES framework could be used to illustrate how various land use policies and management practices affect different stakeholders. In this research for instance, with the help of ES framework, we successfully revealed the divergence in readiness within the same community with respect to the PRRC. These two findings could shed useful light on the sensitivity of different stakeholders with respect to land use changes that allows for the monitoring of the overall effects of land use policies as well as timely corrective actions (Sumarga and Hein, 2014; Scheyer et al., 2015).

## 5. Conclusions

We conducted an integrated approach to identify, evaluate and map the associated ES with PRRC cultivation in which GIS played an important role throughout the process. We found that the classification of satellite images using NDVI, MNDWI and ground points control could be a reliable technique to recognize PRRC areas in the context of coastal wetlands. Our research also shows the capacity of PCA and HCA in exploring the underlying structure of socio-economic data that can explain the variable economic performance of PRRC in the region. These methods are both more informative and capable of simplifying the interpretation of data structure as compared to conventional approaches.

This research adapted the ES framework to evaluate the application of PRRC in the west coast of Vietnam's Mekong Delta. Our findings confirm the suitability of PRRC yet expose some challenges. The latter relate to the divergence of living and farming experience in the community which, though subtle, have the capacity to disturb the efficiency of the cultivation scheme and cut back the values of ES eventually. We also found that one limitation of the current land pricing system is that it appears to have undervalued the land by not considering the environmental benefits. In fact, the valuation decision was made predominantly on the geographical locations. This simplification might lead to the underestimation of negative impacts and reckless land use decisions which would compromise the ecosystem health.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.ecoser.2016.04.007.

## References

Atkinson, G., Bateman, I., Mourato, S., 2012. Recent advances in the valuation of ecosystem services and biodiversity. Oxf. Rev. Econ. Policy 28 (1), 22–47.
Bartlett, M.S., 1937. Properties of sufficiency and statistical tests. Proc. R. Stat. Soc.: Ser. A 160, 268–282.
BCS (Bayer Crop Science), 2015. Positive impacts of Arize-BTE1 toward prawn cultivation in Prawn-Rice Rotational Crop areas. In: Bac, Lieu, Ca, Mau, Kien, Giang (Eds.). From: 〈http://www.cropscience.bayer.com.vn/vi-VN/News-Event-Program-Promotion/LuanCanhTomLua.aspx〉.
Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecol. Econ. 63, 616–626.
Burkhard, B., Kroll, F., Nedkov, S., Muller, F., 2011. Mapping ecosytem service supply, demand and budgets. Ecol. Indic. 21, 17–29.
Chan, K.M.A., Satterfield, T., Goldstein, J., 2012. Rethinking ecosytem services to better address and navigate cultural values. Ecol. Econ. 74, 8–18.
Congalton, R.S., 1991. A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens. Environ. 37, 35–46.
Costanza, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O7Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387, 253–260.
Daily, G.C., 1997. Nature's Services. Island Press, Washington DC, USA.
Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., et al., 2009. Ecosystem services in decision making: time to deliver. Front. Ecol. Environ. 7, 21–28.
de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., et al., 2012. Global estimates of the value of ecosytems and their services in monetary

units. Ecosyt. Serv. 1, 50–61.
European Commission (EC), 2013. Organization for Economic Co-operation and Development, United Nations, World Bank. System of Environmental-Economic Accounting 2012 – Experimental Ecosystem Accounting. United Nations, New York. USA.
Fagerholm, N., Kayhko, N., 2009. Participatory mapping and geographical patterns of the social land scape values of rural communities in Zanzibar, Tanzania. Fennia 187, 43–60.
Fagerholm, N., Kayhko, N., Ndumbaro, F., Khamis, M., 2012. Community stakeholders' knowledge in landscape assessments – mapping indicators for landscape services. Ecol. Indic. 18, 421–433.
Farber, S., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Ecol. Econ. 41, 375–392.
Freeman III, A.M., 2003. The Measurement of Environmental and Resources Values: Theory and Methods, 2nd ed. Resources for the Future, Washington DC.
Hadley, D., D'Hernoncourt, J., Franzen, F., Kinell, G., Soderqvist, T., Soutoukorva, A., Brouwer, R., 2011. Monetary and non-monetary methods for ecosystem services valuation – specific sheet and supporting material. SPICOSA Project Report. University of East Anglia. Norwich.
Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 1998. Multivariate Data Analysis, 5th ed. Prentice-Hall, Upper Saddle River, NJ.
Hayha, T., Franzese, P.P., Paletto, A., Fath, B.D., 2015. Assessing, valuing, and mapping ecosystem services in Alpine forests. Ecosyst. Serv. 14, 12–23.
Helian, L., et al., 2011. Changes in land use and ecosystem service values in Jinan, China. Procedia *5*, 1109–1115.
Husson, F., Josse J., Pages, J., 2010. Principal component methods – hierarchical clustering – partitioning clustering: why would we need to choose for visualizing data. Applied Mathematics Department. Technical Report – Agrocampus.
Husson, F., Josse, J., Le, S., Mazet, J., 2015. FactoMineR: Multivariate Exploratory Data Analysis and Data Mining. R package version 1.31.4. From: ⟨http://CRAN.R-project.org/package=FactoMineR⟩.
Kuenzer, C., Tuan, V.Q., 2013. Assessing the ecosystem services value of Can Gio Mangrove Biosphere Reserve: combining earth-observation and household survey-based analysis. Appl. Geogr. 45, 167–184.
Le, S., Josse, J., Husson, F., 2008. FactoMineR: an R package for multivariate analysis. J. Stat. Softw. 25 (1), 1–18.
Liu, S., et al., 2010. Valuing New Jersey's ecosystem services and natural capital: a spatial explicit benefit transfer approach. Environ. Manag. 45 (6), 1271–1285.
Liu, S., Costanza, R., Farber, S., Troy, A., 2010. Valuing ecosystem services. Theory, practice and the need for a transdisciplinary synthesis. Ecol. Econ. Rev., 54–78.
Loomis, J., Kent, P., Strange, L., Fausch, K., Covich, A., 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecol. Econ. 33, 103–117.
MA (Millennium Ecosystem Assessment), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington D.C., World Press Institute.
Ma, F., Eneji, A.E., Liu, J., 2015. Assessment of ecosystem services and dis-services of an agro-ecosystem based on extended emergy framework: a case study of Luancheng County, North China. Ecosyst. Serv. 82, 241–251.
Martin-Lopez, B., Iniesta-Andridia, I., Garcia-Llorente, M., Palomo, I., Casado-Arzuaga, I., Garcia Del Amo, D., et al., 2012. Uncovering ecosystem service bundles through social preference. Plos ONE *7*, *e38970*.
Nahuelhual, L., Laterra, P., Villarino, S., Mastrangelo, M., Carmona, A., et al., 2015. Mapping of ecosystem services: missing links between purposes and procedures. Ecosyst. Serv. 13, 162–172.
Nguyen, C.T., Nguyen, V.H., Le, X.S., Dang, T.P., 2011. Analysis of risks and bottlenecks of rice-shrimp farming system currently practiced in Ca Mau peninsula. Conference proceedings. In: Proceedings of National Conference of Aquaculture. University of Forest and Aquaculture, Ho Chi Minh city, Vietnam.
Nicholson, S.E., Farrar, T.J., 1994. The influence of Soil Type on the Relationships between NDVI, Rainfall and Soil Moisture in Semiarid Bostwana. I. NDVI Response to Rainfall. Remote Sens. Environ. 50, 107–120.
Parida, B.R., Oinam, B., Patel, N.R., Sharma, N., Kandwal, R., Hazarika, M.K., 2008. Land surface temperature variation in relation to vegetation type using MODIS satellite data in Gujarat state of India. Int. J. Remote Sens. 29, 4219–4235.
Plieninger, T., Dijks, S., Oteros-Rozas, E., Bieling, C., 2013. Assessing, mapping, and quantifying cultural ecosystem services at community level. Land Use Policy 33, 118–129.
PPC Kien Giang (People's Committee), 2014. Decision on land pricing code in Ken Giang province. Decision. No. 35/2014/QD-UBND.
Primmer, E., Furman, E., 2012. Operationalising ecosystem approaches for governance: do measuring, mapping and valuing integrate sector-specific knowledge systems? Ecosyst. Serv. 1, 85–92.
R Core Team, 2015. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. From: ⟨https://www.R-roject.org/⟩.
Remme, R.P., Schroter, M., Lars Hein, L., 2014. Developing spatial biophysical accounting for multiple ecosystem services. Ecosyt. Serv. 10, 6–18.
Richardson, L., Loomis, J., Kroeger, T., Casey, F., 2015. The role of benefit transfer in ecosystem service valuation. Ecol. Econ. 115, 51–58.
Ryan, R.L., 2011. The social landscape of planning: integrating social and perceptual research with spatial planning information. Landsc. Urban Plan. 100, 361–363.
Schagner, J.P., Brander, L., Maes, J., Hartje, V., 2013. Mapping ecosystem services's values: current practice and future prospects. Ecosyst. Serv. 4, 33–46.
Scheyer, C., Gorg, C., Hauck, J., Winkler, 2015. Opportunities and challenges for mainstreaming the ecosystem services concept in the multi-level policy-making within the EU. Ecosyst. Serv. 16, 174–181.
Seidl, R., Rammer, W., Jager, D., Currie, W.S., Lexer, M.J., 2007. Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria. Ecol. Manag. 248, 64–79.
Sumarga, E., Hein, L., 2014. Mapping ecosystem services for land use planning, the case of Central Kalimantan. Environ. Manag. 54, 84–97.
Sumarga, E., Hein, L., Edens, B., Suwarno, A., 2015. Mapping monetary values of ecosystem services in support of developing ecosystem accounts. Ecosyst. Serv. 12, 71–83..
Tabachnick, B.G., Fidell, L.S. 2001. Principal components and factor analysis. In: Using multivariate statistics, 4th ed., Needham Heights, MA: Allyn & Bacon, pp. 582–633.
TEEB Foundations, 2010. The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations. Earthscan, London and Washington D.C..
Teich, M., Bebi, P., 2009. Evaluating the benefit avalanche protection forest with GIS-based risk analyses – a case study in Switzerland. For. Policy Manag. 257, 1910–1919.
Thi, T.H.N., De Bie, C.A.J.M., Smalling, E.M.A., Thai, H.C., 2008. Mapping the irrigated rice cropping patterns of the Mekong delta, Vietnam, through hyper-temporal SPOT NDVI image analysis. Int. J. Remote Sens. 33 (2), 415–434.
Troy, A., Wilson, M.A., 2006. Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer. Ecol. Econ. 60 (2), 435–449.
Tuan, V.Q., Kuenzer, C., Oppelt, N., 2015. How remote sensing supports mangrove ecosystem service valuation: a case study in Ca Mau Province, Vie Nam. Ecosyst. Serv. 14, 67–75.
van Berkel, D.B., Verburg, P.H., 2014. Spatial quantification and valuation of cultural ecosystem services in agricultural landscape. Ecol. Indic. 37, 163–164.
Vietnam National Mekong Committee, 2011. Preliminary Study on Climate Change Adaptation Plan in Kien Giang Province. Final Report.
Wilson, M.A., Hoehn, J.P., 2006. Valuing environmental goods and services using benefit transfer: the state-of-the art and science. Ecol. Econ. 60, 335–342.
Xu, H., 2006. Modification of normalized difference water index (NDWI) to enhance open water features in remotely sensed imagery. Int. J. Remote Sens. 27 (14), 3025–3033.