The economic value of peri-urban wetland ecosystem services in Phnom Penh, Cambodia

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Abstract. Boeng Cheung Aek is a large peri-urban wetland in south Phnom Penh, Cambodia that provides multiple ecosystem services, but increasing urban development has initiated an ambitious program of in-filling. In an effort to demonstrate the importance of the wetland to city planners, we have undertaken this research to document and value the ecosystem services provided by Boeng Cheung Aek. Using a mixed method approach of geospatial technology, household surveys, market value, and avoided cost assessments, we determined the economic value for wastewater treatment, food, and water provisioning in the wetlands is $30.12 million USD per year, but with a range of $15.71-$48.96 million USD per year.

1. Introduction

Ecosystem services are aspects of ecosystems consumed and/or utilized to produce human well-being. The concept of ecosystem services evolved from the field of ecological economics and was formalized about 20 years ago in an effort to underscore the non-market value of natural amenities [1]. In essence, the concept recognizes the importance of natural ecosystems for human existence and tries to deliver a set of tools by which natural resources can be prudently and holistically managed. Ecosystem services generally are divided into four categories: i) supporting; ii) provisioning; iii) regulating; and iv) cultural.

The early work concluded that for the entire global biosphere, the value of ecosystem services was $16-54 trillion USD per year, with an average of $33 trillion USD per year (1994 dollars) [1]. In comparison, Global GNP was around $18 trillion USD per year in 1994. Within Southeast Asia, there is increasing interest in mainstreaming ecosystem services analysis to support better development planning, although barriers to implementation also exist [2,3].

Wetlands provide a variety of ecosystem services and there has been considerable interest in quantifying these services [4]. Boeng Cheung Aek (BCE), a peri-urban wetland in south Phnom Penh, Cambodia, provides a number of ecosystem services and importantly, it is the only existing wastewater treatment option for the southern half of the city. However, urban development pressures are resulting in extensive in-filling of the wetland. The objective of this study is to report initial efforts to document a sub-set of
ecosystem services provided by BCE and the value of their loss should the in-filling continue unabated.

2. Research Methods

2.1 Study Site
The population of Phnom Penh increased from 999,804 in 1998 to 1.731 million in 2015. Wastewater treatment for the city is handled by a system of natural wetlands around the city [5] but growth in population and development have led to the well-publicized and contested in-filling of some of the wetlands [6]. Although BCE provides various ecosystem services, one development possibility would reduce the wetland area from a maximum of 2,000 ha to 520 ha [7]. This in-filling will negatively impact ecosystem service benefits and we hope to provide documentation of these services before they tragically disappear.

2.2 Ecosystem Services Valuation Framework
As a first step in our study, we identified all possible ecosystem services afforded by BCE and these are summarized in Table 1. This paper presents preliminary results of ongoing work and therefore focuses on the methodology and monetization of a subset of ecosystem services in Table 1, namely the provisioning services of food and water and the regulating services of wastewater treatment.

| Ecosystem Service       | Example of Ecosystem Service Provided                                                     |
|-------------------------|-------------------------------------------------------------------------------------------|
| Provisioning services   | Food (e.g. vegetables, fruit, fish); Water supply; Fuel wood                              |
| Regulating services     | Climate regulation (urban heat island), Water storage for flood control; Erosion control (onsite and downstream benefits) Wastewater treatment (onsite and downstream benefits) |
| Cultural services       | Aesthetic values; Cultural heritage (BCE killing field); Community well being and sense of place |
| Support services        | Carbon sequestration; Provision of habitat; Biodiversity                                  |

2.3 Primary Data Collection and Processing
The BCE wetland includes three communes and household surveys for this study took place in three villages, Stueng Chrov, Cheung Aek, and Praek Ta Kong 1, one in each commune (Figure 1). We conducted 178 household surveys, with the distribution of crop ecosystems as follows: water spinach (49), water mimosa (39), water parsley (12), rice (3), corn (6), pumpkin (10), watermelon (4), lotus rhizome (4), natural fish (28), aquaculture (14) and duck raising (3). Due to the challenges in surveying, a snowball approach was used for sampling.
The economic value of each crop ecosystem was calculated as follows:

\[ EV = A(I - E) \]  (1)

where \( EV \) is economic value (USD); \( A \) is total area of cultivation (ha); \( I \) is total income (USD/ha); \( E \) is total expense (USD/ha); and \( I \) is calculated as:

\[ I = P \times O \times T \]  (2)

where \( P \) is product price (USD/kg); \( O \) is harvest yield per time (kg/ha); and \( T \) is the number of crop harvests per year.

Annual fish production and duck raising value were calculated as:

\[ EV = HH(I - E) \]  (3)

where \( EV \) is economic value (USD); \( HH \) is number of households which fish or raise ducks; \( I \) is total income (USD); \( E \) is total expense (USD); and \( I \) is calculated as:

\[ I = P \times \text{kgf} \times T \]  (4)

where \( P \) is the product price (USD/kg; or USD/duck); \( \text{kgf} \) is the product quantity sold per household per day (kg/HH/day); and \( T \) is the number of times collected per year.

2.4 Geospatial Analysis

To support assessment of agricultural activities in BCE, aerial imagery was downloaded (www.ing-holdings.com) and digitized in ArcGIS10.4, resulting in an overlay grid of 2,912 100 × 100 m cells. However, when the grid was overlaid on Google Earth images, some cells had two or three different crop ecosystems. For simplification, each grid cell was assigned one crop ecosystem (if two or more, the dominant crop ecosystem in that cell was assigned). Satellite imagery from Google Earth Pro for 2014-2016 also was used to produce crop ecosystem hotspot maps.

3. Results and Discussion

3.1 Hotspot ES Maps of BCE

The purpose of creating hotspot maps is to support ecosystem service monetization since equations [1-4] require crop area. The hotspot maps were generated using Google Earth images, but due to cloud cover images were not available for every month, 2014-2016. Crop ecosystems for each grid were determined visually from the satellite images and mapped on a monthly, seasonal, and annual spatial basis for 2014, 2015, and 2016. Due to space constraints we only show the monthly and seasonal spatial distributions for 2015-2016 (Figures 2 and 3). The extent of aquatic plants generally was greater in March than November or December (e.g. Figure 2). The seasonal maps (e.g. Figure 3) showed that in...
the rainy season higher water levels may affect the diversity of crops because farmers tend not to plant certain crops in the full rainy season. Therefore, the vegetation sharply increased in the dry season.

Figure 2. Monthly hotspot crop ecosystem maps of BCE in 2016

The geospatial analysis (e.g. Figure 2) showed that the area of aquatic plants was 795 ha and for agricultural plants (rice, corn, pumpkin, watermelon) was 66 ha. Both cropping ecosystems (aquatic and agricultural plants) were used in two different scenarios, one where aquatic plant ecosystems were assumed to have equal areas within BCE (and same was true for agricultural crops) and the other where aquatic and agricultural plant ecosystem area varied. We also note that the satellite image resolution is such that it can be difficult to distinguish some of the plant ecosystems and this is where ground truthing played an important role. Results of the mapping indicate that the main occupation for BCE was aquatic plant cultivation, particularly water spinach and water mimosa since cropping practice is relatively straightforward and farmers can earn more profits from these crops than other types of crops.

Figure 3. Seasonal hotspot crop ecosystem maps of BCE in 2015-2016

3.2 Economic Quantification of Aquatic-Agriculture Plant, Fishing and Duck Raising in BCE

3.2.1 Scenarios of Land Use and Economic Value. A scenario approach was used for monetization because the sampling reflects some uncertainties and we want to identify the most likely value but also bracket that value within a possible range. The price of products identified for the ecosystem services calculation was divided into two categories: i) based on household interviews; and ii) based on the retail value reported in the Phnom Penh Market Indices on May 29, 2017 (http://www.moc.gov.kh/). The two scenarios were created because of the clear difference between the profits that people can earn from selling their products to a middleman compared to their earnings by selling directly in the market by
themselves (Table 2). Although profit from selling directly in the market is higher, farmers prefer selling their products to a middleman because they do not need to spend time and money on transportation and the uncertainty of the retail sales.

We also considered two scenarios in terms of crop ecosystem classification. In the first scenario (Table 2) the area of water spinach, water mimosa, and water parsley were considered the same as we divided the total land use for aquatic plant into three equal portions of 265 ha. As noted, we cannot clearly identify the exact land use for water spinach or water mimosa, so initially we classified them together as “aquatic plants”, but the assumption of equal portions (265 hectares) starts to refine our estimates within a scenario. Similarly, the agricultural crop ecosystems are considered the same, being split into four equal portions of 16.5 hectares (Table 2).

While the area of the aquatic (265 ha) and agricultural crop ecosystems (16.5 ha, except lotus) are assumed equivalent in Table 2, a difference in profit is demonstrated due to the sources of profit scenarios. Among the land-based agricultural plants, corn provided the most income in market-based price while pumpkin leaves provided the most income in household interview-based price. For aquatic plants, water mimosa produced the most benefit because its price is high and it is resistant to rapid changes of weather. On the other hand, water parsley is less favoured for planting, even though its price is higher, as it is sensitive to changes in weather.

Table 2. Economic quantification of identical land use with different sources of price.

| No. | Crop types       | Area (ha) | Based on Household Interview | Based on Market Indices |
|-----|------------------|-----------|------------------------------|------------------------|
| 1   | Water Spinach    | 265       | 3,618,948                    | 8,906,500              |
| 2   | Water Mimosa     | 265       | 6,713,323                    | 27,400,923             |
| 3   | Water Parsley    | 265       | 1,998,632                    | 449,188                |
| 4   | Paddy rice       | 16.5      | 30,552                       | 74,595                 |
| 5   | Corn             | 16.5      | 43,633                       | 86,520                 |
| 6   | Watermelon       | 16.5      | -6,330**                     | -6,311                 |
| 7   | Pumpkin Leaves   | 16.5      | 69,754                       | 38,883                 |
| 8   | Lotus Rhizome    | 9         | 44,845                       | 43,318                 |
|     | **Total**        | 870       | 12,519,687                   | 36,999,927             |

*1 Dollar = 4,016 Riel (ACLEDA Bank exchange rate on 15th June, 2017); ** Negative number shows the loss of profit and was excluded in the calculation.

As seen in Table 2, the total profit of the product was almost 300 percent greater for the market scenario, although the profit of selling pumpkin leaves in the market is less than the profit from the household interviews. The latter result occurred because the unit of measurement for the crop is an individual’s hand, which may produce bias. For example, the household interview responses indicated that bunches of pumpkin leaves were equal to 1 kilogram, but when the crop was measured properly, only 5 bunches were equal to 1 kilogram, so household level profit may be overestimated.

We also looked at the impact that varying the land-use area might have on ecosystem value determinations (Table 3). In addition to satellite image analysis, we conducted ground truthing that suggested 60% of the total aquatic plant cropped area was water spinach while the other 40% was water mimosa. Due to the planting practice, water parsley was planted on water mimosa and it was assumed to be 20% of the total land use of water mimosa. The proportional areas for agricultural plant ecosystems were determined from information provided by Mr. Heom Chhorn the headman for Steng Chrov Village and Mr. Phoung Pat the head man of Cheung Ek Village (local authorities). Table 3 shows that there was some impact if we varied the area of the crop ecosystem, based on ground truthing. However, in
comparing the results for Tables 2 and 3, the greatest variability in our ecosystem services value estimates is due to the source of profit, rather than uncertainty in categorizing the crop ecosystem.

Table 3. Economic quantification for different land use with different sources of price.

| No. | Crop Types    | Area (ha) | Annual profit (*$USD /Year) |
|-----|---------------|-----------|-----------------------------|
|     |               |           | Household Interview | Market |
| 1   | Water spinach | 477       | 6,514,106              | 16,031,700 |
| 2   | Water mimosa  | 254       | 6,434,657              | 26,263,526 |
| 3   | Water parsley | 64        | 482,689                | 108,483   |
| 4   | Paddy rice    | 7         | 12,961                 | 31,647    |
| 5   | Corn          | 27        | 71,399                 | 141,578   |
| 6   | Watermelon    | 9         | -3,453                 | -3,443    |
| 7   | Pumpkin       | 23        | 97,232                 | 54,201    |
| 8   | Lotus rhizome | 9         | 44,845                 | 43,318    |
|     | Total         | 870       | 13,657,890             | 42,674,452 |

3.2.2 Scenario of Animal Husbandry. Based on the data collected in our study and the data from the Mr. Heom Chhorn and Mr. Phoung Pat, we calculated the economic value of fishing, duck raising and aquaculture (Table 4). The difference between the number of households involved in each activity occurred because most producers do not stay home during the day time and status was difficult to confirm. Per Tables 2 and 3, selling the products on the market would give more profit than selling products to a middleman.

Table 4. Monetization scenarios of animal husbandry.

| Input                | Unit       | Local Authority* | Our Study |
|----------------------|------------|------------------|-----------|
| Fishing              | No. of households | Household   | 45        | 28        |
|                      | Interview-based price | USD       | 168,917   | 105,104   |
|                      | Market-based price   | USD       | 444,296   | 276,451   |
|                      | No. of households    | Household | 20        | 14        |
| Aquaculture          | Interview-based price | USD       | -102,324* | -71,627*  |
|                      | Market-based price   | USD       | -88,711*  | -62,097*  |
| Duck Raising         | No. of households    | Household | 10**      | 3**       |
|                      | Interview-based price | USD       | 53,065    | 15,919    |
|                      | Market-based price   | USD       | 78,250    | 23,475    |
| Total value of services based on hhs interview | USD | 221,981 | 121,023 |
| Total value of services based on market       | USD       | 522,546 | 299,926 |

*Negative number shows the loss of profit, so the value of aquaculture was excluded from the total calculation; ** Mr. Heom Chhorn and Mr. Phoung Pat

3.2.3 Economic Quantification of Water Usage in BCE
The water of BCE is used for domestic purposes such as watering plants and feeding the ducks. A study indicated that in the dry season, the water needed for growing rice is 10mm/day, but it was assumed here that other crops also use the same amount of water [8]. Based on crop area and a crop time span of 3 months, the total amount of water usage for growing crops therefore was estimated at 594,000 m$^3$. In addition, based on our survey data, we estimate water use for duck raising is 111.6 m$^3$. Using the total water use estimate and the published purchase price of water in 2017 from the Phnom Penh Water Supply Authority ($0.174USD/m$^3$), the economic value of water usage in BCE was calculated as $103,375 per year. We have not included any domestic water use (e.g. for washing) in this calculation.
3.2.4 Economic Estimation of Water Treatment Capacity in BCE
Earlier work showed that BCE has a fundamental, low cost, and effective capacity for urban wastewater treatment [9]. Using construction and operating costs for activated sludge plants in Thailand and an assumed average wastewater flow rate of 58,500 m$^3$/day (based on municipal pump station records) the annual avoided cost of conventional treatment was calculated, based on a 25-year project lifespan (Table 5). There were more detail on this calculation, but essentially the capital cost to construct an activated sludge treatment plant was estimated as $49.1 million USD with an annual operation and maintenance cost of $0.82-3.7 million USD, depending on the source of electricity [5].

3.2.5 Total Economic Value of BCE
The total economic value calculated for ecosystem services varies by scenario (Table 5), with the most likely estimate of total economic value being approximately $10,344 USD/ha/year. A review about ecosystem service values reported for wetlands and noted globally the range was $3,300 to $25,680 USD/ha/year [10]. In addition, also reported that the mean value of wetland and mangrove ecosystem services in Southeast Asia was $4,185 USD/ha/year [10]. The minimum value of wetland ecosystem services was calculated for the Lower Mekong Basin to be $9,905 USD/ha/year, with a mean value of $12,776 USD/ha/year, and a maximum value of $15,646 USD/ha/year [11]. Our results (Table 5) are consistent with this previous work, but we have not quantified all ecosystem services yet.

| Types of ecosystem services | Minimum Price (USD) | Average Price (USD) | Maximum Price (USD) |
|----------------------------|---------------------|---------------------|---------------------|
| Aquatic-Agriculture plant * | 12,519,687          | 26,462,989          | 42,674,452          |
| Fishing and duck raising ** | 121,023             | 291,369             | 522,546             |
| Water usage                | 103,375             | 103,375             | 103,375             |
| Water treatment            | 2,964,000           | 3,264,000           | 5,664,000           |
| Total (all services)       | 15,708,085          | 30,121,733          | 48,964,372          |
| Average per ha per year ***| 5,394               | 10,344              | 16,815              |

4. Conclusion
In summary, quantifying the economic value of ecosystem services in BCE wetland as facilitated by hotspot mapping and employing the mixed methods of market value and avoided costs is a significant first step to provide scientific information about the potential of ecosystem services for stakeholders or policymakers in consideration of green city development. The total economic value of ecosystem services is roughly $10,344 USD/ha/year, which is consistent with other studies done for wetlands in the Lower Mekong Basin. However, we still have ongoing work to determine off-site or downstream values benefits, flood protection, reduced urban heat island impacts, carbon sequestration, and cultural services.

5. References
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