ISSN: 2639-7455

Research Article

Earth & Environmental Science Research & Reviews

An Approach for Estimating Ecosystem Services as Indicator System for Landscape Management: Petri Net Framework

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Submitted: 09 Jan 2019; **Accepted**: 16 Jan 2019; **Published**: 26 Mar 2019

Abstract
Modelling and simulation using Petri nets offer an approach for estimating Ecosystem Services (ES) at the landscape scale. This can be possible when considering their demand and supply on activities that lead to reduction and improvement of them at the landscape scale, especially in relation to multi-agent. Even though, this is a complex process, but identifying and describing these relationships can be a way further. Petri net modelling framework offers a clear advantage in this respect.

This paper presents the first attempt of using Petri net as a modelling tool to estimate ES. The Petri net is constructed to model the flow of ES after a particular transition event within a landscape. The objective is to provide a modelling framework for estimating ES based on indicator systems that can support their management at the landscape. Aggregated data collected from the UNESCO Biosphere Reserve Spreewald (BRS)-Germany is used for experimentation of the model on a real scenario application. The Petri net estimation technique and indicator system for landscape management of ES are discussed in more details.

Keywords: ES, Estimation, Petri Net, Indicator System, Landscape Management, UNESCO Biosphere Reserve Spreewald

Introduction
The natural ecosystems supply mankind with multitude of resources and processes that they benefit from them known as ES [1]. They are spread over the landscape and their distributions are based on particular catchment areas. The capacity of ES in wetland areas would differ from that of dry land areas. Therefore, this has to be considered when estimating them over a landscape. Many accountability assessments have been used on ecosystems such as MEA that provide taxonomic for estimation methods. Boyd and Banzhof argued that they do not deal properly with non-tangible ES [2]. This means for estimating ES, an inventory process needs to be carried out that provide the appropriate measurements of all their biological, chemical, physical and anthropogenic interactions within a particular sampling area, making it so complex to manage [3]. But describing the behaviour of these processes based on a particular state of ES that is influence by particular transition events (multi-agent activities), then the inflow and outflow of ES can be figured out. Petri nets can support such an approach using networks as parallel composition. Especially when data of ES exist for quantification, indicator system for them can be applied in the modelling framework. Many indicator systems for ES existed that consider pressure states and abundance of services, and the resilience of activities to ES within different scales [1, 4-7].

The use of existing or new indicators for ES can provide a means of quantifying them (see section 2.3). A synthesis from many databases containing indicator systems are used to create an indicator system for agro-forest ES. The indicators are selected considering protected and none protected agro-forest ecosystems to develop baseline indicators on pressure and adaptive states of agro-forest landscapes within the European Union (EU). The synthesis considered species availability with regard to agro-forest taxonomy groups of the Natura 2000, and their pressure state due to the activities taking place in particular areas of consideration that influence or impact ES. Also, it considered how the multi-actors are resilience to them. The databases are combined to provide composite indicators that together with pressure and adaptive indicators can be use to measure changes in ES. It is prepared based on inventory studies from literatures of potential ES in agro-forestry landscape and the UNESCO BRS being the experimental area. The following categories are considered [5-7].

- Species richness based on the number of species availability in each area of consideration
- Species abundance based on population size and density over each area of consideration
- Pressure state comprising of activities taking place within each area of consideration that influence and impact ES, and
- Adaptive state or resilience to pressure states

Species richness and abundance are aggregated to form a composite indicator for species availability leading to 3 indicators for estimating

ES. They are the Species availability, pressure and adaptive state indicators. For instance, when considering the net effect of forestry, cultivation, grazing and other human actives taking place in agro-forestry ecosystems, either one or a combination of them turn to have influence and impact on ES. The different activities taking place on ecosystems due to multi-agent's interactions have positive or negative impacts on ES that can be noticed from their indicators. The flows of these activities at a landscape scale changes the state of ES, which can be used to determine whether the negative impacts outweigh the positive impacts. This can be used to justify an environmental degradation hypothesis, such as water shortage, increase in greenhouse gases potentials and others. In table 1, an indicator system for agro-forest ES is presented. It shows the different categories of ES and their types with indicators for them.

Table 1: Indicator System for Agro-forest Ecosystem Services

Categories of ES	Indicators
Provisioning Service:	
Food	Land use, land cover, food supply, food types, ploughing, fertilisers use, land tenure, mixed farming, irrigation, intensive and mechanised agriculture, grazing
Water	Land cover, water flows, fresh water supplies, water table, water consumption, evapotranspiration, lakes, block rivers, water, channels, dry streams, swamps, dry landscapes, canalisation
Fibre, wood	Land cover, fibre and true quantity, types of fibres and trees
Energy	Energy capture (net primary energy production), entropy export/import, energy budget, solar and wind power parks, energy crops
Bio-chemicals	Types and number of herbs and pharmaceutics, bee wax, bio-chemical and remediation plants
Regulating Services:	
Air quality regulation	Pollutant Sequestration capacity by plants and soil, dust removal capacity, reforestation, deforestation and afforestation, dead trees, green plants
Water quality and quantity regulation (Surface and ground water)	Eutrophication, leaching of organic chemicals in water, water retention capacity, runoff, drainage, alkalisation and salinity, algae bloom, floods, flood breaks
Pests and diseases regulation	Availability and types of pest and diseases, use of herbicides and pesticides
Regulation of Soil and erosion	Microbial soil respiration, land fragmentation, land bareness, soil compatibility
Natural hazards regulation	Landslides, earthquakes, cyclones, volcanoes, tornadoes, natural dryness, climate, winds
Supporting Services:	
Nutrient cycling and soil formation	Carbon and nitrogen net mineralization, metabolic efficiency, photosynthesis
Crop pollination	Type and Availability bees of species, insects and other micro-animal species
Support the Earth surface	Land cover, structure of human development, settlement, natural development, canalisation, water reservoirs, storage tanks, densities
	Preserving Services:
Biodiversity	Types and availability of plant and animal species
Genetic resource	Types and availability of genetic species
Cultural services:	
Spiritual and religious values	Traditions (indigenous culture), religion, sanctuaries, regional produces (cultural identity)
Recreational and ecotourism	Tourist sites, eco-tourism, availability of tourist services, leisure sites (parks, playing grounds), tourist facilities, diversity of landscape, tourists, aesthetics, tourist establishments

Petri nets modelling framework is used to present how the inflow and outflow of ES can be estimated (see sections 2.1 and 2.2). It is a graphical and mathematical modelling technique, which has been used to model flow systems in many fields such as transport, business and industrial processes, genetic, financial, freshwater ecology and molecular biology [8, 9]. Sampled data from the UNESCO BRS (see section 2.3) is used for running the model on a real scenario application. The UNESCO BRS is in the Lusatian region in Germany within the administrative divisions of Dahme-Spreewald, Spree-Neiße and Upper Spreewald Lausitz. The land cover is mainly agro-forestry with different landscape component as indicators for ES.

Methodology

Petri nets can be used for modelling and simulation of continuous, discrete, instantaneous and hybrid systems [9-11]. They can also support stochastic systems for random generation of probabilities of estimates for quality management of data within the simulation procedure [8, 12]. Therefore, there are different types of Petri net modelling technique such as place/transition, time, continuous, discrete and hybrid Petri nets, and also high-level nets like coloured Petri nets. A coloured stochastic Petri net modelling approach is used and it is structured as an inventory system for modelling ES. That is, their inflows and outflows based on the interactions of multi-agent activities and processes that demand and supply ES.

A Petri net consists of places, transitions, and arcs that connect them. Input arcs connect places with transitions, while output arcs start at a transition and end at a place [9, 11]. But a place and place or a transition and a transition cannot be connected together in Petri net. Places contain tokens and a current state of a modelled system (the marking) is given by the number (different types if the tokens are distinguishable) of tokens in each place. The transitions are active components that trigger the flow of ES that can enable an estimate of a change in their state. They modelled multi-agent activities that are taking place (the transition fires) based on their demand and supply for ES, thus changing their state (the marking of the Petri nets). Transitions are only allowed to fire (set to work), if they are enabled, which mean that all the pre-conditions for their activities must be fulfilled (there are enough tokens available in the input places). When a transition fires, it removes tokens from their input places and add them at their output places. The number of tokens removed/added depends on the cardinality of each arc. The interactive firing of transitions in subsequent markings is called token game [10, 11].

In general, actions depend on a limited set of conditions or restrictions that is called local environment or environmental rules. These rules determine the transition events. They are fired (set to work) in flow systems using features of Petri nets such as textual, mathematical algorithms and graphical representation for the modelling, which can enable the estimation of the flow of ES [9]. An example of a Petri net modelling of an ecological process can be multiple resources kinetic for algae growth. Figure 1 presents a Petri net of multiple resources kinetic for algae growth.

The Petri net shows that places are connected to transitions by arrows, and transitions to places, while the tokens/numerical signs in the places are the number of tokens it contains in each place. If the numbers of tokens in a place are more than three, then they are shown at that place as a numerical sign. The flow of tokens on the net is only visible during an animation of the model. The animation of the net provides a qualitative analysis of the model and shows how the tokens flow within it. The numerical sign on one of the arrows is the cardinality of the arc. It determines the rate of flow from their input places to an output place for an algae growth when the transition multiple resources kinetic fires. That is, it removes one token from each of the 4 places (places containing radiation, substrate, nutrients and water temperature) and as a combination of 4 resources indicated by the weight of the arrow allows for the growth of algae.

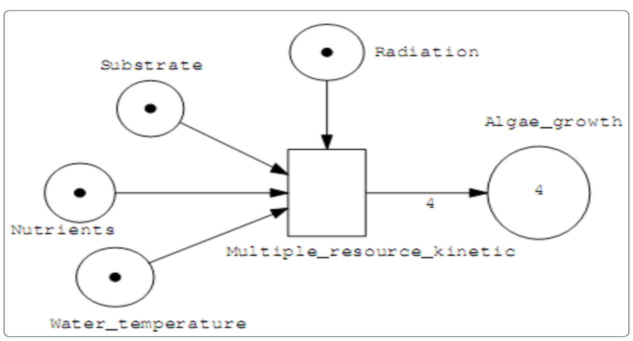

Figure 1: A Petri Net of Multi-resource Kinetic for Algae Growth (diagram generated with software)

Petri Net Model Building for Estimating Ecosystem Services

The Petri net for estimating ES is designed as a generic model that can be used in different landscapes. The Petri net is constructed by considering typical service units for studying ES based on their demand and supply by multi-agent (natural process and multi-actors). That is using the concept of "cost centres" in cost accounting principle to determined multi-agent activities that lead to the consumption or provision of ES. The modelling framework is configured for flow of variables as ES that are contained in places of marking in the net.

The behaviour of a transition exclusively depends on its locality, which is defined as the totality of its input and output objects (pre- and post- conditions, input, output processes, etc.), together with the element itself. The flow system can be use to estimate the stock of ES after a particular transition event. At every place in the model, there are some tokens, which in this case are ES that flow over the model after a transition event providing inflow and outflow of ES. These inflow and outflow are used to estimate ES, thereby determining their stock after a complete transition event. In this case the specification is that places in the net contain marking of tokens ES (ES_1, ES_2, ..., ES_5). Where ES1 are provision services, ES_2 regulatory services, ES_3 supporting services, ES_4 preserving services and ES_5 cultural services are the different types of tokens differentiated by colours (coloured Petri net).

The behaviour of multi-actors triggers the inflow and outflow of tokens after a particular transition event. But this can lead to potential concurrency or conflicting multi-actor actions that can occur. Therefore, the Petri net is constructed as a parallel composition for scheduling activities of multi-agent as they occur within the flow system [13]. This is a big advantage in Petri nets that provide scheduling techniques for parallel composition [9]. ES is modelled as parallel composition of multi-agent activities that are aggregated in service demanding and supplying units as the inflow and outflow to the "stock of ES" for estimation. Figure 2 presents a Petri net for the flow of ES. It shows the various places of "service units" as places.

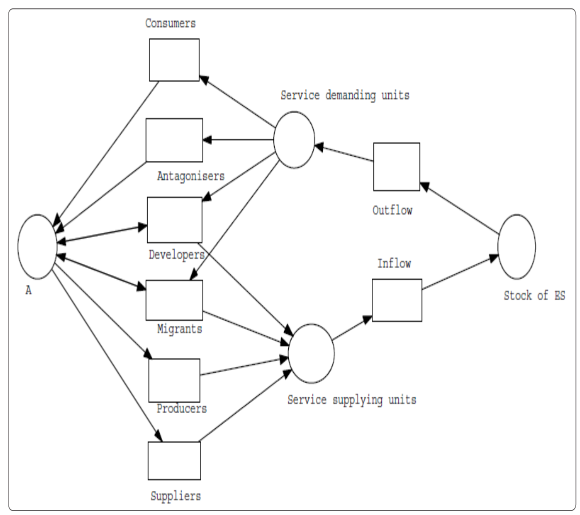

Figure 2: Petri Net for Flow of Ecosystem Services (diagram generated with software)

The multi-agents are transitions that enable the change of ES at a place. The flow directions are sequenced from the place "A" to "Producers, Supplier, Migrants and Developers" through the "inflow" as passive part leading to the "stock of ES" as parallel composition. Then again from the "stock of ES" to the "outflow" that continues through "consumers, developers and migrants" to "A". Therefore, ES can be estimated from the entire amount of in and out flows into the place "stock of ES", which enables the summation of ES from the inflow and outflow and stock of ES within the Petri net simulation framework. The place "A" is logic to stock of ES and it is imaginary because ES are added or removed from their stock. Therefore "A" is only imaginary.

Description of Relationships

A Petri net is formally defined as N that described a triple (S, T, W) and S are the states of the net N, while T are the transitions and W are the weights of the arc. If a marking is defined as a function of tokens and expressed a set of natural numbers $\mathbb{N}_m = \{0, 1, 2, \ldots, m\}$. For instance, if a marking at a place S is n, and then S contains n tokens [14].

S	-	Set of Place of markings	
S	=	$\{s_1, s_2, s_3, s_4\}$	(1)
s_1	-	Imaginary place "A"	
s_2	-	Place "service supplying units"	
s_3	-	Place "service demanding units"	
s_4	-	Place "stock of ES"	
n	-	n_i	
i	=	(1, 2, 3, 4)	(2)

n1 is markings at the place s1, n2 at s2, n3 at s3 and n4 at s4. The components for studying ES are "Comp" defined as markings in places in the Petri net and "ES" are the tokens that flow through net, and then considered the following [14].

Comp	=	$\{Comp_1, Comp_2, Comp_3\}$	(3)
$Comp_1$	-	Land surface	
$Comp_2$	-	Water	
$Comp_3$	-	Biodiversity	
ES	=	$\{ES_1, ES_2, \ldots, ES_5\}$	(4)
$Comp_1$	=	$\{ES_1, ES_2, \ldots, ES_5\}$	(5)
$Comp_2$	=	$\{ES_1, ES_2, \ldots, ES_5\}$	(6)
$Comp_3$	=	$\{ES_1, ES_2, \ldots, ES_5\}$	(7)

Therefore, colour sets can be defined. Colours are used to differentiate the different types of ES [8]. Each place then contains objects of specific colours that would flow through it. This means for each Place (S) a colour domain or colour set cd (S) is defined. If the goal is to measure all ES without differentiation, then all the ES and their categories will have one colour. But for measuring different categories of ES, then the categories are being separated by colours or aggregates of colours (Coloured Petri nets). For example, if a marking $COMP_1$ with tokens of a set of ES ($ES_1, ES_2, \ldots, ES_5$) are to be estimated at different places of flow, then one colour of a set can be defined as "$COMP_1$ ES_1" [14]. Therefore, the colour sets can be defined as;

$$\text{Colours} = \begin{pmatrix} Comp1ES1 \; Comp1ES2 \ldots Comp1ES5 \\ Comp2ES1 \; Comp2ES2 \ldots Comp2ES5 \\ Comp3ES1 \; Comp3ES3 \ldots Comp3ES5 \end{pmatrix} \qquad (4)$$

This means n_i will contain the following colours in each of the places; {($Comp_1ES_1$ $Comp_1ES_2$ …$Comp_1ES_5$), ($Comp_2$ ES_1 $Comp_2$ ES_2 … $Comp_2$ ES_5), ($Comp_3$ ES_1 $Comp_3$ ES_2 … $Comp_3$ ES_5)}. This means, one place has 15 colours of the different tokens. But for estimating the flow of ES, the colours are measure as aggregates of the inflow, outflow from stock of ES. A marking can flow in a place of other markings, if it initially contains that type of markings (coloured set). This argument allows the rule for a change of marking to be described. Markings can only change their places when a transition is fired, but it must have the definition of the colour set of the place (moving to) for it to move in that place. The following are definitions of transitions:

T	-	Set of transition	
T	=	$\{t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8\}$	(5)
t1	-	Transition "Producers"	
t2	-	Transition "Suppliers"	
t3	-	Transition "Migrants"	
t4	-	Transition "Developers"	
t5	-	Transition "Antagonisers"	
t6	-	Transition "Consumers"	
t7	-	Transition "Supply of ES"	
t8	-	Transition "Demand of ES"	

W assigns a number (in this case, only 0 or 1) to every pair (s, t) and (t, s) depending on whether an arrow or not leads from s to t or from t to s, where s∈S and t∈T. The Boolean value 0 and 1 are switch function for the kinetic of the net. The value 1 stands for a flow is enabled and 0 stands for no flow are allowed. If an arrow leads from s_1 to s_2, it is assumed a and b, then T′= {a, b}, W (s_1, a) = 1 and W (s1, b) = 0, where 1 stands for its "arrow" and 0 stands for "no arrow". The real weight can then be expressed on the arc as a multiple, function or algorithm that determines its flow. The marking n can be described as a function satisfying the rules; when $n_1(s_1)= 1$, then $n_1(s_2)= 0$, $n_1(s_3)= 0$ and $n_1(s_4)= 0$, and when the marking n_2 as a function satisfying $n_2(s_1)= 0$, then $n_2(s_2)= 1$, $n_2(s_3)= 0$ and $n_2(s_4)$ and so on till $n_4(s_1)= 0$, $n_4(s_2)= 0$, $n_4(s_3)= 0$ and $n_4(s_4)= 1$. If for instance n1 enables a transition "a", then it occurs as far as the condition for accepting tokens are satisfactory or it rejects. If it accepts, then the resulting marking is n_2. Thus, (N, n_1) [a > (N, n_2) is described. Intuitively, N describes a sequence of two transitions, a and b relating to a communicating sequential process [15]. Therefore, the behaviour of a set (N, n_1) is determined through the transition rule of Petri net. N by itself has no behaviour (as no transition is enabled) and in the marked net (N, n_1), "b" can occur but not "a". The inputs data are the environmental rules that determine the transition events and the inflows of ES (Coloured tokens), which are influenced by multi-agent's activities. The outputs are the stock of ES after transition events. They are simulated to generate estimates of ES for indicator system that can support landscape management.

Data System

Data collected from the UNESCO BRS were normalised, aggregated and encoded in the Petri net for simulation. The indicator system that was established in section 1 is used for measurability of ES based on monitoring observation. They are considered as follows:

1. Species availability indicator = Σ species available × pop size/ Area
2. Pressure indicator = Σ {Natural and human activities impacting ecosystems ± influence (internal and external effects)} ± intensity/ Area, and
3. Adaptive state indicator = Σ {Resilience to Pressure state ± influence (internal and external effects)} ± intensity/ Area

The capacity of ES is ranked from a scale of 0 to 5 to enable their estimation. Table 2 below shows an integrated scheme for interpreting the ranking scale and the parameter estimates for management support systems. It shows the ranking scale from 0 to 5 that has been converted from 0 to 1500 based on the aggregated data and their meaning. This corresponds to the appropriate parameter estimates. The parameter estimates indicate whether there is a balance, improvement or deficit of ES for appropriate landscape management implication. This is supported by a scaling level for meaningful information to enable their interpretability.

Table 2: Interpretation of Ranking Scale and estimation Parameter

Ranking Scale	Conversion (1500)	Meaning	Parameter Estimate
0	0	No relevant capacity	Degraded landscape
1	300	Very low relevant capacity	Very high Deficit of ES
2	600	Low relevant capacity	Deficit of ES
3	900	Medium relevant capacity	Balance of ES
4	1200	High relevant capacity	Improvement of ES
5	1500	Very high relevant capacity	Very high Improvement of ES

Results

The Petri net model was defined and encoded with the data prepared from the UNESCO BRS after a one period of observation monitoring. It was assumed that the stocks of ES are in very high relevant (places "A" and "stock of ES"), while the data for the other values from multi-agent's actions were encoded at the various places on the net. A 100-count simulation run was performed for estimating ES at the region. Figure 3 presents a simulation result of estimates of ES. It shows that the very high relevant capacity of stock of ES (improvement of ES) that was assumed in the region would drop sharply, if the state remains constant. This is because the demand for ES would be drastically increasing, while their supply would have no relevant capacity. This would cause the demand for ES to increase shortly again to almost a high relevant capacity due to the high stock of ES and then would start to drop quickly. This is because there would be no relevant capacity of their supply for recharge that would remain at no relevant capacity throughout the simulation run. This would render the high stock of ES to quickly drop to a no relevant capacity (degradation landscape) and then would remain at that level throughout the simulation. Since there would be no relevant stock of ES, the demand also would drop to a no relevant capacity. All of them would then remain at a no relevant capacity throughout the rest of the simulation. This means if everything remains constant, the future trend from the simulation of ES at the UNESCO BRS indicate an expectation of a high level of landscape degradation. Also, the result serves as an early warning for the need of measures for mitigation, rehabilitation and restoration of ES in the region.

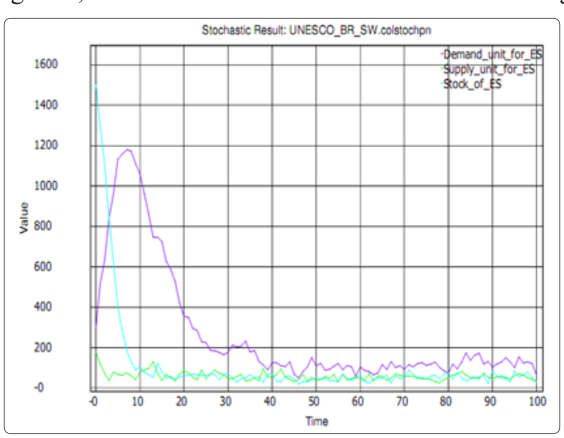

Figure 3: Simulation Result of Ecosystem Services

Conclusion

A Petri net modelling framework has been used to estimate ES at the UNESCO BRS, which can support long term planning and management of them at the landscape. The first attempt with Petri net to model ES shows that it is a good modelling tool for estimating ES at the landscape scale and even beyond. Therefore, this research work can offer a starting point for further research on the use of Petri net for modelling and estimating ES.

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