Index of Ecological Integrity: What should be the approach for regional sustainable management planning?
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Abstract

The world is now passing a transitional “Macroshift”, from industrial age to the global information age and suffering from severe ecological, cultural and socio-economic crisis. A breakthrough is required towards a “sustainability revolution” that can ensure the sustainable future of human existence in this earth. A combination of science and policy, relating science with socio-economic perspectives is very much required to combat such challenges within no time. It is also important to understand the characteristics of anthropogenic disturbances that hampering the natural processes to sustain their integrity. An index of ecological integrity can be the right approach to monitor, evaluate and classify the state of the ecosystems in the regional scale. Such understanding can build up a bridge between stakeholders of different hierarchies and disciplines to work in the same platform. Therefore, this paper reviews and examines: (i) the characteristics of critical issues that are severe threats to regional landscapes, (ii) the consequents and phenomena of effects of such pressures on the components of ecosystem, and (iii) the approach for development of a composite index for ecological integrity in the regional level. The objective is to establish a thought to understand a need and way to develop a composite index of ecological integrity that comprises both aquatic and terrestrial habitats in the regional level.

Key words: Ecological integrity; Index of ecological integrity; Sustainable management; Landscape planning

1. Introduction

Ecological integrity can be defined as the capacity to support and maintain a balanced, integrative, adaptive biological system, having the full range of elements and processes expected in the natural habitat of a region (Karr, Dudley 1981; Karr 1996). It originated from the ethical concept from Aldo Leopold in 1949 and it is been using in the aquatic and terrestrial systems for measuring and evaluating the ecosystem dynamics and health (Karr 1991, 1993; Andreasen et al. 2001). The concept turned into implementation while some developed countries in Europe and the United States used the concept to protect their natural resources. For example in the United States, The Clean Water Act (CWA) 1972, is the first integrated plan and a regulatory part of environmental law for protecting its water bodies (Barbour et al. 2000). Similarly the Austrian Water Act in 1990 is the strong legislative regulation which explicitly concerns the aspects of ecological integrity (Moog, Chovanec 2000).

An Index of Ecological Integrity can help to indicate the magnitude and dimension of changes. It also gives a precise and overall spatio-temporal feature of ecological and biological phenomena of ecosystems. There are numbers of approaches that have been proposed for the development of the index (Karr, Chu 1999; Hughes et al. 2002; DeKeyser et al. 2003; Angermeier, Davideanu 2004; Ortega et al. 2004; Solimini et al. 2008; Hargiss et al. 2008). However, most of them are for very specific area, for example, only for the aquatic ecosystem or
the terrestrial ecosystem. As aquatic and terrestrial habitats are interlinked to each other in landscape point of view, so a regional index of ecological integrity comprises terrestrial and aquatic ecosystems is important.

Among the approaches to develop the index of ecological integrity in the aquatic or terrestrial ecosystems, Karr’s Index of Biological Integrity (Karr, Chu 1999) is the only well accepted and completes one. Andreasen et al. (2001) gave the importance and a detail guideline to develop a terrestrial index of ecological integrity (TIEI), but none could develop an approach for a comprehensive index representing terrestrial and aquatic ecosystems. Therefore, the objectives of this paper are (i) to characterize the critical issues that responsible for the degradation of ecological health in the regional landscapes, (ii) to categorize the synchronized effects of such pressure for evaluation and sustainable management planning, and (III) to develop an approach to establish a composite Regional Index of Ecological Integrity. The index is basically to give a feature of the regional ecosystems, which includes both aquatic and terrestrial ecosystems. To achieve this goal, firstly this study characterizes the critical issues that have been putting pressures and how these are affecting different components of the regional ecosystems. Secondly an approach is drawn how these important components can be measured and indices can be accumulated to develop a Regional Index of Ecological Integrity.

2. Issues related to the regional ecosystems

Many of the natural landscapes in this world, particularly in the tropical region, have been loosing most valuable habitats of flora and fauna over the last few decades (Achard et al. 2002; Lambin et al. 2003; Yunus et al. 2004; Lepers et al. 2005; Wang 2008). Such pressure and excessive unsustainable land use changes, for example agriculture, logging, and aquaculture, fragmenting the natural landscapes and opening the pathway to many types of degradation (Figure 1). The scenario is more severe in lowland forests and wetlands as they are susceptible to the anthropogenic activities (Laurance 1999; Curran et al. 2004; Arroyo-Rodriguez et al. 2007). Though protected areas have been established to protect the natural landscapes from further degradation but they are also experiencing severe pressure in their core and surrounds. Policy and management are very much responsible for the habitat representation status of protected areas to their surrounding ecosystems. In many cases, protected areas are declared without scientific evaluation whether the declared area are capable enough for representing and conserving flora and fauna in that particular region. As a result, a region of natural ecosystem and its biological and structural components become sensitive due to rapid changes. These rapid changes in the landscape accelerating the loss of biodiversity and habitat loss for both flora and fauna. Due to this, natural landscapes loosing connectivity within the habitat patches which is very important for maintaining structure, processes and functions of ecosystems. This phenomena, as a whole, known as degradation of ecosystem or environmental health, which gradually demolishing ecological integrity (Fig: 1).

There are two main types of pressures in the natural landscapes, natural and artificial, where the later can be defined as the effect of anthropogenic activities. It is extremely difficult to summarize common pressures for regional landscapes, as the effects of pressure and their extents may vary with different landscapes or regions. Furthermore, they are also different according to nature and their effects in the different types of landscapes such as wetlands and terrestrial landscapes. However, most of the anthropogenic activities can be defined under few major issues. As a whole, common and drastic anthropogenic activity that degrading natural landscapes are as follows:
• **Direct pressures:**
  i) Urbanization
  ii) Deforestation
  iii) Logging
  iv) Build-up of roads and highways
  v) Commercial agriculture
  vi) Tourism

• **Indirect pressures:**
  i) Policy
  ii) Management
  iii) Education
  iv) Culture
  v) Trade and business

![Diagram of natural landscapes and related pressures](image)

Fig.1: The pattern and processes of natural landscapes in a regional scale. Anthropogenic pressures are degrading the ecological integrity of natural landscapes through fragmentation, ecosystem sensitivity and losing in the connectivity.

These issues are making regional landscapes more vulnerable to maintain their integrity. A natural landscape in a region usually comprises both wetlands and terrestrial landscapes. These landscapes are not isolated; moreover they are interrelated through structural, compositional and
functional attributes (Franklin et al. 1981; Noss 1990). When these three attributes are stable and can work smoothly without external pressure, generally we find that the ecosystem is healthy. It is then capable enough to maintain its integrity, stability and beauty (naturalness). Again, these morphological and functional characters are very much interactive. Aldo Leopold (1949) indicated this in his article of which Karr and Dudley (1981) defined ecological integrity as “the ability of an ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitats within a region”. Among all the natural attributes, ecological integrity can represent all the essential components of the natural ecosystems.

3. Effects that happen due to the pressures

There are several common effects that happen most drastically due to the severe anthropogenic activities. These effects are synchronized and proliferated according to the spatial and temporal nature and volume of the pressures. The initial effect to the naturalness is fragmentation of habitat which creates other degradation sequentially like decreasing connectivity, sensitivity, vulnerability, alteration, and total degradation of its original state.

3.1. Fragmentation

Habitat fragmentation is the most studied problems in landscape ecology which affects at every structural and functional aspects of ecosystem (Harris 1984; Franklin, Forman 1987; Arroyo-Rodriguez et al. 2007). Fragmentation may start from any point of the landscape at any possible micro to massive states. In most cases the impact or the pressure is not imposed for a moment but with very few alternatives it hammers recurrently and other sort of infections started to encroach through the pathway. Habitat fragmentation has caused isolation of remaining population by destroying links between habitat patches. Thus, fragmentation is one of the main threats to the biodiversity loss (Armenteras et al. 2003). There are several severe effects of habitat fragmentation on population have been reported, such as, loss of genetic diversity (Gibbs 2001), barrier to dispersal success (Cramer et al. 2007; Haddad, Baum 1999; Gonzales et al. 1998), strengthening large-scale disturbances, causing temporary to severe extinction in the regional level (Foppen et al. 1999; Donovan, Flather 2002), disruption of biotic interactions (Kruuess, Tschamrtke 2000).

3.2. Connectivity

Landscape connectivity refers to the functional linkage among habitat patches, either there is a structural continuity or because dispersal abilities permit organisms to travel among discrete patches in the landscape (With et al. 1997). Fragmentation affects the habitat connectivity as structural connectivity ensures the movement of organism, gene flows (Tischendorf, Fahrig 2000) among the habitat patches. Changes in the status of wildlife populations and communities resulting from the destruction and fragmentation of their habitats and land managers have to concern them to maintain or restore connectivity of habitats (Bennett 1998). Metapopulation models predict that isolated populations are more likely to go extinct in the long run than populations that are slightly connected (Hanski 1999).

3.3. Sensitivity
A natural landscape of terrestrial or wetland nature contains both flora and fauna that are interrelated with each other and their environment. Through fragmentation, habitat patches loss connectivity and thus lowers the habitat quality. It increases the extinction list (Bailey 2007; Nell 2008) and makes their inhabitants sensitive to their environment. Fragmentation acts as a filter which is permeable to fragmentation-tolerant species and forcing to move out of fragmentation-sensitive species (Fahrig 2003; Henry et al. 2007). Many biotic components of ecosystem show sensitivity due to the changes in micro and macro environment of their habitats (Bailey et al. 2002). Finally an ecosystem become sensitive and extinction rate become alarming. The ecosystems then termed as environmentally sensitive area which rapidly loosing his healthy ecological components to support flora and fauna.

3.4. Vulnerability

Fragmentation, loss of connectivity and increasing sensitivity give birth of vulnerability which is the degree of sensitivity of ecosystem services to global changes and also the degree to which the sector such as, agriculture, forestry, water management, energy, and nature conservation, that relies on ecosystem services is unable to adapt to the changes (IPCC 2001). Through the continuous disturbances and pressure, a set of organisms as well as their ecosystem become vulnerable to sustain their natural health. Anthropogenic disturbances especially intensive land use change makes the species and also their habitat vulnerable which is documented in several research works (e.g. White et al. 1999; Bartlett et al. 2000; Jackson et al. 2004; Metzger et al. 2006).

3.5. Alteration and destruction

The extreme effect of so called development and anthropogenic civilization establish habitat alteration. It imposed changes in the environment which adversely affect ecosystem functions perhaps completely or permanently (Dodd, Smith 2003). Due to urbanization, development or other anthropogenic disturbances alteration also happen to the wetlands and forested lands. In many cases, unsustainable land use practices and lack of clear policy for land use make the destruction faster and it is happening in both developed and developing landscapes.

4. The approaches for combating the challenges

Ecological integrity represents ecosystem health, biodiversity, sustainability, stability, naturalness, wilderness and beauty, which simply encompasses physical, chemical, and biological integrity (Barbour et al. 2000; Andreasen et al. 2001) (Fig. 2). An integrated ecosystem can overcome the usual challenges that may come from natural catastrophe or anthropogenic activities. Ecosystem with high integrity should be relatively resistant to environmental change and stresses and should be able to recover their original conditions or naturalness after a perturbation (Andreasen et al. 2001). Though the concept of ecological integrity still to resolve some questions over the last two decades and still on debate and to be refined (Botkin 1990; Soule, Lease 1995; O’Neill 2000) but the approach is a useful way to maintain the health of ecosystem in regional scale. Thus it can be a comprehensive and useful tool for ecosystem managers and decision makers (Barbour et al. 2000; Andreasen et al. 2001; Ortega et al. 2004).
Physical Integrity
Chemical Integrity
Biological Integrity

Fig 2: Typical feature of components of ecological integrity (Biodiversity and Beauty represents stability, sustainability, naturalness and wilderness on the other hand Ecosystem Health depends on the natural flow and processes of physical, chemical and biological components of the ecosystem).

4.1. How to measure the ecological integrity?

It is impossible to measure everything of potential components in an ecosystem since, for example, no two species exist in the same niche and no single species should be expected to represent the condition of an entire ecosystem (Cairns, Van der Shalie 1980). Ecological integrity generally tested by the indicators that represent the components of structure, composition and processes of an ecosystem (Karr 1981; Noss 1999; Carignan, Villard 2002). An index of ecological integrity can give a general feature of ecosystem health which can be understood easily just like an indicator of inflation (Andreasen et al. 2001). On the other hand, it is still a common problem with many of the scientific assessment to make the outcome understandable to the general public. So an index can make the feature clear to all. In this consequence, many researchers included data observing as many as possible indicators of a particular ecosystem and tried to develop a simple and understandable composite index of ecological integrity (e.g. Karr 1993; Karr, Chu 1999; Andreasen et al. 2001; Carignan, Villard 2002).

4.2. Characteristics of an effective Regional Index of Ecological Integrity (RIEI)

An effective regional index of ecological integrity must represent all the ecosystems present in the region. The index will be a set of multi indices which will represent all the components of a regional scale. Andreasen et al. (2001) outlined six characteristics that an effective index of ecological integrity should have for a terrestrial ecosystem. This study adds some and modifies the characteristics of an effective RIEI as it is arguable that their approach is slightly inadequate to develop an index in the regional scale. Suggested characteristics are as follows and later some descriptions of the additional and modified features are also given:

1. Multi-scaled
2. Grounded in history and succession
   - Natural history of organisms
   - History of successional attributes and evolution
   - Conservation importance
   - Adaptations for environmental changes

3. Relevant and effective

4. Simple

5. Flexible

6. Measurable

7. Adjustable

8. Comprehensive

Selection of appropriate indicators is vital for an effective index of ecological integrity. It requires intensive historic and ecological successional attributes of the studied habitat. Histories of both landscape structure and organisms are equally important and thus the following categories should be considered for developing a regional index of ecological integrity.

- Natural history of organisms,
- History of successional attributes and evolution,
- Conservation importance (e.g. endangered, endemic, threatened), and
- Adaptations for environmental changes.

Both organism and their habitat, successional state, environmental consequents must fit with the judgment of each indicator. Carignan and Villard (2002) suggested that selection of indicators can be useful if (i) many species representing various taxa and life histories are included in the monitoring programme, (ii) their selection is primarily based on a sound quantitative database from the focal region, and (iii) caution is applied when interpreting their population trends (succession/population dynamics) to distinguish actual signals from variations that may be unrelated to the deterioration of ecological integrity. Furthermore, Grumbine (1994) highlighted on maintaining evolutionary and ecological processes, manage landscapes and species to be responsive to both short-term and long-term environmental changes. Considering all the suggestions and studies, selection of representing indicators must relate histories of organisms, evolution, population dynamics, importance on existence (e.g. endangered, endemism), and fitness to the environmental changes. More than one ‘metrics’ (values derived from specific measures, e.g., basal area, species diversity, stand structural class) can be considered for the same indicator to meet the requirement (Faber-Langendoen et al. 2006).

An index of ecological integrity will be effective if it is understandable by public, decision makers and stakeholders of different hierarchies. At the implementation level, more simply in the field level, general public and management personnel will be involved. There should some awareness programme to make the people understand the importance of a regional index of ecological integrity. So the index must be simple and understandable for all the personnel involved. Particularly this effort is needed for a regional scale as the approach required a long-lasting period and a mass involvement is important both in the evaluation and implementation of the process. For the effectiveness of such effort, the index must address endpoints and values that society relates to, such as spiritual, cultural, religious, and esthetic values. Other important issues such as environmental quality and function (water quality, air quality, flood mitigation, waste treatment); recreational values; and commercial values (potentialities of fisheries, timber, tourism and related business) are also need to be included (Andreasen et al. 2001). Then
everybody will understand and realize that the approach is helpful for them in both short-lasting and long-lasting facilities and services.

A regional landscape may be wide but still a part of surrounding region and connected with landscape attributes. As we emphasizes on a composite RIEI that comprises both wetlands and terrestrial landscapes in the regional scale but still it has limitation as structural, compositional and functional components mostly have a long interactive chain that may cover many regions. That is why an effective regional index of ecological integrity should adjustable with its surrounding eco-regions by ecological and landscape attributes. Flexibility concerns the changes in the same ecoregion while adjustability concerns the adjacent regions of targeted region.

With the advent of modern techniques, for example- GIS and remote sensing, it becomes easy to examine spatial and temporal attributes for the development of such an index of ecological integrity. More recent development in the field of landscape analysis e.g. OBIA (Object Based Image Analysis), can facilitate such study. All it needs to set the suitable indicators and metrics for analysis and finally an index can be developed combining the endpoint from all the metrics under the major components (as described in this study). This value will represent the integrity of entire ecosystem. The metrics can be weighted or scored through following valid statistical and arithmetic procedures and models as followed by Karr et al. (1986) and Andreasen et al. (2001) in development of their index of ecological integrity.

5. Conclusions

There is no debate for the importance of a comprehensive index of ecological integrity to measure the dynamics and ecological health of regional scale for sustainable management. Debates and complications are all regarding a valid and comprehensive approach for an index for the ecological integrity at regional level (Simon 1999; Karr, Chu 1999; Andreasen et al. 2001). Basically problems are greater in combining the concerns for understanding the need of such effort to sustainable management of valuable ecosystems rather a valid approach. Though it is a great loophole to understand the ecosystem needs from region to region and nation to nation, there is a great importance for us to have ecological index at landscape or regional level.

A great challenge for development of an effective Regional Index for Ecological Integrity is to convince decision makers and stakeholders of different hierarchies. That is why such an index would be expected to be bulletproof and would have to be problem solving in the landscape level (Andreasen et al. 2001). The task is difficult as lot of expectations to meet but at the same time highest demand for such an index can make the task effective. Many of the previous approaches for an effective index encircled wetlands and watersheds and so far an effective index for ecological/biological integrity lead by Karr is pioneer and unique (see also, Karr, Chu 1999; Andreasen et al. 2001; Angermeier, Davideanu 2004; Ortega et al. 2004). This wide accepted index which started to assess the ecological health of streams then spread to develop analogous indices for assess ecological health for running waters to stagnant water bodies such as pond, lake and including terrestrial ecosystems, e.g. watershed (Angermeier, Davideanu 2004; Ortega et al. 2004). The concept and indices came to the endpoint through implementation for water resource management in many part of the world, from United States to Australia (Moog, Chovance 2000; Barbour et al. 2000).

Andreasen et al., (2001) first approached for some criteria and characterized a comprehensive and useful terrestrial index for Ecological integrity. They suggested and summarized concept, characteristics, and criteria for selection of indicators and metrics for development of an index. Their approach gave importance for the development of a composite
index combining wetland and forested landscape but still that approach has limitation to combine both the ecosystems in the regional scale. This study is approaching for a regional index of ecological integrity (RIEI) which can be an effective tool for decision makers for sustainable management of regional landscape. It is also considering the challenges in the way to develop such a vital index as there is no value of the approach without involvement of land managers and stakeholders. This approach will be able to give a guideline to all who are involved in this holistic effort for measuring, monitoring, and planning ecosystem health in the regional context. As the approach is flexible, simple and comprehensive, it will meet the expectation and will give a satisfactory result. At the same time none can ensure the absolute success of the index which is exclusively dependent on understanding and hence understanding of ecosystem attributes are quite complicated.

Our earth is passing a very critical time when biodiversity loss, extinction rate, degradation of forests and natural resources, and climate change are as much as higher than any other time of world’s history (Pimm et al. 1995). We all are univocal to conserve our natural resources from degradation (Carignan, Villard 2002) but lacking of a unified and comprehensive way to reach the goal. We have no other choice but a strong breakthrough is required towards a “sustainability revolution” (Naveh 2007, 2009). This approach emphasizes on large scale conservation strategy rather than concentrate on site-specific approach. Nevertheless, large scale conservation strategy is cost effective, less challenging, and important for conservation point of view (Noss 1987). Therefore, this study proposes on the Regional Index of Ecological Integrity for conservation and sustainable management of regional ecosystem. It is expecting that proposed RIEI will be a proper guideline to implement the framework for achieving the common goal of sustainable management of natural resources.

References


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