International Journal of Ecology & Development
Year 2014; Volume 28, Issue No. 2; Int. J. Ecol. Dev.
ISSN 0972-9984 (Print); ISSN 0973-7308 (Online)

Importance and Considerations for the development of a composite Index of Ecological Integrity for ecological management

Mohammad Imam Hasan Reza[1,2]

[1]Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor Darul Ehsan, Malaysia.

[2]Southeast Asia Disaster Prevention Research Initiative, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia, Tel: +60389217635; Fax: +60389275629.
Email: rezamih@gmail.com; reza@ukm.my

ABSTRACT

Ecosystem organization is a very complex system. Naturalness of ecological systems is in a tremendous threat due to anthropogenic disturbances. It is important to understand the characteristics of anthropogenic disturbances which have been changing spatial processes and thus affecting the ecological integrity. A combination of science and policy, relating science with socio-economic perspectives is very much required to combat such challenges. An index of ecological integrity can be the right approach to monitor, evaluate and classify the state of the ecosystems in the broader scale for conservation planning. 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 consequences of such pressures on the components of ecosystem, and (iii) a brief outline for a composite index for ecological integrity. The objective is whether a composite index of ecological integrity (IEI) can be develop for the sustainable management planning for the conservation of natural resources in a broader scale.

Keywords: Ecological integrity, ecological management, index of ecological integrity, landscape planning, conservation planning, sustainable management.

Mathematics Subject Classification (MSC): 62P12,

1. INTRODUCTION

Ecological integrity encompasses the components of physical, chemical and biological properties and their robust interactions within the ecosystems. It enables an ecological system to support and maintain a healthy community of organisms that has composition, diversity, and functional organization comparable to those of natural habitats of a region (Heckmann et al. 2008). The concept of ecological integrity has been exploring within environmental sciences, conservation biology and ecology. However, general awareness regarding the importance of maintaining ecological integrity for the restoration of natural systems and their sustainable management are not adequate. As a result, this important aspect is not included in policy and sustainable management initiatives in many part of the world. This approach is particularly important for the safeguard of biodiversity which has been facing a crisis in a time whilst the extinction rates are approximately at the three orders of magnitude than any other records of the

Earth history (Pimm et al. 1995). Therefore, this study attempts to discuss the importance of and a potential approach for evaluating ecological integrity at the broad spatial scale comprising both terrestrial and aquatic habitats.

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 said region (Karr and Dudley 1981; Karr 1996). The term is originated from the ethical concept of Leopold in 1949 where he defined ecological integrity as "a thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise". This definition is rather a qualitative aspect of the integrity of ecological systems. Although, later this concept has been using in the aquatic and terrestrial systems for measuring and evaluating the ecosystem dynamics and health (Karr 1991, 1993; Andreasen et al. 2001), which are mostly the quantitative measurements of ecological state of a region. The concept turned into implementation when some developed countries in Europe and the United States included this approach in policy directives in order 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 and Chovanec 2000).

On the other hand, an index of ecological integrity can assist in indicating the magnitude and dimension of changes. It also gives precise and overall spatio-temporal features of ecological and biological phenomena of ecosystems. Consequently, a considerable number of approaches have been proposed for the development of indexes for ecological integrity in many part of the world (Karr and Chu 1999; Hughes et al. 2002; DeKeyser et al. 2003; Angermeier and Davideanu 2004; Ortega et al. 2004; Solimini et al. 2008; Hargis et al. 2008). Many of these approaches are encircled within the specific ecological unit at a small spatial scale, for example, in the aquatic ecosystems like river, lake, stream water, and pond; or in the terrestrial ecosystems like forest, savannah, and other site scales. Although, these approaches could solve problems in those site specific ecosystems but failed to be used in the broad spatial scales. Practically, the aquatic and terrestrial habitats in a landscape or region have very tight interactive chains in terms of nutrition, energy and gene flow which are needed to be considered for the sustainable management of natural resources. Therefore, an integrated approach to evaluate ecological integrity comprises terrestrial and aquatic ecosystems of a broad spatial extent is essential.

Among the approaches to develop the index of ecological integrity in the aquatic or terrestrial ecosystems, Karr’s Index of Biological Integrity (Karr and Chu 1999) is well accepted and practiced widely. They used biological indicators for measuring the integrity of aquatic system. Andreasen et al. (2001) gave the importance and a detail guideline to develop a terrestrial index of the ecological integrity (TIEI) but their approach did not consider aquatic and terrestrial ecosystems together. Reza and Abdullah (2011) proposed an outline to develop a regional index of ecological integrity (RIEI). However, the importance and usefulness of an index applied in the brad spatial scale is still inadequately discussed and emphasized. In particular, these issues are needed to be understood and realized by the general people who will be involved in the approach. Therefore, this paper is an attempt to discuss the importance about an integrated approach for measuring ecological integrity at broader spatial scale like landscape or regional scale. Subsequently, this article also characterizes the critical issues that disrupt the ecological integrity in landscape, regional to continental scales. Realizing the basic requirements to prioritize the conservation efforts for evaluating and maintaining the ecological integrity in the broad spatial scale, the focal questions of the paper are following:

1. What are the distinctiveness of issues that accountable for the degradation of ecological integrity in the ecological systems of broad spatial scales?
2. How to identify the causes and consequences of such issues for prioritizing conservation planning?
3. How to ascertain applicable indicators in order to develop an approach for the development of an index of ecological integrity in a broader scale?

This paper will start with a theoretical survey and discussion to screen out the critical issues that has been destroying ecological integrity in various spatial scales, particularly in the landscapes to the regional scales. In addition to that, how these pressures are changing spatial processes that lead to the changes of structural, functional and compositional attributes of ecosystems are also discussed. In the following sections, the effects of such pressure which are causing many types of degradations in the ecological systems are described. Based on these discussions, a holistic work flow in order to develop an approach for selecting a set of measuring criteria of ecological integrity in the broad spatial scale comprising both aquatic and terrestrial habitats is outlined. After a brief description of the approach, the possible method to develop an index of ecological integrity (IEI) will be explained, and some conclusions will be drawn.

2. ISSUES RELATED TO THE REGIONAL ECOSYSTEMS

Over the last few decades, many of the natural landscapes in this world, particularly in the tropics, have been degrading its valuable habitats of flora and fauna (Achard et al. 2002; Lambin et al. 2003; Yunus et al. 2004; Lepers et al. 2005; Wang 2008). These pressures and unsustainable land use practices, for example, unprecedented commercial agriculture, transportation network and mushrooming of housing and townships, logging, illegal hunting are fragmenting natural landscapes (Fongwa 2012) and opening pathways to many types of degradation (Figure 1). The state of affairs is more severe in the lowland forests and wetlands as they are susceptible to the anthropogenic activities due to the easy accessibility for the mass people (Laurance 1999; Curran et al. 2004; Arroyo-Rodriguez et al. 2007). At the same time, protected areas are also facing a severe habitat loss both within and around their legislative boundaries in many regions. Whilst protected areas have been established to protect the natural landscapes from further degradation. The scenarios are particularly severe among the protected areas situated in the lowland forests of the tropical region (DeFries et al. 2005). In fact, lack of adequate policy for conservation and improper management are greatly responsible for the restoration of natural habitats and ecosystem representativeness of protected areas of a region. In many cases, protected areas have been declared without scientific evaluation. However, before establishing a protected area, it is necessary to investigate whether the declared areas are adequately capable for representing and conserving flora and fauna of that particular region. On the other hand, protected areas are managed ignoring local people, as such those are highly isolated from surrounding ecosystems and landscapes (Mohapatra 2012). General people are not aware about the importance of those protected areas and their responsibilities to protect those areas for their sustainable livelihoods and existence. As a result, these protected areas have been experiencing enormous anthropogenic pressures e.g., logging, rapid development, encroachment, rapid land use changes and deforestation.

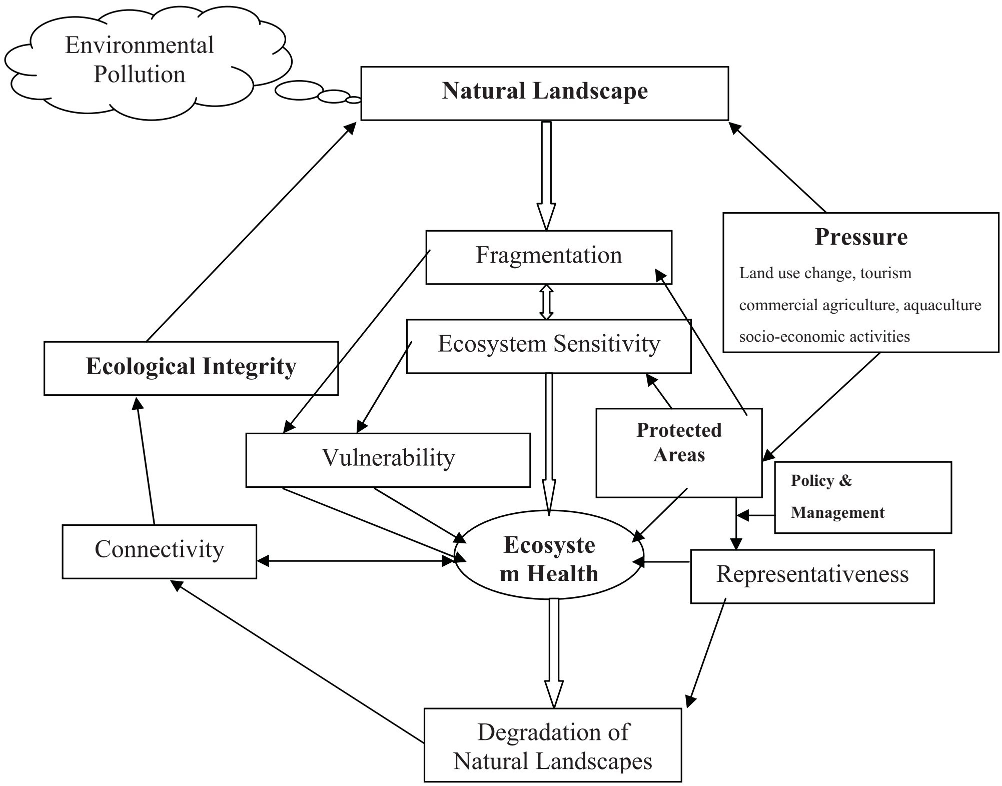

Figure 1: The pattern and processes of natural landscapes in a regional scale. Anthropogenic pressures are degrading the ecological integrity of natural landscapes through fragmentation, ecosystem sensitivity and decreasing landscape connectivity.

Accordingly, a region of natural ecosystems, its biological and structural components, has become sensitive to natural and anthropogenic changes which accelerates the loss of biodiversity. Finally, those habitats gradually have become transformed into unsuitable habitats for both flora and fauna (Reza et al. 2013). These negative impacts lead to the increasing of the degree of fragmentation; isolating of highly integrated ecosystems into small pieces. As a result, fragmented habitats of a region lose connectivity among the habitats to support movement and gene flow of flora and fauna. Finally, a regional ecological system mislay its essential ecological properties to maintain structural, compositional and functional integrity of ecosystems. Generally, this trend known as degradation of ecosystem which is an environmental hazard that gradually annihilate ecological integrity. Figure 1 describes how anthropogenic activities are pressing on the state of the natural organization of a region. These pressures gradually deteriorate the integrity of natural landscapes and protected areas of a region, as well as decrease its valuable characteristics such as naturalness, connectivity, and ecological flow. Consequently, a natural landscape loses its strength and carrying capacity to support its self-organizing ability and thus gradually becomes destroyed or prone to the degradation.

There are two main types of pressures exist on the natural landscapes, natural and artificial, where the latter 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 magnitudes may vary with the differences of landscapes or regions. However, most of the anthropogenic activities can be defined under few major types. As a whole, common and drastic anthropogenic activities that degrade natural landscapes are:

- Direct pressures:
  - i) Urbanization
  - ii) Deforestation
  - iii) Logging
  - iv) Transportation network
  - v) Commercial agriculture
  - vi) Tourism
- Indirect pressures:
  - i) Policy
  - ii) Management
  - iii) Awareness
  - iv) Culture
  - v) Trade and business

These issues are making regional landscapes vulnerable to maintain their integrity. A natural landscape of a region usually comprises of 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 unprecedented external pressure then the ecosystem can maintain good ecological condition. The system is then capable enough to maintain its integrity, stability and beauty (naturalness). Again, these structural and functional characters are very much interactive. Leopold (1949) indicated this harmony of a natural ecosystem as the ecological integrity in his article. Later, Karr and Dudley (1981) defined this ecological harmony as the ability of an ecosystem to support and maintain a balanced, adaptive community. 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 drastic effects that happen mostly 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, accelerating sensitivity, vulnerability, alteration, and finally a total degradation of its original state.

3.1. Fragmentation

Habitat fragmentation is the most studied problem in the landscape ecology, which effects at every structural and functional aspects of ecosystem (Harris 1984; Franklin and Forman 1987; Arroyo-Rodriguez et al. 2007). Apparently the drastic effect of fragmentation is not decipherable but many researchers have identified this spatial process as the proximate cause of degradation of biodiversity and naturalness of the regional ecological system (Fahrig 2003; Castelletta et al. 2005; Cayuela et al. 2006). This process causes isolation of remaining population by destroying links between habitat patches. Thus, fragmentation is one of the main threats to the biodiversity (Armenteras et al. 2003). 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 and Baum 1999; Gonzales et al. 1998), strengthening large-scale disturbances, causing extinction in the regional level (Foppen et al. 1999; Donovan and Flather 2002), and disruption of biotic interactions (Kruess and Tscharntke 2000).

3.2. Landscape connectivity

Landscape connectivity is one of the characteristics of a natural landscape, which refers to the functional linkages among habitat patches. There exist either structural continuity or dispersal abilities, which permit organisms to travel among the discrete patches in the landscape (With et al. 1997). This attribute enables dispersion and gene flow of flora and fauna which is an essential phase of biological diversity. Fragmentation affects the habitat patches through dividing them or disconnecting them in terms of structural and functional attributes of ecological flows and movements. Tischendorf and Fahrig (2000) defined habitat connectivity as the connections that ensure the movement of organism and gene flows among the habitat patches. Changes in the status of wildlife populations and communities resulting from the destruction of their habitats are a vital concern for land managers. Metapopulation models predict that isolated populations are more likely to go extinct in the long run than populations that are functionally connected (Hanski 1999). In this context, it is important to maintain or restore landscape connectivity among the habitat patches (Bennett 1998).

3.3. Environmental pollution

Over the past few decades, the global concern has been amplified due to the increasing environmental pollution worldwide (WHO 2010). Any discharge of materials of energy into air, water or land that causes or may cause acute (short-term) or chronic (long-term) detriment to the Earth's ecological balance or that lowers the quality of life is termed environmental pollution. It leads to the depletion of the ozone layer, global warming, ecological imbalance, and climate change. Pollution is a spatial phenomenon, which increases due to the increase in anthropogenic activities such as industrialization, urbanization and usage of modern devices. The indiscriminate discharge of untreated industrial and domestic wastes into the waterways, the emission of thousands of tons of particles and airborne gases into the atmosphere, disposal of solid wastes, and wholesale destruction of forests have resulted in major environmental disasters and causes imbalance in the ecological systems. An ecological system having good ecological integrity can ensure a healthy ecological system which may protect the system from severe pollution.

3.4. Sensitivity of organism

A natural landscape of terrestrial or wetland contains both flora and fauna that are interrelated with each other and also with their physical environment. Habitat patches that lose structural and functional connectivity due to fragmentation eventually decrease the capability to support flora and fauna and consequently transformed into unsuitable habitats. As a result, many species become extinct in a regional setting (Bailey 2007; Nell 2008) and eventually, inhabitants of that particular ecoregion have become sensitive to the changing environment. Fragmentation acts as 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 demonstrate sensitivity due to changes in micro and macro environment of their habitats (Bailey et al. 2002). Consequently, a group of species have become sensitive to the changing environment and the extinction rate of that particular region becomes alarming. Such ecosystem is then termed as an environmentally sensitive area, which rapidly lose its healthy ecological state as well as integrity to support biological diversity.

3.5. Vulnerability

Fragmentation, decreasing landscape connectivity and escalating sensitivity of a said ecosystem initiate vulnerability for its inhabitants. Vulnerability is the degree of sensitivity which relates the ecosystem services to global changes, and also the degree to which the sectors such as, agriculture, forestry, water management, energy, and nature conservation relying on ecosystem services is unable to adapt to the changes (IPCC 2001). Through the continuous disturbances and pressures, a set of organisms as well as their ecosystem become vulnerable to sustain their amiable environment and natural health. Anthropogenic disturbances such as rigorous land use change makes the species and their habitats 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).

3.6. Alteration and destruction

The extreme effect of so called development and self-centered anthropogenic activities causes habitat alteration. It imposes changes in the environment which adversely affect ecosystem functions either for a certain duration or for a longer time (Dodd and Smith 2003). This so called urbanization and other anthropogenic disturbances alter wetlands and forested lands. In many cases, unsustainable land use practices and lack of clear policy for the land use make the destruction faster; and it is happening in both developed and developing landscapes (Polyakov et al. 2008; Andersson et al. 2011). In the recent time, rapid transformation of natural landscapes into the anthropogenic landscapes of many of the regions particularly in the tropical regions have become a pressing issue.

4. APPROACHES FOR COMBATING THE CHALLENGES

Integrity in the ecological system has diverse meaning such as, ecosystem health, biodiversity, sustainability, stability, naturalness, wilderness and beauty. These terms simply encompass physical, chemical, and biological integrity (Barbour et al. 2000; Andreasen et al. 2001) (Figure 2). An integrated ecosystem can overcome the usual challenges that may come from natural catastrophes or anthropogenic activities. Ecosystem with high integrity, by nature, is relatively resistant to environmental changes and stresses, and should be able to recover their original conditions or naturalness after a perturbation (Andreasen et al. 2001). Although, the concept of ecological integrity still needs to resolve some questions over the last two decades (Botkin 1990; Soule and Lease 1995; O'Neill 2001), this approach is a useful way to maintain the health of ecosystem in the broad spatial scale like regional. Therefore, it approach can be a comprehensive and useful means for ecosystem managers and decision makers (Barbour et al. 2000; Andreasen et al. 2001; Ortega et al. 2004).

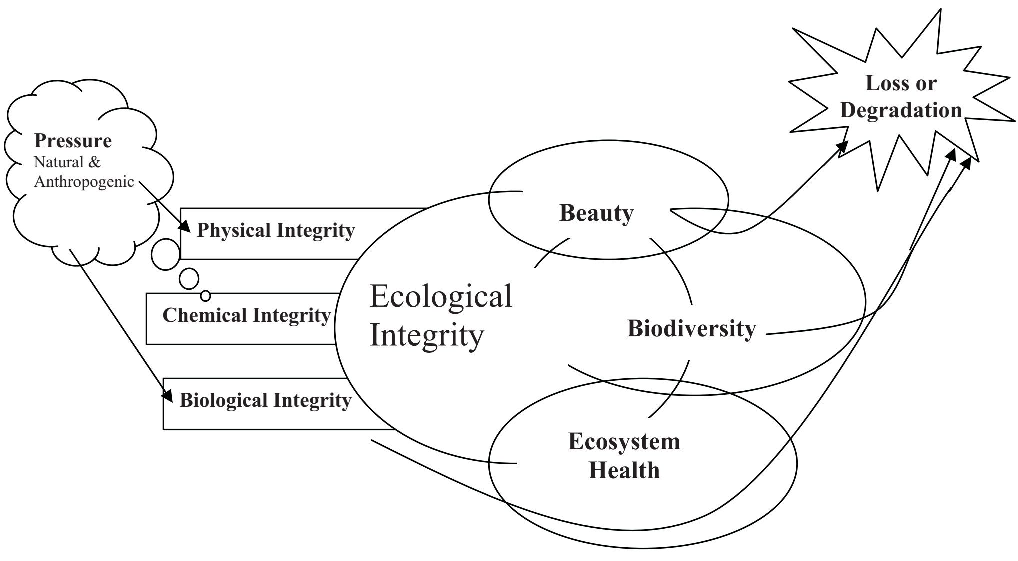

Figure 2: Typical feature of components of ecological integrity. Biodiversity and Beauty represents stability, sustainability, naturalness and wilderness, on the other hand Ecosystem Health depends on the natural flow and processes of physical, chemical and biological components of the ecosystem. External pressure hampers ecological integrity and that reflects through decreased ecosystem health, biodiversity and beauty. (modified from Reza and Abdullah 2011)

4.1. How to measure ecological integrity?

Ecosystem is a complex combination of structural, compositional and functional attributes (Noss 1990; Reza and Abdullah 2011). It perhaps unattainable 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 and Van der Shalie 1980). Ecological integrity measured by the indictors that represent the components of structural, compositional, and functional processes of an ecosystem (Karr 1981; Noss 1999; Carignan and Villard 2002). An index of ecological integrity be able to provide a general feature of ecosystem health which can be understood easily like an indicator of inflation or the sugar level in blood (Andreasen et al. 2001). On the other hand, it is still a common problem with many of the scientific assessments to make the outcome understandable to the general public. Therefore, an index can make the feature clear to the wide range of peoples from general public to the stakeholders of the different sections of sustainable management. In this context, many researchers integrate information investigating 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 and Chu 1999; Andreasen et al. 2001; Carignan and Villard 2002).

4.2. Characteristics of an effective index of ecological integrity (IEI)

An effective index of ecological integrity for regional scale must represent all the ecosystems present in that area. The index will be a set of multi-indices which will represent as many as possible ecological and societal components of a region. Organisms as well as their habitats, succession states, and environmental consequences must be considered while selecting of potential indicators for the index. Carignan and Villard (2002) suggested that selection of indicators can be useful if: (i) many species representing various taxa and indicating the life histories in the monitoring program are selected, (ii) selection is primarily based on a sound quantitative database from the focal region, and (iii) caution can be applied when interpreting their population trends (succession/population dynamics) to distinguish actual signals from variations. Furthermore, Grumbine (1994) highlighted on maintaining evolutionary and ecological processes, manage landscapes and species to be responsive to both short 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, and stand structural class) can be considered for the same indicator to meet the requirement (Faber-Langendoen et al. 2006). Considering these principles, Andreasen et al. (2001) outlined six characteristics that should have for an effective index of ecological integrity for a terrestrial ecosystem. Later Reza and Abdullah (2011) proposed some new and modified characteristics for an effective index of ecological integrity that might suit with regional level. According to them, the index must be multi-scaled; must concern the wide variety of indicators for it to be effective. Therefore, selection of appropriate indicators is vital. It requires also to integrate historic and ecological successional attributes of the region that is considered. Histories of both landscape structure and compositions are equally important and thus the following categories should be considered for developing an index of ecological integrity for a broad spatial scale. The suggested categories are, i) natural history of organisms, ii) history of successional attributes and evolution, iii) conservation importance (e.g. endangered, endemic, threatened), and iv) adaptations for environmental changes.

An index of ecological integrity will be effective if it is simple and understandable by public, decision makers and stakeholders of different hierarchies (Andreasen et al. 2001). This is because; general public and management personnel will be involved in the field level. Effective awareness programmes are essential to make the people be aware of the importance of an index of ecological integrity for conservation of natural resources. Therefore, the index must be simple and understandable to the people involved in the approach. Particularly this effort is needed for a regional scale because the approach required a long-lasting period and mass involvement is important for the evaluation and implementation of the process. For the effectiveness of such effort, the index must address endpoints and values that society emphasizes to for example, spiritual, cultural, religious, and esthetic values which would make the index to be relevant and helpful. 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 to be included (Andreasen et al. 2001). As a consequence, everybody will understand and realize that the approach is helpful for them in both short and long lasting facilities and services.

4.3. How can the index be developed?

With the advent of modern techniques such as GIS and remote sensing, it has become easier to examine spatial and temporal attributes for the development of an evaluation criteria of ecological integrity. Selection of metrics and indicators that based on remotely sensed data in order to develop an index for the broad spatial scale are suggested (Andreasen et al. 2001; Reza and Abdullah 2011). Both structural and functional components of ecosystems can be accommodated with the suit of metrics. As it is reviewed that different types of factors related to the spatial processes like fragmentation, ecosystem sensitivity, land degradation, environmental pollution, vulnerabilities and landscape connectivity are impacting on ecological systems abruptly that reduce the capacity of the ecosystem to support flora and fauna must be accounted. Moreover, policy relevant issues like conservation planning, natural resource management, protected areas management are also directly related to the sustainable management paradigm. Hence, this study suggests selection of a set of metrics related to the structural, compositional and functional attributes of the above mentioned components is necessary.

A group of experts will have to work together to select the candidate metrics and then those can apply in the ecological integrity measuring approach. Selection of indicators are widely discussed in many literatures, and many of them are suitable for the site scale (Karr and Chu 1999; Hughes et al. 2002; DeKeyser et al. 2003; Angermeier and Davideanu 2004; Ortega et al. 2004; Solimini et al. 2008). However, environmental and ecological indicators (also called ecological endpoints by EPA) are measurable characteristics, which are related to the structural, compositional, or functional aspects of ecological systems of a broad scale like landscape, regional, and continental. Table 1 is documenting a set of indicators which may be associated with each category or subcategory. Consideration of maximum of these indicators can assure a successful multi-metric index for the ecological integrity. However, in many cases, form of indicators may vary for different regions and climatic zones. It can be proposed that the indicators based on the remotely sensed data are highly capable to address most of these characteristics. However, in many other cases, a number of field study based biological data can also be adjusted with the multi-metric index.

Table 1: Summary of major categories and subcategories of ecological indicators developed by EPA (modified from Young and Sanzone 2002).

Categories of Ecological Integrity	Sub-categories	Useful Tools
Landscape Condition	• Extent of Ecological System/Habitat Types • Landscape Composition • Landscape Pattern and Structure	RS, GIS, LE
Biotic Condition	• Ecosystems and Communities - Community Composition - Trophic Structure - Community Dynamics - Physical Structure • Species and Populations - Genetic Diversity - Population Structure - Population Dynamics - Habitat Suitability • Organism Condition - Physiological Status - Symptoms of Disease or Trauma - Signs of disease	RS, GIS, GS, ExA
Chemical and Physical Characteristics	• **Air Quality and Climate** • **Soil Quality** • **Water Quality** • Nutrient Concentrations - Nitrogen - Phosphorus - Other Nutrients • Trace Inorganic and Organic Chemicals	RS, GIS, ExA
Ecological Processes	• Energy Flow - Primary Production - Net Ecosystem Production - Growth Efficiency • Material Flow - Organic Carbon Cycling - Nitrogen and Phosphorus Cycling - Other Nutrient Cycling	RS, GIS, GS, ExA
Hydrology and Geomorphology	• Surface and Groundwater flows - Pattern of Surface Flows - Hydrodynamics - Pattern of Groundwater Flows - Salinity Patterns - Water Storage • Dynamic Structural Characteristics - Channel/Shoreline; Morphology, Complexity - Extent/Distribution of Connected Floodplain - Aquatic Physical Habitat Complexity • Sediment and Material Transport - Sediment Supply/Movement - Other Material Flux	RS, GIS, GS, ExA
Natural Disturbance Regimes	• Frequency • Intensity • Extent • Duration	RS, GIS, GS

[RS= Remote sensing, GIS= Geographic Information System, GS= Ground Survey, ExA= Exclusive Analysis through field study]

After a successful selection process and testing of a set of suitable indicators and metrics, a data set could be developed. Finally, an index could be developed combining the endpoints from all the metrics, and that will be a unit value. It can be within the short range of number, i.e., 1-5, indicating from bad to excellent or vice-versa which may depend on the expert judgment (Reza et al. 2013). This value will represent the integrity of the entire ecosystem. The metrics can be weighted or scored through valid statistical and arithmetic procedures and models that have been followed in many previous works (see Karr et al. 1986; Andreasen et al. 2001; Ortega et al. 2004; Reza et al, 2013).

5. CONCLUSION

Currently, concerns are emphasizing on the importance of a comprehensive index of ecological integrity which can measure the dynamics and ecological integrity in the broad spatial scale for sustainable management (Borja et al. 2009). However, still there are debates and complications to establish a valid and comprehensive approach for an index for the ecological integrity at regional level (Simon 1999; Karr and Chu 1999; Andreasen et al. 2001; Timko and Innes 2009). On the whole, problems are greater in understanding the concept and usefulness of a combined index for sustainable management of valuable ecosystems. It is of prime importance to understand the ecosystem compositions from region to region and nation to nation. It also necessitates having an ecological index at regional level.

There poses a great challenge for developing an effective index for ecological integrity where it is crucial to convince decision makers and stakeholders of different hierarchies (Fongwa 2012). For this reason, such an index can be considered to be wide-ranging and problem solving in the landscape to regional level (Andreasen et al. 2001; Borja et al. 2009). In practice, the task is difficult, but very important for safeguarding natural ecosystems which have been degrading at a faster rate. Moreover, it is required to consider the degree of destruction (Mbile et al. 2013). 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 and Chovance 2000; Barbour et al. 2000). Although a few efforts outlined for a composite index combining wetland and terrestrial landscapes but still those have limitations to combine both the ecosystems at the broad spatial scale. This study is approaching for an index of ecological integrity at wide spatial scale, which can be an useful tool for sustainable management decision process. It can be anticipated that this approach will be able to provide a guideline to researchers and managers for measuring, monitoring, and planning ecosystem health in the landscape to regional context. As the proposed approach is designed for it to be flexible, simple and comprehensive, it may able to meet the expectation and may provide satisfactory outcomes. This effort must need to incorporate general people and community in order to develop an effective approach for reaching the conservation and restoration goal for safeguarding biodiversity and natural resources (Torri and Herrmann 2012). At the same time, none can ensure the absolute success of the index which exclusively depends on understanding while ecosystem attributes are quite complicated.

Our earth is passing a very crucial time when loss of biodiversity components, extinction rate, degradation of forests and natural resources, and climate change issues are much critical than any other time of world’s history (Pimm et al. 1995). We all are univocal to conserve our natural resources from degradation (Carignan and Villard 2002), however, an integrated and comprehensive way to reach the goal is yet far reachable. This approach emphasizes on a large scale conservation strategy rather than concentrate on site-specific approach. Yet, large scale conservation strategy is cost effective, less challenging, and important for conservation point of view (Noss 1987). Therefore, this approach might be considered to apply as the Index of Ecological Integrity for conservation and sustainable management of regional ecosystems. It is expecting that proposed index may able to contribute in order to have a useful guideline to implement the framework for achieving the common goal of sustainable management of natural resources.

5. ACKNOWLEDGEMENTS

The author is very much thankful to Rok Ciglič of Geografski Inštitut Antona Melika, Slovenia for his valuable suggestions to improve the article. The author is also grateful to Orowa A. Sikder of University of Oxford for his help to improve the language of this article.

6. REFERENCES

Achard, F., Eva, H.D., Stibig, H.J., Mayaux, P., Richards, T., Malingreau, J.P. 2002, Determination of deforestation rates of the World's humid tropical forests. Science 297, 999-1002.

Andersson, E., Brogaard, S., Olsson, L. 2011, The political ecology of land degradation. Ann. Rev. Environ. Res. 36, 295-319.

Andreasen, J.K., O'Neill, R.V., Noss, R., Slosser, N.C. 2001, Considerations for the development of a terrestrial index of ecological integrity. Ecol. Indic. 1, 21-35.

Angermeier, P.L., Davideanu, G. 2004, Using fish community to assess streams in Romania: initial development of an index of biotic integrity. Hydrobiologia 511, 65-78.

Armenteras, D., Gast, F., Villareal, H. 2003, Andean forest fragmentation and the representativeness of protected areas in the eastern Andes, Colombia. Biol. Conserv. 113, 245-256.

Arroyo-Rodriguez, V., Aguirre, A., Benitez-Malvido, J., Mandujano, S. 2007, Impact of rain forest fragmentation on the population of a structurally important palm species: *Astrocaryum mexicanum* at Los Tuxtlas, Mexico. Biol. Conserv. 138, 198-206.

Bailey, S.A. 2007, Increasing connectivity in fragmented landscapes: An investigation of evidence for biodiversity gain in woodlands. For. Ecol. Manage. 238, 7-23.

Bailey, S.A., Haines-Young, R.H., Watkins, C. 2002, Species presence in fragmented landscapes: modeling of species requirements at the national level. Biol. Conserv. 108, 307-316.

Barbour, M.T., Swietlik, W.F., Jackson, S.K., Courtemanch, D.L., Davis, S.P., Yoder, C.O. 2000, Measuring the attainment of biological integrity in the USA: a critical element of ecological integrity. Hydrobiologia 422/423, 453-464.

Bartlett, J.G., Mageean, D.M., O'Connor, R.J. 2000, Residential expansion as a continental threat to U.S. coastal ecosystems. Popul. Environ. 21(5), 429–468.

Bennett, A.F. 1998, Linkages in the Landscape: The role of Corridors and Connectivity in Wildlife Conservation. IUCN, Gland, Switzerland and Cambridge, UK.

Borja, A., Ranasinghe, A., Weisberg, S.B. 2009, Assessing ecological integrity in marine waters, using multiple indices and ecosystem components: challenges for the future. Mar. Pollut. Bull. 59, 1-4.

Botkin, B.B. 1990, Discordant Harmonies, Oxford University Press, New York.

Cairns, J.Jr., Van der Shalie, W.H. 1980, Biological monitoring: Part I- early warning systems. Water Res. 14, 1179-1190.

Carignan, V., Villard, M.A. 2002, Selecting indicator species to monitor ecological integrity: a Review. Environ. Monit. Assess. 78, 45-61.

Castelletta, M., Thiollay, J., Sodhi, N.S. 2005, The effects of extreme forest fragmentation on the bird community of Singapore Island. Biol. Conserv. 121, 135-155.

Cayuela, L., Golicher, D.J., Benayas, J.M.R., Gonzalez-Espinosa, M., Ramirez-Marcial, N. 2006, Fragmentation, disturbance and tree diversity conservation in tropical montane forests. J. Appl. Ecol. 43, 1172-1181.

Cramer, J.M., Mesquita, R.C.G., Williamson, G.B. 2007, Forest fragmentation differentially affects seed dispersal of large and small-seeded tropical trees. Biol. Conserv. 137, 415-423.

Curran, L.M., Trigg, S.N., McDonald, A.K., Astiani, D., Hardiono, Y.M., Siregar, P., Caniago, I., Kasischke, E. 2004, Lowland forest loss in protected areas of Indonesian Borneo. Science 303, 1000–1003.

DeFries, R., Hansen, A., Newton, A.C., Hansen, M.C. 2005, Increasing isolation of protected areas in tropical forests over the past 20 years . Ecol. Appl. 15, 19-26.

DeKeyser, E.S., Kirby, D.R., Ell, M.J. 2003, An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecol. Indic. 3, 119-133.

Dodd, C.K., Smith, L.L. 2003, Habitat destruction and alteration: historical trends and future prospects for amphibians (In: Amphibian conservation, Ed: R.D. Semlitsch), Smithsonian Institution, Washington DC.

Donovan, T.M., Flather, C.H. 2002, Relationships among North American songbird trends, habitat fragmentation and landscape occupancy. Ecol. Appl. 12, 364-374.

Faber-Langendoen, D., Rocchio, J., Schafale, M., Nordman, C., Pyne, M., Teague, J. 2006, Ecological integrity assessment and performance measures for wetland mitigation. Final Report, March 15, 2006. Nature Serve, Arlington, VA.

Fahrig, L. 2003, Effects of habitat fragmentation on biodiversity. Ann. Rev. Ecol. Evol. Syst. 34, 487-515.

Fongwa, E.A. 2012, Ecosystem services as an indicator for strategic environmental assessment: towards an adaptive sustainability appraisal evaluation framework. Int. J. Ecol. Dev. 22(2), 12-26.

Foppen, R., Ter Braak, C.J.F., Verboom, J., Reijnen, R. 1999, Dutch sedge warblers Acrocephalus schoenobaenus and West African rain-fall: empirical data and simulation modeling show low population resilience in fragmented marshlands. Ardea 87(1), 13-127.

Franklin, J.F., Cromack, K., Denison, K., McKee, A., Master, C., Sedell, J. 1981, Ecological characteristics of old-growth Douglas-fir forests - General Technical Report PNW-118, USDA Forest Service, Portland, OR

Franklin, J.F., Forman, R.T.T. 1987, Creating landscape patterns by forest cutting: ecological consequences and principles. Landsc. Ecol. 1, 5-18.

Gibbs, J.P. 2001, Demography versus habitat fragmentation as determinants of genetic variation in wild populations. Biol. Conserv. 100, 15-20.

Gonzales, A., Lawton, J.H., Gilbert, F.S., Blackburn, T.M., EvansFreke, I. 1998, Metapopulation dynamics, abundance, and distribution in a microecosystem. Science 281, 2045-2047.

Grumbine, R.E. 1994, What is ecosystem management? Conserv. Biol. 8, 27-38.

Haddad, N.M., Baum, K.A. 1999, An experimental test of corridor effects on butterfly densities. Ecol. Appl. 9, 623-633.

Hanski, I. 1999, Metapopulation Ecology. Oxford University Press, New York.

Hargiss, C.L.M., DeKeyser, E.S., Kirby, D.R., Ell, M.J. 2008, Regional assessment of wetland plant communities using the index of plant community integrity. Ecol. Indic. 8, 303-307.

Harris, L.D. 1984, The fragmented forest: Island Biogeography theory and the preservation of biotic diversity. University of Chicago Press, Chicago, IL.

Heckmann, K.E., Manley, P.N., Schlesinger, M.D. 2008, Ecological integrity of remnant montane forests along an urban gradient in the Sierra Nevada. For. Ecol. Manage. 255, 2453-2466.

Henry, M., Cosson, J., Pons, J. 2007, Abundance may be a misleading indicator of fragmentation-sensitivity: The case of fig-eating bats. Biol. Conserv. 139, 462-467.

Hughes, J.E., Deegan, L.A., Weaver, M.J., Costa, J.E. 2002, Regional application of an index of estuarine biotic integrity based on fish communities. Estuaries 25(2), 250-263.

IPCC, 2001, Impacts, adaptation and vulnerability. Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC) - Cambridge University Press, Cambridge, UK.

Jackson, L.E., Bird, S.L., Matheny, R.W., O'Neill, R.V., White, D., Boesch, K.C., Koviac, J.L. 2004, A regional approach to projecting land-use change and resulting ecological vulnerability. Environ. Monit. Assess. 94, 231-248.

Karr, J.R. 1981, Assessment of biotic integrity using fish communities, Fisheries 6, 21-27.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., Schlosser, I.J. 1986, Assessing biological integrity in running waters: a methods and its rationale, Special Publication 5, Illinois Natural History Survey, Champaign, IL.

Karr, J.R. 1991, Biotic integrity: a long-neglected aspect of water resource management. Ecol. Appl. 1, 66-84.

Karr, J.R. 1993, Defining and assessing ecological integrity: beyond water quality. Environ. Toxicol. Chem. 12, 1521-1531.

Karr, J.R. 1996, Ecological integrity and ecological health are not the same (In: Engineering within ecological constraints, Ed: P. Schulze), National Academy of Science, Washington, DC.

Karr, J.R., Dudley, D.R. 1981, Ecological perspective on water quality goals. Environ. Manage. 5(1), 55-68.

Karr, J.R., Chu, E. 1999, Restoring Life in Running Waters: Better Biological Monitoring. Island Press, Washington, DC.

Kruess, A., Tscharntke, T. 2000, Species richness and parasitism in a fragmented landscape, experiments and field studies with insects on *Vicia sepium*. Oecologia 122, 129-137.

Lambin, E.F., Geist, H.J., Lepers, E. 2003, Dynamics of land-use and land-cover changes in tropical regions. Ann. Rev. Environ. Res. 28, 205-241.

Laurance, W.F. 1999, Reflections on the tropical deforestation crisis. Biol. Conserv. 91, 109-117.

Leopold, A. 1949, A Sandy County Almanac and Sketches Here and There. Oxford University Press, Oxford and New York.

Lepers, E., Lambin, E.F., Janetos, A.C., DeFries, R., Achard, F., Ramankutty, N., Scholes, R.J. 2005, A synthesis of information on rapid land-cover change for the period 1981-2000. BioScience 55, 15-124.

Mbile, P., Stolle, F., Boundzanga, G., Mane, L., Loumeto, J., Homb, M., Ifo, S., Ouissika, B., Tessa, B., Poungui, S., Itsoua, G. 2013, Readiness for reducing emissions from deforestation and forest degradation under uncertain, national circumstances. Int. J. Ecol. Dev. 24(1), 27-48.

Metzger, M.J., Rounsevell, M.D.A., Acosta-Michlik, L., Leemans, R., Schröter, D. 2006, The vulnerability of ecosystem services to land use change. Agric. Ecol. Environ. 114, 69-85.

Mohapatra, B. 2012. A study on components of community based management of urban open space. Int. J. Ecol. Dev. 23(3), 99-115.

Moog, O., Chovanec, A. 2000, Assessing the ecological integrity of rivers: walking the line among ecological, political and administrative interests. Hydrobiologia 422/423, 99-109.

Nell, M.C. 2008, Patch connectivity and genetic diversity conservation in the federally endangered and narrowly endemic plant species Astragalus albens (Fabaceae). Biol. Conserv. 141, 938-955.

Noss, R.F. 1987, From plant communities to landscapes in conservation inventories: a look at the Nature Conservancy (USA). Biol. Conserv. 41, 11-37.

Noss, R.F. 1990, Indicators for monitoring biodiversity: a hierarchical approach. Conserv. Biol. 4, 355-364.

Noss, R.F. 1999, Assessing and monitoring forest biodiversity: a suggested framework and indicators. For. Ecol. Manage. 115, 135-146.

O'Neill, R.V. 2001, Is it time to bury the ecosystem concept? (with full military honors, of course!). Ecology 82(12), 3275-3284.

Ortega, M., Velasco, J., Millan, A., Guerrero, C. 2004, An ecological index for littoral wetlands in agricultural catchments of semiarid Mediterranean regions. Environ. Manage. 33(3), 412-430.

Pimm, S.L., Russell, G.J., Gittleman, J.L., Brooks, T.M. 1995, The future of biodiversity. Science 69, 347-350.

Polyakov, M., Majumdar, I., Teeter, L. 2008, Spatial and temporal analysis of the anthropogenic effects on local diversity of forest trees. For. Ecol. Manage. 255, 1379-1387.

Reza, M.I.H., Abdullah, S.A. 2011, Regional Index of Ecological Integrity: A need for sustainable management of natural resources. Ecol. Indic. 11, 220-229.

Reza, M.I.H., Abdullah, S.A., Nor, S.M., Ismail, M.H. 2013, Integrating GIS and expert judgment in a multi-criteria analysis to map and develop a habitat suitability index: A case study of large mammals on the Malayan peninsula. Ecol. Indic. 34, 149-158.

Simon, T.P. 1999, Biological Response Signatures: Indicator Patterns Using Aquatic Communities. CRC Press, Boca Raton, FL 33487, USA.

Solimini, A.G., Bazzanti, M., Ruggiero, A., Carchini, G. 2008, Developing a multrimetric index of ecological integrity based on macroinvertebrates of mountain ponds in central Italy. Hydrobiologia 597, 109-123.

Soule, M., Lease, G. 1995, Reinventing Nature? Island Press, Washington, DC.

Timko, J.A., Innes, J.L. 2009, Evaluating ecological integrity in national parks: case studies from Canada and South Africa. Biol. Conserv. 142, 667-688.

Tischendorf, L., Fahrig, L. 2000, How should we measure landscape connectivity? Landsc. Ecol. 15, 633-641.

Torri, M.C., Herrmann, T.M. 2012, Cultural relations and local ecological concerns as baseline for wildlife co-management and bioculture conservation. Int. J. Ecol. Dev. 22(2), 88-101.

Wang, Y.H. 2008, Palm community structure and land-cover changes in the San Juan Biological Corridor, Costa Rica. Biotropica 40(1), 44-54.

White, D., Preston, E.M., Freemark, K.E., Kiester, A.R. 1999, A hierarchical framework for conserving biodiversity (In: Landscape ecological analysis: issues and applications, Eds: J.M. Klopatek, R.H. Gardner). Springer-Verlag, New York, NY, USA, pp. 127-153.

With, K., Gardner, R.H., Turner, M.G. 1997, Landscape connectivity and population distributions in heterogeneous environments. Oikos 78, 151-169.

WHO, 2010, The World Health Report- Health Systems Financing: The Path to Universal Coverage. World Health Organization Press, Geneva, Switzerland.

Young, T.F., Sanzone, S. 2002, A framework for assessing and reporting on ecological condition. EPA Science Advisory Board, Washington, DC.

Yunus, A.J.M., Nakagoshi, N., Ibrahim, A.L. 2004, Riparian land-use and land-cover change analysis using GIS in Pinang river watershed, Malaysia. Tropics 13, 235-248.