Ursula L. Kaly

Smart Indicators, the Environmental Vulnerability Index (EVI) and describing ecosystem health

---

This paper describes lessons learned from the development of the South Pacific Applied Geoscience Commission (SOPAC) Environmental Vulnerability Index (EVI) that could be used in the development of indicators of the status or 'health' of ecosystems at a range of scales. The EVI was developed to describe the vulnerability of natural environments at the scale of entire states to a range of natural and human hazards and uses an indicators and index approach. It embodies three methodological aspects that are relevant to providing information for the management of any ecosystem. The first of these is the explicit definition of 'pristine' conditions (even if there are recognised alternative unstable states) as the direction that all management actions should take. This acknowledges that different uses of the ecosystems will keep their health at other than pristine levels. The indicators developed for the EVI and for coral reefs, used as examples of different scales here, would act not only to identify the current status of countries or reefs, but could be used to define thresholds for management. The second insight is that humans are part of the greater context within which ecosystems now function. This means that human choices and behaviours are an integral part of the structure and function of ecosystems and should be included as indicators of their health. Finally, I discuss the need for smart indicators for the EVI and ecosystems in general. This means that indicators need to be developed that summarise the structure and function of a large number of transactions occurring on, for example, coral reefs, without our necessarily knowing how each works or what condition it is in. Smart indicators have built within them some expression of how well a reef is faring in relation to optimum conditions and other reefs elsewhere.

INTRODUCTION

If humans are to be truly able to manage ecosystems including those as complex as coral reefs they are going to need a reliable, simple, relatively inexpensive way of checking on the 'health' of the ecosystems and being able to make some assessment of how they are going in their attempts to manage them in relation to some ideal. This would form part of an iterative system of management with the ability to constantly adjust management options in relation to real outcomes and unpredictable behaviour on the part of reefs. Problems with this adaptive management approach were highlighted recently in a special feature in Conservation Ecology (1,2). Problems include difficulties in developing acceptable predictive models, conflicts between ecological values and management goals, inattention to non-scientific information, and unwillingness to implement long-term risky or costly programmes. By suggesting that human behaviour be incorporated into the information collected for a coral reef management model, Done and Diop (3) have attempted to take adaptive management a step further. They suggest the incorporation of human systems (socio-economic, use/conservation and policy/management) as part of the overall ecosystem complex to be managed. That is, measures of the health and viability of coral reefs includes in its greater context the way that people choose to use and manage them and the socio-economic context from which they make their choices.

The concept of health in relation to reefs, or any ecosystem, is a slippery one. We have no way of indicating the ideal number of species, community characteristics, energy flows or ecosystem services for even a single reef, let alone arrive at some guidelines for the range of complex systems we are concerned with across the globe. Despite not really being ready for the challenge, we are forced by necessity to start taking action (5) and learning as we go (6). In the past we have not as a group of scientists, planners and managers looked into coral reef ecosystems to try and find simple measures that would indicate health and provide some way of easily measuring changes through time. We have not looked hard enough for those measures that would provide a proxy or summary for the millions of processes that must be going on within human and natural ecosystems and on all kinds of time scales.

In this paper, I wish to focus on how we might go about obtaining the kinds of information we might need through indicators as a basis for management of coral reefs as an example of a single ecosystem and through the EVI which has been developed for assessing the vulnerability of natural environments at the scale of entire states. The information would have to be collected in relation to defined ideal conditions for human and ecosystem measures. I will then suggest ways of constructing indicators in relation to targets for the health of coral reefs and the healthy behaviour of humans in relation to them. Finally, I will deal with what I will term 'smart indicators' which might be an approach to providing relatively simple measures of how well reefs and their humans are faring in terms of coexistence.

THE EVI APPROACH TO ENVIRONMENTAL MANAGEMENT AT THE SCALE OF COUNTRIES

The Environmental Vulnerability Index (EVI) was developed by the South Pacific Applied Geoscience Commission (SOPAC, Fiji) as a response to calls for measures of the vulnerability of states from the Alliance of Small Island States (AOSIS) and the Barbados Programme of Action (7). The EVI was designed to provide a relatively quick and inexpensive mechanism for characterising states in terms of the vulnerability of their natural environments to natural and anthropogenic hazards (8). The alternative would be *ad hoc* assessments for each state which would be costly in terms of time and resources and which could not provide a common basis for comparison.

The EVI uses 49 indicators of exposure of the natural environments of a state to hazards and their intrinsic and extrinsic resilience to hazards (table 1). The table of indicators is included here because it shows the range and complexity of indicator questions considered necessary to measure vulnerability of natural environments. The measures include both natural and human components, forming three types of sub-index: The REI (Risk Exposure Index) provides information on the types and intensity of risk to natural and anthropogenic hazards. The IRI (Intrinsic Resilience Index) measures signals relating to the innate characteristics of a state which tend to make it resilient to hazards, while the EDI (Environmental Degradation Index) provides an assessment of the present condition of the natural environments assuming that those in the best condition will be most resilient to future shocks. Information collected for a state for each of the indicators is compared with ideal conditions and/or those conditions found world-wide so that data may be mapped onto a 1-7 scale. That is, the conditions for any state with respect to a single indicator will be represented somewhere on that 1-7 scale. The scale itself may be linear, non-linear or discontinuous and was developed to accommodate heterogeneous types of information (yes/no, percentage or numerical). The scores derived from this mapping are then averaged to produce an overall EVI and sub-indices. Because data are mapped on the 1-7 scale, for which a high score is considered more vulnerable, it is possible to use the individual scores as a way of identifying problem areas in terms of risk or environmental degradation (7, 9).

The EVI relies on four assumptions of importance to this discussion. At its basis, the EVI assumes that (i) the more pristine environments are, the better will be their resilience to natural and anthropogenic shocks. It also assumes that (ii) natural environments in good condition generally serve the needs of humans better than damaged ones (particularly for ecosystem services). The EVI assumes that (iii) human behaviours, choices and socio-economic conditions are part of environmental vulnerability and seeks to measure these as part of the index. Finally, it assumes that (iv) indicators may be found which describe and summarise a host of complex processes which must be operating and which vary in terms of their final values in a way that relates to (the largely immeasurable) details of interest in the system being measured.

In many ways, the needs to be met by the EVI are similar to those for managing the world's ecosystems. Although not directly applicable in its present form, the approach taken for the EVI could be adapted to the task of providing information for the protection of biodiversity, ecosystem management and identifying areas for action.

SETTING TARGETS FOR INDICES

There are three aspects of ecosystem condition of concern to us if we are to provide information and decision support for any ecosystem, such as coral reefs. These are: (1) The ideal condition we would like our system to be in; (2) The present state of a reef in relation to the ideal and defined management thresholds; and in order for our management to work in the long run: (3) The total viability and health of coral reefs made up from a composite picture at a range of spatial scales.

The first two assumptions of the EVI relate to explicitly setting targets for the condition of natural environments against which the performance of a particular state could be measured. This applies also to coral reefs in the present discussion. It needs to be explicitly-stated that 'pristine' or 'natural' conditions of a reef are the direction in which all management should aim, and that thresholds along that arrow may mark certain management choices. The purpose of indicators and indices would then be to locate a particular reef or group of reefs in terms of their health along the axis from 'degraded' to 'pristine'.

These above points relate specifically to not setting management arrows so that they point towards a particular usage type or management zone (e.g. open access fishing area).

Doing so would make it difficult to assess damage sustained through human pressures because the new management target could become an artificial reef community which might not best serve our aims at preserving biodiversity and human welfare. There is also a question of being able to accumulate coral reef data over larger scales to examine overall viability and status of the world's reefs. To do this, we need a common basis for comparison – I suggest this common basis should be some measure of 'pristineness' of reefs. The health of the world's coral reefs depends on the overall picture made up of its many pixels, highlighting the value of geographic information systems (GIS).

HUMANS AS PART OF ECOSYSTEMS

Humans are explicitly incorporated as indicators in the EVI, and in the categories identified by Done and Diop (3). A total of 38% of the EVI's indicators are direct measures of human choices and behaviour in relation to environmental vulnerability. There are socio-economic indicators: 25-27, 46, 47, 48-49; those dealing with use/conservation: 18, 23, 29, 30, 32-35, 37, 38-39; and policy/management: 44-45, 47 (table 1). In addition to these, indirect human measures are implicit in some of the remaining indicators (e.g. indicators 17, 19, 20-21). By incorporating humans directly into the model and indicators, it is expected that we will be better able to observe interactions between humans and their natural environments and alert institutions when any part of the system starts to slide backwards along the management arrow. Clearly, the search for indicators for the management of the world's coral reefs will need to incorporate humans as an explicit and fully integrated part of the information and decision-support system.

SMART INDICATORS FOR CHECKING THE HEALTH OF ECOSYSTEMS

'Smart indicators' could be defined as those which capture a large number of elements in a complex interactive system while simultaneously showing how the value obtained relates to some ideal or agreed-upon condition. The central aim of the EVI was to populate it with only smart indicators, and the search for appropriate smart indicators is on-going. The basic assumption of smart indicators is that the value of a chosen indicator is a culmination of perhaps millions of transactions that must have been operating appropriately to result in the value obtained. Thankfully, this does not require our full knowledge of every transaction because if this were a requirement, we would never be able to use indicators at all. Further, to some extent all indicators are 'smart' – this is essentially a search for the smartest and most efficient for our purposes. In the EVI for example, indicator 36 deals with the maximum SO_2 concentration in the largest city of a state. This indicator is obviously intended to capture industrial discharges, but has within it the density of those discharges, choices people make about the form that discharge takes and the ability of the environment to attenuate them. In turn, the ability of the environment to attenuate discharges captures other features of the system such as forest cover, wind patterns etc.

In the case of coral reefs, a similar search for smart indicators will be required. Some possible avenues for development have been identified and possible smart indicators are being examined for corals, other invertebrates, fishes, recruitment and physical features (4). Humans and other reef categories will need to be incorporated in the future.

Central to the concept of smart indicators is the idea that good and bad performance is inherent in the way the indicator is expressed. For the EVI, this was achieved by mapping the value of an indicator on a scale ranging from 1 (relatively resilient) to 7 (very vulnerable). This approach serves two important functions. Firstly, for the managers and scientists it forces us to decide on actual values for the indicator that are 'good' or 'bad'. This has not been an easy task because information on the vulnerability and limits to viability of ecosystems is generally lacking (5). Further, for the EVI it was necessary to make the index globally-applicable. This means that the range of values for an indicator not only has to indicate vulnerability, but also be applicable across all conditions found on the planet.

The second function of inherently expressing the value of an indicator is of greatest interest to the users of the EVI. Irrespective of whether the final EVI is calculated or not, any single indicator gives us a performance rating for that measure that contains within it our best understanding of how ecosystems respond to hazards. This means that the user need not be an expert to read the results - the work has already been done in the selection of the indicators and the setting of response levels. For users, smart indicators mean near-instant results, making them amenable to use by non-scientists, until now one of the weaknesses of adaptive methods of management (10).

For coral reefs it may be sufficient to provide cut-off levels for each indicator, rather than mapping them onto a graded scale. One promising smart indicator that has been suggested (4) takes the form of measuring the amount of incident wave energy translated across a reef. For a healthy reef, the amount of energy passing the reef should be no more than 10% of the incident energy. This smart indicator has built into it the idea of a limit so that users can understand whether their reef is healthy or not, and incorporates information on hundreds of measures and processes that must be operating well to pass the test. These processes might include good recruitment of corals and fishes, high rugosity of the reef, good cover by corals and algae, a good upwards growth rate and all of the minor and major transactions that would be going on within a healthy reef ecosystem to result in the translation of only 10% of incident wave energy. It is a range of indicators such as this that is urgently needed for better management of coral reefs.

CONCLUSIONS

Providing information and decision support for the urgent task of preventing the further decline of the world's ecosystems requires, in part, the development of rapid methods for assessing their health. The approach taken during the development of the Environmental Vulnerability Index provides us with some direction for achieving this. The first lesson derived from the EVI is that the indices require the explicit statement of ideal conditions that ecosystems should be in, and that this ideal should be on a continuum that points towards natural or pristine conditions. The second lesson is that humans are part of the world's ecosystems and that their choices and behaviours need to be monitored as part of an ecosystem's health just as importantly as any measure of diversity or ecosystem structure. This suggests that measures of ecosystem health need to include human indicators. Finally, I have introduced the concept of smart indicators in the context of the EVI and of coral reefs. For indicators to provide the information necessary and to bridge the distance between science and users, it is necessary that they be end-point indicators. This requires that they be crafted so that they embody details of which we might not be aware and that they convey in their expression an immediate understanding of the status of the country or ecosystem being managed.

References and Notes

1. Gunderson, L. 1999. Resilience, flexibility and adaptive management – Antidotes for spurious certitude? *Conservation Ecology 3(1):* 7 [online] (http://www.consecol.org/vol3/iss1/art7).
2. Johnson, B.L. 1999. Introduction to the special feature: Adaptive Management – Scientifically sound, socially challenged? *Conservation Ecology 3(1):* 10 [online] (http://www.consecol.org/vol3/iss1/art10).

3. Done, T. and Diop, S. 1999. Information management and decision support for marine biodiversity protection and human welfare: coral reefs. *Background paper for Information management and decision support for marine biodiversity protection and human welfare: Coral Reefs: a workshop.,* 14pp.
4. AIMS, 1999. Information management and decision support for marine biodiversity protection and human welfare: coral reefs: a workshop. Done, T and Lloyd, D, (eds) *Australian Institute of Marine Science, Townsville, UNEP, Nairobi and CRC Reef Research Centre.*
5. Daily, G.C. 1999. Developing a scientific basis for managing earth's life support systems. *Conservation Ecology 3(2):* 14 [online] (http://www.consecol.org/vol3/iss2/art14).
6. Walters, C.J. and Holling, C.S. 1990. Large-scale management experiments and learning by doing. *Ecology 71,* 2060-2068.
7. Kaly, U.L., Briguglio, L., McLeod, H., Schmall, S., Pratt, C. and Pal, R. 1999a. Environmental Vulnerability Index (EVI) to summarise national environmental vulnerability profiles. *SOPAC Report to NZODA, New Zealand,* 38pp.
8. Kaly, U.L. and Pratt, C. The Environmental Vulnerability Index and Profiles: Outcome-focused Environmental Management at the Scale of Countries, *Ambio*, this volume.
9. Kaly, U.L., Briguglio, L., McLeod, H., Schmall, S., Pratt, C. and Pal, R. 1999b. *Report on the Environmental Vulnerability Index (EVI) Think Tank, 7-10 September 1999, Pacific Harbour, Fiji. SOPAC Technical Report 299 to NZODA, New Zealand,* 77pp.
10. Shindler, B. and Cheek, K.A. 1999. Integrating citizens in adaptive management: A propositional analysis. *Conservation Ecology 3(1)*: 9 [online] (http://www.consecol.org/vol3/iss1/art9).

ACKNOWLEDGMENTS

The development of the EVI has been generously supported by New Zealand, Norway, Ireland and Italy. Additional support was given by the SOPAC Member Countries, the United Nations Environment Programme (UNEP), the Australian Institute of Marine Science, the South Pacific Regional Environment Programme (SPREP), the Pacific Island Forum Secretariat, the Secretariat for the Pacific Community, the University of Malta and the World Meteorological Organisation (WMO).

TABLE 1. Indicators used for calculating the Environmental Vulnerability Index (EVI). Indicators fall into three sub-indices as follows: The REI = Risk exposure sub-index; IRI = Intrinsic Resilience Sub-index; and EDI = Environmental Degradation sub-index. Categories refer to risks to the natural environment as follows: Met = meterological, G = geological, CC = country characteristics, B = biological, A = anthropogenic. Response levels for the indicators are still being developed and are not provided here.

Indicator Number	Sub-Index	Category	Indicator
1	REI	Met	Greatest average annual deviation in Sea Surface Temperatures (SST) in the last 5 years as compared with the long term mean (30 years)
2	REI	Met	Number of days over the last five years during which the maximum recorded wind speed (3 sec wind gusts) is greater than 20% higher than the average maximum wind speed for that month. (Use 30-year average for each month as reference points and data to be accumulated over all reference climate stations and be divided by the number of stations)
3	REI	Met	Number of months over the last five years during which rainfall is greater than 20% lower than the 30 year average for that month (over all reference climate stations / number of climate stations)
4	REI	Met	Number of months over the last five years during which rainfall was greater than 20% higher than the 30 year average for that month (over all reference stations / number of climate stations)
5	REI	Met	Number of days over the last five years in which the maximum temperature was greater than 5°C higher than the mean monthly maximum (reference mean is from the 30 year average) (over all reference stations/ number of climate stations)
6	REI	Met	Number of days over the last five years in which the minimum temperature

			was greater than 5°C lower than the mean monthly minimum (reference mean from the 30 year average) (over all reference stations/ number of climate stations)
7	REI	G	Number of volcanoes with potential for eruption greater than or equal to Volcanic Explosive Index of 4 (VEI 4) within 100km of country land boundary per area of land
8	REI	G	Cumulative earthquake energy within 100km of country land boundaries per land area with Local Magnitude (ML) greater than or equal to six (>= 6.0) and less than or equal to depth of fifteen kilometres (<= 15km) over 5 years
9	REI	G	Number of tsunamis or storms surges with run up greater than 2 metres above Mean High Water Spring tide (MHWS) per 100km coastline since 1900
10	IRI	CC	Total land area (sq km)
11	IRI	CC	Ratio of length of shoreline or land border to total land area
12	IRI	CC	Distance to nearest continent within 10 degrees latitude (km).
13	IRI	CC	Altitude range (highest point subtract the lowest point in country)
14	IRI	CC	Percent of land area less than 10 metres above sea level
15	IRI	CC	Percent of land area below 10 metres in elevation within 2 kilometres to coast composed of unconsolidated sediments (excluding coral reefs)
16	IRI	CC	Number of known endemic species per square kilometre land area
17	REI	B	Number of reported (and verified) organism outbreaks (pathogens, blooms, plaques etc) over the last five years per land area
18	REI	B	Total tonnage of freight imported per year per square kilometre of land area
19	EDI	B	Number of introduced species per square kilometre land area (IUCN Definitions)
20	EDI	B	Number of endangered and threatened species per square kilometre land area (IUCN Definitions)
21	EDI	B	Number of species known to have become extinct since 1900 per square kilometre land area (IUCN Definitions)

22	EDI	B	Percentage of natural and regrowth vegetation remaining (e.g. forests, mangroves. prairies, saltmarshes, tundra, desert, savannah)
23	EDI	B	Tonnage of intensively farmed animal products (includes aquaculture, pigs, chickens, cattle, etc.) produced per year per square kilometre land area
24	EDI	B	Percent of fisheries stocks over-fished (FFA/FAO definitions)
25	EDI	A	Density of people living in coastal settlements (i.e. with a city centre within 100km of the coast)
26	REI	A	Total human population density (number per km2 land area)
27	REI	A	Annual human population growth rate (average over last five years)
28	REI	A	Net percentage of land area changed by removal of natural vegetation over the last five years
29	REI	A	Annual number of international tourists multiplied by the average length of stay in the country over one year per land area (over the last five years)
30	REI	A	Litres of untreated industrial and domestic wastewater discharged per day per square kilometre of land area
31	REI	A	Total net tonnage of generated and imported toxic, hazardous and municipal wastes per square kilometre land area average last 10 years
32	REI	A	Mean percent of hazardous, toxic and municipal waste "effectively" managed or treated per year
33	REI	A	Number of spills of oil and hazardous substances greater than1000 litres during the last five years on land, in rivers or within territorial waters per square kilometre of land area
34	REI	A	Number of nuclear, chemical and other major industrial facilities (e.g. oil rigs) that could cause significant environmental damage per square kilometre land area
35	REI	A	Number of vehicles per square kilometre of land area
36	REI	A	Maximum 24 hour SO_2 concentration (microgram/m^3) (average over last five years)
37	REI	A	Tonnes of nitrogen (N), phosphorus (P) and potassium (K) fertilisers used

			per year per square kilometre of agricultural land (average last five years)
38	REI	A	Tonnes of pesticides used per square kilometre of agricultural land (average last five years)
39	REI	A	Number of new fisheries stocks or expanded fisheries efforts (greater than 20% increase in catches) added to the country over the last five years (within territory)
40	EDI	A	Percent of land area degraded
41	EDI	A	Mean percentage of water usage per year met from renewable and non-declining sources.
42	REI	A	Tonnes of mining material (ore + tailings) extracted per square kilometre per land area per year average last five years
43	EDI	A	Percentage of land, rivers and coastal zone affected by mining and quarrying
44	EDI	A	Percent of terrestrial zone set aside as reserves
45	EDI	A	Percent of marine zone set aside as reserves (mean high tide to continent shelf)
46	EDI	A	Number of war or civil strife years over the last 50 years within the territory
47	EDI	A	Environmentally related legislation with regulations
48	EDI	A	Percentage of population with access to safe sanitation
49	EDI	A	Area of land engaged in the agriculture or field testing of any genetically modified organisms

Ursula Kaly is a Senior Researcher attached to the South Pacific Applied Geosciences Commission (SOPAC) in Suva, Fiji and the University of Wollongong, in Australia. She trained in marine ecology at the University of Sydney and obtained a PhD on the ecology of mangrove fauna. Her research focuses on human impacts on and conservation of marine and coastal ecosystems. She has worked extensively on environmental management issues and methods of detecting change in ecosystems in the Pacific Region and other parts of the world. She may be contacted at the South Pacific Applied Geosciences Commission (SOPAC), PMB, GPO Suva, Fiji, e-mail: uschikaly@bigpond.com.

Craig Pratt is the coordinator of the EVI Project at SOPAC, Fiji. He graduated from Macquarie University, Sydney with an MSc on Environmental Studies. His expertise is in the field of environmental management in developing countries, and he has worked extensively in 18 Pacific Island Countries. He may be contacted at the South Pacific Applied Geosciences Commission (SOPAC), PMB, GPO Suva, Fiji, e-mail: craig@sopac.org.