Environmental Vulnerability Index (EVI) to summarise national environmental vulnerability profiles

By:

Ursula Kaly[1], Lino Briguglio[2], Helena McLeod[3],
Susana Schmall[3], Craig Pratt[3] and Reginald Pal[3]

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[1] Environmental Adviser, Tuvalu Government, Tuvalu
[2] Islands and Small States Institute, Foundation for International Studies, University of Malta, Malta
[3] South Pacific Applied Geoscience Commission (SOPAC), Fiji

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1. Vulnerability index – environment

Abstract

This report describes the development of a vulnerability index for the environment which could be calculated on the scale of entire states for the purpose of ranking them and providing a single-figure expression of their relative environmental vulnerabilities. This work was done in response to a call made in the Barbados Plan of Action, the Alliance of Small Island States (AOSIS) and an increasing awareness that small island developing states face disadvantages to their development associated with their remoteness, small size, dispersion, economic conditions and limited natural resources. In the past vulnerability indices have been developed which describe the risks associated with economic and social conditions, climate change, sealevel rise, natural disasters and anthropogenic impacts. Most of these indices describe the vulnerability of human systems; there have been very limited attempts to describe effects on the environment. Human systems and the environment are dependent on one another so that risks to the environment of a state will eventually translate into risks to humans. This is the first attempt to construct an index that focuses on the vulnerability of the environment.

An Environmental Vulnerability Index (the EVI) was constructed, based on a theoretical framework that identified three aspects of vulnerability: risks to the environment (natural and anthropogenic), the innate ability of the environment to cope with the risks (resilience) and ecosystem integrity (the health or condition of the environment as a result of past impacts). These three aspects correspond to three sub-indices, the REI, IRI and EDI, which are the Risk Exposure sub-Index, Intrinsic Resilience sub-Index and Environmental Degradation sub-Index respectively. The EVI was calculated as a weighted average of scores allocated in the range of 0-7 derived from a total of 57 indicators.

A preliminary EVI was calculated for three countries, Australia, Fiji and Tuvalu. The preliminary EVI value for Tuvalu was the highest of the three countries indicating that its environment is the most vulnerable. The score obtained for Fiji was intermediate in value, and that for Australia was the lowest, though the difference between Fiji and Australia was relatively smaller than that between Fiji and Tuvalu. There were similar levels of risk in each of the countries, the most degradation in Australia and the least intrinsic resilience in Tuvalu. These results, though promising are only preliminary because the EVI requires refinement and there was insufficient time to collect all of the required data from all of the countries and because there were some inconsistencies in the quality of the data. We expect that each of these problems can be overcome.

The EVI developed here will require further refinement before it becomes fully operational. The results show that it is possible to obtain a single figure measure of vulnerability and that data which were previously thought to be difficult to obtain can be obtained. The methodology selected in the computation of the index can produce results which could have operational usefulness for ranking countries according to their environmental vulnerabilities.

It is envisaged that the EVI would be recalculated every 5 years to provide updates on the vulnerability status of countries. This index highlights the need for governments to upgrade their collection and collation of environmental statistics. In addition, the breakdown of results into meteorological, geological, anthropogenic, and other categories of risk highlights areas of concern for environmental action.

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Background

Small Island Developing States (SIDS) face serious disadvantages to their development associated with an interplay of factors such as remoteness, geographical dispersion, vulnerability to natural disasters, a high degree of economic openness, small internal markets, limited natural resources and fragile ecosystems. These issues have been recognised and increasingly highlighted in international fora during the last decade.

Initial attempts at constructing a vulnerability index focused on economic aspects and followed a proposal by the Maltese Ambassador during a 1990 UNCTAD expert meeting on the problems of small island developing states.

vulnerability indices, human impact is considered an exogenous factor, and human systems not the recipients of the impact.

Environmental vulnerability differs from vulnerability of human systems because the environment is complex with different levels of organisation from species to interdependent ecosystems and the complex linkages between them. Because data are often not available and indicators for health and vulnerability of the environment have to be physically measured, indicators may be heterogeneous in nature and not expressible in common units. This means that developing an index for the environment will need a new approach.

The need for an EVI

The need for an environmental vulnerability index was recognised at the Global Summit on Small Island States held in Barbados in 1994 where the United Nations formally expressed the desire in paragraphs 113 and 114 of the Barbados Plan of Action for the development of a such an index. The benefits of producing an EVI are that it can attract attention to certain states which are considered 'more vulnerable' and it summarises vulnerability based on meaningful criteria which can be considered by donors when allocating financial aid and projects.

The overall aim of this study was to begin the development of an environmental vulnerability index consistent with the Barbados Plan of Action and needs of the Alliance of Small Island States (AOSIS). The EVI developed here could then be combined with an economic vulnerability index to give a composite index which in a single figure format incorporates the environmental and economic concerns of a state. It is envisaged that the EVI and CVI would be recalculated every 5 years to examine changes through time as well as relative rankings of countries.

The specific aims were to:

- Review current work already completed or underway addressing environmental vulnerability of SIDS;
- Build on past work on environmental vulnerability, if appropriate, or approach the problem from a new perspective where other attempts have had limited success;
- Identify variables which may be used in the construction of an environmentally descriptive vulnerability index for Pacific SIDS;
- Develop a logical framework and methods of calculating and index for environmental vulnerability;
- Identify and collect data which would be used to calculate the environmental index;
- Identify gaps in the available data;
- Identify future directions for the further development of an internationally acceptable environmental vulnerability index;

- Compile a report for widespread circulation and consideration prior to the Donor Round Table leading up to CSD-7 and the UN General Assembly special session on SIDS in September 1999; and
- Further efforts towards the development of a composite vulnerability index as described in the Barbados Program of Action and meet the needs enunciated by AOSIS.

Mini review of previous work on vulnerability indices

Fifteen studies were reviewed which examine the relative vulnerabilities of states in terms of risks to human and natural systems. Most of the studies were concerned with risks to human economic and social systems (13), while only 5 attempted to describe effects on the natural environment. The risks of concern also varied among studies. Anthropogenic risks were considered in 11 studies; 6 studies examined climate change and sealevel rise; and 6 studies considered natural disasters as part of their risk. Only 1 study specifically examined the effects of both humans and natural hazards on the environment. It is the object of this study to fill this gap by developing an environmental index based on a wide array of environmental indicators which includes both natural and anthropogenic risks.

Features of past vulnerability indices

1. There has been some confusion with terminology. In one study, an Ecological Vulnerability Index was developed which actually looked at the vulnerability of human systems to natural disasters and inherent geographic characteristics, rather than vulnerability of the environment. We propose that vulnerability indices should be named by their responders, not risks. Human vulnerability indices include Economic, Quality of Life and Human Development Indices. This is the first study to attempt a true Environmental Index.
2. The logical framework for past indices has tended to be lacking. The successful development of an EVI requires a logical framework to ensure that the index is not just driven by data availability, terms are fully defined, appropriate indicators are found and the model can be tested.
3. The number of indicators varied among studies. Studies with only a few indicators (3-6) tended to focus on human systems. When the number of indicators used was moderate (12-15) more emphasis was placed on natural disasters and ecological variables. Only one study used a large number of indicators (60) and it was the only one which produced a list of indicators for anthropogenic pressures on the environment. The lesson here is that more indicators are required when complex ecological systems become the focus of the index being constructed.
4. Five different methods of evaluating or scoring the indicators were identified from the studies reviewed. Some of these were considered for the present study.
5. Five different methods were identified for aggregating the value of the indicators into an index or sub-indices. None of these was considered appropriate for the EVI. A modification of two methods identified from past indices was used.

Theoretical framework for the EVI

The maintenance of ecosystem or ecological integrity is at the heart of the development of a vulnerability index for the environment, because it is ecosystem integrity that is threatened by natural and anthropogenic hazards. The notion of ecosystem integrity is so complex that it cannot be expressed through a single indicator, but rather requires a set of indicators at different spatial, temporal and hierarchical levels of the ecosystem. Ecosystem integrity depends on biodiversity, ecosystem functioning and resilience, all of which are such interrelated variables, that factors which affect just one of these can have far-reaching ecosystem-wide consequences.

The risks to the environment are any events or processes that can cause damage to ecosystem integrity. These include natural and human events and processes such as 'the weather' and 'pollution'. Some researchers have identified natural hazards as those in which natural environmental conditions depart from 'normal' to such an extent that systems of interest (human, environmental) may be adversely affected. The problem with this definition is that unless we identify certain natural events as being anthropogenically altered (e.g. anthropogenically-accelerated sea-level rise), all events are 'normal'. The implication from this line of reasoning is that the changes we see to the natural world as a result of natural hazards are deemed 'unacceptable' from a human perspective. This means that except in the case of anthropogenic risks, in an assessment of environmental vulnerability, what we really are examining is unacceptable departures from our (human) view of how the environment should change. For the purposes of this study, we will accept that risk events should include those which cause sudden and seemingly-negative impacts on natural systems as a way to evaluate vulnerability.

Although most identifiable risk events are capable of causing damage, it is only the larger and more intense events that are likely to cause wholesale changes in the environment, at least in the short to mid term. Some of the more important risks which can impact on the environment include meteorological events (e.g. cyclones, droughts, heatwaves), geological events (earthquakes, tsunamis, volcanoes), anthropogenic impacts (mining, habitat destruction, pollution), climate change and sealevel rise.

The entities at risk, termed the 'responders' include ecosystems, habitats, populations and communities of organisms, physical and biological processes (e.g. beach building, reproduction), energy flows, diversity, ecological resilience and ecological redundancy.

Three aspects of environmental vulnerability were identified which would need to be incorporated into an EVI. These are:

1. The level of risks (or pressures) which act on the environment within the state, forming the Risk Exposure sub-Index (REI) which examines the frequency and where possible, the intensity of risk events which may affect the environment. These are based on levels

observed over the past 5-10 years for most risks, but may include data for much longer periods for geological events. The REI is a measure of potential risk only: There is no logical expectation that patterns of risk expression during the immediate history of a state will necessarily result in similar risk levels today or in the future;

2. Intrinsic vulnerability or resilience of the environment to risks, forming the Intrinsic Resilience sub-Index (IRI) which refers to characteristics of a country which would tend to make it less/more able to cope with natural and anthropogenic hazards; and
3. Extrinisic vulnerability or resilience as a result of external forces acting on the environment, forming the Environmental Degradation sub-Index (EDI) which describes the ecological integrity or level of degradation of ecosystems. The more degraded the ecosystems of a country (as a result of past natural and anthropogenic hazards), the more vulnerable it is likely to be to future risks.

Features of the EVI

In developing the EVI, we set criteria on certain features of the index to ensure that it would be able to perform the tasks for which it was developed. The criteria were that the EVI should be intuitively understandable (set within a range from which highly vulnerable states have immediate recognition as such), impartial, suitable for international comparisons and able to differentiate among countries, applicable at different spatial scales (regional, country, island), refinable, presented in breakdown and single figure formats and easy to calculate using a user-friendly computer interface.

Methodology

Because the risks are many and ecosystem resilience and integrity are complex in character, it was necessary to use indicators to characterise them. This means that not all aspects are covered, but that a subset of variables is selected which describes frequency and intensity of risks, intrinsic vulnerability, effects on ecosystems, groups of organisms, physical features of the environment and mitigators of effects.

For the purposes of the EVI the following definitions relating to indicators and indices were used:

- An **indicator** was defined as any variable which characterises the level of risk, resilience or environmental degradation in a state;
- A **sub-index** (the REI, IRI and EDI) was defined as an aggregated average of the scores for indicators which related separately to risk, resilience or degradation; and
- An **index** (the EVI) was defined as an aggregated average of each of the three sub-indices (REI, IRI, EDI) to give an overall measure of the environmental vulnerability of a state. The EVI is then, a **composite** of each of the three sub-indices.

The criteria for the selection of indicators was that they should be applicable over the entire scale of interest (countries, regions), spread over different geographic, habitat and climatic types, relatively easy to understand, well defined, have data available now or with assistance in the future and be as uncorrelated as possible (to limit redundancy).

A total of 57 indicators of environmental vulnerability were finally selected for inclusion in the index. This included 39 indicators of risk (REI), 5 indicators of resilience (IRI) and 13 indicators of environmental integrity or degradation (EDI) (Annex 2). Many of the indicators were expressed as a fraction of area of land or coast rather than simply absolute numbers because it is risk density or proportion of area degraded that is of interest from an environmental perspective.

Although a larger number of indicators would have been preferred to obtain a wider picture of risks, resilience and ecological integrity, many of the indicators initially selected were discarded because they either did not have data available and data were unlikely to be procured in the near future, they were ambiguous or bimodal in their responses; or were redundant and the information they intended to capture was present in another indicator.

Data for calculating the EVI (and initially setting the response levels) were collected for three countries: Fiji, Tuvalu and Australia to provide some initial testing of the model. These data were obtained from country reports, UN, WHO, SOPAC, SPREP, FAO and other publications from international agencies, centres for risk assessment and management (e.g. Tsunami Centre, NOAA), local experts and government officers. Without being able to go to the countries to train and focus attempts of local authorities to the task of collecting or collating the required data, some indicators were unavailable for this initial testing.

Quantifying vulnerability

Our overriding principle in constructing the EVI was not to introduce complexities into the model unless there was a justifiable reason to do so.

Environmental indicators are of a heterogeneous nature, that is they include variables for which the responses are numerical, qualitative and on different scales (linear, non-linear, or with different ranges). To deal with the heterogeneity, it was necessary to map the possible responses to the variables onto a 0-7 scale where 1-7 was used for the spread of values and 0 or N was used for 'non-applicable' and 'no-data' responses.

Response levels (maximum, minimum and intermediate divisions) for each of the indicators were set wherever possible using the technical literature or by consultation with generalists and specialists in each field. Some levels were set using the data from Tuvalu, Fiji and Australia where available, or as estimates when these sources were unavailable.

Six of the 57 indicators were assigned an intrinsic weighting factor of 5, while the remaining indicators were given the default weighting of 1. This is the equivalent of giving the six weighted indicators the equivalent value of 5 indicators. This weighting was applied to indicators considered to be of central importance to the question of vulnerability in the model. To ensure that the final EVI, REI, IRI and EDI scores remained between the values of 0 and 7, it was necessary to adjust the weighting factors by dividing the intrinsic weighting value (1 or 5) by the average of all weighting values within each sub-index. The 0-7 scores were then multiplied by the adjusted weighting factor prior to accumulation in the sub-index to which they belonged.

The EVI and sub-indices were calculated using an EXCEL workbook. The workbook (Version 7-EVI-calculator.xls) is comprised of seven linked worksheets, each dealing with a different aspect of calculation and reporting. Report Level 1 was the highest level and gives the value of the EVI and sub-indices for each country and measures of confidence in the data. Report Level 2 gives a breakdown of the REI and EDI sub-indices showing relative contribution of meteorological, geological, anthropogenic risks and mitigating factors and ecosystem and biodiversity indicators. Report Level 3 gives the adjusted and raw scores for each individual indicator. A separate copy of the calculator is required to evaluate the vulnerability indices for each country.

After adjustment for intrinsic weighting, the scores for each indicator within a sub-index were averaged to produce a sub-index value of between 0 and 7. Where data were unavailable for an indicator, that indicator was omitted from the average, not given a 0 score, so that it made no contribution to the mean. Because there were also indicators for which the response was 'not applicable' (such as volcanic eruptions in Tuvalu), we calculated two types of index for the EVI and sub-indices. These we termed the Nett and Gross vulnerabilities. Nett vulnerability omits those indicators considered not applicable in a country and describes vulnerability to risks that actually apply in a country. Gross vulnerability assigns a zero value to non-applicable indicators and describes vulnerability in relation to all risk indicators used in the model and therefore vulnerability in a total sense.

In parallel with scoring each indicator against the 1-7 scale, we built into the EVI a way of assessing the reliability of data. These reliability values are reported alongside each index and should be read with them. The data reliability scores give the number indicators which were not applicable, the number with no data; the number of responses which were based on real data; and the number of responses based on 'best guess' or estimated by the operator and/or authorities.

Preliminary results for Tuvalu, Fiji and Australia

The preliminary EVI value for Tuvalu was the highest of the three countries indicating that its environment is the most vulnerable. The score obtained for Fiji was intermediate in value, and that for Australia was the lowest, though the difference between Fiji and Australia was relatively smaller than that between Fiji and Tuvalu.

	Australia	Fiji	Tuvalu
EVI (Nett)	3.04	3.79	5.04

When the EVI was decomposed into the REI, IRI and EDI sub-indices and categories of risk, a more complex pattern emerged. The risk exposure index (REI) was similar for the three countries, varying only between 3.13 $_{nett}$ for Australia and 3.49 $_{nett}$ for Tuvalu. The intrinsic resilience index (IRI) varied the most among the countries with Australia having the best resilience score (1.00 $_{nett}$) and Tuvalu having the worst (7.00 $_{nett}$). An almost reverse pattern was seen for the EDI. In this sub-index, the highest score (worst conditions) was obtained by Australia and the lowest by Fiji. The values of the sub-indices suggests that the different aspects which form vulnerability can operate independently of one another. Tuvalu was characterised by poor intrinsic resilience, and moderate risks and degradation. In contrast, Australia was characterised by very good intrinsic resilience, but high degradation. Fiji had the greatest vulnerability to meteorological and geological events, and Australia the greatest risk to pollution.

The values obtained for nett and gross indices differed little. Although this suggests that there may be no need to separately calculate the two index types, the present study did not provide a good test because there were very few indicators which were 'not applicable' across all three countries. It is expected that the nett and gross index values will be required when the EVI is extended globally and a greater range of climatic and geographic areas are built into the model.

These results are only very preliminary. The EVI and sub-indices will only provide a reasonable measure of vulnerability if most of the indicators can be filled-in for a country. We suggest here that at least 80% of the indicators (46 of the 57 questions) should be filled out by any one country for a reasonable estimate of vulnerability. In this report, we were unable to reach this threshold for any country. The data are available for the remaining indicators, but are buried, or need to be requested from authorities and will take some time and effort to procure. There were also problems with quality of the data, as we often found conflicting estimates in the literature. These temporary deficiencies in the data means that all the EVI values obtained here are indicative: they are by no means completed estimates and should be read with caution.

In conclusion, the EVI model gives single-figure measures of environmental vulnerability that appear to be able to distinguish countries and identify sources of vulnerability within a country. For the moment, it appears that of three countries tested, Australia is the least vulnerable, and Tuvalu the most. There were similar levels of risk in each of the countries, the most degradation in Australia and the least intrinsic resilience in Tuvalu. These results are only preliminary because there was insufficient time to collect all of the data required for these three countries and there were some problems with reliability of the data. We expect that each of these problems can be overcome and the results suggest that the EVI will be a useful tool for characterising vulnerabilities of states.

Strengths and weaknesses of the EVI

As for all methods of summarising and modelling data, the EVI developed here is associated with a number of strengths and weaknesses which must be understood for its proper application and use.

Strengths: The EVI is based on a theoretical framework that prompted us to find indicators for all identified aspects of vulnerability. It is able to incorporate quantitative and qualitative data on different response scales and identifies two types of vulnerability (Nett and Gross) simultaneously allowing for a world-wide comparison of states and as assessment of the real risks likely to affect a state. It also identifies areas in which local environmental agencies could improve data collection. Although at present it focuses on Oceania, it is extendable world-wide by the incorporation of new indicators.

Weaknesses: The index does not exclusively rely on published data resulting in omissions and a high cost of data collection. There is some subjectivity in assigning weights to indicators and non-linearities to the scores. The mapping of data on a 7 point scale may result in a loss of detail compared with directly using numerical data. In common with all indices, the EVI is affected by the indicators chosen and the results obtained may differ if different variables were chosen. Local variations, short and long term effects and other details could not be incorporated into the model without making it too complex. The index is also subject to problems with differences in interpretation of in-country users, though this could be minimised with training.

Future directions and conclusions

The environmental vulnerability index developed here will require further refinement before it becomes fully operational. This will include review of the indicators selected and the levels selected in a world-wide context, adding indicators for parts of the model which are underrepresented, and identifying indicators which should be incorporated and for which data should be collected. Refinement of the EVI will require peer review and inputs from highly-specialised experts. Mechanisms for this include running a 'think tank' and by publishing in an international reviewed journal. It will also be necessary to carry out consultations with the SIDS. A second mechanism for refining the index will be to go to, say, 10 SIDS to build their capacity to work with the EVI and to collect data which may at present be buried rather than lacking. Data should also be procured from developed countries by request. When sufficient data have been collected and the indicators refined, it will be necessary to test the performance of the model to identify biases, remove redundant variables, test its ability to differentiate countries, the method of accumulating scores and assess the availability and confidence in the data. It will also be necessary to develop a user-friendly computer calculator for the EVI. The final stage in the development of the EVI will be to combine it with other indices, such as the Economic Vulnerability Index to give an indication of overall vulnerability of states.

The results show that it is possible to obtain a single figure measure of vulnerability which incorporates the risks, intrinsic resilience and health or integrity of the environment. This study also shows that data which were previously thought to be difficult to obtain can be obtained. The methodology selected in the computation of the index can produce results which could have operational usefulness for ranking countries according to their environmental vulnerabilities. It is envisaged that the EVI would be recalculated every 5 years to provide updates on the vulnerability status of countries. This index highlights the need for governments to upgrade their collection and collation of environmental statistics. In addition, the breakdown of results into meteorological, geological, anthropogenic, mitigating and other categories of risk highlights areas of concern for environmental action.

1 Introduction

1.1 Background of the project

There has been growing international recognition that Small Island Developing States (SIDS) face serious disadvantages to their development associated with an interplay of factors such as remoteness, geographical dispersion, vulnerability to natural disasters, a high degree of economic openness, small internal markets, and limited natural resources (Briguglio 1995). These issues have been recognised and increasingly highlighted in international fora during the last decade. It was not until 1990 that the construction of a Composite Vulnerability Index (CVI) to measure the degree of overall vulnerability of developing countries was first formally proposed to the United Nations by the Maltese Ambassador.[4] (Briguglio, 1997).

The issue of vulnerability of states to human and natural stressors on economics, other aspects of human development, resources and the environment is still in its development phase. Attempts have been made to provide measures of vulnerability in single figure composite index form for:

- Economic vulnerability (Briguglio, 1993, 1995, 1997; Wells, 1996, 1997; Atkins et al. 1998; Chander, 1996;);
- Climate change and sea-level rise (IPCC, 1991, 1994; Pernetta, 1990; Downing, 1992; Formel, 1996);
- ENSO phenomenon (NOAA, 1997);
- Human impacts on the environment (Erlich, 1991, UNEP, 1998; Eurostat, 1998); and
- Effect of natural disasters on human systems (Albala-Bertrand, 1993; Pantin, 1997).

These above indices mostly attempt to describe the vulnerability of human systems to economic, social, climatic and other environmental factors. A few of the above studies have included some environmental responses in their indices, but no studies to date have attempted to construct a vulnerability index which describes risks to and responses of the environment, rather than on human systems.

It is now clear that vulnerability of states includes risks and their results on both the human and natural systems. Humans depend on the environment and its resources for sustaining life and for development. The environment, in turn, is dependent on both natural events and appropriate management by humans. This means that overall, vulnerability of a state[5] should ultimately include measures of both human and natural systems and the risks that affect them. With the development of an Environmental Vulnerability Index (EVI), an important step towards developing a composite index will have been made.

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4 The proposal was made at the Meeting of Government Experts of Island Developing Countries and Donor Countries and Organisations, held under the auspices of UNCTAD in June 1990.

5 The entities "states" being investigated in this study are politically independent territories.

1.2 What is vulnerability?

Vulnerability and resilience are two closely-related ideas. The term vulnerability refers to proneness to damage due to lack of protection or precariousness or the risk of being affected by a negative impact. Where vulnerability is considered high, resilience will be considered low and *visa versa*, and the two terms are used as opposites interchangeably in the field of vulnerability indices. For the purposes of this study, we will define the two terms as follows:

Vulnerability is defined as the potential for attributes of a system to respond adversely to the occurrence of hazardous events; and
Resilience is defined as the potential for attributes of a system to minimise or absorb the impacts of extreme events.

States are vulnerable to many factors which can affect them economically, environmentally, socially and politically. All states are vulnerable to varying degrees. We are interested in identifying those which are the most vulnerable in a relative sense. Economic vulnerability occurs when the economy of an entity, such as an independent state, is at risk from negative impacts arising from external forces. Political vulnerability may be experienced when, for example, a state's territorial boundaries are under threat and when forces within and outside the state exert a destabilising influence on the political and administrative establishment. Finally, social vulnerability occurs when, for example, natural disasters force massive upheavals of residence, and when external influences break down the traditional fabric of the state's society. All of these aspects of a state have been examined from the point of view of vulnerability.

The focus of this study is on vulnerability of the environment itself, including physical and biological aspects of ecosystems, diversity, populations, communities and species. Unlike previously-developed indices, the focus is *not* on risks to humans or their property. Instead, we are concerned with the risks to the environment as an entity in itself and as the fundamental basis of human livelihoods. A state may be vulnerable environmentally if its ecosystems, species and processes are susceptible to damaging anthropogenic and natural pressures and these pressures are high.

Environmental vulnerability differs from economic or social vulnerability because:

- "The environment" includes complex systems with different levels of organisation from species and physical features of the habitat up to entire interdependent ecosystems with a flow of organisms, energy and information between them and complex, often unpredictable and synergistic or antagonistic interactions between variables;
- Quantitative data are often not available for describing these ecosystems, flows and processes;

- Unlike human general indicators which can be used world-wide under the assumption that the needs of people and the thresholds for risk are similar (e.g. death toll, property damage, loss of shelter), environmental indicators may vary geographically, even within a species;
- Economic indices can be expressed in money units, which can be translated as a world-wide comparable unit. Aspects of the environment represent very different processes which can not be expressed with one single unit.

This means that developing an index for the environment will need a new approach.

1.3 The need for an environmental vulnerability index

The need for an environmental vulnerability index was recognised at the Global Summit on Small Island States held in Barbados in 1994 where the United Nations formally expressed the desire in paragraphs 113 and 114 of the Barbados Plan of Action for the development of a such an index. These paragraphs:

113: Small Island Developing States, in co-operation with national, regional and international organisations and research centres, should continue to work on the development of vulnerability indices and other indicators that reflect the status of SIDS and integrate ecological fragility and economic vulnerability. Consideration should be given to how such an index, as well as relevant studies undertaken on SIDS by other international institutions, might be used in addition to other statistical measures as quantitative indicators of fragility.

114: Appropriate expertise should continue to be utilised in the development, compilation and updating of the vulnerability index. Such expertise could include scholars and representatives of international organisations that have at their disposal the data required to compile the vulnerability index. Relevant international organisations are invited to contribute to the development of the index. In addition, it is recommended that the work currently under way in the United Nations system on the elaboration of sustainable development indicators should take into account proposals on the vulnerability index.

There is a number of benefits that can be derived from the construction of a vulnerability index, including that:

- The index can attract attention towards the issue of vulnerability of certain states and territories
- It allows states to undertake self-assessment; and
- It presents a single-value measure of vulnerability based on meaningful criteria which can be considered by donor countries and organisations when taking decisions regarding the allocation of financial aid and technical assistance, or for assigning special status to those states which are found to be the most vulnerable.

1.3 Aims of this study

The overall aim of this study was to develop the methodology for the construction of an environmental vulnerability index and to produce tentative vulnerability scores for a sample of countries, consistent with the Barbados Plan of Action and the needs enunciated by the Alliance of Small Island States (AOSIS). That is, to develop an index which summarises the vulnerability of the environment of states to natural and man-made hazards.

The environmental index developed in this study was not intended to describe the vulnerability of human systems or their responses to natural risks (as has been attempted in the past), but humans and their activities would be taken as part of the possible risks to the integrity of 'the environment'. This index could be combined later with an index which describes economic vulnerability so that a composite index which in a single figure incorporates economic concerns and the environment could be produced. It is envisaged that the EVI and any composite index would be recalculated for each state every 5 years to examine changes in the levels of risk and resilience through time as well as ranking the countries.

The specific aims of this project were to:

- Review current work already completed or underway addressing environmental vulnerability of SIDS;
- Build on past work on environmental vulnerability, if appropriate, or approach the problem from a new perspective where other attempts have had limited success;
- Identify variables which may be used in the construction of an environmentally descriptive vulnerability index for Pacific SIDS;
- Develop a logical framework and methods of calculating an index for environmental vulnerability;
- Identify and collect data which would be used to calculate the environmental index;
- Identify gaps in the available data;
- Identify future directions for the further development of an internationally acceptable environmental vulnerability index;
- Compile a report for widespread circulation and consideration prior to the Donor Round Table leading up to CSD-7 and the UN General Assembly Special Session on SIDS in September 1999; and
- Further efforts towards the development of a composite vulnerability index as described in the Barbados Program of Action and meet the needs enunciated by AOSIS.

2 Mini review of previous work on vulnerability indices

2.1 *Vulnerability indices in general*

Considerable work has been carried out on the development of indices which compare the relative vulnerabilities of countries in terms of risks to human economic and social systems, notably by Briguglio (1995; 1997), Chander (1996), The Commonwealth Secretariat (Wells, 1996, 1997; and Atkins et al., 1998), Pantin (1997), and Adger (1996, 1998).

Of 15 studies on vulnerability indices reviewed in this project, only 5 attempt to describe effects of natural and/or anthropogenic risks on environmental variables. In contrast, 13 out of the 15 studies describe the effects of natural and/or anthropogenic risks on humans (see also Annex 3). The risks of concern also varied among the studies. Anthropogenic risks including those which affect economies and social systems and those which affect ecologies were of concern in the majority of studies (11 out of 15). Six of the studies were concerned with risks relating to climate change and sealevel rise, usually on both human and natural systems. Six out of the 15 studies saw natural disasters as one of the risks to which the human systems were vulnerable.

Only 1 study of the 15 examined (UNEP, 1998) looked specifically at the effects of both humans and natural disasters on the environment. It is the objective of this study to fill this gap, by developing a comprehensive environmental vulnerability index based on a wide array of environmental indicators which includes both anthropogenic and natural risks.

2.2 *Environmental vulnerability indices*

The most important studies on environmental vulnerability indices were those produced by Ehrlich and Ehrlich (1991), Atkins et al. (1998) and those which deal with sea-level rise and climate change (e.g. IPCC, 1991, 1992; Yamada et al., 1995; Sem et al., 1996) (see also Annex 3). An additional study being undertaken by the European Union Statistics Department (Eurostat, 1998) attempts to identify common environmental indicators which may be examined in all European countries to provide a comparison of pressures on the environment. Although these workers have not attempted (as yet) to aggregate their scores into an index, the approach they have taken so far is similar to the first stages of an environmental vulnerability index.

In addition to the above studies, is one undertaken by Pantin (1997). Although Pantin terms his work an "Ecological Vulnerability Index', the term is misleading. He has instead measured effects of natural and man-made disasters or problems (cyclones, earthquakes, anthropogenic sea-level rise etc.) on human systems. Pantin's study (1997) is really another type of human vulnerability index and does not address stresses or responses of the environment.

2.3 Summary of approaches and methods used in past vulnerability indices and lessons learned from them

2.3.1 Terminology

Most vulnerability indices developed so far are concerned with human vulnerability and do not estimate the vulnerability of the environment. There has been some confusion with terminology and we propose here that vulnerability indices should be clearly named and grouped so that they identify the responders (or exposure units) with which they are concerned, not the risks. This study is the first attempt to produce a true Environmental Vulnerability Index, for which the risks to and responses of the environment are the focus, whether of direct interest to humans, or not.

2.3.2 Framework

The logical framework for previously-developed vulnerability indices has tended to be poorly defined and developed. Largely this has been the case because the indices have dealt with relatively simple human systems the attributes for which are relatively well defined and understood. For the successful development of an environmental index, however, a logical framework is of central importance. Without one, the index will tend to be driven by data availability, terms will be poorly defined, the indicators being used may not appropriately describe the risks and results of environmental hazards and testing of the performance of the model will be impossible (no hypotheses to test).

2.3.3 Methodology

Number of indicators

The number of indicators used to quantify vulnerability fell into three categories. The majority of studies used only a small number of indicators (3-6), and these were usually the studies which focused on human systems, with only some reference to natural disasters. Four studies used a moderate number of indicators (12-15), which except for the UNDP Human Development Index (UNDP, 1998) tended to introduce more emphasis on natural disasters and ecological indicator variables (Yamada et al., 1995; Pantin, 1997; UNEP, 1998). Only one study used a large number of indicators (60). This was the Eurostat (1998) list of indicators for anthropogenic pressures on the environment and is the only study that specifically focuses on effects on ecosystem integrity. The lesson here is that more indicators are required when complex ecological systems become the focus of the index being constructed.

Methods for scoring

Various methods were used in previous studies for measuring vulnerability. The value of indicators was scored using one of the following techniques:

- Raw value (not later aggregated into an index), Eurostat (1998);
- Values transformed or expressed as %, fractions or additive scores to deal with dissimilar units (Pernetta, 1990; UNEP, 1998);
- Numerical value standardised to a range of 0-1 using the formula:

$$V_i = \frac{(X_i - \text{Min } X_i)}{(\text{Max } X_i - \text{Min } X_i)}$$

  Where: V_{ij} = measure of vulnerability contributed by the ith indicator in country j, Xij = numerical value of the ith indicator in country j, Min and Max X_i = minimum and maximum value of the ith indicator across all countries being compared. (Briguglio, 1993, 1995, 1997; Chander, 1996; Wells, 1996, 1997; Pantin, 1997);
- Indicator values mapped onto a categorical scale, e.g. -3 to 0 to +3 (Yamada et al, 1995, Sem, 1996); and
- Conversion of all indicators to $ value (Yohe, 1991).

Most of these methods for scoring the values of indicators were developed to eliminate problems with heterogeneous data sets. That is, data which were expressed in different units (e.g. kg vs km^2 vs mm) or which have different ranges (0-10 vs 560-1020).

Aggregating indicator scores into an index

The method used for aggregating the values (whether transformed as discussed above, or not) into indices also varied among studies. The main methods used were:

- No aggregation: individual indices presented separately (Eurostat, 1998);
- Simple additive or multiplicative formula-style index with or without weightings (Pernetta, 1990; Ehrlich and Ehrlich, 1991; Yohe, 1991);
- Numerical data for key vulnerability sub-indices assumed to represent the underlying vulnerability factors (X_1,X_2,…X_n), standardised to common units and averaged to obtain a composite vulnerability score (Briguglio, 1992, 1995, 1998; Chander, 1996; Wells, 1996;
- Quantitative and qualitative data on vulnerability and resilience of elements of a system, standardised to common units the difference between which forms a measure of sustainable capacity (SCI) (e.g. Yamada et al. 1995);

- Vulnerability was *a priori* assumed to be represented by an observable variable Y (e.g. output volatility) and regressed against $X_1, X_2, \ldots X_n$ (which represent the underlying vulnerability sub-indices). The estimated coefficients on X_1, X_2, …. X_n so obtained were then used as weights to aggregate the sub-indices (Atkins et al., 1998).

3 A theoretical framework for environmental vulnerability

3.1 The risks and ecosystem integrity

The maintenance of ecosystem or ecological integrity is at the heart of the development of a vulnerability index on the environment, because it is ecosystem integrity that is threatened by natural and anthropogenic hazards. The notion of ecosystem integrity is so complex that it cannot be expressed through a single indicator, but rather requires a set of indicators at different spatial, temporal and hierarchical levels of ecosystem organisation (Jones and Kaly, 1995; De Leo and Levin, 1997). Ecosystem integrity depends on biodiversity, ecosystem functioning and resilience, all of which are such interrelated variables, that factors which affect just one of these can have far-reaching ecosystem-wide consequences.

The first step towards the development of the EVI must be to clearly identify the risks we are concerned about and define what these risks are capable of affecting. In general, however, we will not be able to couple individual risks and effects in such complex interactive systems. The approach is this study was to examine these variables with proxy measures and indicators (see Section 4).

3.3.1 The risks

In a general sense, a risk may be defined as any event or process that can cause damage to the environment. These include natural and human events and processes such as 'the weather' and 'pollution'. For example, Campbell and Ericksen (1990) defined natural hazards as those in which natural environmental conditions depart from 'normal' to such an extent that people, property and social systems may be adversely affected. The problem with this definition is that unless we identify certain natural events as being anthropogenically altered (e.g. anthropogenically-accelerated sea-level rise), all events are 'normal'. For studies which do focus on effects on 'the environment' these natural hazards are also seen as risks to nature. The implication from this line of reasoning is that the changes we see to the natural world as a result of natural hazards are deemed 'unacceptable' from a human perspective. This means that except in the case of anthropogenic risks, in an assessment of environmental vulnerability, what we really are examining is unacceptable departures from our (human) view of how the environment should change. For the purposes of this study, we will accept that risk events should include those which cause sudden and seemingly-negative impacts on natural systems as a way to evaluate vulnerability. There is, however, increasing evidence that environmental upheaval is a natural and important part of ecosystem creation and maintenance (e.g. storms which remove coral communities and deposit them on islands and expand the land area while allowing space from where they were removed for other species to exist for some time).

Clearly, though most identifiable risk events are capable of causing damage, it is only the larger and more intense events that are likely to cause wholesale changes in the environment, at least in the short to mid term. A meaningful EVI would tend to focus on the more important events, given that quantification and even identification of all events is impossible. The following is a list of some of the more important risks which can impact on the environment:

1. Meteorological events: Cyclones, storms, surges, droughts, floods, heat waves and cold snaps, the ENSO phenomenon, tornadoes;
2. Geological events: Landslides, earthquakes, tsunamis, volcanoes, subsidence, erosion and accretion, altered tidal range;
3. Anthropogenic impacts: Exploitation of resources (e.g. mining, hydrocarbon extraction and use, fisheries), habitat destruction, human population pressure, inappropriate environmental management, developments which affect coastal processes, pollution, toxic wastes, solid wastes, urbanisation, agriculture and aquaculture, tourism, wars and civil strife.
4. Climate change: Warmer atmospheric and oceanic temperatures, changing rainfall patterns, increased incidence of extreme events (e.g. changes in frequency or increased intensity of tropical cyclones), changes in wave patterns, extinction of species unable to adapt to habitat and related changes (as a risk to ecosystem function), disruption of ecosystems, ozone depletion;
5. Sealevel rise
6. Astronomical events: Solar flares, astronomical low tides

3.1.2 The entities at risk: 'Responders'

Defining the environment which is at risk, or the 'responders', is a more difficult task and is an issue which has largely been side-stepped by most workers in the field of vulnerability. In this study, we define the environment at risk to mean all of the physical, biological and process elements of the natural world excluding humans and their structures. This includes:

- Ecosystems (identifiable groupings of organisms and their habitats)
- Habitats (the places in which organisms live)
- Populations and communities of organisms (identifiable groups of organisms that interrelate)
- Physical and biological processes (beach building, reproduction, recruitment)
- Energy flows (nutrient cycling and import/export)
- Species (losses of particular species e.g. mangroves can redefine the ecosystem)

- Diversity (includes geographic, ecosystem, community, population, species and genetic diversity)
- Ecological resilience (the ability of ecosystems to 'bounce back' after being disturbed)
- Ecological redundancy (species which carry out similar functions in an ecosystem)

All of these aspects of the environment may be subject to alteration as a result of action of any of the risks identified above. It is important to note also, that complex relationships exists between the risks and the environment affected. That is, the environment is not just subject to a risk, but may modify its action either during a given event or at a later stage. For example, a cyclone may change the shape of a beach by dumping new material on it and the new material acts as a better barrier to later cyclone damage (e.g. cyclone Bebe in 1972 created a large storm bank on Funafuti).

3.2 The three aspects of environmental vulnerability

Environmental vulnerability of an entity such as a state, may be viewed as having three aspects, namely:

1. The level of risks (or pressures) which act on the environment within the state;
2. Intrinsic resilience of the environment to risks; and
3. Extrinisic or resilience as a result of external forces acting on the environment.

All of these three aspects of vulnerability need to be incorporated into an EVI if we are to obtain an overall picture of the proneness to environmental changes due to risks. That is, vulnerability is made up of risk pressure (REI), intrinsic resilience (IRI) and extrinsic resilience (EDI), so that EVI=REI+IRI+EDI. These are each discussed in detail below.

3.2.1 Risk exposure as part of vulnerability and the REI sub-index

Risks are largely considered external forces which act on the environment (accepting that feedback effects can and do occur). A measurement of the amount of risk expressed as the frequency and expected intensity of risk events (exposure) is necessary within the EVI. A measurement of risk exposure allows comparisons from state to state (and time to time) of the amount of hazardous events likely to impact on the environment at any one time.

We did not attempt to extrapolate the risk levels likely to affect the environment into the future, by measuring the recent past levels of risk. This approach has two advantages:

1. It does not rely on complex mathematical modelling of risk events which requires a lot of data not currently available; and
2. By using relatively recent data (for most risks, though not those which operate on geological time scales) there is an opportunity for the EVI to change with each update (every 5 years) as levels of risk exposure change. This would be particularly important

for anthropogenic risks (pollution, population pressure) and for those which may be responding to longer term cycles (such as climate).

For the EVI we calculate a 'Risk Exposure sub-Index' or REI which examines the frequency and where possible, the intensity of risk events which may affect the environment. These are based on levels observed over the past 5-10 years for most risks, but may include data for much longer periods for geological events. The REI is a measure of potential risk only; there is no logical expectation that patterns of risk expression during the immediate history of a state will necessarily result in similar risk levels today or in the future.

3.2.2 Intrinsic vulnerability / resilience and the IRI sub-index

Intrinsic resilience refers to the innate ability of natural systems to maintain their integrity when subject to disturbance (Holling, 1973; Ludwig et al., 1997). Conversely, intrinsic vulnerability is the innate fragility of a system. It is an expression of relative natural immunity to hazards.

For most environmental systems, we do not know what this natural immunity to hazards is. There are insufficient data, for example, to describe the ability of a reef to withstand a cyclone of, say, Category 2 if it were to hit directly and take 6 hours to pass. Predicting which ecological variables (e.g. species, processes) might be affected and what effect this would have on ecosystem diversity, function and future resilience is at present not possible. For the purposes of calculating an EVI we have focused on broader indicators which will give us approximate measures of resilience at the scale of entire states. The indicators used which refer to characteristics of a country which would tend to make it less/more able to cope with natural and anthropogenic hazards form the IRI (Intrinsic Resilience sub-Index). For example, the absolute land size of a state is used assuming that the larger, the more resilient because refuges from hazards are more likely and recolonisation after disturbance will be possible from these refuges. Large absolute size also means that only a small portion of the state might be affected by any single hazard event.

Clearly, indicators which show natural rates of recovery or productivity should also be included, but data for these measures are generally lacking. An exception might be measures of productivity being estimated in tropical Papua New Guinea mangroves (Robertson et al., 1991) and estimates of the tonnages/km^2 of reef fishes produced in the Pacific Region (Dalzell et al., 1996). The underlying assumption if these indicators were included in the IRI would be that greater productivity rates can lead to faster rates of recovery and hence the ability for ecosystems to withstand greater disturbance.

3.2.3 Extrinsic vulnerability / resilience and the EDI sub-index

Extrinsic vulnerability / resilience refers to the ability of ecosystems to continue to maintain their integrity after already suffering impacts from the same or other hazards. We have assumed that the greater the number and intensity of hazards which have impacted on a system, the greater its level of vulnerability to future stresses is likely to be. Because neither the natural resilience nor the altered resilience of any ecosystem (impacted by, say, even a single cyclone) is known, let alone the resilience which might arise as a result of summed or interactive effects, it is impossible to estimate extrinsic vulnerability. Instead, we have opted for a proxy measure of extrinsic vulnerability for inclusion in the EVI. The indicators we have chosen attempt to describe the ecological integrity or level of degradation of ecosystems. This forms the Ecosystem Degradation sub-Index (EDI). The more degraded the ecosystems of a country (as a result of past natural and anthropogenic hazards), the more vulnerable it is likely to be to future risks.

3.3 Features of an environmental vulnerability index (EVI)

In developing the EVI, we set criteria on certain features of the index to ensure that it would be able to perform the tasks for which it was developed. All of the following criteria were built into the EVI model. The EVI index should be:

1. **Intuitively comprehensible:** That is, the final value of the EVI and its sub-indices should be expressed on a scale which has immediate recognition for users. We have set the range of values between 0 and 7 with higher scores indicating higher vulnerability;
2. **Impartial:** That is, it should provide an unbiased measure of vulnerability of states to real natural and anthropogenic risks;
3. **Suitable for international comparisons:** The index should encompass the range of variables found in different countries and their extremes of occurrence;
4. Able to **differentiate among countries**: The index had to provide a spread of values so that differences among countries would be highlighted;
5. **Applicable at different spatial scales:** This would allow for regional and country comparisons within the international community, as well as comparisons within countries for identifying areas of weakness at the individual government level;
6. **Refinable through the indicators used but not directly by individual countries:** This would make the index adaptable so that it can be applied globally and can be upgraded as additional data come to light. Limiting changes to the EVI administrator and technical review, ensures a level basis for comparisons among countries is maintained;
7. **Presented in breakdown and single figure formats:** The EVI is a composite index formed by combining the REI, IRI and EDI sub-indices which themselves can be separated into anthropogenic and natural hazards, risk and mitigating factors and ecosystem and biodiversity effects. By providing a breakdown of each of these, a

clearer understanding of the nature of national vulnerabilities is possible. This simultaneously allows overall comparisons and the identification of specific problem areas;

8. **Calculated using a user-friendly computer interface:** This reduces the possibility of user errors and speeds the process of accurate calculation of the EVI.

3.4 Why use indicators?

As was noted in Section 3.1 above, examining ecosystem integrity is a complex business and cannot be measured directly or expressed through a single indicator. Neither can risk to the environment be measured as an absolute amount since many potential risks may apply, not all of which are identifiable such as low-level or diffuse impacts (e.g. non-point source impacts such as run-off of pesticides). Risks can also apply at different places, times and intensities.

In trying to determine how to measure and manage ecosystem integrity, De Leo and Levin (1997) identified reductionist and wholist approaches to examining ecosystems. A reductionist approach emphasises the structural aspects of natural systems and focuses on individual species and population dynamics of species within isolated ecosystems. A wholistic approach focuses on macro-level functional aspects such as energy flows, nutrient cycling and productivity. These structural and functional aspects of ecosystems tend to lead to different definitions of ecosystem integrity:

1. Focus on structural aspects (reductionist approach) leads to a definition in which the loss of even one species or the damage of a link between some components implies a loss of integrity because the ecosystem is no longer complete;
2. Focus on functional aspects (wholistic approach) leads to the conclusion that the loss of some species may not be important because redundancies within functional groups will maintain functional integrity (De Leo and Levin, 1997).

We have attempted to include both aspects of ecosystem integrity in our indicators of environmental vulnerability.

The evaluation of environmental vulnerability requires the use of a broad base of indicators targeted at each of the components of vulnerability (the REI, IRI and EDI) and at different spatial, temporal and hierarchical levels of ecosystem organisation (Jones and Kaly, 1995; De Leo and Levin, 1997; Kaly and Jones, 1998). At the scale of an entire country, this is not an easy task. Ideally, indicators are required which describe:

- Frequency and intensity of the most important risks;
- Intrinsic vulnerability / resilience to risks such as characteristics of a country that render it susceptible to hazards (such as anthropogenic sea-level rise); natural rates of regeneration or productivity which make it likely to recover from disturbances quickly and more completely before the arrival of the next hazard etc;

- Ecosystems: Loss of habitats, keystone species, ecosystem functions, goods and services;
- Groups of organisms: Loss of diversity, populations of organisms and genetic diversity, and ecological redundancy;
- Elements of the physical environment (water, storm banks, coastal processes, flood plains, lands close to sea-level);
- Rare and endangered species and those of economic importance which may be more than normally targeted by human activities; and
- Mitigators of the effects of hazards such as legislation which modifies human risks, monitoring programmes which provide early warning of ecosystem damage.

Attempts were made in this study to include a large number of indicators from each of these categories, though availability of data tended to set a practical limit to the number finally included in the EVI model.

4 Methodology used

4.1 Indicators of vulnerability

For the purposes of the EVI the following definitions relating to indicators and indices were used:
- An **indicator** was defined as any variable which characterises the level of risk, resilience or environmental degradation in a state;
- A **sub-index** (the REI, IRI and EDI) was defined as an aggregated average of the scores for indicators which related separately to risk, resilience or degradation; and
- An **index** (the EVI) was defined as an aggregated average of each of the three sub-indices (REI, IRI, EDI) to give an overall measure of the environmental vulnerability of a state. The EVI is then, a **composite** of each of the three sub-indices.

4.1.1 Criteria for the selection of indicators

With the preceding theoretical arguments in mind, the indicators for the calculation of the EVI and its sub-indices were finally selected on the following criteria:

- Applicable over different scales. Or they should at least be calculable over the entire scale of interest (the default being an entire country, but applicable also to regions or within countries);
- Spread over the different geographic, habitat and climatic types (e.g. tropical, temperate, terrestrial, coastal, marine);
- Relatively easy to understand;
- Unbiased;

- As well-defined as possible so that data are comparable and measure the same variable from country to country and operator to operator;
- Spread over different levels of organisation (ecosystems, biodiversity, processes);
- Data available and relatively reliable and collected as a matter of routine by authorities in a country. Data available in existing or on-going publications were preferred if they also met the other criteria (Section 4.1.3);
- Data which should be available if a consultant could go to the country to assist in its collation or for which programmes directed at its collection or collation could be proposed and implemented; Indicators for which data that were considered unlikely to be available under each of the above two criteria were omitted from the model (Section 4.1.3);
- The indicators should be as unrelated as possible to each other. Redundant indicators do not add much additional information to the EVI (though for some indicators, this criterion may only be assessed by mathematical testing - expressed as correlations in the data).

4.1.2 Indicators for the three sub-indices

A total of 57 indicators of environmental vulnerability were finally selected for inclusion in the index. This included 39 indicators of risk (REI), 5 indicators of resilience (IRI) and 13 indicators of environmental integrity or degradation (EDI) (Annex 2). Many of the indicators were expressed as a fraction of area of land or coast rather than simply absolute numbers because it is risk density or proportion of area degraded that is of interest from an environmental perspective.

Although a larger number would have been preferred to obtain a wider picture of risks, resilience and ecological integrity, many of the indicators initially selected were discarded because they either:

1. Had no data available and data were unlikely to be procured in the near future (see also Section 4.1.3);
2. Were ambiguous or bimodal in their responses; or
3. Were redundant and the information they intended to capture was present in another indicator.

No data

For example, catch-per-unit-effort data on fisheries, percentage of coastal areas eroded, tonnes of plastics produced or imported yearly, numbers of hydrocarbon spills and carriage of toxic wastes through territorial lands or waters would have all provided important indicators of risks and ecosystem integrity. All of these indicators and others like them were discarded because data were considered impossible to obtain for most countries.

Bimodal response or ambiguous

The percentage of land area urbanised in contrast to decentralised was considered as a potential indicator of general human impacts and the amount of wastes and toxic compounds which would have to be absorbed and rendered harmless as an ecosystem service. It is not however clear which option represents the greater risk to the environment. In highly urbanised areas, impacts are concentrated and absorption of wastes and other substances spreads from the urbanised centre to the surrounding ecosystems often resulting in severe pollution and localised impacts or stress. In areas of low human population density, the concentrations of wastes is low, but large areas of land are disrupted by clearing, farming and other activities leading to habitat destruction.

Redundant

Production of hydrocarbons and deviations in rainfall patterns during El Nino events are examples of two indicators discarded because they are represented in other indicators which were included in the model. Although the indicators differed in their content, it was considered that the risks they represent (such as oil spills, production of greenhouse gases, floods or droughts) were already present in or too correlated with an indicator concerned with hydrocarbon usage and months with greater and less than average rainfall respectively.

4.1.3 Collecting the data on indicators

There are four categories of data available for calculating the EVI:
1. Data which are easily available and published by reputable international organisations as a matter of routine;
2. Data which are not published by reputable international organisations, but are collected by the respective governments or could easily be collected or reasonably approximated, in a matter of weeks, without the assistance of a suitably-trained consultant;
3. Data which are difficult to obtain, but could be produced or reasonably approximated in a matter of months with the assistance of suitably trained consultants;
4. Data which are very difficult or impossible to obtain or reasonably approximate, even with the assistance of a consultant.

We focused on data in categories 1 and 2, and with sufficient funding available could also include data category 3. Data in category 4 were not included.

Data for calculating the EVI (and initially setting the response levels) were collected for three countries: Fiji, Tuvalu and Australia to provide some initial testing of the model. These data were obtained from country reports, UN, WHO, SOPAC, SPREP, FAO and other publications from international agencies, centres for risk assessment and management (e.g. Tsunami Centre, NOAA), local experts and government officers. Without being able to go to the countries to train and focus attempts of local authorities to the task of collecting or collating the required data, some indicators were unavailable for this initial testing. It is expected that during refinement of the EVI in Phase II, these gaps in data will be filled and the model tested more rigorously (see Section 7).

4.2 Quantifying vulnerability

Our overriding principle in constructing a vulnerability index for the environment was one of parsimony. That is, despite the inherent complexities in trying to describe the risks to and effects on integrity of the environment, we did not introduce complexities in calculating the EVI unless there was a justifiable reason to do so.

4.2.1 Mapping of data on indicators on a 0 - 7 scale

Mapping data

The indicators incorporated into the EVI model were of a heterogeneous nature. For some, responses were qualitative and took the form of 'yes' or 'no' answers or graded from 'none' to 'some' to 'a large amount'. For others, numerical data were available which could have been used in their raw state. But even for the numerical data, scales were heterogeneous occurring on a sliding linear or non-linear scale or having different maximum and minimum values. To deal with this heterogeneity, we chose to map the possible responses to each indicator on a simple scale from 1-7[6].

The 1-7 scale was chosen because it allows for a reasonable amount of spread among the possible values of the data. This is important because one of the central aims of the EVI is to provide spread among states in terms of their vulnerabilities: a scale which is too compressed would make the creation of spread difficult. The approach permits the processing of binary data, where only a 'yes' or 'no' answer is possible. In this case a 'yes' answer could be assigned the maximum value of 7 and a 'no' answer the minimum value of 1, or some values in between. The scale of 1-7 also has a central score which means that the well understood concepts of average, maximum and minimum can be used to anchor the responses for non-numerical data as in the following example:

SCORE						
1	**2**	**3**	**4**	**5**	**6**	**7**
The lowest incidence possible	Significantly less than average	Slightly less than average	Average	Slightly more than average	Significantly more than average	The highest incidence possible

[6] There was some discussion as to the appropriateness of the mapping scales of 0 – 7 and 1 – 7 which will be resolved in further stages of the EVI development.

The 1-7 scale also allows for non-linear and discontinuous scoring. Individual indicators can be modelled to approximate exponential, quadratic or other non-linear functions. A few examples of the versatility of this scoring system are shown in the table below.

- Indicators for which effects are assumed to increase or decrease in direct response to their frequency or intensity were scored using the simple **Linear Effect** model. In this case, seven equal divisions are made and these are mapped directly to the 1-7 scoring scale;
- Indicators for which effects at large intensities or frequencies reach a certain threshold and tend not to change much past that threshold were scored using the **Diminishing Marginal Effects** model. That is, indicators for which there is a decreasing rate of effect with increasing intensity or frequency;
- The **Increasing Marginal Effects** model could be used when there was an increasing rate of effect with increasing intensity or frequency of the indicator;
- The **S-shaped Effect** was also considered in our model, but not finally used. In this model, both ends of the indicator scale are associated with large effects, while intermediate values show little changes in response.
- The **Discontinuous** and **Part** scales were used as special cases of each of the above, to truncate an indicator at a value thought to represent the point at which it has a major effect on the vulnerability scale.

Examples of the possibilities, assuming that the observed values range between 1 and 70:

	SCORE						
Shape of underlying curve	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Linear effect	1-10	11-20	21-30	31-40	41-50	51-60	61-70
Diminishing marginal effect	1-18	19-29	30-39	38-48	49-56	57-63	64-70
Increasing marginal effect	1-5	6-12	13-21	22-32	33-44	45-57	58-70
S-shaped effect	1-18	19-29	30-39	40-42	43-46	47-56	56-70
Discontinuous	<2			2-25	26-40	41-60-	61-70
Part scale	>20%	11-20%	5-10%	<5%			

The scoring methods used involved a degree of subjectivity since the score will depend on the assumed shape of the underlying relationship. On the positive side, however, this method allows for mapping responses of indicators that when increased by X times increase risk by less or more than X times.

A special case for non-applicable or no data responses: The values of 0 and N

Although active scoring of indicators occurs between the values of 1 to 7, we reserved the score of 0 for cases in which a question was considered not applicable for a state The value N was used for cases in which it was considered necessary to remove an indicator's signal from the index being calculated. This was done when there were no data available or, for one index type, when an indicator was considered not applicable. Please see Section 4.2.3 for full explanation of the two indices this leads to.

4.2.2 Setting the response levels for indicators

Response levels for each of the indicators selected were set wherever possible using the technical literature or by consultation with generalists and specialists in each field. Some levels were set using the data from Tuvalu, Fiji and Australia where available, or as estimates when these sources were unavailable.

4.2.2 Weighting

Six of the 57 indicators were assigned an intrinsic weighting factor of 5, while the remaining indicators were given the default weighting of 1. This is the equivalent of giving the six weighted indicators the equivalent value of 5 indicators. This weighting was applied to indicators considered to be of central importance to the question of vulnerability in the model. For example, total land area, percentage of forests remaining and human population measures were all considered key indicators which impacted significantly on the vulnerability of a state.

To ensure that the final EVI, REI, IRI and EDI scores remained between the values of 0 and 7, it was necessary to adjust the weighting factors by dividing the intrinsic weighting value (1 or 5) by the average of all weighting values within each sub-index. The 1-7 scores were then multiplied by the adjusted weighting factor prior to accumulation in the sub-index to which they belonged.

4.2.3 Calculating the sub-indices and the EVI

The EVI and sub-indices were calculated using an EXCEL workbook. The workbook (Version 7-EVI-calculator.xls) is comprised of seven linked worksheets, each dealing with a different aspect of calculation and reporting as follows:

1. Questions table: The indicators and their categorisation and levels;
2. Input screen: Responses to the indicator questions and the confidence in the data are entered here;
3. Response matrix: Results of scoring and adjustments due to weighting are calculated automatically;
4. Lookup help: Definitions of terms used;
5. Report Level 1: Highest level of reporting. Overall EVI and sub-indices calculated for two types of index (see below). Confidence in the data is also reported here;

6. Report Level 2: Breakdown of the REI and EDI sub-indices showing relative contribution of meteorological, geological, anthropogenic risks and mitigating factors and ecosystem and biodiversity indicators;
7. Report Level 3: Adjusted and raw scores are reported for each individual indicator.

A separate copy of the calculator is required to evaluate the vulnerability indices for each country.

After adjustment for intrinsic weighting, the scores for each indicator within a sub-index were averaged to produce a sub-index value of between 0 and 7. Where data were unavailable for an indicator, that indicator was omitted from the average, not given a 0 score, so that it made no contribution to the mean. Because there were also indicators for which the response was 'not applicable' (such as volcanic eruptions in Tuvalu), we calculated two types of index for the EVI and sub-indices. These we termed the Nett and Gross vulnerabilities[7] and describe the following information:

Nett vulnerability - NA is blank. In this type of index, any indicators which were considered not applicable (scored as NA in the EXCEL calculator) were completely removed from the calculation of the indices. In EXCEL this was simply accomplished by assigning these indicators the value 'N' instead of a score between 0 and 7. This type of index measures the vulnerability experienced within a state. That is, the vulnerability of the state relative to those indicators which actually occur there. For Tuvalu, the question on volcanoes was scored NA because there are no active volcanoes in the country. The indicator volcanoes is irrelevant to Tuvalu and is not part of the suit of risks which can affect the country (except through indirect effects though gases and ash from an eruption elsewhere in the region).

Gross vulnerability - NA is 0. In this type of index, indicators which were considered not applicable were scored a 0 value. This means that the indicator contributed to the denominator of the averaging fraction, but not the numerator. This measures vulnerability in a total sense: Although Tuvalu has no volcanoes, volcanoes are considered part of the risks available in the world, and a zero score here shows that Tuvalu's risk to volcanoes is zero. Using this measure tends to increase the index value for countries which span large geographic and climatic ranges because the numerator is more likely to accumulate scores for a common denominator in all countries (not withstanding indicators for which data are not available). However, this will tend to be balanced by the fact that scores in such countries are averaged over their entire areas, including areas which might not be affected by the risk that the indicator describes, tending in turn to reduce the vulnerability value.

[7] There was discussion as to which index is most appropriate for international inter-country comparison. This will be discussed further in the next phase of EVI development.

4.2.4 Confidence in and source of the data

In parallel with scoring each indicator against the 1-7 scale, we built into the EVI a way of assessing the reliability of data. These reliability values are reported alongside each index and should be read with them (like a mean with its standard deviation). In the example below, the Nett and Gross EVI and sub-indices are all reported along with the number of indicators available in each category (fixed); the number of indicators which were not applicable, the number with no data; the number of responses which were based on real data; and the number of responses based on 'best guess' or estimated by the operator and/or authorities.

	Nett	Gross	Total # indicators available	# Not applicable	# No Data	# based on data	# best guess
Environmental Vulnerability Index (EVI):	4.45	4.10	57	8	2	30	17
Risk Exposure Sub-index (REI):	3.98	3.22	39	7	2	18	12
Intrinsic Resilience Sub-index (IRI)	5.56	5.56	5	0	0	3	2
Environmental Degradation Sub-index (EDI):	3.82	3.52	13	1	0	9	3

5 Preliminary results for Australia, Fiji and Tuvalu

To provide an initial test of the EVI, we chose three countries to encompass a range of climatic, geographic, environmental and human systems. Australia, Fiji and Tuvalu were selected because data for them was relatively easy to obtain. It is expected that coverage will be extended to others in the Pacific Region, and later to all countries.

The preliminary results presented below should not be read as final EVI values for the three countries. We were unable to obtain all of the required data for all of the countries within the timeframe of this report (partly because it was the Christmas/New Year period and local authorities were unavailable for providing data). We are, however, confident that the data can be obtained. We had to proceed with the data we were able to obtain for the purposes of this report.

5.1 Values obtained for the EVI and sub-indices

5.1.1 Index values

The EVI value for Tuvalu was the highest of the three countries (5.04_{nett}), indicating that its environment is the most vulnerable. The score obtained for Fiji (3.79_{nett}) was intermediate in value, and that for Australia was the lowest (3.04_{nett}), though the difference between Fiji and Australia was relatively smaller than that between Fiji and Tuvalu (Table 1 and Figure 1).

When the EVI was decomposed into the REI, IRI and EDI sub-indices, a more complex pattern emerged. The risk exposure index (REI) was similar for the three countries, varying only between 3.13_{nett} for Australia and 3.49_{nett} for Tuvalu (Table 1). The intrinsic resilience index (IRI) varied the most among the countries with Australia having the best resilience score (1.00_{nett}) and Tuvalu having the worst (7.00_{nett}). An almost reverse pattern was seen for the EDI. In this sub-index, the highest score (worst conditions) was obtained by Australia and the lowest by Fiji (Figure 2). The values of the sub-indices suggests that the different aspects which form vulnerability can operate independently of one another. Tuvalu was characterised by poor intrinsic resilience, and moderate risks and degradation. In contrast, Australia was characterised by very good intrinsic resilience, but high degradation.

When the sub-indices were further decomposed into different categories of risks, it was found that Fiji had the greatest vulnerability to meteorological and geological events, and Australia the greatest risk to pollution (Table 1).

Table 1: Summary of results of calculating values for the EVI and sub-indices for Australia, Fiji and Tuvalu. Values are given for Nett and Gross index values and a categorical breakdown of the REI and EDI. The total number of indicators available for each index is given. NA=Number of indicators which were not applicable for the country (assigned no value in Nett and a 0 value in Gross indices); ND=No data currently available (assigned no value).

		AUSTRALIA				FIJI				TUVALU			
	# Indicators	Nett	Gross	NA	ND	Nett	Gross	NA	ND	Nett	Gross	NA	ND
EVI	**57**	**3.04**	**3.04**	**0**	**38**	**3.79**	**3.68**	**1**	**17**	**5.04**	**4.91**	**2**	**20**
REI	39	3.13	3.13	0	25	3.48	3.48	0	7	3.49	3.39	1	15
Metereological	6	1.30	1.30	0	5	2.55	2.55	0	0	1.31	1.33	0	5
Geological	4	0.65	0.65	0	2	3.27	3.27	0	2	-	0.00	1	3
Anthropogenic	29	3.70	3.70	0	18	3.73	3.73	0	5	3.58	3.64	0	7
Habitat	1	-	-	0	1	-	-	0	1	0.66	0.67	0	0
Agriculture	5	3.59	3.59	0	3	4.61	4.61	0	2	1.53	1.56	0	2
Fisheries	5	1.30	1.30	0	4	2.18	2.18	0	1	1.64	1.67	0	3
Government	4	0.87	0.87	0	1	4.12	4.12	0	1	4.11	4.17	0	0
Mining	3	-	-	0	3	2.91	2.91	0	0	0.66	0.67	0	0
Pollution	8	3.91	3.91	0	6	2.36	2.36	0	0	2.41	2.44	0	2
Risk Factors	31	4.03	4.03	0	20	3.41	3.41	0	5	3.37	3.22	1	14
Risk mitigating Factors	8	0.65	0.65	0	5	3.76	3.76	0	2	3.76	3.81	0	1
IRI	5	1.00	1.00	0	3	4.67	4.67	0	3	7.00	7.00	0	1
EDI	13	5.00	5.00	0	10	3.22	2.90	1	7	4.63	4.35	1	4
Ecosystems	10	7.00	7.00	0	9	3.52	2.85	1	6	5.50	4.99	1	3
Biodiversity	3	4.00	4.00	0	1	2.78	3.00	0	1	2.00	2.12	0	1

Figure 1: Graph of the overall EVI results obtained for Australia, Fiji and Tuvalu (Nett and Gross scores).

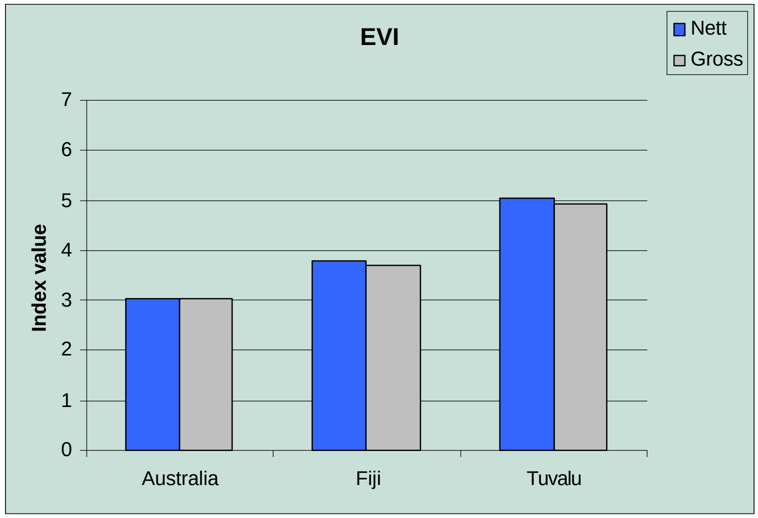
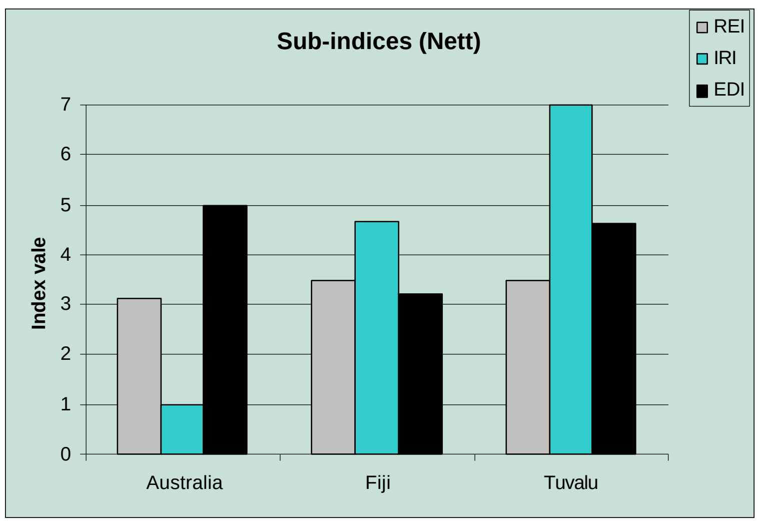


Figure 2: Breakdown of the EVI scores for Australia, Fiji and Tuvalu into the three sub-indices for Nett scores only.



5.1.2 Nett and gross vulnerabilities

The values obtained for nett and gross indices differed little. The greatest difference observed between the two methods of scoring was 0.13 on the 0-7 scale. Although this suggests that there may be no need to separately calculate the two index types, the present study did not provide a good test. There were very few indicators which were not applicable across all three countries, so the difference between the scoring types did not come into effect. It is expected that the nett and gross index values will be required when the EVI is extended globally and a greater range of climatic and geographic areas are built into the model.

5.1.3 Confidence in the results and data

As was stated above, these results are only very preliminary. The EVI and sub-indices will only provide a reasonable measure of vulnerability if most of the indicators can be filled-in for a country. We suggest here that at least 80% of the indicators (46 of the 57 questions) should be filled out by any one country for a reasonable estimate of vulnerability. In this report, we were unable to reach this threshold for any country. For Australia, Fiji and Tuvalu we were able to find data for 19, 40 and 37 indicators, respectively. We are aware that data are available for the remaining indicators, but are buried, or need to be requested from authorities and will take some time and effort to procure. The shortage of data means that all the EVI values obtained here are indicative: they are by no means completed estimates and should be read with caution.

We also had some problems with the quality of data. For example, whilst looking up values for area of land and sea for each of the countries, we found widely varying estimates in published sources. It will take some time to determine which are the correct estimates. Other problems with the data were that they were expressed in different ways in the different countries, or accumulated under different conditions (e.g. the definition of a 'drought' in Australia is not the same as in Fiji). Our partial solution to this problem was to design questions for the indicators which were independent of local definitions. For some indicators, it will be necessary to ask for the data to be supplied in different forms to those now provided by the relevant authorities.

5.2 Conclusions

The EVI model gives single-figure measures of environmental vulnerability that appear to be able to distinguish countries and identify sources of vulnerability within a country. For the moment, it appears that of three countries tested, Australia is the least vulnerable, and Tuvalu the most. There were similar levels of risk in each of the countries, the most degradation in Australia and the least intrinsic resilience in Tuvalu. These results are only preliminary because there was insufficient time to collect all of the data required for these three countries and there were some problems with reliability of the data. We expect that each of these problems can be overcome and the results suggest that the EVI will be a useful tool for characterising vulnerabilities of states.

6 Strengths and weaknesses of the EVI

As for all methods of summarising and modelling data, the EVI developed here is associated with a number of strengths and weaknesses which must be understood for its proper application and use. It should be noted here that the weaknesses in this model are inherent and relate to the methods used. Any improvements on the methods and changes to the model will lead to a new suite of strengths and weaknesses which will also have to be understood for appropriate use of the model. This work was not a search for the 'perfect' vulnerability calculator since all approaches will have associated with them certain weaknesses. At best we can hope to minimise them.

6.1 Strengths

The EVI calculator developed here is based on a theoretical framework that prompted us to find indicators for all of the identified aspects of vulnerability. In addition, it is:

- Comprehensive in its scope including indicators from a wide range of the most important risks and measures of environmental resilience and integrity;
- Able to incorporate qualitative indicators for which no numerical data are available;
- Innovative, since it distinguishes between risk, health (integrity) and resilience;
- Inclusive of two types of vulnerability. The nett and gross vulnerabilities simultaneously provide a basis for world-wide comparisons of states and an assessment of the real risks likely to affect a state;
- Able to incorporate non-linear relationships between causes and predicted effects;
- Able to prompt local environmental agencies to increase and improve data collection;
- Allows states to undertake self-assessment and policy refinement regarding their own environmental vulnerability; and
- So far it is limited more-or-less to the area of Oceania. This is reflected in the present choice of indicators. If the project is extended world-wide, other indicators can be easily incorporated into the model to encompass the additional risks and other indicators which had no relevance for the region (e.g. risks to frosts, ice and snow avalanches).

6.2 Weaknesses

The major identified weaknesses of the EVI model developed here are:

- The index does not rely exclusively on published official data, resulting in relatively high cost of obtaining data and omissions. This means that it will initially require the presence of a consultant in developing countries to obtain some of the data which would otherwise not be easily accessible. The index is subject to problems with different in-country users responding to the indicators with their own interpretations. This could be minimised if in-country training is carried out to assist users the first time the index is calculated for that country;

- There is some subjectivity in assigning weights and non-linearities to the scores. Also, long and short term effects have not been differently weighted;
- The mapping of data on a seven point scale may result in loss of detail compared with using numerical data directly;
- As for all indices of this kind, the index is driven by the indicators chosen. That is, a different set of indicators might result in very different vulnerability profiles and rating of countries. The index is also to some extent driven by availability of data. Some indicators had to be discarded due to a lack of data availability. In addition, while assessing the exposure and integrity of a country, local variations have not been taken into account;
- Intrinsic vulnerability is not well represented due to a lack of data on carrying capacity, productivity and energy flows. Years of research are required on a range of ecosystems before these data become available;
- Gross vulnerability includes signals for indicators which do not occur in countries. This tends to give lower vulnerability scores for large countries which span large geographic and climatic ranges because they are more likely to accumulate values in their numerators for a common denominator in all countries (except for indicators for which data are at present unavailable). This might be balanced by the fact that scores in such countries are averaged over their entire area, which might include areas not affected by the risk that the indicator describes, giving an apparently less vulnerable profile.

7 Conclusions and future directions

7.1 Promising results

The results described in the previous section show that it is possible to obtain a single figure measure of environmental vulnerability. This measure is a composite of the risks, intrinsic resilience and health or integrity of the environment. This study also shows that data which were previously thought to be difficult to obtain could be procured, albeit with the assistance of environmental consultants. The methodology selected in the computation of the index can produce results which could have operational usefulness for ranking countries according to their environmental vulnerabilities. This index highlights the need for governments to upgrade their collection and collation of environmental statistics. In addition, the breakdown of results into meteorological, geological, anthropogenic, mitigating and other categories of risk highlights areas of concern for environmental action.

7.2 Refining the EVI and extending it globally

The environmental vulnerability index developed here will require further refinement before it becomes fully operational. In a sense, determining the vulnerabilities of countries is always a question of examining them in the context of all possible conditions. Limiting the ranges of indicators and their response levels to the Pacific Region does not tell us much about how specific countries fare in a world-wide context. In this study we have tried to set the response ranges of the indicators selected to reflect this understanding. It has also been noted above, that the value of the EVI is dependent on the types of indicators selected and that the relative vulnerabilities of countries could change if different indicators were used. One of the most important tasks for developing the index will be to review each of the indicators and the response levels set to ensure that:

- The EVI model is applicable to all geographic and climatic regions - mostly this would be achieved by the addition of new indicators;
- The model may include adequate measures of risk and integrity of the environment, but more attention is required on measures of intrinsic resilience (e.g. productivity);
- Response levels of the indicators include the entire range of possibilities for each risk or measure of resilience and integrity; and
- Indicators for which data should be collected but are currently unavailable should also be identified.

One of the most important mechanisms by which the EVI may be refined is to subject it to an international 'think tank' and other forms of peer review. For the think tank, the aim is to assemble a small group of highly-specialised experts in the fields of statistics, biodiversity, biogeography, indices which summarise complex data, weather and climate, disaster research, ecosystem management, fisheries, forestry and productivity. It will also be necessary to carry out consultations with the countries themselves.

A second mechanism for refining the index will be to visit, say 10, countries to build their capacity to work with the EVI and collect data which at present may be available in forms not immediately useable for the EVI. For example, Tuvalu has only just begun recording its meteorological data on an electronic database (since October 1998), with all data prior to that being available only as hard copy data sheets. Data from additional developed countries should be available by request.

When sufficient data have been collected and indicators have been refined it will be necessary to test the performance of the model. This will tell us how the EVI performs for different types of countries and will highlight any biases that might be inherent in the EVI. Specifically, it will be necessary to:

- Test for correlations among the indicators to remove those which are redundant and do not significantly add to our assessment of vulnerability;
- Empirically test the model and indices and their ability to differentiate countries (create 'spread');

- Test the method for accumulation of scores and examine other possible options which might give better results; and
- Assess the availability of data and confidence in the data procured.

To facilitate the use of the EVI by countries and regional managers, it will also be necessary to develop a user-friendly computer calculator. We have used an EXCEL workbook in this study to calculate the indices for Tuvalu, Fiji and Australia, but this is cumbersome and can easily be damaged by users. A calculator written in Microsoft ACCESS would provide a Windows-based calculator which will be easy to use and which cannot be damaged inadvertently by users.

The final stage in the development of the EVI will be to combine it with other indices, such as the Economic Vulnerability Index (Briguglio, 1993, 1995, 1997) to give an indication of overall vulnerability of states.

7.3 Institutional considerations

It is important that the Environmental Vulnerability Index be given some sort of 'ownership', so that its development can continue in a consistent and organised manner. The economic vulnerability index of Briguglio (1993, 1995, 1997) suffered in its development because it did not have a proper institutional framework at its inception making its subsequent refinement sporadic. There was a lack of consensus regarding the underlying methodological procedures that should be used for the economic vulnerability index.

The environmental vulnerability index has started off in an institutional framework within SOPAC at the technical level, and this augurs well for its consistent development. It should also be given a proper framework at the political level, and it is suggested here that it could be adopted by the Pacific Forum with the aim of strengthening its political profile.

As it continues to develop for other regions, other regional technical and political organisations could be invited to assist by computing the EVI in their respective regions, with SOPAC and the Pacific Forum remaining the co-ordinators of the process.

8 Conclusions

The construction of and environmental vulnerability index is possible. Despite certain inherent limitations (which are common to all indices) the results obtained in this study suggest that we should be able to distinguish among countries in terms of their relative vulnerabilities to natural and anthropogenic risks to the environment. To do this it is important that the index be expanded so that it is applicable on a global scale. It is only in the context of the global scale that the relative vulnerabilities of the SIDS can be assessed.

In addition to the spatial application of the EVI discussed in the previous paragraph, the EVI could also be applied temporally. That is, it could be recalculated through time to show changes in relative vulnerabilities in response to changes in the human population, legislative changes, climate change and other factors which might vary the levels of risk, resilience and integrity of the environment. We suggest that the EVI, once fully operational, should be recalculated for all participating countries every 5 years.

Much work remains to be done to refine this index to make it fully operational. Despite this, our original aim to show that the development of an EVI is possible has been achieved. This work, in addition to contributing to research on the development of country characterising indices in general, will serve to prompt governments to upgrade their capacity for the collection of environmental data.

9 Definition of acronyms and terms

Composite index	An aggregated score of several indices or sub-indices
Ecosystem goods	Include tangible items obtainable within an ecosystem, such as fishes or sand
Ecosystem services	Functions provided by an ecosystem such as biodegradation, absorption of toxins and CO_2 etc.
Ecosystem	Organisms, their physical environment, and relationships between them and outside areas. Usually defined spatially.
EDI	Environmental degradation sub-index
Exposure units	Refers to human exposure to impacts. May be identified spatially at a number of scales - country level or island or community group. (Sem et al. 1996). In this report, this definition is extended to include exposure of all aspects of the environment.
GIS	Geographic information systems
Index	An aggregated score of sub-indices to give an overall measure of vulnerability of a state
Indicator	Ant variable which characterises the level of risk, resilience or environmental degradation in a state.
IRI	Intrinsic resilience sub-index
Natural disaster	A natural event of sufficient intensity which strikes natural systems or a human population that is vulnerable to it (e.g. Johnson et al., 1995)
Natural hazards	(i) Natural or man-made events that have a harmful effect on human beings and / or the environment or which present a risk to life or property (e.g. Johnson et al., 1995; American Geological Society, 1984, In: Alexander, 1990); (ii) A hazard may be regarded as a predisaster situation, in which some risk of disaster exists, principally because human society has placed itself in a situation of vulnerability' (Alexander, 1990).
REI	Risk exposure sub-index
Resilience	The potential for attributes of a system to minimise or absorb the impacts of extreme events. In Sem et al. 1996, this is expressed as an integer value between 0 and +3.
Risk	Expected degree of loss or damage to natural or human systems (e.g. Johnson et al., 1995, p.2); Hazard x vulnerability (Johnson et al., 1995; Alexander, 1990)
SIDS	Small island developing states
SOPAC	South Pacific Applied Geosciences Commission, Suva, Fiji
SPREP	South Pacific Regional Environment Programme, Apia, Samoa
Sub-index	An aggregated separate score for indicators of risk, resilience or degradation as REI. IRI and EDI respectively
VA	Vulnerability assessment
VI	Vulnerability index
Vulnerability	The potential for attributes of a system to respond adversely to the occurrence of hazardous events. In Sem et al. 1996, this is expressed as an integer value between 0 and -3.

10 References

Adger, W.N. 1996. Approaches to vulnerability to climate change. CSERGE (Centre for Social and Economic Research of the Global Environment, UK) Working Paper GEC 96-05, 63pp.

Adger, W.N. 1998. Indicators of social and economic vulnerability to climate change in Vietnam. CSERGE (Centre for Social and Economic Research of the Global Environment, UK) Working Paper GEC 98-02, 39pp.

Atkins, J., Mazzi, S. and Ramlogan, C. 1998. A Composite Index of Vulnerability. Commonwealth Secretariat, London.

Briguglio L. 1997. Alternative Economic Vulnerability Indicators for Developing Countries with Special Reference to SIDS. Report Prepared for the Expert Group on Vulnerability Indices UN-DESA, 17-19 December 1997.

Briguglio, L. 1992. Preliminary Study on the Construction of an Index for Ranking Countries According to their Economic Vulnerability, UNCTAD/LDC/Misc.4.

Briguglio, L. 1993. The Economic Vulnerabilities of Small Island Developing States. Study commissioned by CARICOM for the Regional Technical Meeting of the Global Conference on the Sustainable Development of Small Island Developing States, Port of Spain, Trinidad and Tobago, July 1993.

Briguglio, L. 1995. Small Island States and their Economic Vulnerabilities. World Development. 23:1615-1632.

Campbell, J.R. and Ericksen, N.J. 1990. Change, extreme events and natural hazards. In: Climate change impacts on New Zealand: Implications for the environment, economy and society. Ministry for the Environment, pp19-28.

Chander 1996 - 43pp

Chander, R. 1996. Measurement of the Vulnerability of Small States. Washington, 43pp.

Dalzell, P, Adams, T.J.H., Polunin, N.V.C. 1996. Coastal fisheries in the Pacific Islands. Oceanography and Marine Biology Annual Review, 34:395.

De Leo, G.A. and Levin, S. 1997. The multifaceted aspects of ecosystem integrity. Conservation Ecology 1(1):3. http://www.consecol.org/vol1/iss1/art3

Downing, T.E. 1992. Climate change and vulnerable places: Global food security and country studies in Zimbabwe, Kenya, Senegal and Chile. Research Report 1, Environmental Change Unit, University of Oxford.

Ehrlich, P.R. and Ehrlich, A.H. 1991. Healing the planet. Addiison-Wesley Publication Co. Inc., Menlo Park, CA.

Holling, C.S. 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4:1-23.

Houghton, J.T., Jenkins, G.J. and Ephraums, J.J. (eds). 1990. Climate change: the IPCC Scientific Assessment. Cambridge University Press, England.

IPCC. 1991. The seven steps to the vulnerability assessment of coastal areas to sea-level rise - Guidelines for case studies. IPCC Report, 24pp.

IPCC. 1992. Global climate change and the rising challenge of the sea. IPCC RSWG Report, 34pp.

Johnson, R.W., Blong, R.J. and Ryan, C.J. 1995. Natural hazards: Their potential in the Pacific Southwest. Australian Government Publishing Service, Canberra, 60pp.

Jones, G.P. and Kaly, U.L. 1995. Criteria for selecting marine organisms in biomonitoring studies. Pp. 39-56, In: "Detection of Ecological Impacts: Conceptual issues and application in coastal marine habitats", (Schmitt, R.J. and Osenberg, C.W., eds), University of California Press.

Kaly, U.L. and Jones, G.P. 1998. Minimum designs for measuring ecological impacts on coral reefs. Proc. 8th Int. Coral Reef Symposium, Panama June 1996.

Ludwig, D., Walker, B. and Holling, C.S. 1997. Sustainability, stability and resilience. Conservation Ecology 1(1):7. http://www.consecol.org/vol1/iss1/art7

Pantin, D. 1997. Alternative Ecological Vulnerability Indicators for Developing Countries with Special Reference to SIDS. Report Prepared for the Expert Group on Vulnerability Indices, UN-DESA, 17-19 December 1997.

Pantin, D.A. 1997. Alternative ecological vulnerability indices for developing countries with special reference to small island developing states (SIDS). Report to UN Department of Economic and Social Affairs, 22pp.

Pernetta, J.C. 1990. Projected climate change and sea-level rise: A relative impact rating for the countries of the Pacific Basin. In: Pernetta, J.C. and Hughes, P.J. (eds). Implications of expected climate changes in the South Pacific Region: an overview. UNEP Regional Seas Report 1990, p14-23.

Robertson, A.I., Daniel, P.A. and Dixon, P. 1991. Mangrove forest structure and productivity in the Fly River Estuary, Papua New Guinea. Marine Biology, 111(1):147.

Sem, G., Campbell, J.R., Hay, J.E., Mimura, N., Ohno, E., Yamada, K., Serizawa, M., and Nishioka, S. 1996. Coastal vulnerability and resilience in Tuvalu: Assessment of climate change impacts and adaptation. Integrated Coastal Zone Management Programme for Fiji and Tuvalu Phase IV, SPREP, EAJ, OECC Report, 130pp.

UNCTAD. 1998. Specific Problems of Island Developing Countries. LDC/Misc/17.

UNDP. 1998. Human Development Report. UNDP, New York, 228pp.

UNEP Island Directory. 1998. Explanation of island indicators. http://www.unep.ch/islands/indicat.htm

UNEP. 1998. Human development report 1998. UNDP Report. Oxford University Press, 228pp.

United Nations - DPCSD. 1997. Vulnerability Index (Revised Background Paper). SD-SIDS Unit.

United Nations. 1994. Report on the Global Conference on the Sustainable Development of Small Island Developing States, A/Conf. 167/9.

Wells, J. 1996. Composite vulnerability index: A preliminary report. Commonwealth Secretariat, London.

Wells, J. 1997. Composite vulnerability index: A revised report. Commonwealth Secretariat, London.

Yamada, K, Nunn, P.D., Mimura, N., Machida, S. and Yamamoto, M. 1995. Methodology for the assessment of vulnerability of south Pacific Island countries to sea-level rise and climate change. Journal of global environmental engineering, 1:101-125.

Yohe, G.W. 1991. The cost of not holding back the sea - Economic vulnerability. Ocean and shoreline management, 15:233-255.

Annex 1 Terms of reference for this study

Objective

To pursue the development of an ecological/environmental vulnerability index consistent with the Barbados Plan of Action and the needs enunciated by the Alliance of Small Island States (AOSIS).

Background

Two particular paragraphs of the Barbados Plan of Action, paragraphs 113 and 114, refer to the need for a vulnerability index for Small Island Developing States (SIDS).

113. Small Island Developing States, in cooperation with national, regional and international organisations and research centres, should continue to work on the development of vulnerability indices and other indicators that reflect the status of SIDS and integrate ecological fragility and economic vulnerability. Consideration should be given to how such an index, as well as relevant studies undertaken on SIDS by other international institutions, might be used in addition to other statistical measures as quantitative indicators of fragility.

114. Appropriate expertise should continue to be utilised in the development, compilation and updating of the vulnerability index. Such expertise could include scholars and representatives of international organisations that have at their disposal the data required to compile the vulnerability index. Relevant international organisations are invited to contribute to the development of the index. In addition, it is recommended that the work currently under way in the United Nations system on the elaboration of sustainable development indicators should take into account proposals on the vulnerability index.

Of particular interest is the expression of the need for a single index that is composite, and incorporates an expression of both the economic and ecological (environmental?) vulnerability of SIDS compared with other states.

Much has been written about vulnerability of small states (e.g. Commonwealth Secretariat 1997) and in particular SIDS (e.g. Briguglio 1995). However, the recent Expert Group Meeting convened by the SIDS Unit of UNDESA failed to arrive at a solution that adequately addressed the Barbados Plan of Action. The position of SIDS was presented as an address to that meeting by the Chair of AOSIS. The following is an extract from that address.

"…Small Island states proceed, of course, from the basis of their relative disadvantage: geographic often oceanic isolation, small size, economic fragility, and their acknowledged vulnerability to environment, ecological and natural disasters. It has always been a matter of particular concern for our countries that the current criteria for determining socio-economic status is not comprehensive enough and not a true measure of the economic and social strength of the small island developing states. The anomaly borne out by Professor

Briguglio's work, for instance, is that many small island developing countries register relatively high gross national product per capita; yet in reality, their economies are very susceptible to any external economic fluctuations and environmental shocks, no matter how minimal.

For us, the Barbados Plan of Action for the Sustainable Development of Small Island Developing States provides the basis and raison d'être for the Vulnerability Index. We need full and proper understanding of all the components and technical nature of vulnerability, and so that we can plan and seek from the international community vital support for our efforts at sustainable development for our part AOSIS has endeavoured for some time to spark some momentum into the work on the Index, though we were pleased that the fourth and fifth Sessions for the Commission on Sustainable Development specifically recognised the need to accord sufficient priority to it.

Thus far, the issue of the vulnerability of the small island developing countries has tended to be projected more on the political level. In the daily lives of our Governments and citizens, there are indeed constraints, whether one calls them unique or special constraints, they are real enough obstacles which hinder the search for sustainable development. In particular contexts, as for example in the ongoing debate on global climate change, small islands countries are acknowledged to be highest among the most vulnerable and the least able to adapt to the impact of climate change. Available data, including critically important elements of the relative resilience and adaptability of small island countries, would no doubt need to be fully investigated and assessed as to their technical nature and implications. This Expert Group Meeting is therefore most timely and necessary in that we need assessment at expert and technical level on the specific variables and criteria applicable for Vulnerability Indices, and so that we can come to a more complete and proper understanding of these matters…"

Given the manner to which vulnerability indices are being used in the international arena it appears critical that a single vulnerability index be developed expressing economic as well as environmental/ecological parameters as a matter of urgency.

In order to address this matter it appears apparent that there is a lack of adequate data for all SIDS for both economic and ecological/environmental (natural disasters) parameters which impact on an island economy. Also there is a lack of an acceptable methodology to combine the two sets of data into one composite vulnerability index. As a result there is a need to increase and strengthen all efforts to develop such an index.

The UN Expert Group in December 97 could not construct a composite index. It suggested retaining a vulnerability index based on economic parameters whilst agreeing that efforts to develop an environmentally sensitive vulnerability index continue.

New Zealand as current Chair of CSD has indicated its support to Pacific SIDS to pursue the development of an environmental vulnerability index by way of this current project being implemented by SOPAC. Support for this initiative was expressed by UNDP at the PIC Partners Meeting, 9th July 1998.

The Forum Economic Ministers Meeting (8th July 1998) agreed to adopt a common Forum position with the objective of the UN adopting a vulnerability index, and with the aim of having such an index included among the criteria for determining LDC status, and for deciding eligibility for concessional aid and trade treatment.

As a result of a Commonwealth Ministerial Mission the World Bank and the IMF established a Task Force for Small States on 13th July 1998 to study the legal, environmental and economic vulnerability of small states not currently eligible for IDA-funding.

Study Description – Strategy

1. Review and build on current work already completed or underway addressing environmental vulnerability of SIDS
2. Work with SPOCC regional agencies and others (internationally, regionally and nationally) to develop a report for New Zealand to table at CSD-7.
3. Carry out this study in conjunction with the GEO-2 exercise currently underway within the SPOCC agencies and being co-ordinated by SPREP.
4. Identify parameters which may be used in the construction of an environmentally sensitive vulnerability index for Pacific SIDS.
5. Source data.
6. Identify gaps in these data and develop concept papers for projects which focus on a common objective to ensure that these gaps are filled.
7. Convene a session on environmental vulnerability indices at the upcoming SPREP-UNEP Oceans meeting to enable widespread consultation with experts and country representatives.
8. Define future actions to: (i) further the development of an acceptable environmental vulnerability index for Pacific SIDS and (ii) further efforts towards the development of a composite vulnerability index as described in the Barbados Program of Action and meet the needs enunciated by AOSIS.
9. Compile a report for widespread circulation and consideration prior to the Donor Round Table leading up to CSD-7 and the UN General Assembly special session on SIDS in September 1999.

Reporting

Draft report to be submitted by SOPAC to New Zealand by 31st December 1998.

Annex 2 The vulnerability indicators used

In this annexe, we provide a description, categorisation and the response levels set for the questions used in this study to measure aspects of vulnerability. For many of the risk indicators, the observed value is expressed as a ratio in relation to the area of land or sea available. The reasoning behind this is that it is the *density* of risks, not the absolute number that affects the environment. The ability of ecosystems to tolerate impacts depends on how much of the ecosystem is affected at any one time (allowing for refuges for recolonisation) and how much ecosystem is available to absorb the effects of a risk. For example 1 tonne of a pollutant spread over 100 km^2 is expected to have a smaller detrimental effect than the same amount spread over 1 km^2 (all else being equal) because the concentration of the pollutant will be lower and any toxicity thresholds are less likely to be exceeded.

Question number: 1
Sub-index: REI
Categorisation: Meteorological
Factor type: Risk Factor
Intrinsic weighting: 1

Deviation in average sea temperatures during moderate or greater El Nino (NOAA) (^oC)

Scoring levels:

1	2	3	4	5	6	7
0	0.1-1	1.1-2	2.1-3	3.1-4	4.1-5	>5

Question number: 2
Sub-index: REI
Categorisation: Meteorological
Factor type: Risk Factor
Intrinsic weighting: 1

Number of months over last 5 years during which rainfall is more than 20% above 30yr average for that month (flood risk)

Scoring levels:

1	2	3	4	5	6	7
0	1-10	11-20	21-30	31-40	41-50	51-60

This question examines the risk to flooding and other effects associated with high rainfall from the perspective of ecological systems. Greater than average rainfall can affect reef areas by freshwater and silt inputs, cause damage to rivers and deltas and flood inland areas, all of which can result in ecological disturbance. Number of months should be averaged for all major weather stations in the country.

Question number: 3
Sub-index: REI
Categorisation: Meteorological
Factor type: Risk Factor
Intrinsic weighting: 1

Number of months over last 5 years during which rainfall is more than 20% below 30yr average for that month (drought risk)

Scoring levels:

1	2	3	4	5	6	7
0	1-10	11-20	21-30	31-40	41-50	51-60

This question examines drought conditions, not from a human perspective, but from the perspective of stress to ecological communities. By expressing the question in this form, easily-accessible meteorological data can be used to measure the risk to shortages of rainfall based on normal rainfall patterns. For most countries this will have to be assessed on a region by region or island by island basis. Number of months should be averaged for all major weather stations in the country.

Question number: 4
Sub-index: REI
Categorisation: Meteorological
Factor type: Risk Factor
Intrinsic weighting: 1

Number of category 1-5 cyclones (<994 hPa central pressure) / decade / 10,000 sq. km (last decade only)

Scoring levels:

1	2	3	4	5	6	7
0	0.01-0.1	0.11-1	1.1-10	11-100	101-1,000	>1,000

The categories of cyclones referred to in this question are described in Johnson et al. (1995, p 14). We have included all categories of cyclone because even Category 1 cyclones can cause severe disruption of natural ecosystems. The calculation has been standardised to 10,000 km^2 of land area to create whole number units.

For this and following questions:

$$\text{Value} = \frac{\text{Number of cyclones}}{\text{Land area in sq. km}} * 10{,}000$$

Question number: 5

Sub-index: REI

Categorisation: Meteorological

Factor type: Risk Factor

Intrinsic weighting: 1

Mean number of days per year (last five years) in which the maximum temperature was >5oC above the mean monthly maximum (calculated over last 30 years)

Scoring levels:

1	2	3	4	5	6	7
0	1-2	3-4	5-6	7-10	11-15	>16

Question number: 6

Sub-index: REI

Categorisation: Meteorological

Factor type: Risk Factor

Intrinsic weighting: 1

Mean number of days per year (over last five years) in which the minimum temperature was >5oC below the mean monthly minimum (calculated over last 30 years)

Scoring levels:

1	2	3	4	5	6	7
0	1-2	3-4	5-6	7-10	11-15	>16

Question number: 7

Sub-index: REI

Categorisation: Meteorological

Factor type: Risk Factor

Intrinsic weighting: 1

Number of severe storms and tornadoes / 10,000 sq. km / decade (last 10 years)

Scoring levels:

1	2	3	4	5	6	7
0	0.01-0.1	0.11-1	1.1-10	11-100	101-1,000	>1,000

This question refers to severe storms commonly defined as producing wind gusts of 90km/h (48 knots) or greater, hail storms that produce stones 2cm in diameter or greater, and storms that can produce flash-flooding, lightning and tornadoes (Johnson et al. 1995). The definition of severe storms varies from country to country, so for the purposes of the EVI we will define here that the Australian system for defining storms should be used.

Question number: 8
Sub-index: REI
Categorisation: Geological
Factor type: Risk Factor
Intrinsic weighting: 1

Number earthquakes over the last 50 years / 10,000 sq. km land area with intensity of >6.0 Richter

Scoring levels:

1	2	3	4	5	6	7
0	0.01-0.1	0.11-1	1.1-10	11-100	101-1,000	>1,000

We have chosen to use the old Richter Scale rather than the newer Modified-Mercalli intensity scale which is based on non-instrument assessment (Johnson et al. 1995). By focusing on earthquakes of 6 or greater on the Richter Scale, we have omitted the majority of smaller, more frequent earthquakes that are of little significance from an environmental disturbance point-of-view. The long time scale reflects the expected frequency of these geological events - although the 50 year measurement window will move with each update of the EVI (every 5 years), it is not expected that this indicator will change much for a state, forming one of its relatively unchanging risk features.

Question number: 9
Sub-index: REI
Categorisation: Geological
Factor type: Risk Factor
Intrinsic weighting: 1

Number tsunamis with run up 2m+ over last 50 years / 10,000 sq. km coastal area

Scoring levels:

1	2	3	4	5	6	7
0		0.001-0.01	0.011-0.1	0.11-1	1.1-4	>5

This question deals with tsunamis of Magnitude 1 or greater (Johnson et al. 1995) which are considered moderate and high tsunami potentials.

Question number: 10
Sub-index: REI
Categorisation: Geological
Factor type: Risk Factor
Intrinsic weighting: 1

Number of volcanoes with potential for explosive eruptions / 10,000 sq. km land area

Scoring levels:

1	2	3	4	5	6	7
0		0.001-0.01	0.011-0.1	0.11-1	1.1-4	>5

Volcanoes present several different types of hazards which may impact negatively on ecosystems. These include lava flows, ash clouds, sulphur dioxide gas with associated sulphuric acid aerosols, and possible landslides and tsunamis (Johnson et al. 1995). The definition of 'potential for large explosive eruptions' is as per Johnson et al. (1995).

Question number: 11
Sub-index: REI
Categorisation: Anthropogenic, Habitat destruction
Intrinsic weighting: 1

Percent land area burned by forest fires per year (worst year of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0	<1%	1-2.9%	2-3.9%	4-5.9%	6-10%	>10%

Although most forest fires are likely to be anthropogenic in origin, it is acknowledged here that some are natural and no distinction is made in this question on origin of fires. This question does not include grasslands or shrublands which tend to be limited in their destructive potentials (Johnson et al. 1995). Forest fires can cause ecological disruption to large areas of terrestrial ecosystems which may take many years to recover.

Question number: 12
Sub-index: REI
Categorisation: Anthropogenic, Agriculture
Factor type: Risk Factor
Intrinsic weighting: 1

Percentage of agriculture land under subsistence / organic agriculture

Scoring levels:

1	2	3	4	5	6	7
80-100%	60-79%	40-60%	21-40%	11-20%	1-10%	0%

Agricultural lands under organic and most forms of subsistence agriculture are less likely to be associated with problems of erosion, increased run-off, soil depletion, pesticides and wholesale habitat destruction than mechanised agriculture.

Question number: 13
Sub-index: REI
Categorisation: Anthropogenic, Agriculture
Factor type: Risk Factor
Intrinsic weighting: 1

Tonnes of pesticides produced or imported / 10,000 sq. km land area / year (average last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0	1-100	101-500	501-1,000	1,001-5,000	5,001-10,000	>10,000

This question examines the loading of agricultural and urban land areas with pesticides which can then combine into further toxic compounds and/or find their way into streams, groundwater, coastal areas and therefore other ecosystems.

Question number: 14
Sub-index: REI
Categorisation: Anthropogenic, Agriculture
Factor type: Risk Factor
Intrinsic weighting: 1

Tonnes of N,P,K fertilisers produced or imported / 10,000 sq. km land area / year (average last 5 yrs)

Scoring levels:

1	2	3	4	5	6	7
0	1-100	101-500	501-1,000	1,001-5,000	5,001-10,000	>10,000

When these fertilisers find their way into other ecosystems (usually aquatic) they can lead to problems of algal blooms (including toxic algae such as those which lead to red tides and paralytic shellfish poisoning - PSP) and eutrophication.

Question number: 15
Sub-index: REI
Categorisation: Anthropogenic, Agriculture
Factor type: Risk Factor
Intrinsic weighting: 5

Rate of deforestation of primary forest (% of remaining forest lost per year) (average of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0	0.1-1%	1.1-2%	2.1-3%	3.1-4%	4.1-5%	>5%

Question number: 16
Sub-index: REI
Categorisation: Anthropogenic, Agriculture
Factor type: Risk Factor
Intrinsic weighting: 1

Percentage of agriculture land which is mechanised, monoculture and/or commercial

Scoring levels:

1	2	3	4	5	6	7
0	1-10%	11-20%	21-40%	40-60%	60-79%	80-100%

Chemical farming methods includes the use of insecticides, herbicides, fungal agents, vermicides etc, for aquaculture this includes antibiotics. Also included in this question is the use of chemical fertilisers including hydroponics.

Question number: 17
Sub-index: REI
Categorisation: Anthropogenic, Fisheries
Factor type: Risk Factor
Intrinsic weighting: 1

Number of commercial inshore fishing vessels / 10,000 sq. km coastal area / year (average of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0-100	101-250	251-500	501-1,000	1,001-1,500	1501-2,000	>2,000

This question approximates the amount of fishing pressure in the nearshore ecosystems. Catch per unit of effort data would have been a better measure of fishing pressure, but data are unlikely to be available.

Question number: 18
Sub-index: REI
Categorisation: Anthropogenic, Fisheries
Factor type: Risk Factor
Intrinsic weighting: 1

Number of commercial offshore fishing vessels / area of EEZ / year (average of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0-10	11-25	26-50	51-100	101-150	151-200	>200

This is an approximate measure of the amount of off-shore and pelagic fisheries pressure in the state.

Question number: 19
Sub-index: REI
Categorisation: Anthropogenic, Fisheries
Factor type: Risk Factor
Intrinsic weighting: 1

Destructive fishing methods used? (dynamite, cyanide, muro ami, rotenone)

Scoring levels:

1	2	3	4	5	6	7
No			Some			Common

Destructive fishing methods usually are a result of and further exacerbate problems of not only overfishing, but also habitat destruction. When the fish habitats are destroyed the renewability of the fishery resource decreases.

Question number: 20
Sub-index: REI
Categorisation: Anthropogenic, Fisheries
Factor type: Mitigating Factor
Intrinsic weighting: 1

Number patrols run (boat or plane) / 10,000 sq. km of EEZ / year (average of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
>100	11-100	1.1-10	0.11-1	0.011-0.1	>0-0.01	0

Question number: 21
Sub-index: REI
Categorisation: Anthropogenic, Fisheries
Factor type: Mitigating Factor
Intrinsic weighting: 1

Fisheries observer programmes?

Scoring levels:

1	2	3	4	5	6	7
Yes						No

Question number: 22
Sub-index: REI
Categorisation: Anthropogenic, Government
Factor type: Mitigating Factor
Intrinsic weighting: 1

Percent of marine zone set aside as reserves (mean high tide to continental shelf)

Scoring levels:

1	2	3	4	5	6	7
>20%	11-20%	6-10%	1-5%			0%

Reserves means fully protected areas in which no fishing or collecting can occur. Other categories of zonation such as those with an open season or which allow limited fishing are not considered reserves.

Question number: 23
Sub-index: REI
Categorisation: Anthropogenic, Government
Factor type: Mitigating Factor
Intrinsic weighting: 1

Environmental Legislation

Scoring levels:

1	2	3	4	5	6	7
Law					Draft	None

Question number: 24
Sub-index: REI
Categorisation: Anthropogenic, Government
Factor type: Mitigating Factor
Intrinsic weighting: 1

Percent of development projects accompanied by EIA (Environmental Impact Assessment)

Scoring levels:

1	2	3	4	5	6	7
95-100%	70-94%	50-69%	21-49%	6-20%	1-5%	0%

Question number: 25
Sub-index: REI
Categorisation: Anthropogenic, Government
Factor type: Mitigating Factor
Intrinsic weighting: 1

Percent of terrestrial zone set aside as reserves

Scoring levels:

1	2	3	4	5	6	7
>20%	11-20%	6-10%	1-5%			0%

This question refers only to national parks and sanctuaries of natural habitat areas within which no hunting or collecting is permitted.

Question number: 26
Sub-index: REI
Categorisation: Anthropogenic, Mining
Factor type: Risk Factor
Intrinsic weighting: 1

Tonnes of coral extracted / year / 10,000 sq. km of coastal zone (average of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0-100	101-250	251-500	501-1,000	1,001-1,500	1501-2,000	>2,000

Question number: 27
Sub-index: REI
Categorisation: Anthropogenic, Mining
Factor type: Risk Factor
Intrinsic weighting: 1

Kilotonnes of sand / gravel extracted / year / 10,000 sq. km coastal area (average of last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0-100	101-250	251-500	501-1,000	1,001-1,500	1501-2,000	>2,000

Question number: 28
Sub-index: REI
Categorisation: Anthropogenic, Mining
Factor type: Risk Factor
Intrinsic weighting: 1

Kilotonnes of all mining material (ore + tailings) extracted / 10,000 sq. km land area / year (average last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0-100	101-250	251-500	501-1,000	1,001-1,500	1501-2,000	>2,000

Question number: 29
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Total tonnage of imported toxic or hazardous wastes / 10,000 sq. km land area / year (average last 10 years)

Scoring levels:

1	2	3	4	5	6	7
0	1-50	51-200	201-300	301-500	501-1,000	>1,000

Question number: 30
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Millions of litres of hydrocarbons used / 10,000 sq. km land area / year (average over last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0-100	101-200	201-300	301-400	401-500	501-600	>600

Question number: 31
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Number of nuclear facilities (power, medical/research facilities, waste, weapons) / 10,000 sq. km land area

Scoring levels:

1	2	3	4	5	6	7
0		<0.1	0.1-1	1.1-10	11-100	>100

Question number: 32
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Number of shipping ports which maintain and/or produce ships / 10,000 sq. km area of coastal zone

Scoring levels:

1	2	3	4	5	6	7
0	1-2	3-4	5-6	7-8	9-10	>10

Question number: 33
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Electricity consumption kilowatt hours / capita / year

Scoring levels:

1	2	3	4	5	6	7
0-1,000	1,001-2,000	2,001-3,000	3,001-5,000	5,001-7,000	7,001-10,000	>10,000

Question number: 34
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Number of cars / 1,000 persons

Scoring levels:

1	2	3	4	5	6	7
0-10	11-20	21-100	101-200	201-350	351-500	>500

Question number: 35
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Percent of toxic wastes disposed of by high temperature incineration (average last 5 years)

Scoring levels:

1	2	3	4	5	6	7
100%	71-99%	41-70%	21-40%	11-20%	1-10%	0

High temperature incineration is considered a better way of disposing of toxic compounds because it bypasses the creation of further toxic compounds by low temperature burning and interactions among compounds. General solid wastes, including drugs can be incinerated at between 800-900^{o}C. 1200-1300^{o}C are required for hazardous toxic wastes and plastics (to bypass dioxin production), although there might still be toxins in the chimney stack and the ash residue (Andrew Munro (SPREP), pers comm).

Question number: 36
Sub-index: REI
Categorisation: Anthropogenic, Pollution
Factor type: Risk Factor
Intrinsic weighting: 1

Percent of population with at least secondary sewage treatment

Scoring levels:

1	2	3	4	5	6	7
100	80-99	60-79	40-59	20-39	1-19	0

Question number: 37
Sub-index: REI
Categorisation: Anthropogenic, Population
Factor type: Risk Factor
Intrinsic weighting: 5

Annual population growth rate (average over last 5 years)

Scoring levels:

1	2	3	4	5	6	7
Negative		0%	0.1-1%	1.1-2%	2.1-3%	>3%

Question number: 38
Sub-index: REI
Categorisation: Anthropogenic, Population
Factor type: Risk Factor
Intrinsic weighting: 5

Total human population density (per sq. km land area)

Scoring levels:

1	2	3	4	5	6	7
0	1-100	101-200	201-300	301-400	401-500	>500

Question number: 39
Sub-index: REI
Categorisation: Anthropogenic, Population
Factor type: Risk Factor
Intrinsic weighting: 1

Standing stock of tourists / 100 sq. km land area (Standing stock = # tourists x average # days stay / 365) (average for last 5 years)

Scoring levels:

1	2	3	4	5	6	7
0	1-50	51-100	101-150	151-200	201-250	>250

Question number: 40
Sub-index: IRI
Categorisation: Country characteristics
Factor type: Risk Factor
Intrinsic weighting: 5

Total land area (sq. km)

Scoring levels:

1	2	3	4	5	6	7
>1,000,000	100,001-1,000,000	10.001-100,000	5,001-10,000	1,001-5,000	100-1,000	<100

This question has been assigned a high intrinsic weighting because it is considered one of the pivotal questions addressing resilience for a state. States which are large will tend to have larger numbers of habitats and species, refuges for recolonisation of species after an impact event and a tendency for impacts to affect only a small part of the state (rather than all of it).

Question number: 41
Sub-index: IRI
Categorisation: Country characteristics
Intrinsic weighting: 1

Ratio of length of shoreline : total land area (fragmentation)

Scoring levels:

1	2	3	4	5	6	7
<0.05	0.06-0.1	0.2-0.5	0.5-0.9	1-1.4	1.5-2	>2

States with a large coastline to land area ratio tend to be fragmented or elongated and narrow meaning that more of the land area can be accessed by sea-based threats. On the other hand, however, fragmentation also offers some resilience because islands isolated from those which have been impacted may contain the same habitats and species and act as a refuge for recolonisation of impacted areas.

Question number: 42
Sub-index: IRI
Categorisation: Country characteristics
Intrinsic weighting: 1

Number of endemic species per 10,000 sq. km land area

Scoring levels:

1	2	3	4	5	6	7
0	<0.26	0.26-1	1-25	26-50	51-100	>100

Countries with large numbers of endemic species will tend to be more vulnerable to risks because localised extinctions cannot be resupplied from elsewhere by natural or augmented recolonisation. The loss of endemic species can lead to far-reaching secondary impacts on the functioning of ecosystems. This indicator includes mammals, birds, reptiles, amphibians, fishes and plants.

Question number: 43
Sub-index: IRI
Categorisation: Country characteristics
Intrinsic weighting: 1

Percent of land area <20m above sealevel

Scoring levels:

1	2	3	4	5	6	7
0	1-19%	20-39%	40-59%	60-79%	80-89%	90-100%

States with a large percentage of their land areas below 20m above sealevel will tend to be vulnerable to sea-level rise, tsunamis and storm surges.

Question number: 44
Sub-index: IRI
Categorisation: Country characteristics
Intrinsic weighting: 1

Percent of coastal land area composed of unconsolidated sediments (i.e. not native rock base)

Scoring levels:

1	2	3	4	5	6	7
0	1-19%	20-39%	40-59%	60-79%	80-89%	90-100%

This question identifies states which are largely composed of unconsolidated sediments (atolls, archipelagos, banks e.g. Bahamas, Tuvalu, St Brandon (Mauritius)). Their vulnerabilities to tsunamis and cyclones may be greatly compounded because it is possible for these states to lose land area.

Question number: 45
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Has nuclear testing occurred?

Scoring levels:

1	2	3	4	5	6	7
No						Yes

Question number: 46
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Percent age area of land desertified since 1950

Scoring levels:

1	2	3	4	5	6	7
0	1-2%	3-4%	5-6%	7-8%	9-10%	>10%

Question number: 47
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Percentage of degraded coral reef area (ICRI Reef Check)

Scoring levels:

1	2	3	4	5	6	7
0			1-9%	10-49%	50-79%	80-100%

Question number: 48
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 5

Percentage of primary / old growth forests or vegetation remaining (e.g. prairies, savannah, desert, tundra)

Scoring levels:

1	2	3	4	5	6	7
90-100%	61-89%	31-60%	21-30%	11-20%	1-10%	0%

Question number: 49
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Percent of fisheries stocks overfished

Scoring levels:

1	2	3	4	5	6	7
0	1-10%	11-20%	21-30%	31-40%	41-50%	>50%

Question number: 50
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Percentage of land under agriculture including plantation / forestry (now)

Scoring levels:

1	2	3	4	5	6	7
0-10%	11-20%	21-30%	31-50%	51-60%	61-79%	80-100%

Question number: 51
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Number of mariculture farms / 10,000 sq. km coastal area

Scoring levels:

1	2	3	4	5	6	7
0	<1	1.1-2.5	2.6-5	5.1-7.5	7.6-10	>10

Question number: 52
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 5

Percentage of original mangrove / saltmarsh area remaining

Scoring levels:

1	2	3	4	5	6	7
90-100%	71-89%	61-70%	51-60%	11-50%	1-10%	0%

Question number: 53
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Number of harmful algal blooms including ciguatera, red tides etc over the last 5 years / 10,000 sq. km coastal area

Scoring levels:

1	2	3	4	5	6	7
0			1-2	3-5	5-10	>10

Question number: 54
Sub-index: EDI
Categorisation: Ecosystems
Intrinsic weighting: 1

Percent total land area affected by mining / quarrying

Scoring levels:

1	2	3	4	5	6	7
0	<0.1%	0.1-1%	1-3%	4-6%	7-10%	>10%

Question number: 55
Sub-index: EDI
Categorisation: Biodiversity
Intrinsic weighting: 1

*Number of species which have become extinct this century / 10,000 sq. km land and (coastal area * 0.5)*

Scoring levels:

1	2	3	4	5	6	7
0	<0.1	0.1-0.5	0.6-1.0	1.1-5	6-10	>10

These figures should be available for mammals, birds, reptiles, amphibians, fishes and plants (e.g. IUCN Red List). Because the coastal area is defined as a 1km strip on either side of high tide mark, it was necessary to divide the coastal area by half to avoid overlap with the measurement of land area.

Question number: 56
Sub-index: EDI
Categorisation: Biodiversity
Intrinsic weighting: 1

*Number of endangered and threatened species / 10,000 sq. km of land and (coastal area * 0.5)*

Scoring levels:

1	2	3	4	5	6	7
0	<0.1	0.1-0.5	0.6-1.0	1.1-5	6-10	>10

Question number: 57
Sub-index: EDI
Categorisation: Biodiversity
Intrinsic weighting: 1

Number of introduced terrestrial species / 10,000 sq. km land area (over last 100 years)

Scoring levels:

1	2	3	4	5	6	7
0	<0.1	0.1-0.5	0.6-1.0	1.1-5	6-10	>10

Annex 3 Summary table of other vulnerability indices developed