Ecological Risk Assessment Guidelines

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FOREWORD

The context for socio-economic development in South Africa changed dramatically since the first democratic elections in 1994. The new constitution that followed in 1996 emphasises various aspects relating to human rights, amongst others, *"ecologically sustainable development and use of natural resources while promoting justifiable economic and social development"*. Progressive legislation was drafted to give affect to these stipulations. The National Water Act (1998) and the National Environmental Management Act (1998), amongst others, specifically support environmentally sustainable development. The implementation of these acts needs to be supported with technologies that can be used to characterise the status of the environment, consider opportunities for development, evaluate and compare different development options, and provide information that will promote effective decision-making. Ecological risk assessment is a structured approach that describes, explains and organises scientific facts, laws and relationships and provides a sound basis to determine sufficient protection measures and to develop utilisation strategies. The risk assessment process has the potential to improve communication between scientists, managers and the public, thereby promoting mutual understanding and collaboration. Appropriate use of this guideline document will thus promote cooperative governance and sustainable development.

M.V. MOOSA
MINISTER OF ENVIRONMENTAL AFFAIRS AND TOURISM

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INTRODUCTION

Document Background

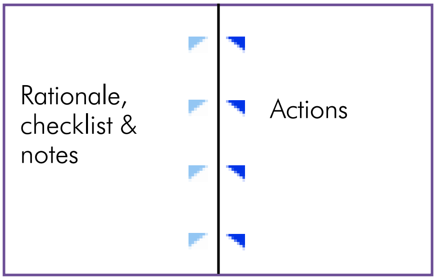
Informed decision-making is a prerequisite to effective resource management. A common understanding and adoption of ecological risk assessment (ERA) in South Africa will improve decision-making in support of various national policies related to environmental management. To this end, existing ERA approaches were examined and adapted for South African conditions.

This guideline document balances the need for a detailed manual to conduct ERA's and a framework document that will establish a common approach on which a broad range of environmental assessments can be based. The purpose of the guidelines is to assist risk assessors who have domain-specific knowledge and competence and to assist risk managers in the application of ERA.

> An ecological risk assessment is a process of sound scientific integrity. It should take account of relevant political, economic and social issues, but they should not be biased or compromised by them.

Guidelines Layout

The ERA methodology presented in this document distinguishes between actions in the process (presented on the right-hand pages) and the rationale and important notes for each task (on the left-hand, facing pages). This distinction should clarify communication and, hence, understanding of the process.



Case study outlines are included in Appendices A, B and C.

Risk Assessment

Probabilistic analysis originated in the gambling domain around 3500BC. It was applied to the actuarial sciences around 1700 and subsequently adopted for engineering and environmental assessments.

This South African guidelines document for ERA is based on developments in North America, Europe and Australia, seeking a balance between exhaustive analyses and practical application.Therefore, the development and evaluation of appropriate risk hypotheses is proposed.

The following definition for ERA, as proposed by the US EPA, has been adopted for South African use.

> ERA is the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

Risk in the context of ecological risk assessment and risk management is defined by the following necessary components:

- Subject: A hazard or stressor that initiates risk, including an exposure pathway (Affected *by* what = stressor)
- Object: The target upon which the stressor or hazard is expected to have an effect (The effect *on* what = receptor)
- Effect: The type, magnitude and characteristics of the effect being assessed (the response of the receptor (object) given a specific stressor (subject))
- Expression of likelihood: Probability of effect or other expression of expectation appropriate to the assessment.

An ERA can be prospective (predictive) or retrospective (diagnostic). Either the null hypothesis or an alternative hypothesis can be tested to protect against Type I and Type II errors respectively.

Risk Management

Risk management is an action (giving effect to a decision) where the decision is based on explicit knowledge of the likelihood of events and their consequences.

The risk assessment process ensures that scientific rigour underpins a risk management decision in the face of uncertainty. A risk assessment (including ERA) is not a different process from existing environmental practices but provides a risk-based approach for processes such as EIA, EMP, development plans, etc. The ERA process provides guidance on project scoping, risk communication and risk management. The guidelines provide terms of reference for specialist studies. Specialist studies which comply with the guidelines will provide informative, concise and relevant decision support.

The ecological risk assessment process is divided into 5 stages, of which 3 are classified as formal stages. Each stage comprises several tasks.

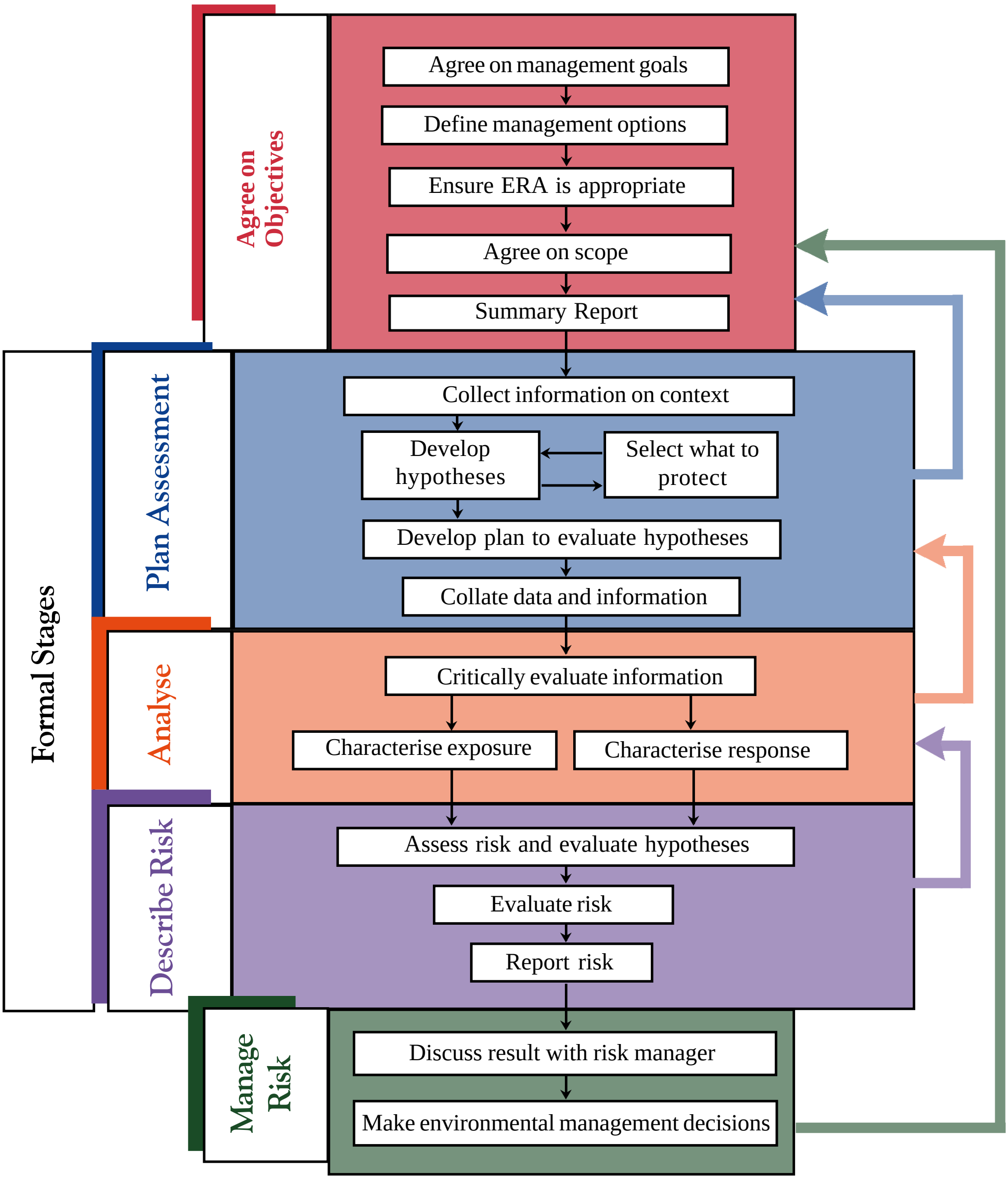


Figure 1. Process for ecological risk asessment (Adapted from Murray & Claassen, 1999)

Agree on Objectives

Management goals should support sustainable development.

Agree on Management Goals

Although risk management is performed independently of ERA, the risk manager must effectively communicate the managerial goals and information needs to the assessor.

Risk management will improve if the risk manager has access to appropriate ecological information. This can be accomplished by aligning the assessment to management goals.

Define Management Options

Articulate the problem clearly in its human and environmental context.
Accommodate inputs from those affected by a decision. The decision should reduce and balance risks relative to their political, social, economic, legal, and cultural implications.

Ensure Appropriateness of ERA

An expression of relevant risk (combining uncertainty and variability) improves the risk management process because it provides a sound scientific basis on which to base decisions.

A risk assessment provides the risk manager with a deeper understanding of the meaning and context of the associated risk.
Dealing with uncertainty and variability supports effective decision-making.
A risk management framework needs to be in place to accommodate and use results from the ecological risk assessment.

Agree on Scope

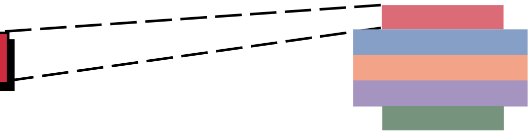
Managerial goals and information needs must be supported by the assessment, and should affect the scope.

A clear scope will lead to effective communication of the results of the ERA to interested and affected parties.

Produce Summary Report

The report will ensure clear communication between the risk manager, risk assessor and interested and affected parties.

Agree on Objectives



A planning process precedes the formal assessment. The risk manager, stakeholders and the risk assessor agree on the objectives of the assessment. The risk assessor and the risk manager share responsibility for this stage.

Agree on Management Goals

The risk manager is responsible for establishing the management goals. These goals should take account of stakeholder inputs and the socio-economic environment. The risk assessor, in agreement with the risk manager, must ensure that assessment and points can be related to management goals.

Define Management Options

The management decisions that will be informed by the ERA must be defined explicitly. The assessment can only be designed to support the relevant decision(s) if the options are clearly defined. The risk assessor and risk manager need to ensure alignment between the assessment and the management options.

Ensure Appropriateness of ERA

Determine whether an ERA will best enable managers to make informed environmental decisions, compared to other approaches, such as expert opinion, technological standards or a precautionary approach.

Agree on Scope

Both the risk assessor and risk manager must agree on the scope of the ERA within the constraints of data availability, scientific knowledge, financial resources and spatial and temporal scales. Of particular importance is the level of uncertainty that the risk manager will tolerate. The lower the tolerance the more extensive the assessment is likely to be. The scope of the ERA may require the assessment to be at a screening level or a detailed, site-specific level.

Produce Summary Report

Produce a summary report on the outcome of the *Agree on Objectives* phase. It serves as a record of discussions and provides the terms of reference for subsequent work.

Plan Assessment

The risk assessor is primarily responsible for the formal stages of the ecological risk assessment. Ongoing communication between the risk assessor and risk manager will ensure optimum alignment.

Collect Information on Context

Understanding the behaviour of ecosystems and their response to stressors is essential because it promotes:

Quantitative predictability - The more the behaviours of the stressor and the ecosystem are understood the greater the degree of quantitative predictability

Risk interpretation - The more the risk assessor understands the ecosystem the more capable he/she will be of providing a holistic description of the effects of the stressor on the ecosystem to the risk manager

Reduced uncertainty - The more the system is understood, the more confidence there will be in the predictions

Ecosystem knowledge arises from monitoring, experimentation, modelling, etc. It also takes account of natural variability in the ecosystem. Knowledge of the stressor comes from chemical, physical or biological measures, modelling, experimentation and engineering design specifications. It should be focused on the stressor's behaviour in the environment and take account of natural variability in the stressor system.

Develop Hypotheses

In-depth consideration should be given to ensuring all the important relationships are included. Failure in this regard can seriously affect the results of the risk assessment by significantly contributing to uncertainty.

A good cause-effect diagram will facilitate clear understanding and communication.

Components of Cause–effect diagram

	Example 1	Example 2	Example 3
Sources	Emission stacks	Effluent discharge	Construction
Stressors	Heavy metals	Pesticides	Structure
Exposure routes	Speciation/transport	Fate/dispersion	Migration barrier
End point	Plant	Invertebrates	Wildlife
Response	Growth	Death	Migration
Measure	Production	Abundance	Count
Ecosystem links	Herbivores	Fish	Plants

Plan Assessment

The development of an analysis plan is the first formal stage of an ERA. The risk assessor is responsible for this stage.

Collect Information on Context

Collect available information and data to achieve the following:

- Evaluate information related to environmental policy and the management context.
- Address issues including the sources of stressors, stressors' characteristics and exposure mechanisms as well as spatial and temporal aspects.
- Describe characteristics of the ecosystem potentially at risk as well as the likely ecological effects of the stressors on the ecosystem.

Develop Hypotheses

Draw up a cause-effect diagram of sources, stressors, exposure routes, end points, responses and measures representing the risk hypotheses.
Develop (a) risk hypothesis(es). The hypothesis(es) describe(s) what will be evaluated during the assessment.

> Risk hypotheses are predictions of relationships between stressor, exposure and the response of the assessment end points.

Components of Cause–effect diagram (continued)

Example 4	Example 5	Example 6	Example 7
Erosion	Interbasin transfer	Ship hull & ballast	Agriculture
Top soil loss	Different gene pool	Exotic species	GMO
Biome characteristics	Canal/pipeline	Shipping route	Dispersion
Crops	Fish	Shellfish	Native
Growth	Character	Dispersion	Competition
Yield	DNA print	Count	Diversity
Insects	Invertebrates	Otter	Predators

Select what to Protect

Relevance includes ecological and management relevance.

Confirm ecological relevance: End points should help sustain the natural structure, function and biodiversity of the ecosystem. End points should also be sensitive to the stressor under the amount of exposure likely to occur.

Confirm management relevance: It must be ensured that the previously identified management decisions can be informed and, hence, the goals achieved. In this sense, the assessment end points should ideally be values that people care about.

Develop Plan to Evaluate Hypotheses

Measures of effect: Evaluate the response of the assessment end point when exposed to the stressor.
Measures of exposure: Establish mechanisms by which exposure occurs and determine level of exposure.
Measures of ecosystem and receptor characteristics: Describe the assessment end points.

The analysis plan should comply with all the requirements for scientific integrity.

> How will the data analyses support the evaluation of the risk hypothesis(es)?

> The plan should clearly identify the data that need to be measured before the next stage is started.

Collate Data and Information

Aspects that need to be considered when collating data are:

- Variability (exposure and response)
- Uncertainty (sampling error, unknown, hypothesis uncertainty etc.)
- Data characteristics:
  - Age of study
  - Method employed
  - Independence
  - Replicates
  - Calibration
  - Statistical significance
  - Resolution
  - Relevance

> The method for evaluating the response of an assessment end point to the stressor are dealt with in detail in the plan assessment.

> Revisit the risk hypothesis(es) if new information provides insights in support of an improved hypothesis(es)

Select what to Protect

Describe the ecosystem potentially at risk according to functional and/or structural relationships (e.g. Ecosystem model).
Identify potential assessment end points:
  Identify the ecological entities considered to be of value.
  Identify the characteristic of the entities that are potentially at risk.
Confirm scientific (ecological and management) relevance.
Rigorously select assessment end point(s).

Assessment end points are the definitive measures that scientifically and ecologically represent the broader management concerns.

Develop Plan to Evaluate Hypotheses

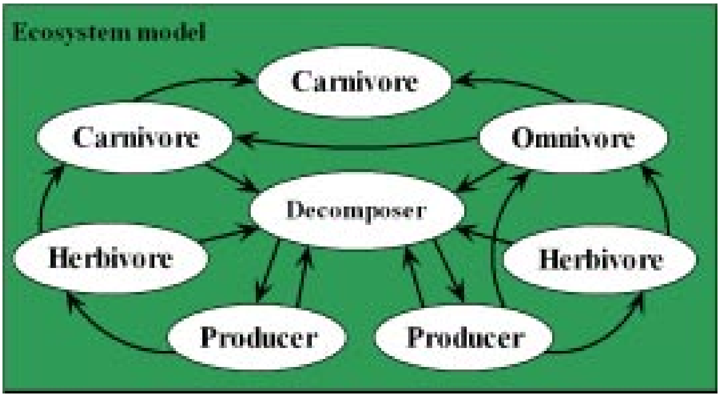
Develop an analysis plan that describes how the risk hypotheses will be assessed. Select and describe the measures of exposure, measures of effect and measures of ecosystem and receptor characteristics. Independent lines of evidence should be considered. Indicate how data will be analysed or modelled and how results will be presented. Discuss the analysis plan with the risk manager to ensure that the results will allow consideration of options and inform sound decisions. The analysis plan should be peer reviewed.

Collate Data and Information

Collate detailed information that is relevant to the risk hypothesis and analysis plan.

Collate = Examine + Compare

Ecosystem model



New insights obtained during this phase may necessitate that the *Agree on Objectives* phase be revisited

Analyse

Evaluate information

This activity is a more detailed examination of existing information than that carried out in the previous stage.

Data sources include laboratory and field studies, experience from other similar situations, structure-activity relationships and models.

QSAR (Quantitative Structure Activity Relationships): The quantified mapping of molecular structure characteristics (such as number of methyl groups, or electronegativity) onto activity characteristics (such as blood-brain-barrier penetration, antimalarial activity, strength of binding to humic acids).

Potential sources of uncertainty include the following: Unclear communication, errors in the information itself (descriptive errors), gaps in the data, uncertainty about a quantity's true value and model uncertainties.

Variability can be due to natural variability in the stressor and/or ecosystem.

Characterise exposure

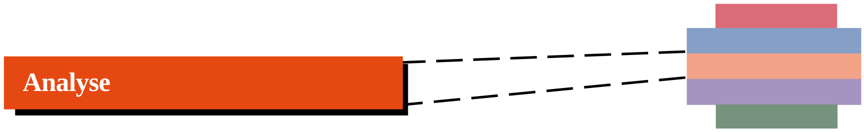
These may include partitioning of chemicals, attributes of physical stressors, dispersion of biological stressors by diffusion or jump-dispersal. It is important to identify secondary stressors caused by the primary stressor since they can significantly influence the result of a risk assessment.

Without exposure there can be no risk

Characterise Responses

Response analysis should include many different information sources. Lines of evidence that are developed in this way will strengthen the risk assessment.

The exposure and response profile should include an analysis of uncertainty and variability.



The analysis of information is the second formal stage of an ERA. The risk assessor is responsible for this stage.

Evaluate Information

Critically evaluate existing studies. Establish the strengths and limitations of data from various sources. Compare the purpose and scope of existing studies carefully with those of the risk assessment. Use only data from studies that display due diligence and scientific rigour.
Measure new data, if necessary. New data can be obtained through measurements, modelling, experimentation etc. This would be driven by the data required to reach the specified objectives.
Evaluate uncertainty. Describe uncertainties in the exposure-effects relationships and, preferably, quantify what is known and not known. Distinguish between natural variability due to stochastic processes and uncertainty due to lack of knowledge.

> Data that are not available, but which are critical to the assessment, are measured and/or modelled during the analysis of the gathered information

Characterise Exposure

Describe the place where the stressor is produced. Address the intensity and timing of stressor induction and/or where one becomes aware of its presence (spatial, magnitude and temporal dimension). Evaluate the mechanisms and pathways of the stressors' dispersion from the source.
Describe the exposure (i.e. stressor and receptor contact). Describe how, when, where and to what degree the stressor and receptor will occur simultaneously. Consider both contact and mechanisms of effect generation and associated uncertainties.
Integrate this information into an exposure profile, which is a summary of what is known.

Characterise Responses

Relate stressor levels to ecological effects, preferably quantitatively. Ecological effects should be reflected at the expected/existing stressor levels. Establish cause-and-effect relationships (causality), including sources of uncertainty. Develop an integrated stressor-response profile that integrates existing and new information. Clearly link what needs to be protected (assessment end point) with what can be measured (measures of effect).

> Information gathered at this stage may necessitate an iteration of the *Plan Assessment*-stage.

Describe Risk

Assess Risk and Evaluate Hypotheses

Testing the previously defined hypothesis(es) allows the assessor to integrate measures of likelihood, variability and related uncertainties. The output is then strongly focused on informing the relevant decision.

Risk estimates can be obtained in many ways, such as:
- Qualitatively, based on professional judgement.
- Single-point estimate, usually as a ratio (exposure value/benchmark value).
- Evaluating the relationships between the entire stressor and response profiles.
- Incorporating variability in exposure or effects.
- Using process models upon which to base risk estimates.
- Estimates can be based on results from field studies.

Evaluate Risk

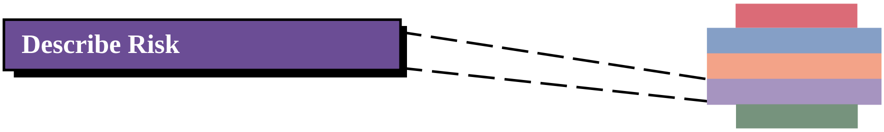
The significance of the risk in the context of the management options needs to be clear.

Evaluating the likelihood of occurance and significance of effects in the context of management options ensures relevant decision support

Report Risk

The risk is reported to the risk manager as described in the next stage.

The report should facilitate communication of risk to policy makers in industry, government and other interested and affected parties. This allows broader participation in, and scrutiny of, the process. Resource managers, the public and experts can differ considerably on the perception of risk and the significance thereof. Before any communication of the reported risk can take place, the risk assessor discusses the results with the risk manager. The risk report includes:
- Summary report of the *Agree on Objectives* phase
- Development plan with reviewers comments
- Exposure and response analyses
- Evaluation of risk
- Final reviewers' comments



Characterising risk is the final formal stage of an ERA. The risk assessor is responsible for this stage. It comprises the following actions.

Assess Risk and Evaluate Hypotheses

Determine the nature, magnitude, extent and likelihood of adverse effects on assessment end points. This is done by integrating the exposure and effects data from the Analyse-stage according to the Analysis Plan.
Evaluate lines of evidence. Use fundamentally different (i.e. independent) approaches to arrive at conclusions. It can include comparisons with literature or benchmark values (quotients), field studies and modelling.

Evaluate Risk

It is essential that a technical narrative accompany the estimated risk.

Describe the risk in the context of the management decision(s). Evaluate the nature and intensity of the effects, the spatial and temporal scales and the potential for recovery in the context of the decision to be made.

Report Risk

Present the results of the risk assessment clearly and concisely. The approach to and format of risk reporting should be appropriate to the target audience. Include detail needed for management decisions.

> The target audience is primarily the risk manager, but the report should also facilitate communication to those affected by the decision.

The risk report should give a detailed account of each of the stages.

> An iteration with the *Analyse*-stage may be required if the analysis is not sufficient to base a decision on.

Manage Risk

Sound, credible and effective risk management depends largely on informed stakeholders and society.

Discuss the Results with the Risk Manager

An ERA process is iterative by nature. It is possible that the process will be completed first at a rather superficial level. The results are examined to decide if enough sound information is available to enable management decisions. The assessment may be repeated at a more detailed level. Individual stages may also require internal iteration.

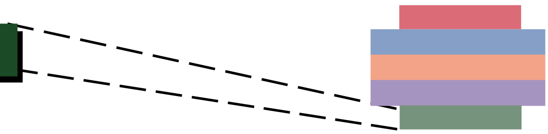
Make Environmental Management Decisions

A comparative risk assessment evaluates various risk hypotheses or considers a continuum in the stressor-response relationship. This enables a risk manager to set risk-based priorities. Resource allocation can then be focused on risks that are more significant.

A decision that alters risk may require another iteration of the ecological risk assessment process.

Risk management may also mean that no action is taken, specifically when mitigation is more damaging.

Manage Risk



During the Risk Management stage, the risk manager uses the results obtained from the ecological risk assessment to make decisions. The risk manager implements the appropriate option. Depending on the options it may involve instituting an action or no action at all.

> The objective of assessing risk is to support risk management.

Discuss the Results with the Risk Manager

The risk assessor, having completed the formal ecological risk assessment process, discusses the results with the risk manager.

The risk manager ensures that environmental management decisions are soundly informed by the risk assessment results. Another more detailed ecological risk assessment may be requested and a new analysis plan formulated, if it is needed for management decision making.

Several iterations of the ERA process may be necessary.

Make Environmental Management Decisions

Once satisfied that the results are of sufficient certainty and detail, the risk manager can then make decisions and implement them.

The risk manager uses the results along with other relevant social, legal, political or economic information to make decisions on how to proceed. This may include invoking mitigation measures, monitoring progress and communicating results to the public.

Affected parties	Individuals or groups that are, or may be, affected by a hazard. The effect could be through direct exposure to the hazard or result indirectly from it.
Adverse effects	The negative consequences (perceived or otherwise) of exposure to a sufficient dose of a hazardous substance to cause harm
Analysis	The systematic application of specific theories and methods for the purpose of collecting and interpreting data and coming to qualitative or quantitative conclusions.
Assessment end point	An explicit expression of the environmental value that is to be protected. An assessment end point includes both an ecological entity and specific attributes of that entity. For example: Fish are a valued ecological entity, reproduction of fish is a specific attribute. Together they form an assessment end point.
Ecological risk assessment	The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. The assessment may describe the type, magnitude and probability of the effect and relate to a specific spatial and temporal context.
Ecosystem	Any unit that includes all of the organisms, the physical environment and the interactions in a given area so that a flow of energy leads to clearly defined trophic structure, biotic diversity and material cycles (i.e. exchange of material between living and non-living parts).
Effective decision-making	Effective decisions support the management objectives, consider stakeholder inputs relevant to the decision, are reasonable given the available information, are made without wasting time and can be implemented.
Effective resource management	Resource management is done in the context of sustainable development. Effective resource management would lead to a balance between the need to utilise resources on the one hand and the need to protect them on the other.
EIA	Environmental impact assessment is a process of predicting and evaluating the effects of an action or series of actions on the environment, then using the conclusions as a tool in planning and decision-making
EMP	Environmental management plans as a product of environmental assessments propose management actions that would lead to the achievement of management ocbjectives.

Endpoint See Assessment endpoint

Exposure The contact between the hazardous substance and a person, population or ecosystem.

GMO Through molecular biology, genetic engineering, or genetic modification, individual genes can be located and transferred to different cells (in a different individual, or a different species). The organisms produced are called genetically-modified organisms (GMO).

Hazard A state or set of conditions that may result in an undesired event, the cause of risk. In environmental toxicology, the potential for exposure of organisms to chemicals at potentially toxic concentrations constitutes the hazard.

Hypothesis A statement of condition that can be tested in the assessment. The conventional approach is to falsify the hypothesis, thus rejecting it (a-test). The hypothesis can also be accepted (ß-test).

Interested parties Individuals or groups whose interest in a specified issue is motivated by reasons other than its direct effect on them.

Likelihood An expectation of a specific outcome. It could be based on quantitative analyses, qualitative assessments, expert opinion or perception.

Lines of evidence Information derived from different sources or by different techniques that can be used to evaluate risk hypothesis(es).

Management goals The desired outcome of management actions

Management options The alternative courses of action that are available to a manager to achieve a desired effect

Model A mathematical, physical or conceptual representation of some component of the world.

Policy Statements of intent that define the focus, scope and boundaries of actions within a specific domain.

Probability A statistical expression of likelihood (typically values ranging from 0 to 1)

Receptor The ecological entity exposed to the stressor

Risk The likelihood of an undesired effect

Risk characterisation A synthesis and summary of information about a hazard and associated effects so that it addresses the needs and interests of decision makers and interested and affected parties. The terminology "characterise risk" is replaced by "describe risk" in this guideline document.

Risk communication The exchange of information about the existence, nature, form, severity or acceptability of risk among risk assessors, risk managers, scientists, decision-makers, news media, interest groups, the general public, etc.

Risk hypothesis A statement that defines the key question(s) of the assessment. It guides the assessment and is not necessarily true or false.

Risk management The process of assessing and evaluating alternatives to control hazards, end points' exposure to stressors and ecological effects. Decisions should be made and implemented to conclude the process.

Spatial aspects Geographical descriptors relating to direction, distance, surface area and volume.

Stakeholders Individuals or groups that have an interest in a specific issue. Stakeholders include interested parties, affected parties and those with a responsibility related to the issue.

Stressor Any physical, chemical or biological entity or process that can induce an adverse response.

Temporal aspects Descriptors related to time. These could include start time, duration, finish time, pattern, frequency and relative time.

Type I error Occurs when an insignificant difference is taken as significant.

Type II error Occurs when the lack of significant difference is taken as evidence of no difference.

Uncertainty That which is not completely known. This is mostly due to in complete data or an incomplete understanding of dynamics and interactions.

Variability The occurrence of a range of posibilities (or values) in the stressor, exposure to the end point or ecosystem characteristics. Variability is generally a function of stochastic processes.

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CASE STUDY OUTLINE A: INDUSTRIAL EFFLUENT

CASE STUDY OUTLINE B: SUSTAINABLE UTILISATION

CASE STUDY OUTLINE C: MARINE POLLUTION

Key reference with amplified technical information are: Calow (1998), Suter (1993), UK DOE (1995) and USEPA (1998).

CASE STUDY OUTLINE A: INDUSTRIAL EFFLUENT

Agree on Objectives

Management Goals:

Stakeholders were concerned about the perceived impacts of Egoli Industries' effluent on Hugem Park. Specific concerns were related to the endangered *Goldie sp*. Egoli Industries' goals were to:

- Determine the risk posed by their effluent on downstream ecosystems
- Manage their effluent to protect the *Goldie sp*.
- Maintain a good relationship with stakeholders

Management Options:

Egoli Industries had several management options. These were:

- Optimise their manufacturing process to attain minimum waste production
- Use "best available technology" to reduce metal levels in effluent
- Negotiate with water users to reduce abstraction in order to increase the dilution of effluent
- Employ other methods of waste disposal, e.g. recycling, drying, export, etc.

Appropriateness of ERA:

ERA was considered to be appropriate because:

- It provides managers with an evaluation of various management options.
- Social, economic and ecological issues can be compared because the probability, magnitude and characteristics of combined effects are determined.
- It addresses realistically the complexity of problems through explicitly evaluating variability and uncertainty.

Scope of the study:

The study was bounded by the following parameters;

- Spatial:
  The Egoli industrial site and downstream Hugem National Park. The resolution was at the level of ecological communities.
- Temporal:
  The study included historical data and considered the industry's lifetime.
- Detail:
  The site-specific study considered weekly water quality, the population status of *Goldie sp*. and relevant toxicological data (specifies resolution of data in exposure and effects).
- Financial:
  The study had to be completed by three project members within 2 months. Local expertise was used where possible.

Summary report:

This was a detailed record of the preceding "Agree on Objectives" discussions.

Plan Assessment

Information:

The following information was collected:

- Management context: Egoli Industries support pro-active environmental management.
- The legislation on biodiversity is the key regulatory consideration
- Egoli Industries' metal-containing (M^+) effluent is discharged into the river.
- The river transports M^+ to Hugem Park. M^+ can undergo chemical transformation during transport.
- The impacts are due to effects on fecundity and mortality of sensitive species.
- The high conservation importance of Hugem Park is due to the occurrence of the endangered *Goldie sp*.
- The cause-and-effect relationships are presented in the following diagram.

Hypotheses:

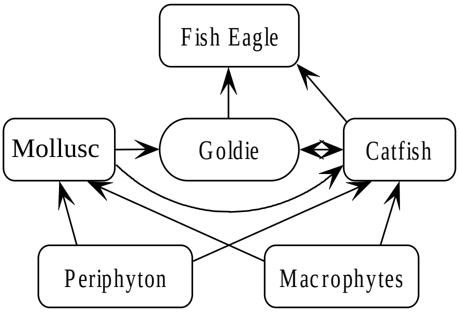
The following risk hypotheses were considered:

- "Current metal levels in the river do not pose an unacceptable threat to the *Goldie sp.*"
- "Future metal levels in the river will not pose an unacceptable threat to the *Goldie sp.*"

What to protect:

The *Goldie sp.* was selected as the assessment end point because:

- It integrates ecological impacts, confirming its ecological importance (ecosystem diagram ⟶).
- It is sensitive to the effects of the metal.
- Its status renders it important for biodiversity and providing goods and services.



Plan to evaluate risk hypotheses:

- The current status was evaluated through compiling and comparing data on effluent quality, river water quality, toxicology and ecosystem structure.
- Fate and transport modelling and predictions based on eco-toxicology data were used to evaluate a range of possible future impacts.

Data and information:

Data that were collated included:

- M^+ concentrations in the effluent and the river
- Chemical characteristics of the diluent water
- Observed laboratory transformations of M^+ species (literature)
- Surveys of the *Goldie sp.* and associated ecosystems
- Toxic response of similar species to M^+
- The details of the management options

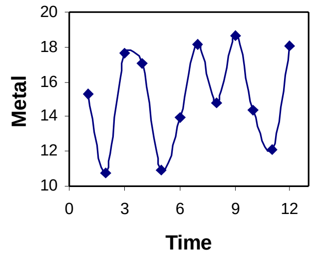
Analyse

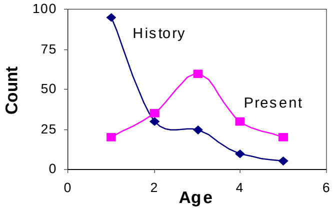
Evaluate information:

- Historical data were available on M^+ concentrations (and other important water quality determinants) in the effluent and the river. Data were collected at a weekly interval through acceptable analytical procedures. Possible reductions in M^+ were determined from the details of the management options.
- The status of the *Goldie sp.* and associated ecosystems prior to development were assessed. The current status of the *Goldie sp.* and associated ecosystem, the river flow and M^+ concentrations in Hugem Park were measured in this task.
  Fecundity and mortality data (toxicology) were available for the taxonomic group representatives

Exposure:

As an aquatic species, the *Goldie sp.* is directly exposed to water (dermal, gills, digestive tract) and ingests contaminants together with food. The concentration of the bioavailable form of M^+ in the water is presented in the accompanying graph. The potential future M^+ concentration was calculated through fate and transport modelling. It can range from 4 to 12 M^+ units at the site where *Goldie sp.* occur, depending on the management action.

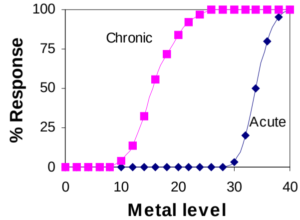




Responses:

The historical (prior to industrial activity) and present *Goldie* population structures are presented in the adjacent figure. Although the abundance is the same, the population structure is different.

The dose-response relationship for other species in the taxonomic group of *Goldie sp.* is presented in the adjacent figure. Chronic (inhibition of fecundity at age 3-4) and acute (mortality of age 1) effects are shown.



Describe Risk

Risk hypotheses:

The risk hypothesis of present conditions was evaluated by comparing historical and current population data. The present abundance of *Goldie sp.* was similar to historical records. The acute toxicity data supported the trend, with acute toxicity being indicated above 30 M^+ units. The marked difference in population structure suggested chronic impacts. The evaluation was further supported by toxicological data, where chronic effects on species in the taxonomic group were observed above 10 M^+ units, with 100% effect on fecundity at 25 M^+ units. Present metal values fluctuate between 10 and 20 units. This supported the evaluation that the current metal levels affect the population structure. If the current trend continued, the *Goldie sp*. population would not be viable in 3 to 5 years time. The same data indicated that possible future levels would only affect fecundity at metal levels between 10 and 12 units. Acute effects were not expected under potential future scenarios. (Various statistical methods could be employed to quantify the risk)

Evaluate risk:

The evidence suggested that the current metal levels had a significant effect on the *Goldie sp*. population structure. No acute effect on the *Goldie sp*. population was indicated. Egoli Industries could institute management actions to limit the in-stream metal concentration to 10 units.

Report risk:

The preceding evaluation was reported in a format appropriate for the target audience

Uncertainties were due to:

- Extrapolation between *spp*. and ecosystem
- Other gene pool used for toxicology
- Lack of analytical precision
- Lack of data on Goldie biology
- Adsorptive capacity of in-stream particulates and sediments
- Sampling error

Variability was affected by:

- River flow
- Effluent quality
- Other abstractions
- Seasonal trends
- Diurnal fluctuations in pH, temperature, DO and EC
- *Goldie sp.* Susceptibility to M^+

The variability is accounted for in the determination of risk, while the uncertainties are not such that the confidence in the assessment is compromised.

Manage Risk

Discussion:

The results were discussed to ensure that the risk manager was clear on the study characteristics and the significance and limitations of the results.

Decision:

The results of the assessment informed effective decision-making. Therefore, no further analyses were suggested. The manager was able to implement decisions based on appropriate ecological and other relevant information.

CASE STUDY OUTLINE B: SUSTAINABLE UTILISATION

Agree on Objectives

Management Goals:

A state-owned property sustains a unique biome, which includes endemic species. The neighbouring community has been harvesting Fetchit for the past 10 years, but due to the increasing needs of the community, the demand for Fetchit has risen sharply. The conservation status of the area is high, with significant eco-tourism potential. The management goal is to: "Balance the development needs of the local community with eco-tourism potential and conservation priorities."

Management options:

- Stop or control the harvesting of Fetchit
- Restock/replace Fetchit in the area
- Provide an alternative source of Fetchit

Appropriateness of ERA:

ERA could be used to inform decision-making because:

- Different development options could be evaluated
- Cumulative effects could be assessed
- It would provide an objective scientific evaluation

Scope of study:

Data availability:

Very little was known about the specific area and associated ecosystems.

Scientific knowledge:

Studies have been done on ecosystems with similar ecological characteristics.

Spatial scale:

The local community's property, the ocean and agricultural areas bounded the study.

Temporal scale:

The study was to consider long-term effects (50-100 yrs).

Uncertainty:

Because of the critical nature of the resource, very little tolerance (uncertainty) could be accommodated in the decision.

Summary report:

A detailed record of preceding discussions was documented.

Plan Assessment

Information on context:

- Legislation regarding the protection of endemic species existed. The Act proposed sustainable development as the minimum requirement.
- The frequency of harvesting and mass taken were recorded.
- Harvesting methods may have had an impact on species that utilised similar habitat.

Cause-effect:

Fetchit harvesting ▶ Reduced production & abundance ▶ *N. demic* reduced

What to protect:

A functional ecosystem model was developed to decide what to protect.
The function of Fechit in the ecosystem was summarised as follows:

- Food source for *S. entails*
- Competes for resources with *N. demic*
- Competes for habitat (niche) with *A. monarch*, *M. poster*
- Creates habitat for *K. ritters*, *D. gers*, *N. demic*
- Helps with dispersal of *D. rifters*

Selected end points were Fechit and *N. demic*
Fechit attributes: Abundance, production and reproduction
N. demic attribute: Abundance

Develop risk hypothesis:

The assessment evaluated whether Fechit could be harvested without compromising the sustainability of Fechit and *N. demic* populations.

Plan to evaluate hypothesis:

1. Describe relationship between harvesting and Fechit
   - Harvesting data (kg/ha + frequency)
   - Detailed surveys (kg/ha)
   - Pilot studies (harvesting vs production)
   - Ecosystem modelling (sustainability of populations)
2. Describe relationship between Fechit and *N. demic*
   - Detailed surveys
   - Functional relationship (qualitative model)
   - Pilot studies (Fechit : *N. demic*)

Collate data:

Harvesting data were available – Survey methods were known and accepted
Need to collect other data – Used accepted methods to ensure <5% error in measurements.

Analyse

Evaluate information:

Measure new data

- Detailed surveys
- Pilot studies

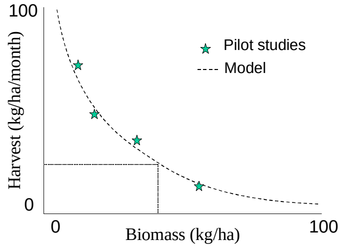
Characterise exposure:

Current harvesting:

50kg/ha, once monthly

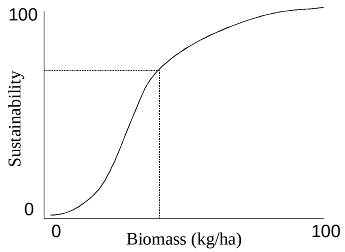
Potential harvesting:

15kg/ha, weekly or
700 kg/ha, annually

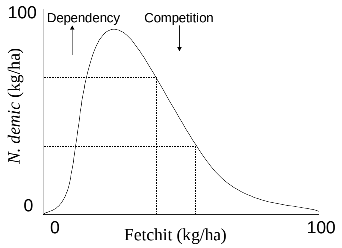


Characterise response:

An inverse relationship exists between harvesting and biomass production of Fetchit. The top figure shows modelled and measured data. The sustainability of the Fetchit population is affected by the biomass, with the relationship indicated in the middle figure.



N. demic is dependent on Fetchit for habitat, but also competes for resources with Fetchit. The relationship is depicted in the adjacent figure, with the optimal range indicated between the dotted lines.



Describe Risk

Assess risk:

1: Harvesting at 20kg/ha/month will ensure a biomass of acceptable sustainability.
2: For optimal *N. demic* population, 300-700kg Fetchit/ha needs to be maintained (then *N. demic* = 10-25 kg/ha).

Uncertainties that should be considered when making use of the assessment include:

- Long term trends
- Seasonality
- Genetic diversity

Report risk:

The preceding evaluation was reported in a format which was appropriate for the target audience.

Manage Risk

Discussion:

The results were discussed to ensure that the risk manager was clear on the study characteristics, significance of the results and limitations.

Decision:

The manager was able to make effective decisions based on appropriate ecological and other relevant information. The results met the brief of the assessment and could, therefore, inform a decision. No further analyses were suggested.

Notes:

- The evaluation of exotic or invasive species could also be assessed in a similar way.
- *Other biological stressors include disease and genetic modification.*

CASE STUDY OUTLINE C: MARINE POLLUTION

Agree on Objectives

Management Goals:

An increasing incidence of crude oil spills threatened vulnerable coastal ecosystems. A management plan needed to be developed to:

- Reduce the likelihood of spills.
- Minimise vulnerable ecosystems' exposure to spilt oil.
- Optimise remediation of exposed ecosystems.

Management Options:

The Maritime Safety Authority and the relevant government department had the following options:

- Specify routes whereby potentially dangerous cargo can be transported.
- Control entry of high-risk vessels to sensitive areas.
- Reduce potential exposure to vulnerable ecosystems in the event of a spill.
- Mitigate impacts on vulnerable species in the event of exposure, including contingency plans.

Appropriateness of ERA:

An ERA would enable effective management decision-making because:

- The hazard could be characterised, which would lead to the institution of appropriate preventive actions.
- The evaluation of exposure routes and mechanisms would allow for the development of an optimal hazard management programme.
- The integration of potential ecosystem responses and consequences would support the development of mitigation actions.

Scope of the study:

The study was bounded by the following parameters;

Spatial:

A 500 km buffer around two vulnerable coastal populations.

Temporal:

The study considered current and potential future impacts.

Detail:

The study was conducted at a detailed level, allowing the collection of site-specific information and the development of simulations.

Financial:

8 Experts and 20 support staff completed the study in 14 months.

Summary report:

A detailed record of the preceding Agree on Objectives discussions was produced.

Plan Assessment

Information:

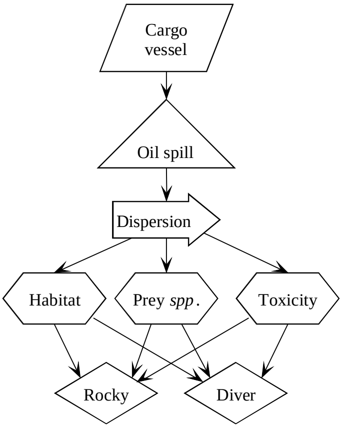
The following information was collected:

- Global demand and supply of crude oil
- Frequency and timing of vessels passing through the study area
- Safety records of three classes of cargo vessels
- Characteristics of crude oil transported
- Ocean currents and characteristics that could affect spilt oil dispersion
- Susceptibility of two coastal populations to crude oil
  Rocky is dependent on habitat, which is adversely affected by spilt oil.
  Diver is directly affected through the toxic effects of crude oil.

Hypotheses:

The following hypothesis was evaluated:

- "Vessels carrying crude oil do not pose an unacceptable risk to *Diver* and *Rocky* populations"
- Unacceptable was defined as:
  The probability of adverse effects being more than 1×10^{-3} (one in a thousand) annually.
  Adverse effects were defined as fatality to more than 5% of an exposed population or chronic effects in more than 25% of exposed populations.
- The causal relationship between an oil spill and adverse ecological effects was presented in the adjacent figure.



What to protect:

- *Diver* was selected as an assessment end point because they have a high conservation status, they integrate effects in the food chain (predators) and they are sensitive to crude oil exposure.
- *Rocky* was selected as an end point due to their importance as a food source for local communities and their dependency on habitat of good integrity.

Plan to evaluate hypotheses:

- The likelihood of a spill (the hazard) occurring was determined through evaluating safety records of three classes of vessels (failures/1000 km travelled).
- The probability of exposure was determined through modelling the dispersion of spilt oil in the ocean.
- Pollutant levels that would induce acute and chronic effects were determined from historical and modelled information.

Data and information:

Data that were collated included:

- Current and potential shipping routes, frequency of use and cargo type
- Safety records of vessels carrying crude oil
- Oceanographic and climate information
- A suitable simulation model and parameters
- *Diver* and *Rocky* sensitivity to crude oil

Analyse

Evaluate information:

- Data were available at the required resolution and confidence for shipping routes and safety records and magnitude of spills.
- The simulation model was calibrated to predict the dispersion and fate of spilt oil in the study area.
- There was uncertainty about the effect of global climate change on local conditions.
- Assays were conducted to evaluate the susceptibility of *Diver* and *Rocky* to crude oil.

Exposure:

- The probability of a significant oil spill (> 10^6 units) was determined as follows:
  - (Vessels per annum x Failures per 1000 km travelled)
    - Class A : (100 x 0.00001) = 0.001
    - Class B : (240 x 0.00005) = 0.012
    - Class C : (35 x 0.0013) = 0.0455
  - Summed probability of a significant spill (per annum) = 0.0585
- The oil concentrations that would reach the *Diver* and *Rocky* habitats could be simplified (hypothetically) to:

  $C = V/pr^2 + (\text{wind} + \text{current} - \text{biodegradation})$

  Where: C = Oil concentration (units/km^2) V = spilt volume
  r = Population's distance from spill p = 22/7
  Wind + current - biodegradation = distribution functions accounting for variability
- The *Diver* population was 30 km and *Rocky* was 28 km from the shipping route.

Responses:

The populations' toxicological response to oil was described as follows (units oil/km^2):

No Observed Effect Concentration (NOEC)

Diver = 2×10^1 *Rocky* = 1×10^2

Lowest Observed Effect Concentration (LOEC)

Diver = 8×10^1 *Rocky* = 3×10^2

Concentration lethal to 5% of population (LC_5)

Diver = 1×10^3 *Rocky* = 5×10^2

Concentration that induced chronic effects in 25% of population (EC_{25})

Diver = 4×10^2 *Rocky* = 6×10^2

Describe Risk

Risk and hypotheses:

The probability of a significant spill in the study area was 0.0585

- Significant exposure to the populations were:
  Diver : 4×10^2 units/km^2 (chronic effects)
  Rocky : 5×10^2 units/km^2 (acute effects)
- The expected exposures in the event of a spill was thus:
  C = V/pr^2 + (wind + current – degradation)
  Diver : = $10^6/(22/7)*30^2$ + (± distribution)
  = 353 units/km^2 (± distribution)
  Rocky : = $10^6/(22/7)*28^2$ + (± distribution)
  = 378 units/km^2 (± distribution)
- The probabilities of significant effects were calculated through incorporating the distribution functions for wind, current & degradation (through Monte Carlo simulations):
  Diver : Probability of > 4×10^2 units/km^2 = 0.03
  Rocky : Probability of > 5×10^2 units/km^2 = 0.001
- The risks posed by crude oil vessels to the respective populations were calculated as the products of the likelihood of the hazard occurring and the probabilities of significant effects if they do.
  Diver : 0.0585 x 0.03 = 1.76×10^{-3}
  Rocky : 0.0585 x 0.001 = 5.86×10^{-5}

Evaluate risk:

- The risk posed by crude oil vessels to the *Diver* population is higher than the acceptable risk of 1×10^{-3}.
- The risk posed to the *Rocky* population is acceptable in the context of the management thresholds.
- The risk to the *Diver* population was mostly affected by class C vessels and driven by chronic response.

Report risk:

- The calculated risks, together with the associated uncertainties, were reported in a clear yet concise format.

Manage Risk

Discussion:

- During discussions of the results, it was clear that the study provided adequate information on which to base a decision.

Decision:

- The regulations for Class C vessels were upgraded to reduce the risk.
- Mitigation actions were put in place to rehabilitate the Diver population in the event of a spill.

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