Socioeconomic Effects of Climate Change in the Florida Keys

Scoping the feasibility to conduct a subsequent two-year research program

30 September 2005

ECONOMIC STRATEGIES

Hans Hoegh-Guldberg
Economic Strategies Pty Ltd
55 Whiteley Road
Oberon NSW 2787 Australia
+61 2 6336 0239
esi@lisp,com.au

Contents

Summary and Acknowledgments

This report scopes the feasibility of conducting a study of socioeconomic effects of climate change in the Florida Keys over the fiscal years 2005-06 and 2006-07. It provides a rationale for the study based on the project brief guiding the scoping exercise (Chapter 1), which is followed by brief reviews of the scientific evidence, environmental factors, and the social and economic evidence (Chapters 2 to 4). The rationale for using scenario planning as the main analytic tool for the future is outlined in Chapter 5, and the concluding chapter indicates that the main two-year study is feasible within a budget of $60,000 per annum for FY 2006 and FY 2007.

Thanks are due to many people for assistance and advice, including Roger Griffis, Bob Leeworthy, Norm Meade, Al Strong, Mark Eakin, Felipe Arzayus and several others stationed at NOAA Headquarters at Silver Spring, MD, Andy Hooten of AJH Environmental Services, Bethesda, MD, Brian Keller and Fiona Wilmot at the Florida Keys Marine Park Sanctuary premises at Marathon, FL, Karen Koltis of the Office of Insular Affairs of the US Department of the Interior, Washington, DC, and John McManus and Felimon Gayalino of the National Center for Caribbean Coral Research in Miami.

Since being in the United States in June 2005, I entered into some useful email correspondence with Phil Dustan, Bob Ginsburg, Walt Jaap, Bill Precht, Manoj Shivlani and Alina Szmant and thank them for their advice and support. Last but last least thanks are due to William Skirving for advice throughout the scoping project, and to Ove Hoegh-Guldberg who read and advised on the draft scoping report, especially the scientific content.

I am sure there are omissions in the list above, and apologize in advance.

Hans Hoegh-Guldberg

September 30, 2005

1 The Project

1.1 Background: Great Barrier Reef study

At the 10th Annual Coral Reef Symposium in mid-2004 in Okinawa, Japan, Ove Hoegh-Guldberg described a combined scientific and socioeconomic study of the future of Australia's Great Barrier Reef (GBR) and the adjacent coastal areas of Queensland under climate change.[1] Based at the University of Queensland, Brisbane, he is recognized worldwide as an expert on coral reefs with a main focus on the impacts of climate change.[2] He is one of nine members of The Australian Climate Group which WWF Australia and the Insurance Australia Group (IAG) convened in 2003 in response to the increasing need for action on climate change in Australia,[3] and chairs the World Bank-UNESCO research group on coral bleaching and climate change.

The GBR report by Hans and Ove Hoegh-Guldberg had been published a few months previously by WWF Australia and the Queensland Tourism Industry Council.[4] The report was in three main parts: 1: The scientific evidence, 2: Regional analysis (which presented the economic and social evidence), and 3: The future. A brief final part contained policy recommendations, ranging from global to local. The collaboration was the second between the two authors, both following a similar pattern though most clearly enunciated in the GBR report. The previous report, for Greenpeace, looked at the impact of climate change and coral bleaching on the Pacific nations.[5]

Hans Hoegh-Guldberg's[6] career spans more than four decades of economic research, which for the past twenty years has focused on cultural and more recently on environmental matters. In 1997 he developed an interest in scenario planning, which became an essential element of the research programs for the two reports.[7] In fact, the unique attribute emerging from the two authors' collaboration was the idea that the scientific and socioeconomic analysis of the future was best undertaken in a scenario-planning framework.

Scenario planning became a powerful management tool after the 'stable and predictable' western world that people thought existed in the 1960s evaporated under the pressure of influences such as the civic movements in the latter part of the decade, the Vietnam War, and the impact of the 1970s oil crises.

Scenarios were also the chosen tool in the futures analysis by the Intergovernmental Panel on Climate Change. Planning the GBR study, the authors found that the four IPCC world scenarios developed in 2000 for the Third Assessment Report provided a suitable framework.[8] From each of these global stories they developed specific scenarios for Australia, Queensland, and the GBR and adjacent regions, and produced quantitative estimates of reductions in economic product in each region for each scenario due to the changed conditions.

1.2 Developing a concept for Florida Keys

The Coordinator of NOAA's Coral Reef Conservation Program (CRCP), Roger B. Griffis, attended the Okinawa Symposium and thought that the approach taken in the GBR study might work, with modifications, for the Florida Keys, the area containing the only living coral reefs around mainland USA. Initial discussions within NOAA's National Environmental Satellite, Data and Information Service (NESDIS) involved team leader Alan Strong, remote sensing oceanographer William Skirving, and Coral Reef Watch (CRW) operations manager Felipe Arzayus. Andy Hooten of AJH Environmental Services also made important contributions during this conceptual stage.

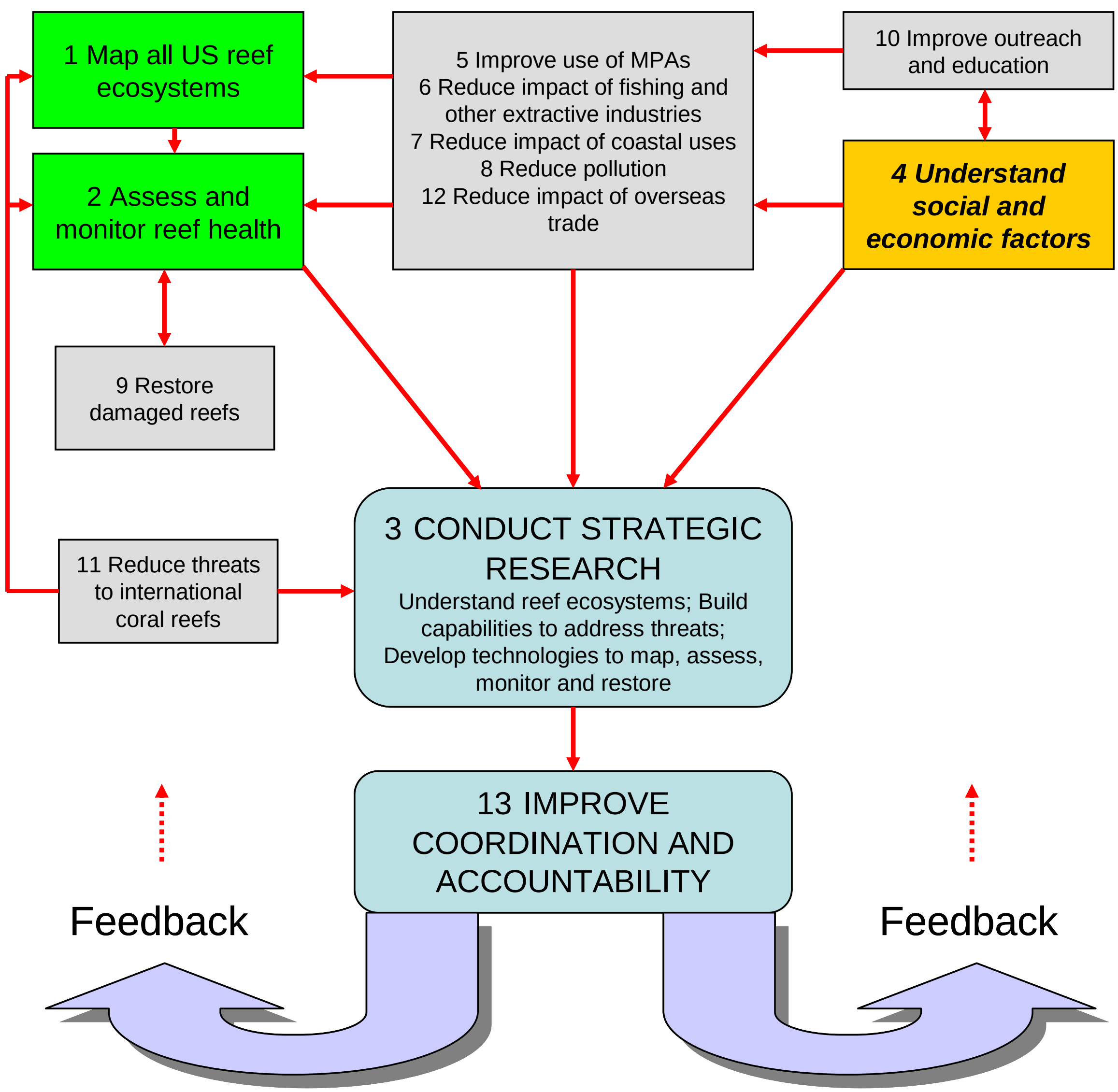
An internal NOAA-CRCP proposal to carry out a scoping inquiry in the latter part of FY 2005 followed. The object was to determine the feasibility of a project aiming to predict the socioeconomic effects that would arise from future coral bleaching as a result of projected climate change.[9] The outcome would then be used to provide a range of policy recommendations.

The range of intended users of the project is wide: NOAA, Non-Government Organizations, Federal, State and Territorial agencies, the Coral Reef Task Force (CRTF), and Congress.[10]

According to the NOAA-CRCP proposal, the goals and conservation objectives from the National Coral Reef Strategy[11] that most closely relate to this project are to acquire an understanding of social and economic factors through increased socioeconomic research and to monitor human uses. It is important to relate this goal (top right-hand part of Chart 1.1) to the other goals of the overall strategy. The chart suggests that three goals are primary drivers:

Chart 1.1: Interrelations between NOAA/CRTF goals

(numbers relate to goal number in goals and objectives statement)



the mapping of ecosystems, the assessment and monitoring of reef health, and the need to understand the social and economic factors.[12] The latter goal is especially important because it influences many other goals: It interacts with goal 10, to improve outreach and education, which thus has a special status in the hierarchy of goals, and it directly influences goals 5-8: to increase the use of Marine Protected Areas and to reduce extractive industries, impact of coastal land use, and general pollution. Goal 12, to reduce the impact of international trade in coral products, is also included in this group of goals (shown in large box at top of Chart 1).

The need to conduct strategic research (goal 3), a central element in any strategic plan, is driven by two main forces: the need to assess, monitor and improve reef health and, again, the need to understand the social and economic factors. The latter goal has an important influence on the natural-science based goals, especially on the assessment and monitoring of reef health – the arrows in the top part of the chart run from, not towards, the socioeconomic box.

The other main influences on goals 1 and 2 (mapping and reef health) are external. Goal 11 concerns the reduction of threats to international coral reefs, including the need to fight pollution and prevent unsustainable and destructive fishing practices, and to help ensure integrated coastal management and effective management of marine protected areas. In the present context, however, the most important feedback from the United States involvement on the international scene is probably increasingly associated with climate change because of the worldwide focus on that subject and its various effects on coral reef ecosystems.

Strategic planning begets policies, and the final goal (13) is interpreted to concern the need to improve cooperation and accountability. The whole existence of a policy-making framework and the coordinating and collaborative processes described in connection with goal 13 is based on legislation and executive orders, which are driven by policy. Furthermore, these processes secure *feedback* to the prior goals and objectives shown in Chart 1, and thereby ensures the existence of a dynamic decision-making process.

In conclusion, the potential impact of studying the Florida Keys ecosystems, environmental and economic characteristics is extensive. The NOAA-CRTF planning structure implies that socioeconomics is a main driver of the whole strategic planning process. This implication needs to be clearly understood in the description and promotion of this socioeconomically based project.

The NOAA-CRTF planning document also assesses priorities to deal with threats:

- In Florida, the high-priority threats are global warming and coral bleaching, diseases, coastal development and runoff, coastal pollution, fishing, and ships, boats and groundings. Tropical storms, tourism and recreation, trade in coral and live reef species, marine debris and alien species are rated medium-priority threats. The only low-priority threats in the Florida context are security trading activities and offshore oil and gas exploration (p 96).
- Of the three objectives listed within the goal of understanding social and economic factors (goal 4), the assessment of human uses of reefs is considered as a high priority, assessing the value of reef resources as a medium priority, and assessing the socioeconomic impact of reef management as a low priority. The high-priority objectives relating to other goals are to map all shallow reefs; every aspect of assessing and monitoring reef health (conducting rapid assessments and monitoring, monitoring coral, fish and other living resources, monitoring water and substrate quality, and evaluating the implications of global climate change for coral health); and the strategic objectives of understanding reef processes, diseases and coral bleaching (p 100).

- Other high-priority objectives in Florida are: strengthening existing MPAs, reducing overfishing, reducing dredging and other habitat impacts, reducing nutrient pollution, improving response capabilities in relation to the restoration of damaged reefs, and increasing awareness through education and outreach. Finally, the goal of improving coordination and accountability is also given high priority in Florida (p 100).
- Many other assessments in the *Coral Reef Action Strategy* will add to the understanding of current priorities, including the threats associated with each of the 13 goals. For example, the high-priority threats associated with the goal of understanding social and economic factors are: global warming/climate change, overfishing, destructive fishing practices and habitat destruction, coastal development, coastal pollution, sedimentation and runoff (p 34).

1.3 Requirements of scoping study

The following excerpts from the NOAA-CRCP proposal illustrate the nature of the project and the requirements of the scoping study in FY 2005 for which the proposal asked for $15,000 of direct funding to cover fees, international and domestic travel, and accommodation.

> *It is increasingly important for the coral conservation program, sanctuaries and other agencies to justify their expenditure on coral conservation efforts, be they management, science, restoration, MPAs, etc. There is no information available on the impacts of climate change on the socioeconomic aspects of coral reefs. This project will begin to address the dearth of this type of information. The project will run over three years and the first year will aim to scope the larger project. This will involve the collection of as much of the relevant socioeconomic, climate and ecological data as possible. A report will be written that addresses what data is available, how much more would be needed for the project proper, and where it would come from. A full project design would also be included in this report.*
>
> *This project is based on research conducted by Ove and Hans Hoegh-Guldberg on the Great Barrier Reef. … Apart from the geographic region, the main differences between the GBR project and this one will be the inclusion of state-of-the-art NOAA predictions on future bleaching, which will be based on a combination of the Intergovernmental Panel on Climate Change (IPCC) model predictions and the NESDIS CRW algorithms for now-casting coral bleaching. This will be the first study of its type conducted within US waters and will provide valuable and unique data on a previously unstudied aspect of coral reef management. This will not directly help the coral ecosystems however it will indirectly help via the provision of a way of valuing corals as a socioeconomic resource.*
>
> *Clearly* [the] *methodology* [used in the GBR study] *will need to be altered to suit the Florida Keys and the US context within which the project will be conducted. The output from the collaborative efforts between NOAA CRW and Princeton University to predict coral bleaching with the use of the IPCC climate model projections will be combined with basic socioeconomic and environmental data to determine a number of plausible scenarios for the fate of the Florida Key corals and the socioeconomic implications of these changes. These will then be used as a basis to form policy recommendations. During the first year, this project will be restricted to a scoping exercise where not only will data be mined, but other logical investigators will be sought. The only deliverable from this project will be a report on the scope and makeup of the larger project (to be conducted over the next two years). This report will also contain a detailed account of the existing data sources and a preliminary analysis of some of these data.*

The project is planned to be a total of three years long. The first is designed to scope the project since it is very difficult to determine the size of the last two years without first understanding how much socioeconomic data is already collated and available. The prediction of future bleaching and ecosystem data is not hard to quantify. The necessary size of the final project is hard to determine, however the milestones and stages are not. In the second year, the bleaching prediction efforts being conducted between CRW and Princeton as part of a separate project will be directed towards the derivation of a prediction for the Florida Keys as one of its outcomes so that this may be used by this socioeconomic project. The environmental data will be collated and the present Florida Keys will be described. The large job of collating the socioeconomic data will begin. In the second year, the socioeconomic data will be finalized. The effects of ecosystem change will be determined and combined with the bleaching prediction to project the possible future state of the ecosystem. These will then be combined with the socioeconomic data to convert ecosystem change into socioeconomic terms. These will then be used to provide policy recommendations.

These requirements are best addressed based on key statements in the NOAA-CRCP proposal. However, some statements have to be assessed in the light of other statements in the proposal, and on discussions during the author's visit to Silver Spring, MD, and the Florida Keys in June 2005. The comments following each dot point below indicate the extent of the present scoping research and how it is seen to fit into subsequent stages. The comments also indicate that flexibility is required to allow the scoping research to provide as efficient a foundation as possible for the subsequent two years' research.

- **The project is based on the GBR research.**

  This was the rationale behind the NOAA-CRCP proposal to study the Florida Keys. The proposal stressed the importance of incorporating state-of-the-art model projections of coral bleaching based on the CRW/Princeton University collaboration. This seems to have been perceived as a departure from the GBR study, but it represents at most a difference in methodology, as the projections in the GBR study were also firmly based on scientific models as described in Part 1 of the GBR report.

  The differences may be greater at the socioeconomic level and will have an important effect on the approach. Monroe County has a small number of permanent inhabitants (less than 80,000) compared with coastal Northern and Central Queensland's one million. It is visited by more people, but the proportion specifically interested in reefs is smaller, especially compared with Far North Queensland around Cairns. The administrative and community structure is also very different. Finally, the physical long-term threat to coastal communities following significant reef degradation is greater than in Queensland, especially if hurricanes are expected to increase in frequency and intensity. While recent evidence points towards greater storm activity throughout the planet,[13] Florida has long been prominent as a hurricane location.

  These factors do not invalidate adapting the basic approach of the GBR study, with the scientific and socioeconomic research feeding into a futures analysis based on alternative long-term scenarios. In fact, the presentation of the study to a wide audience at NOAA on 1 June 2005[14] evoked widespread agreement that the approach could be advantageously adapted to the Florida Keys.

- **There is no information available on the impact of climate change on the socioeconomic aspects of coral reefs.**

This is so, but socioeconomic analysis of residents and visitors in the Florida Keys area is well advanced, thanks to the work under NOAA/NOS chief economist Bob Leeworthy as program director for the Socioeconomic Monitoring Program for the Florida Keys National Marine Sanctuary (FKNMS). The program uses contingent valuation analysis which can provide an effective tool for setting up hypothetical situations for survey respondents to consider (such as a given increase in temperature, or reducing coral cover by a given percentage). It would be important to incorporate such a segment into the comprehensive surveys of visitors and residents which are presently being planned for 2006 as a sequel to the 1995-96 surveys, and it is understood that this remains a possibility.

Socioeconomic analysis of the Florida Keys area is also undertaken elsewhere, but there is a need to determine whether the accepted definition of this research instrument entirely covers the needs of the current project. The GBR study relied to a considerable extent on macroeconomic analysis, including the identification of data for key industries, notably tourism and fisheries, and the use of gross regional product (GRP) data – the local equivalent to Gross Domestic Product (GDP) and Gross State Product (GSP), which would relate to counties in the USA.[15] There is also a need to update and further develop the links between the socioeconomic survey data and the macroeconomic concepts, which were first derived from the 1995-96 surveys of Florida Keys visitors, and subsequently extended to 2000-01.[16]

In conclusion, the advanced use of socioeconomic research centered on the Florida Keys visitors and residents puts this project in a strong position. It represents at the very least a powerful data input describing the behavior, attitudes and preferences of visitors and residents. There was little comparable information available to support the GBR analysis.

- **Scoping the larger project in the first year will involve the collection of as much of the relevant socioeconomic, climate and ecological data as possible.**

  Scoping studies are usually undertaken to indicate data availability – inventories of available data – rather than to compile detailed databases, and the concluding parts of the NOAA-CRCP proposal quoted above indicate that the main collection of economic data should take place during year 2 of the project (FY 2006). The role of the scoping phase is to identify and evaluate the relevant data rather than presenting the actual statistics.

  Similar considerations apply to other data, including the detailed records which form the basis for the *South Florida Data Navigator* developed under John McManus's leadership.[17] The website shows the nature of the data, but ranges are shown rather than exact figures. The project during year 2 will hope to gain access to the actual data in appropriate detail (probably basically splitting the Keys into Upper, Middle and Lower, and Tortugas, with forays into more intensive analysis of particular geographical areas as required).

- **The scoping report will address what data are available, how much more would be needed for the project proper, and indicating where it would come from.**

  This challenge applies to all types of data, socioeconomic, industry and macroeconomic, environmental and scientific. Data collection will, as indicated above, be undertaken mainly during FY 2006.

- **The CRW/Princeton effort to predict coral bleaching with the use of the IPCC climate model projections will be combined with basic socioeconomic and environmental data to determine a number of plausible scenarios for the fate of the Florida Key corals and the socioeconomic implications of these changes.**

This slightly abbreviated statement from the NOAA-CRCP proposal demonstrates that the GBR study's scenario planning approach is the expected working model in this study.[18] The author gained the same impression from discussions with NOAA personnel during his visit to the US, and from the response to his presentation of the GBR study. However, the approach to the scenario construction itself is not quite as set out above; in the GBR study, the basis for the projections was the highly generalized narratives and associated numerical projections for the four marker scenarios of the IPCC report which were carried out at an international rather than local level. The socioeconomic and environmental data, and even the assumptions about coral bleaching, depend on the chosen scenarios and do not determine these scenarios as suggested in the NOAA-CRCP proposal. For example, the climate change assumptions associated with each chosen scenario will determine the projected values from the NOAA CRW/Princeton University model.

It is also inadvisable to adopt too uncritical an approach to the IPCC model, which is aging and has been shown to have a number of flaws as discussed in Part 3 of the GBR study. Since the scenarios used in the *Third Assessment Report* will be six or seven years old when this study is being written, a cautious and skeptical approach is required which may incorporate significant deviations from the global IPCC scenarios with equally significant consequences for the local derivations of these scenarios.

- **The scoping report will include a full project design.**

  The full project covers FY 2006 and 2007. The estimated full cost including the scoping research, based on what would have been an appropriate costing of the GBR study, is $135,000-150,000, which suggests a minimum annual average of $60,000 in the coming two years for a basic study to meet the objectives set down in the NOAA-CRCP proposal.

1.4 Subsequent years

The NOAA-CRCP proposal suggests the following milestones during year 2 (FY 2006):

- The separate NOAA-CRW/Princeton project to predict coral bleaching for the Florida Keys is adapted to support the socioeconomic project, to deliver results within FY 2006.

  Since the coral bleaching projections depend on particular scenarios, it is assumed that NOAA-CRCP's statement means that the CRW/Princeton model will be calibrated to fit a base projection of coral bleaching, which will then be adapted to each scenario when these are developed during FY 2007 (see below).

- Environmental data are collated and the current Florida Keys situation described in detail.
- The collection of socioeconomic, industry and macroeconomic data is concluded.

The main sequence of tasks in FY 2007 is, according to the NOAA-CRCP proposal:

- Integrating the effect of ecosystem change with coral bleaching projections to project the future state of ecosystems.
- Combining the results with the socioeconomic data to convert ecosystem change into socioeconomic terms.
- Developing appropriate policy recommendations.

These steps appear reasonable with their identified elements of projections of coral bleaching and mortality, environmental assessments of pollution and other causes of reef damage, and associated socioeconomic responses. The specific identification of environmental factors (part of the GBR study projection but subsumed into the regional analysis) is an advance on the GBR prototype. On the other hand, the macroeconomic orientation of the GBR study is not reflected in the NOAA-CRCP proposal, and its interpretation of what is involved in scenario planning analysis needs to be redefined as discussed in the second-last dot point of Section 1.3.

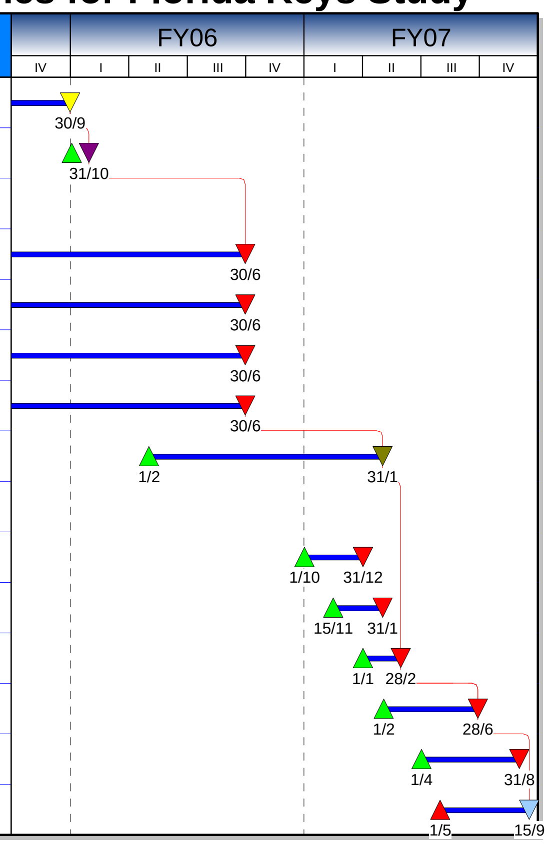
The support of the GBR study approach as a general model, modified to suit the Florida Keys framework, has already been noted following the presentation of the GBR study at NOAA on 1 June 2005 and subsequent discussions with NOAA personnel. Given that four main building blocks have now been identified (base-case bleaching projections, environmental assessment, socioeconomic and macroeconomic analysis, and futures analysis), Chart 1.2 identifies milestones for years 2 and 3 (FY 2006 and 2007) after reaching the first milestone when the current scoping exercise is concluded by the end of September 2005.

The preliminary milestones are indicated by connectors in Chart 1.2 linking them into a crude ‘critical path’:

- 30 September 2005: Conclusion of scoping study within FY 2005 in the form of a report to be used as a basis for detailed planning of years 2 and 3.
- 30 June 2006: Conclusion of data collection for the socioeconomic, macroeconomic, environmental and bleaching streams (main activity during FY 2006).
- 31 January 2007: Development of future scenarios, a process started soon after New Year 2006 and concluded an estimated four months into FY 2007. It was suggested during the

Chart 1.2: Preliminary Milestones for Florida Keys Study

TASK	Start	End
INITIAL SCOPING STUDY	1/6/05	30/9/05
DECISION TO PROCEED WITH STUDY	4/10/05	31/10/05
IDENTIFY AND ANALYZE DATA		
Socioeconomic	1/6/05	30/6/06
Macroeconomic	1/6/05	30/6/06
Environmental (ecosystem)	1/6/05	30/6/06
Coral bleaching	1/6/05	30/6/06
DEVELOP FUTURE SCENARIOS	1/2/06	31/1/07
INTEGRATION OF BUILDING BLOCKS		
Integrate bleaching and ecosystem data	1/10/06	31/12/06
Convert into socioeconomic terms	15/11/06	31/1/07
Integrate into macroeconomic framework	1/1/07	28/2/07
Futures analysis based on scenarios	1/2/07	28/6/07
Policy recommendations	1/4/07	31/8/07
FINAL REPORT	1/5/07	15/9/07



author's visit that the time perspective might be up to 100 years, though the emphasis would probably be on the 'medium term' when climate change has not yet run its full course (this definition implies that the length of the 'medium term' may vary from scenario to scenario). The current concept is to develop a series of perspectives from as little as five years, for example five, 10, 20, 50 and 100 years ahead.[19] Three or four different scenario stories would be developed and each finalized with physical projections of key variables. Input to scenario stories would be sought from individuals and groups, the latter engaged in scenario workshops as in the GBR study. The approach is discussed in Chapter 5.

- 28 February 2007: Integration of all socioeconomic, environmental, choral bleaching, industry and macroeconomic databases.
- 30 June 2007: Futures analysis of the integrated databases within the three or four different chosen scenarios concluded.
- 15 September 2007: Final report.

The tempo of this program may appear fairly slow. However, adopting a two-year timeframe from the time of completing the scoping study report will provide better opportunity to establish cooperation with other agencies and academic institutions, enriching the basic approach and giving these other agencies and institutions a sense of 'co-owning' the project. It may also attract additional funds to supplement a tight budget.

Developing the scenarios over a full year, coinciding with several months of data identification and analysis, will also assist in providing dialogue and guidance to the study. Quite apart from that, it helps to ensure that the scenario stories will be more thoroughly tested for credibility from stakeholders in the study.

1.5 Rest of this scoping report

Chapter 2 deals with the scientific basis for the proposed study, including the parallel study by NOAA-CRW/Princeton University to develop specific projections of coral bleaching for the Florida Keys. A better historical perspective is also advocated, to support the long-range projections in each scenario. It has not yet been possible to establish, for example, what the coral cover would have been, say, 100 years ago. We therefore do not know precisely to what extent the reefs around the Keys have already deteriorated from anthropogenic factors. However, as discussed below, there is an abundance of fragmented evidence and some long-term studies that suggest a massive decline has occurred over the last 30-50 years, and studies of fossil evidence can help in the understanding of the current reef degradation.

These factors are a main topic in Chapter 3, which is concerned with the environment and threats to the ecosystems along the Keys. It also enumerates the likely data sources and provides some preliminary judgments, though detailed analytic research into these matters must await the availability of actual data from sources such as the *South Florida Data Navigator*. Again, attempts are made to combine the analysis of current data with statistics of older origin to provide a historical perspective of how environmental impact has been aggravated – and what has been done or could be done about it.

Chapter 4 deals with the economic evidence, ranging from the socioeconomic studies under NOAA's auspices to industry and macroeconomic data. Again, historical evidence is considered important to provide a picture of past trends. Such trends provide indications even though the time is past when they were considered the most important or even sole determinants of what the future might bear.

The break with that way of thinking occurred – or should have occurred – when techniques such as scenario planning became strategic tools for handling essentially unpredictable futures. Scenario planning and other approaches to analyzing the future are the subject of Chapter 5.

The final chapter, 6, briefly sums up the project design (already illustrated by Chart 1.2) and indicative costing.

2 Scientific Evidence

Scientific and environmental evidence is closely intertwined because of the combined impact of anthropogenic and natural factors on reef quality. It nevertheless makes sense to deal with these topics successively because of the nature of the data and because the scientific evidence is about impact and the environmental evidence that pinpoints the causes (which will be mentioned briefly in Chapter 3).

That coral bleaching and mortality is a central subject is clearly in accordance with the whole direction of the project laid down in NOAA's brief. As in the GBR study, however, the severity of bleaching impacts depends to a large extent on synergistic environmental factors such as pollution and runoff caused by industrial, agricultural, tourism and general urban developments in the adjacent coastal areas, and activities in the reef areas themselves including recreational and commercial fisheries and tourism in its various manifestations. The whole approach to coral bleaching must involve the analysis of environmental stresses, first in the past and present situation, and ultimately under a range of future scenarios.

2.1 Status of world's coral reefs

Inquiries into the availability of scientific data from a range of contacts have yielded mixed evidence. According to some sources, there is no systematic database, while others claim it is a matter of specifying what data are required.[20]

Initial guidance to the identification of evidence of the status of coral reefs is derived from the general reports on the status of the world's coral reefs relating to 1998 and subsequent two-year intervals up to 2004. This provides a global perspective as well as a general local analytic base.

The latest summary report of the status of the world's coral reefs edited by Clive Wilkinson[21] contains mixed evidence of reef health (pp 7-8). An estimated 20% of reefs have been effectively destroyed and show no immediate prospects of recovery – but approximately 40% of the 16% of the world's reefs that were seriously damaged in 1998 are either recovering well or have recovered. However, the report predicts that 24% of the world's reefs are under imminent risk of collapse through human pressures, and a further 26% are threatened with collapse in the longer term. Aggravated human pressures come primarily from poor land management practices and over-fishing, which along with pollution help shift the advantage from corals to macroalgae.

The status of coral health varies from region to region. Major reef declines in the wider Caribbean region have proceeded so far that these reefs no longer resemble those of 30 years ago, with coral cover on many Caribbean reefs declining by up to 80% (though with some signs of recent recovery).[22] The least encouraging prognosis is for reefs in the high biodiversity areas of Southeast Asia and the Indian Ocean, where human pressures continue to rise. On the other hand, reefs in the Pacific and around Australia remain quite healthy according to the report.

2.2 Global threats

The Wilkinson report notes that many reefs continue to recover after the global coral bleaching event in 1998, with stronger recovery in well-managed and remote reefs – but the recovery is not uniform and '*could be reversed if the predicted increases in ocean temperatures occur as a result of increasing global climate change*' (p 8). The coral bleaching in 1998 was a never-before-experienced '*1 in a 1,000-year event in many regions*' and caused the death of millennium-old corals. *But*:

> *Increasing sea surface temperatures and CO_2 concentrations provide clear evidence of global climate change in the tropics, and current predictions are that the extreme events of 1998 will become more common in the next 50 years, i.e. massive coral bleaching mortality will not be a 1/1,000 year event in the future, but a regular event* (p 8).

Returning to the issue of climate change, Wilkinson notes a prediction that most reefs 'will continue to recover and eventually revert to the similar levels of coral cover of reefs pre-1998; **provided** that there are no repeats of damaging events similar to 1998.'

> *Unfortunately, the evidence from the Intergovernmental Panel on Climate Change, NOAA in USA, and other researchers does not provide any confidence, and the authoritative predictions are that coral reefs will continue to suffer from rising levels of climate change, with increasing sea surface temperatures in the tropics leading to regular bouts of coral bleaching and mortality in summer months* (p 23).

Other major predicted impacts of global climate change listed by Wilkinson (p 24) include:

- an increase in the frequency and intensity of tropical storms (of which hurricanes Katrina and Rita in September may – or may not – be portents),
- more frequent and severe switches in global climate making El Niño-La Niña events more regular occurrences,
- rising sea levels,
- potential shifts in ocean currents, and
- increasing acidification of reef waters from rising atmospheric CO_2 constituting yet another increasingly recognized serious threat because they lead to decreased calcification rates in coral reef organisms (p 24).

Other global threats include coral disease and major coral predators such as the crown-of-thorns starfish, with evidence pointing to 'human disturbance as a contributing and catalytic factor behind these increases' (p 8). Recent research linking these phenomena to changes such as declining water quality appears to be strengthening.[23]

2.3 The onus is on management

The World Summit on Sustainable Development in 2002 called for the establishment of larger marine protected areas and a major international effort to reduce losses in biodiversity. In the Great Barrier Reef, the amount of no-take areas was increased in 2004 from 5% to 33%, following careful scientific analysis and extensive public consultation. However, many countries lack the resources of trained personnel, equipment and finance to ensure effective protection and enforce regulations.

This further tilts the advantage towards countries such as the United States and Australia that have adequate resources and a substantial level of public awareness. It is nevertheless notable that while 16% of reefs in the US Caribbean were destroyed in 1998, the Wilkinson report could not establish the percentage that had recovered in subsequent years. It also notes that the proportion of reefs at critical stage was the second-highest of the 17 regions analyzed (at 56% second only to the East Antilles), and a further 13% were threatened. This leaves only 15% of reefs at low or no threat level (p 9).

2.4 The Florida Keys

This area is recognized as among the best researched and managed. *Reefs at Risk*[24] in 1998 summarized the status of the Florida Keys reefs as follows (p 22):

> *Almost all reefs of the Florida Keys are at moderate threat, largely from coastal development, inappropriate agricultural practices, over-fishing of target species such as conch and lobster, and pollution associated with development and farming.*

The assessment of the status of the reefs in the Florida Keys in 2004 was written by a large team generally well-known for their insights and expertise.[25] It is noted that the Florida Keys extend from Miami to the Dry Tortugas and are included in the Florida Keys National Marine Sanctuary covering 9,850 km^2, of which 1,400 km^2 is coral reef and hard bottom habitat. The reef includes a range of distinct habitats such as offshore patch reefs, seagrass beds, back reefs, reef flats, bank or transitional reefs, intermediate reefs, deep reefs, outlier areas and sand and soft-bottom areas. The other major reefs are in three parallel lines: a shallow reef with a low cover of algae and small octocorals; a second reef dissected by channels and numerous octocorals; and a third deeper reef with the most diverse hard coral populations.

Of the three major groups of reef-building corals, staghorn coral (*Acropora cervicornis*) was reported to be recovering from bleaching and disease damage, though this appears to be contradicted by other evidence. Moderately sized colonies of *Montastraea annularis* now occur on the deeper reef, though not abundantly. The third major reef-building coral in the Caribbean and tbe most threatened, elkhorn coral (*Acropora palmata*), does not occur in the deeper areas.

According to the Wilkinson report (2004) the Florida Keys contain 64 recorded hard coral species, two fire corals and 55 species of octocoral. There has been a 5% absolute decline in stony coral cover since 1996, and species richness declined between 1996 and 2003 in 76 monitoring stations, while it increased in 15 and was unchanged in 14 stations. The incidence of diseased stony corals has shown an alarming increase from 20 stations in 1996 to 95 stations in 2003, with more diseases being observed. Coral bleaching remains a problem, although it is understood that disease has been the main cause of the decline in coral cover in the Sanctuary since 1997.

Poor water quality and pollution from fertilizers, sediments and nutrients from Southeast Florida pose considerable threats, as does sewage due to the porosity of soil on the Keys. The Sanctuary in response has increased water quality sampling to over 200 tri-monthly sampling stations in the Sanctuary and the Shelf, and 100 monthly stations in Florida Bay, Biscayne Bay and the mangrove estuaries of southwest Florida.[26] The monitoring has identified the major nutrient sources, the diversity across the area and elucidated large-scale water transport pathways according to the description.

Statistics on fisheries indicate that the Florida Keys has 389 reef fish species among a total of 517 fish species. Fishing impact is highest near Miami and lowest in the Dry Tortugas. In 2001, 6.7 million recreational fishers made 28.9 million fishing trips in Florida and caught 171.6 million fish with half being released or discarded. The recreational fishing fleet increased by more than 500% between 1964 and 2002, while commercial vessel numbers grew by 150%. Fish sizes, such as grouper, have been steadily declining. The report details more examples of massive over-fishing in the area. It also reports that legal-sized spiny lobsters continue to be larger and more abundant in no-take zones than in neighboring fished areas.

Anthropogenic threats to the Florida Keys reefs are exacerbated by the fact that these reefs represent the northern extension of Caribbean flora and fauna which makes the area vulnerable to winter cold fronts. Reefs in the area are also affected by diseases such as white band disease which affect the reef-building acroporid corals. Over-fishing continues to grow as a problem with the commercial fishing fleet increasing by 26% and the recreational fishing fleet by 465% between 1995 and 2000. 400-600 boats run aground each year with 15% damaging the coral. Nutrition enrichment is a problem close to shore (mainly to the north) with increased observations of harmful algal blooms and covering of extensive areas by the cyanobacterium *Lyngbya confervoides*. The water quality monitoring program is revealing other impacts such as elevated nitrogen levels in nearshore areas.

Coral bleaching was observed in 1997 and 1998 – the first time in successive years though there were many episodes in non-successive years from 1973 onwards.[27] These events were not well documented because there were no appropriate monitoring programs at the time. There have been no severe bleaching events since 1998 according to the report.

Managerially, an ecosystem-based plan to conserve, protect and manage the natural and cultural resources of the Florida Keys now prohibits oil exploration, mining, large shipping traffic, anchoring on and touching corals, and collecting coral in the Sanctuary. Twenty-three no-take zones designated in 1997 covered less than 1% but allowed protection of 65% of shallow reef habitats, with beneficial effects showing up in three years for some major fish species. In 2001, the designation of the 518 km^2 Tortugas Ecological Reserve increased the amount of coral reef in no-take zones within the Sanctuary to 10%.

The 2004 Wilkinson report concludes that gaps remain in current monitoring and conservation capacity:

- Coastal water quality is a key issue, and a comprehensive monitoring program is needed (this may now be happening)
- Research on the response of reef communities to changing water quality is also required. Reef monitoring in the area is limited by a lack of comprehensive information about marine communities, as well as baseline assessments for all monitoring sites in the region.
- Data are also needed on reef fish including cryptic species and fish in deeper waters, and for the fish communities in seagrass and mangrove habitats.
- Only 50% of Florida's coral reefs and associated habitats have been mapped, which makes it difficult to determine which areas should be included in new no-take areas. Major mapping gaps include the reefs on the southeast coast, the Middle Grounds banks and deeper regions of the Tortugas.

In conclusion (p 446),

> *Citizens, stakeholders, elected officials, and resource managers must work together to improve water quality, minimize physical damage to corals and seagrasses, reduce non-point pollution, and raise awareness to introduce a stronger sense of stewardship for coral reef conservation. Immediate action is needed to curtail alarming declines in coral reef condition throughout Florida. Local communities, which are culturally and economically supported by the reefs are working to implement management strategies and focus attention on the need for more reef protection. They aim to control adverse human pressures such as the environmental impact of fisheries, dredging, vessel anchorages, freshwater management, and nutrient flows into southeastern Florida. Communities in the Florida Keys are continuing to seek solutions to reduce wastewater and stormwater problems, and limit habitat degradation and over-fishing.*

Recently a study was announced into the coral health of the entire Florida Keys area (and beyond).[28] It is funded by the Florida Department of Environmental protection and carried out under the auspices of The Nature Conservancy, which conducts the Florida Reef Resilience Program headed by Philip Kramer. The Director of FDEP's Coastal and Aquatic Managed Areas, Katherine (Kacky) Andrews, noted that the aim of the study is to provide improved management tools, not 'science for science's sake'. Billy Causey of the FKNMS applauded the study, which he had been involved in trying to get going for a decade. In future, according to Kramer, organizers want to conduct similar studies before, during and after major bleaching events.

In conclusion, the general evidence on coral health and associated variables suggests the following minimum requirements for data collection:

- The database needs to extend as far as possible into particular locality types including the different types of habitat outlined, whether coral reefs or adjacent seagrass or mangrove communities forming part of the ecosystem.
- This evidence is probably most conveniently summarized regionally into Upper, Middle and Lower Keys, plus Dry Tortugas, which has special features due to its more distant location.
- Trends in the area of coral reef and coral cover, by main species and with sufficient location detail.
- Health of other distinct habitats in the ecosystem.
- Number of species of fish, crustaceans and other groups: total and under threat.
- Past bleaching events and the degree of subsequent recovery, by location.
- Detailed water quality indicators from past and current monitoring programs.
- Fish and lobster size trends.
- Disease trends.[29]

2.5 The need for a past time perspective

While in Washington, DC, in connection with this project, the author inquired about sources of past data to indicate trends in overall health indicators such as coral cover. The reason – further developed in Chapter 5 on scenario building – was that even if we must expect discontinuities to continue in the future, the past still provides clues to the future that will help underpin the analysis. At the time, there was little response to the request in the scientific field, though it was possible to go back almost twenty years in the environmental and economic area using a report written at the time.

The past perspective is, however, regarded as highly relevant in the scientific area as well. The Caribbean chapter of Wilkinson (2004), authored by Andrews et al (2004), briefly describes the situations in the Caribbean at various time intervals in the past, and in ten years from now (the latter is shown for interest only as it is purely speculative):

- **100 Years ago:** Virtually all coral reefs were healthy with normal fish populations. Clear, low-nutrient waters were the norm and reefs were dominated by healthy branching corals, urchins, large schools of game fish, sharks, and algal grazers.
- **In 1994:** Coral reefs of the Caribbean had been heavily damaged by disease, coastal development, coral bleaching, and over-fishing. The scientific community was documenting the decline and public awareness was increasing. Management plans were

being written for areas protected in National Marine Sanctuaries and Parks and universities, governments, and NGOs conducted research and monitoring. The more isolated reefs in the Western Atlantic were in better condition because they were not affected by land-based stresses.

- **In 2004:** Reefs in the Caribbean and Western Atlantic range in condition from excellent to poor with reefs near population centres showing damage from land-based pollution, fishing, disease, bleaching, and ship groundings. In areas stressed by over-fishing and coastal development, recovery from the sea urchin die-off and coral bleaching events of the late 1980s and early 1990s is slow. However, the capacity to understand, monitor and manage coral reefs, and their use is expanding. More coral reefs are managed in protected areas and enforcement of existing regulations is improving in some of these areas.
- **Predictions for 2014:** Reefs away from population centers will remain healthy, unless the adverse predictions for global climate change of more tropical storms and thermal stress (bleaching events) occurs. Human stresses around populated islands will continue, but if governments maintain or build their capacity and commitment to improving reef ecosystem management, these stressors and resulting damage should be minimized. (pp 432-433)

It should be possible to secure similar assessments for the Florida Keys and its parts. As far as the past is concerned, it has not been possible to refer to literature written thirty or more years ago, but such literature exists as briefly hinted below. Academic researchers such as Walter Jaap and Robert Ginsburg, and FKNMS superintendent Billy Causey, to name but a few, have decades of detailed practical experience of the rate of degradation of the area, and any resilience that has preserved it at where it is now. Phillip Dustan for over 30 years has watched Carysfont Reef at Key Largo and concluded that coral populations have declined precipitously since 1974, when quantitative monitoring began. He describes this in great detail with the conclusion (backed by satellite images and observing that the stressors are probably synergistic in nature):

> *The coral reefs of the Florida Keys are in catastrophic decline from nested multiple stressors. This includes direct and indirect anthropogenic impacts across local and global scales.*[30]

Gilbert L Voss in 1988 wrote a popular book on the Florida coral reefs in Florida.[31] Born in 1918, he had been a prominent member of staff of the Rosenstiel School of Marine and Atmospheric Science of the University of Miami since the 1940s.[32] While his book gives no specific description of reef degradation, it provides a vivid description of the general situation 17 years ago in passages such as the beginning of his concluding Chapter 9 (p 65), dealing with the alternatives:

> *There is no question that the marine life of the Florida Keys is in jeopardy and that the water quality is deteriorating. This can be seen very clearly by the declining numbers of fish along the reef and the shallow grass beds, and the documented deteriorating health of the coral reefs. The increasing amount of white spotting or dead areas on corals, coral bleaching, the occurrence of black band disease, all speak eloquently – and sadly – of the problem. The loss of most of the longspine black sea urchins several years ago indicates that not only corals are being affected.*
>
> *Water quality in the keys is affected primarily by factors emanating from the shore: pesticides, fertilizers, sewage, chemical-laden rain runoff, marina pollution, decreased water transparency caused by eutrophication, dredge and fill, land fill and increasing boat traffic.*

Physical destruction of the corals is caused by direct contact by humans: boat groundings, anchor damage, spear guns, snorkelers and scuba diver body contact and swim fin contact, to mention only the most prevalent.

Nothing is new according to this. While a technical physical description of damage to corals is lacking from this book, Voss wrote many scientific papers during the preceding thirty or forty years, as did others. It should be possible to add a longer historical perspective across many decades, supplementing the much briefer era of modern comprehensive monitoring and analysis.[33] One unpublished environmental assessment by Voss from 1983 was indeed put on the Internet in 2002.[34]

In recent years there has been a new approach to use the past as a key to the future. It promises to at least supplement what may be possible to glean from observations in papers written over the past forty or fifty years, and perhaps much more than that. It is described by Precht and Miller[35] in a chapter of a forthcoming book on geological approaches to coral reef ecology. They use paleontology, the evidence of fossil records, as a key to the future, demonstrating that the elkhorn coral, *Acropora palmata*, tends to be dominant in 'good times' but is the first to go under when the system gets stressed.

They describe the current problem bluntly: The ecology of Caribbean and western Atlantic coral reefs has changed dramatically in recent years and these reefs are now believed to be in crisis. This is especially true along the Florida reef tract.[36] Three common species were the primary reef builders: *Acropora palmata* (elkhorn coral), *A. cervicornis* (staghorn coral) and the *Montastraea annularis* species complex. The thickly branching elkhorn coral was dominant in the reef crest and the shallowest depths (0-5m). The more thinly branching staghorn coral was dominant at intermediate depths (5-25m) on exposed reefs and ranged into shallower habitats on more exposed reefs. The massive corals of the *M. annularis* complex were and remain common in a variety of reef habitats from <5 to >30m.

Precht and Miller conclude that living reefs in Florida have been in a state of flux for 25 years. Among these changes has been the near-elimination of the dominant coral species *A. palmata* and *A. cervicornis*, with concomitant increases in macroalgae. Winter cold fronts, hurricanes, global warming (causing coral bleaching) and coral disease are stressors in the Florida Keys that have well-known cause-and-effect relationships. These rapid and extreme events have strongly influenced the trajectory of these coral communities. Specifically, white-band disease, a putative bacterial infection of the *Acropora* spp. has overwhelmed the system, changing the way reefs look and function.

The authors suggest that these stresses are not necessarily the result of human interference, though the correct interpretation is probably that stresses are not entirely due to human interference, as some of these changes have occurred in the past (at much slower rates of change). It appears that the current episode is not unique. Throughout the Quaternary, before human life, Florida's reefs were subject to numerous large-scale disturbances which have reorganised the coral community structure. Being at the northern limit of coral growth in the Western Atlantic, Florida is subjected to a host of conditions unfavourable to prolific reef development. 'In fact, we are lucky to have reefs at all in Florida. Disease epidemics, coral bleaching events, extreme weather conditions including hurricanes and cold fronts, as well as the average annual position of the Gulf Stream all affect the ecological history of reefs in Florida.'

Although the patterns of successive disturbance events have been different, the common result has been to end *Acropora* shallow-reef dominance. 'These ecological shifts in coral community composition are preserved in the fossil record of these reefs and allow us to use the past as a key to predicting the future of reefs in a world now besieged by numerous disturbances and the influence of man. As Gene Shinn has repeatedly emphasized, the story written in the geologic history of coral reefs is our most reliable guide to their uncertain future.'

The interpretation, then, appears to be that even without human beings, Florida's reefs appear to be particularly vulnerable because of their relatively extreme geographic position. Adding humans into the equation exacerbates the problem.

The Precht and Miller chapter is accompanied by a lengthy bibliography, and other chapters in the forthcoming volume promise to have equally relevant contents (the chapter by Pandolfi and Jackson mentioned in the previous endnote and a chapter on coral reef response to climate change by Joan Kleypas).[37] While it is not clear whether these other contributions contain specific reference to the Florida Keys, the volume would provide one promising starting point for further identification of specific scientific papers.

Coral bleaching in the Keys has been the subject of at least three papers according to Precht and Miller, with the first episode recorded by Walter Jaap in 1973. The papers are listed in endnote 27.

It is noted in conclusion that the international analysis of the status of coral reefs also includes a perspective from the end of the Pleistocene, 10,000 years ago, describing when modern coral reefs began at the end of the last ice age (Wilkinson 2004:11). The description of this pristine world is not followed through to the regional analysis in the two volumes.

2.6 Identification of scientific research for the main study

The concept of engaging a scientist with the relevant skills to identify the main sources and create a database for the study (during year 2) was raised during the author's stay in Washington, DC, in June 2005. This has been taken into account in the study design (Chapter 6), and it is further proposed that he or she may have a further role to play during the final stage of the study in year 3.

It should be added that identification of scientific sources, rather than new scientific research, is the aim at this stage of the study. It would be impossible to add to the database with new research, but the main impression gained from the preparatory work during the scoping phase is that the database, properly organized and managed, will prove to be sufficient for the study.

The same goes for the 'mirror' research required for the next subject of environmental factors, briefly outlined in Chapter 3.

3 Environmental Impact

This chapter briefly lists some key documents and sources. It goes into little detail because, in effect, environmental impact is the mirror of the scientific research discussed in Chapter 2.

3.1 The FKNMS draft management plan

The key document relating to environmental management of the Florida Keys is the FKNMS Draft Revised Management Plan, dated February 2005. It contains detailed descriptions of threats to the Florida Keys ecosystem, noting that its deterioration is no longer a matter for debate but is noted by visitors, residents and scientists alike. 'The threats causing these visible signs of decline are numerous and often complex, ranging from direct human impacts to global climate changes (p 18).

The management plan outlines a comprehensive series of action plans and associated strategies across a variety of subjects including sanctuary science; education, outreach and stewardship; enforcement and resource protection; resource threat reduction; and administration, community relations and policy coordination. This is too detailed to include here, but the document because of its scope is the key source for the detailed planning of environmental impact analysis for the study.

It also contains detailed lists of institutions – academic, government and other – involved in the various actions and strategies.

3.2 The South Florida Data Navigator

The development of this comprehensive database by the Rosenstiel School of Marine and Atmospheric Science is a major forward step. It is freely available on the Internet[38] in detail down to individual streets and neighborhoods, though the study would aggregate this into three or four regions with local detail mined mainly as required to build up these perspectives.

The Data Navigator is based on the Geographic Information System (GIS) to describe the spatial distribution of the data. It deals with four 'cases': water quality, coastal activities, coral reef health, and seagrass health, in relation to a general list with the following main groups:

- Hydrography (including water currents, storm tracks, inland water bodies, ground water and water quality)
- Ecology (including pollution watch points, coastal research and monitoring, forest and mangrove cover, benthic habitat and disturbance, reef fish (virtual census), physical geography and soils)
- Socioeconomic parameters (including legal boundaries, shipping tracks, ports and marinas, population numbers, roads, land use and cover, and coastal tourism and recreation).

Each category contains a comprehensive listing of metadata (data sources) and descriptions of data quality, data organization, distribution and other attributes.

The data navigator does not currently provide exact numbers but show ranges. It is understood that exact numbers will become available.

As well as the data navigator, the NCORE website contains other information of potential interest to the project, including descriptions of specific projects such as physical oceanographic studies, impact of nutrients on reefs in the Florida Reef Tract, and references to other research into the impact of climate change on coral reefs. It thus contains the link between data relating to environmental factors and the synergistic impact of environmental degradation and climate change.

3.3 Other environmental data and assessments

During the study period numerous documents have been collected containing environmental data and assessments. Two of these deserve special mention:

- In cooperation with NOAA, the US Environmental Protection Agency and the State of Florida in 1994 started a Water Quality Protection Program to monitor seagrass habitats, coral reefs, hard-bottom communities, and water quality. The *Coral Reef Evaluation and Monitoring Project: 2004 CREMP Executive Summary, May 2005* sets out the major criteria for coral reef monitoring:
    - Sanctuary-wide spatial coverage
    - Repeated sampling procedures
    - The development of statistically valid findings to document the status and trends in coral communities.
- The *Florida Keys Coral Reef Monitoring Project* is a large-scale, multiple-investigator project funded by the EPA and designed to assess the status and trend of Florida's offshore reefs, patch reefs, and hard-bottom communities over a five-year period. The project provides the first real opportunity in the Florida Keys to address the question of whether and how the reefs are changing at the spatial scales required to detect large-scale patterns and discriminate between hypotheses.

3.4 Research planning

The collection program for environmental data will inevitably overlap the process of identifying scientific data (using a specially engaged scientist). However, the FKNMS management plan and the need to extract data through the South Florida Data Navigator and similar sources suggest that there will be a large associated area of data gathering (which will be undertaken largely by the project consultant).

4 Economic and Social Factors

There are a number of dimensions to deal with under this heading. First, the socioeconomic survey program developed under the leadership of NOAA's Bob Leeworthy provides what is probably the most comprehensive survey-based data program in the world. The key survey was conducted in 1995-96 with a follow-up in 2000-01, and a new baseline survey is currently being planned for 2006, which fits in with the conduct of the proposed study.

4.1 Work by NOAA's Coastal and Ocean Resource Economics Program

The first main report related to 1995-96 and juxtaposed perceived importance of particular attractions and attributes in the Florida Keys area with the degree of satisfaction in the opinion of visitors to the area. The idea was that the satisfaction dimension should be treated most seriously if visitors also considered a particular attribute as important.[39]

The survey conducted in 2000-01, while more limited in scope than the 1995-96 survey, provided an opportunity to measure change in satisfaction and importance levels over five years.[40] For example, the publication's Table 1 showed that at least for the boating samples, visitors' importance ratings had increased and satisfaction ratings fallen for almost all the 25 attributes used in the survey. The situation was different for residents, which generally found the attributes less important, and the satisfaction ratings also less important, in 2000-01 compared with five years earlier.

The new survey was also able to show results relating to the no-take zones introduced in 1997, though not the Tortugas Ecological Reserve which was introduced on 1 July 2001.

The main survey documents are supplemented by a large number of other publications, all of which have been downloaded during this scoping exercise. The most important of these other publications deal with the economic impact of tourism activity on the economy.[41]

The work carried out by Leeworthy and his colleagues constitutes an important asset for the proposed study. To date, however, it has not been specifically concerned with climate change, but there may be an opportunity to include this aspect in the forthcoming 2006 surveys of visitors and residents. One possibility would be to use the technique of contingent behavior, as in previous NOAA surveys and elsewhere.

One paper among several consulted[42] applies a contingent visitation analysis to estimate the effects of changes in climate and resource variables on nature-based recreation demand. The vehicle is a visitor survey of the Rocky Mountains National park and the issue is climate change. The relevant questions are as follows:

- If at the beginning of the year you knew Rocky Mountain National Park weather and conditions would be as described in Scenarios 1 and 2 rather than the current scenario, would you
  - Visit more often/less often?
- Would the changes in weather and resources described in Scenarios 1 and 2 affect your length of stay on a typical trip?
  - Would you stay …. days longer/shorter/no change?

The scenarios (baseline, 1 and 2) specified number of days with high and low temperature (>80°F, <10 °F), precipitation, as well as other variables such as hiking trail access, wildlife and vegetation).

A similar approach might be possible in relation to climate change or coral cover, except that the typical visitor may not be especially interested in or knowledgeable about coral cover and quality. The line of questioning may not be so much in contingent valuation terms but more like the following:

- Why do you primarily come to the Florida Keys (for the fishing? diving? casinos? etc). If fishing is a prime attraction and the fish are likely to be much harder to catch, this may reveal some important information. If the main attraction is casinos, climate change may have no impact on behavior.
- Perhaps followed by: Would you come if the coral reef disappeared?

These issues are submitted to Bob Leeworthy and his colleagues. Without being actively engaged in the survey design, it is difficult to comment further. The main point is that it would be extremely useful to have a question or questions about climate change as part of the 2006 survey design.

4.2 Other socioeconomic work

The other main body of socioeconomic research related to the Florida Keys is carried out at the University of Miami by David Letson, Daniel Suman and Manoj Shivlani. The last-mentioned of these three colleagues has provided several references which will be of use in the study. Shivlani is currently heading a study that examines the macroeconomic effects on the fishing industry in the Florida Keys, and has worked on other projects including the socioeconomic impacts of the cruise ship industry in Key West, the microeconomic impact of the spiny lobster trap fishery in the Florida Keys, changes in effort and distribution of fishing effort following the closure of the Tortugas Ecological Reserve in the Lower Keys, diver evaluation of marine reserves in the Lower and Upper Keys and Biscayne National Park, and other projects.

He suggests that as the two main industries in the region are tourism (by a long way) and commercial fisheries, the impact of climate change studied under the rubric of socioeconomics would have to relate to those industries as well as incorporating some discussion on shifts in property value, which is a large revenue generator for Monroe County.

4.3 Macroeconomic data

We have identified a range of economic and demographic statistics which can form a nucleus for macroeconomic analysis (in addition to the contribution made by the NOAA surveys under Bob Leeworthy). Economic data range from local statistics such as *Monroe Business 2000*, *Monroe County 1999 Report*, *Key West and Monroe County Demographics*, and *Key West Cruise Ship Data January 1994 – May 2005.* Other statistics include:

- 1997 Economic Census – main industry groups: number of establishments, value of sales, receipts or shipments, annual payroll, and number of employees (for Monroe and neighboring counties)
- 2000 county business patterns in a considerably detailed industrial classification, showing employment, annual payroll, and total employment in employment size classes (for Monroe and neighboring counties)
- Time series of earnings in all industries, and groups of industries, from 1969 and currently collected until 1994 (Monroe and neighboring counties)
- Similar statistics for earnings and other income variables

- Labor force time series for Monroe and neighboring counties
- A wide range of demographic statistics for each county from the 2000 Census.

There are no regional economic product statistics at county level as there was for Australia. However, Gross State Product statistics are available, which may assist in an analysis of local county statistics to allow a 'gross county product' to be estimated. This 'GCP' measure will need to be supplemented by statistics of particular industries or activities such as coastal management, which may be expected to be affected by changing demand patterns in future years.

4.4 Need for long-term statistics

When in Washington, the author explored the availability of statistics that matched an earlier era when different issues about coral health applied. The reason was the same that he advanced in the interest of obtained long-term data about corals – to provide an adequate basis for the assessment of future trends in the Florida Keys area.

He was fortunate in getting access to a detailed set of statistics from about 1987 compiled for an investigation of environmental conditions in Monroe County, courtesy of Andy Hooten. They are not displayed here but will be analyzed in the main study if it goes ahead.

4.5 Data gaps, collection and analysis

This phase of the study is clearly within the competence area of the consultant. The identification of data gaps will probably reveal a lack of statistics needed to build a 'GCP' for Monroe and other counties – nevertheless, such a measure will be built if at all possible (which we expect it to be). The ultimate purpose of the macroeconomic and industry analysis is to estimate the macroeconomic impact of climate change under the range of chosen scenarios.

5 Scenario Planning in Context

5.1 What is scenario planning and why use it?

Over the past thirty or forty years, mechanical projections from past trends have become less acceptable as indicators of future events. Rather than predicting from past trends, the focus has been on identifying a range of possible outcomes depending on policy choices, social and technological influences and other indicators which may not all pull in the same direction. As a result, past trends can no longer be automatically extrapolated into the future (if they ever could).

This does not invalidate analysis of past trends. Past growth in given statistical indicators provides some strength to the argument that there will be some future growth, at least in the medium term. But there are so many conflicting influences across the social, economic, ecological, cultural, technological and political spectrum that these trends cannot be expected to continue unhindered. The assumption of uninterrupted economic growth, for instance, depends ultimately on factors of sustainability, whether ecological or social or both, and whether it is realistic to apply a technological fix. For example, can we assume that increasing inequity either nationally or internationally or both will be forever accepted by the community in the interest of maximum production and assuming that benefits will eventually trickle down to the less privileged classes and nations? This depends to a considerable extent on whether 'trickle-down effects' have been perceived to work in the past, which is indeed very doubtful.

This example is advanced for illustration only, and has no intended political content. Some scenarios may be based on assumptions that future societies will enjoy an increased equity of gains from economic growth. Other scenarios may present equally plausible assumptions that increased inequities will cause changes either through political or social change, or both, and have different consequences down the timeline.

Scenarios, in short, are alternative stories about future worlds in which certain circumstances prevail that have some connection with a past social, cultural, technological, economic, ecological, and political world. Circumstances, however, are almost certain to deviate over time from what might look predictable from the present but may nevertheless be based on perfectly plausible or credible sets of assumptions.

Scenario planning took flight when analysis of the future based on regular past trends no longer seemed plausible, roughly from the late 1960s and early 1970s. Some rearguard action among economic and financial analysts resulted in the invention of 'base case', 'optimistic' and 'pessimistic' assumptions supposed to qualify the main projections (so-called sensitivity analysis), but the preference more or less came back to the 'more likely' middle base case. Configuring quite different worlds became the realm of the scenario planner – worlds that had to be regarded as equally possible so, most importantly, probability analysis could not be applied to each of the possible outcomes.[43] We can plan to mitigate 'worst-case' scenarios, but we cannot assume they are less likely to occur than other possible outcomes.

The device of developing 'equally credible' scenarios is central to scenario planning analysis. In its modern version, it was developed largely by Royal Dutch Shell and is explained in a classic text by Kees van der Heijden who was for many years the chief scenario planner in that company.[44] It is often reported that one scenario from the initial run around 1970 postulated a world in which world oil prices increased strongly – which caused Shell to cut its production plans drastically while its competitors continued to expect demand to keep growing at 7-8% per annum when actual growth disappeared entirely after the initial oil shock in 1973-74.[45]

There is no way we can plausibly predict one possible future for the coral reefs of the Florida Keys. It will depend on a range of factors at world, national, state and local level. These factors will again be influenced by the economic, ecological, social, cultural, technological and political factors of the day – and how we can imagine that these factors will develop over the course of the scenario-planning horizon.

Scenario planning does not stand alone. It is part of a package of future-orientated analytic techniques defined, for instance, by the *Foresight* program under the UK Office of Science and Technology (OST).[46] It suggests that the technique of horizon scanning may involve other techniques (trend/driver analysis, modeling and visioning) which all feed into the art of scenario planning. Other future-orientated techniques could be applied as well, but the concept is probably adequately defined and certainly proved itself in the GBR study:

- It was used to develop four different, equally plausible and equally probable main scenarios based on the SRES work of the Intergovernmental Panel for Climate Change, especially its four overall stories designated A1, A2, B1 and B2, where 'A' indicated an economic and 'B' an environmental orientation, and '1' a global and '2' a regional orientation.
- These worlds, taken from the IPCC Third Assessment documents specified in Chapter 1, were modified in various ways to eliminate or minimize flaws such as the use of exchange-based rather than purchasing power parity-based comparisons between countries (the most severe criticism that has been leveled against these scenarios).[47]
- They were then applied in an Australian, Queensland and GBR context, with the aid of a series of scenario-planning workshops, and subsequently quantified (impact compared to a base case on value of tourism and fisheries, and on adjacent coastal economies). This is described in detail in the GBR report.

5.2 Scenario planning in the Keys study

It has already been recommended that the scenario-planning technique be used in the Florida Keys study also. However, there are differences from the GBR study which suggest a more flexible approach.

First, despite NOAA's brief which was discussed in Chapter 1, we do not recommend that the IPCC scenarios are used uncritically as a basis for the Florida Keys study. There are at least two reasons or this. First, the IPCC scenarios will by 2006-07 be seriously out of date and have already been exposed to major criticism that cannot be ignored. Secondly, the situation in the Florida Keys arguably has a stronger local content. Hence, 'the world' may be US-sized rather than global, though global elements affecting humankind will obviously need to be addressed.

The balance between local and global elements in the scenario construction will have to be defined during the planning stage in year 2. The decision is not fundamental at this stage as long as it is recognized that scenario planning – in whatever form that is eventually decided – is an essential element of the process.

The time horizon of the scenarios will range from the relatively short term (five years) to at least a sketch of a century-long perspective. However, there is a need to focus on a 'medium term' when climate change has not yet completely supplanted the current range of environmental factors currently degrading the Florida reef systems. The time horizon for this 'medium term' is a function of climate change itself, which means that it will vary with the particular scenarios adopted.

It is most important to distinguish between the general factors acting to degrade the reefs in the Florida Keys, and the climate change factor which is generally expected to take over as the dominant factor in time. This accords with the statement in the NOAA brief that the issue of climate change has never before been recognized as a prime factor to be considered in the Florida Keys context.

It is recommended that four scenarios be developed based on individual interviews and group discussions initiated by the author. The three scenario workshops conducted during the GBR study (in the Queensland locations of Port Douglas, Townsville and Brisbane) proved highly efficient and inspirational, and a similar approach should be possible at locations in Florida, and at NOAA in Silver Spring. Given that a significant amount of preparation will be needed from the project leader, the outcome should be an improvement on the Queensland results in the Florida Keys study.

6 Project Design

The design outline was indicated on Chart 1.2 in the first chapter of this report. The steps and milestones can be summarized as follows:

6.1 Year 2 (FY 2006)

Following a decision to proceed with the study early in the fiscal year, four parallel research streams are envisaged:

- Socioeconomics (NOAA/FKNMS surveys, analysis of other research)
- Macroeconomic, including industry, research (tourism, fisheries and other reef-dependent industries; further demands from other industries such as coastal management; impact on coastal industries and communities in 'regional GDP' and employment terms)
- Environmental factors based on a variety of sources including the South Florida Data Navigator, Florida Fish and Wildlife Conservation Commission, FKNMS, and academic research
- Coral bleaching data and new research (singled out in the brief as the added and as yet largely un-researched threat to coral health interacting with environmental factors, and including the CRW/Princeton model mentioned in the research brief).

The data collection for these four streams is planned to be concluded by the end of June 2006 and constitutes the main activity in FY 2006. It is necessary, however, to start work on the scenarios during the year (say, beginning of February) in view of the lengthy process involved in developing these. This would include interviews and workshops towards the end of the fiscal year.

6.2 Year 3 (FY 2007)

The main activities during FY 2007 are:

- Finalization of future scenarios covering all agreed time perspectives as discussed in previous sections (by end of January 2007 to fit in with the next group of activities)
- Integration of three main building blocks by end of February (including incorporation of scenarios into these blocks):
    - Ecosystem and bleaching data (by end of December 2006)
    - Conversion into socioeconomic terms (by end of January 2007)
    - Integration into macroeconomic framework (by end of February, which represents a major milestone in the project).
- Futures analysis based on the scenarios is scheduled for the period from the beginning of February to the end of June 2007 – a major step concluding the analytic part of the study.
- Work on policy recommendations should start to take shape (maintaining close contact with NOAA during this process) from April and should be substantially concluded by the end of August.
- This time schedule is intended to facilitate progressive drafting and writing of the report from about the beginning of May to mid-September 2007.

6.3 Proposed study team and estimated costs

The proposed core team (external to NOAA) is as follows:

- Economic analysis and scenario development: Hans Hoegh-Guldberg of Economic Strategies Pty Ltd, Oberon, Australia (co-author of the GBR report which provides some of the background for the currently proposed study)
- Project management and US contact: Andy Hooten of AJH Environmental Services, Bethesda, MD (estimated cost: $10,000 per annum for two years). Duties will include coordination of people and workshops, reviewing reports, and maintaining communications with NOAA and other organizations as required.
- Scientific database developer (year 1) and adviser on scenario assumptions (mainly year 2): One or two persons to be appointed (estimated cost: $5,000 in year 2 and $4,000 in year 3).

The estimated out-of-pocket expenditure is mainly associated with Hans Hoegh-Guldberg's travels. Based on three trips to Washington, DC and Florida, estimated travel costs are $3,300 per trip, and accommodation costs $10,500 based on a total of nights. Other costs include office expenses and publications ($1,000) and costs associated with scenario planning workshops and interviews, estimated at $2,000.

The estimated project cost is summarized below. The allocation of consulting time feasible within this schedule is 90 days per annum. The experience from the GBR study is that this is tight, and that the total time involvement could exceed the estimate in view of the considerable learning, data gathering and analytic process that remains.

Estimated cost of project, FY 2006 and 2007

	FY 2006	FY 2007
Travel: $3300 per trip (Economy class)	$6,600	$3,300
Consultant time ($375/day - 90 days per annum)	$33,750	$33,750
Hotel and daily costs during travel ($350/day – 30 days)	$3,500	$7,000
Office supplies and publications	$500	$500
Scenario development workshops = $2,000	$500	$1,500
Scientists: $9,000 (database establishment, review)	$5,000	$4,000
US coordination = $10,000 pa	$10,000	$10,000
TOTAL	$59,850	$60,050

Endnotes

Chapter 1

[1] Ove Hoegh-Guldberg and Hans Hoegh-Guldberg (2004b), *Biological, Economic and Social Impacts of Climate Change on the Great Barrier Reef*, ICRS 2004, Okinawa, 10th Annual Coral Reef Symposium (http://www.plando.co.jp/icrs2004/). Abstract: click 'Oral presentations July 2 (Fri)' and scroll to 'Oral 2-11 Coral Reefs and Global Change V: Prediction and Societal Implications of Bleaching 10th ICRS'.

[2] A frequently quoted paper is Ove Hoegh-Guldberg (1999), Coral bleaching, Climate Change and the Future of the World's Coral Reefs, *Marine and Freshwater Research* 50:839-866.

[3] Tony Coleman, Ove Hoegh-Guldberg, David Karoly, Ian Lowe, Tony McMichael, Chris Mitchell, Graeme Pearman, Peter Scaife and Anna Reynolds (2004), *Climate Change: Solutions for Australia*, The Australian Climate Group (http://www.iag.com.au/pub/iag/sustainability/publications/climate/intro.shtml).

[4] Hans Hoegh-Guldberg and Ove Hoegh-Guldberg (2004a), *The Implications of Climate Change for Australia's Great Barrier Reef* (http://www.qtic.com.au/WWF.htm).

[5] The first report was for Greenpeace: Ove Hoegh-Guldberg, Hans Hoegh-Guldberg, David Stout, Herman Cesar and Axel Timmermann (2000), *Pacific in Peril: Biological, economic and social impacts of climate change on Pacific coral reefs* (http://www.greenpeace.org.au/climate/pdfs/pacific_in_peril_report.pdf).

[6] Henceforth in this report referred to as 'the author'.

[7] The author's first venture into scenario planning (1998) was to construct four futures for Indonesia following the collapse of the Soeharto regime ('Annual Situation Report 1998 Volume 1: Four Scenarios to 2008', *Indonesia Outlook Vol 3, No 1, August 1998*, Economic Strategies Pty Ltd, Oberon Australia).

[8] Nebojša Nakićenović et al. (2000), *IPCC Special Report on Emissions Scenarios*, especially Chapters 1 and 4 (http://www.grida.no/climate/ipcc/emission/index.htm). Some modifications to the four main IPCC scenarios were introduced into the GBR study to boost their plausibility. They are fully explained in the GBR report.

[9] NOAA Coral Reef Conservation Program – Internal (NOAA-CRCP 2005), FY 2005: Socioeconomic impacts of predicted climate change related coral bleaching for the Florida Keys.

[10] Presumably local communities and organisations also have a strong potential interest, especially in Monroe County. The findings would also be relevant for universities with coral reef programs and for the design of similar inquiries for other coral reef-dependent regions such as Hawaii and other Pacific areas, the Caribbean and elsewhere.

[11] NOAA in cooperation with Coral Reef Task Force (NOAA/CRTF 2002), *A National Coral Reef Action Strategy*.

[12] These three goals (1, 2 and 4), together with 3: Conduct strategic research, make up one of two 'action themes' according to NOAA/CRTF (2002): 'Understanding coral reef ecosystems' (1-4). The action theme of the rest (5-13) is 'Reducing the adverse impacts of human activities'. Chart 1.1 goes beyond this grouping by attempting to link the various goals into a coherent whole. Goal 3 (Conduct strategic research) has been 'elevated' into an activity which all other activities should influence, while goals 1, 2 and 4 provide the primary drivers in the framework. Goal 13 (Improve coordination and accountability) is given the policy-making role with associated feedback. The intended result is the creation of a dynamic and inter-related set of goals, as explained in the text.

[13] Storm Warning, Editorial in *New Scientist* 24 September 2005.

[14] Hans Hoegh-Guldberg, *The Great Barrier Reef and Climate Change* (2005), based on a report by Hans and Ove Hoegh-Guldberg, with tentative notes on implications for Florida Keys study. PowerPoint presentation, NOAA, Silver Spring, MD, 1 June 2005.

[15] The term 'socioeconomic' may already be understood to include economic aggregates defined as 'industry' and 'macroeconomic' in the text. It is spelt out to ensure the latter levels are recognized.

[16] Donald B K English, Warren Kriesel, Vernon R Leeworthy and Peter C Wiley (1996), *Economic Contribution of Recreating Visitors to the Florida Keys/Key West,* Athens, GA: Outdoor Recreation and Wilderness Assessment Group, Southern Forest Research Station, USDA Forest Service. Athens, GA: Department of Agricultural and Applied Economics, University of Georgia. Silver Spring, MD: Strategic Environmental Assessments Division, National Ocean Service, National Oceanic and Atmospheric Administration. – Vernon R Leeworthy and Patrick Vanasse (1999), *Economic Contribution of Recreating Visitors to the Florida Keys/Key West: Updates for Years 1996-97 and 1997-98* (http://marineeconomics.noaa.gov/SocmonFK/publications). – Vernon R Leeworthy and Peter C Wiley (2003), *Profiles and Economic Contribution: General Visitors to Monroe County, Florida, 2000-2001* (http://marineeconomics.noaa.gov/Reefs/Monroe.pdf).

[17] See for instance J W McManus, A L Hazra and J L Gayanilo Jr (2005), *Data Navigator (South Florida): User Guide*, National Center for Caribbean Coral Reef Research, University of Miami – Rosenstiel School of Marine and Atmospheric Science. Rev. 1.25p.

[18] A major article on the CRW/Princeton project was published in the latest issue of *Global Climate Change Biology* (Simon D Donner, William J Skirving, Christopher M Little, Michael Oppenheimer and Ove Hoegh-Guldberg, Global Assessment of coral bleaching and required coral adaptation due to climate change).

[19] This is a bolder approach than that taken in the GBR study, where the formal socioeconomic analysis was confined to a 20-year perspective supplemented by qualitative pointers from 2020 to the middle of the 21st century. In contrast, the scientific analysis in the GBR study went to the end of the century and even beyond.

Chapter 2

[20] Given that the data requirements can be adequately defined, the Florida Fish and Wildlife Conservation Commission (for instance) has a policy to share anything it collects because it is government-sponsored research.

[21] Clive Wilkinson (2004), Executive Summary, in Clive Wilkinson (editor), *Status of Coral Reefs of the World: 2004,* Australian Institute of Marine Science, Townsville, Queensland.

[22] T P Hughes (1994), Catastrophes, phase-shifts and large-scale degradation of a Caribbean coral reef. *Science* 265:1547-1551.

[23] J Brodie, K Fabricius, G De'ath and K Okaji (2005), Are increased nutrient inputs responsible for more outbreaks of crown-of-thorns starfish? An appraisal of the evidence. *Mar Pollut Bull.* 2005;51(1-4):266-78

[24] Dirk Bryant, Lauretta Burke, John McManus and Mark Spalding (1998), *Reefs at Risk: A map-based indicator of threats to the world's coral reefs*, World Resources Institute (WRI), International Center for Living Aquatic Resource Management (ICLARM), World Conservation Monitoring Centre (WCMC) and United Nations Environment Program (UNEP).

[25] Katherine Andrews, Jenny Wheaton, Larry Nall, Carl Beaver, Walt Jaap, Brian Keller, V R Leeworthy, J A Bohnsack, Tom Matthews, Jerald Ault, Fleur Ferro, Gabriel Delgado, Dough Harper, John Hunt, Bill Sharp, Christy Pattengil-Semmens, Steve Smith, Richard Spieler, R E Dodge, D Gilliam and Bill Goodwin (2004), *Status of Coral Reefs in the U.S. Caribbean and Gulf of Mexico: Florida.* Part of Chapter 16 of Clive Wilkinson (ed), *Status of Coral Reef of the World: 2004, Volume 2*, Global Coral Reef Monitoring Network, Australian Institute of Marine Science, Townsville, Queensland.

[26] Southeast Environmental Research Centre, Florida International University, *2004 Annual Report of the Water Quality Monitoring Project of the Water Quality Protection Program for the Florida Keys National Marine Sanctuary*, including Executive Summary and Data. CD ROM. The inclusion of the Florida southwest mainland will provide a baseline to study how 're-plumbing' of the Everglades has altered water flows and pollution levels in Florida Bay.

[27] Walter Jaap (1979), Observations on zooxanthella expulsion at Middle Sambo Reef, Florida Keys, *Bull. Mar. Sci.* 29:414-422. – B D Causey (2001), Lessons learnt from the intensification of coral bleaching from 1980-2000 in the Florida Keys, USA. In R V Salm and S L Coles (eds), *Coral Bleaching and Marine Protected Areas: Proceedings of the Workshop on Mitigating Coral Bleaching Impact through MPA Design.* Honolulu: Asia Pacific Coastal Marine Program Report #0102. – J A Kleypas, R W Buddemeier and J-P Gattuso (2001), The future of coral reefs in an age of global change, *Geol. Rundsch.* 90:426-437.

[28] Coralie Carlson (2005), Florida conducting coral reef study, *Associated Press 5 September 2005.*

[29] In addition to proper scientific source material, it may be worthwhile exploring information that might be derived from the volunteer organization Reef Check (www.reefcheck.org). While one has to be wary of the potential simplicity of such data, properly handled and assessed it has the possibility of adding significant regional information regarding coral cover and fish densities.

[30] Phillip Dustan (2003), Ecological Perspectives: The decline of Carysfort Reef, Key Largo, Florida 1975-2000. In *Ecological Forecasting: new tools for coastal and marine ecosystem management*, NOAA Tech Mem NOS NCCOS 1, pp37-43.

[31] Gilbert L Voss (1988), *Coral Reefs of Florida*, Pineapple Press, Saratosa, Florida.

[32] Jane Yehle, *A Snapshot History of the Rosenstiel School of Marine and Atmospheric Science 1940-2005* (www.rsmas.miami.edu/info/history).

[33] *Reefs at Risk*, published in 1998 and co-authored by John McManus of the Rosenstiel School of Marine and Atmospheric Science, has a foreword by Sylvia Earle of the National Geographic Society, describing how more than forty years ago she 'slipped into a sunlit ocean, clear as air, not far from Miami, Florida, and glided into a kaleidoscope forest of lavender sea fans, cavernous sponges, and giant stands of elkhorn coral' – and abundant fish and other organisms around. – 'Recently, I returned hoping to relocate that underwater Garden of Eden, but found only barren coral skeletons shrouded with gray-brown sediment. Again, it seemed that I had traveled in time, only now the direction was a swift fast-forward fantasy, a glimpse of the future. In my lifetime, I had witnessed change on a geological scale, wrought by my species. The rapid growth of population in central and south Florida has had hidden costs—the consumption, in decades, of species and natural ecosystems millions of years in the making.'

[34] Gilbert L Voss, *AnEnvironmental Assessment of the John Pennekamp Coral Reef State Park and the Key Largo Marine Sanctuary (Unpublished 1983 report).* University of Miami RSMAS 2002.

[35] William F Precht and Steven L Miller (2006), Ecological Shifts along the Florida Reef Tract: The past as a key to the future. Chapter 10 in R B Arenson (ed), *Geological Approaches to Coral Reef Ecology*, Springer Verlag, New York. In press. Precht and Miller also refer to Chapter 9 of the same volume: J Pandolfi and J B C Jackson, Broad-scale Patterns in Pleistocene Coral Communities from the Caribbean: Implications for ecology and management, which seeks to demonstrate that the predictable patterns of community membership and dominance of acroporid species in the Caribbean throughout the Pleistocene epoch allow for a baseline of pristine coral community composition before human exploitation.

[36] E A Shinn (1988), The geology of the Florida Keys, *Oceanus* 31:46-53; F Ward (1990), Florida's coral reefs are imperiled, *Natl. Geo.* 178:115-132; B H Lidz (1997), *Fragile Coral Reefs of the Florida Keys: Preserving the Largest Reef Ecosystem in the Continental U.S.* Open-File Report 97-453. St Petersburg: U.S. Geological Survey.

[37] Joan Kleypas, Constraints on predicting coral reef response to climate change (Chapter 14).

Chapter 3

[38] http://typhon.rsmas.miami.edu.

Chapter 4

[39] Vernon R Leeworthy and Peter C Wiley (1996), *Importance and Satisfaction Ratings by Recreating Visitors to the Florida Keys/Key West* and other reports in a series describing visitor behavior in the Keys area in 1995-96 (all downloaded for future purposes). The author noted when first reading the publication that he had used – indeed invented for the purpose though the approach is apparently used in marketing analysis – the same approach in a very different area: surveys of users of Australian public libraries.

[40] Vernon R Leeworthy, Peter C Wiley and Justin D Hospital (2004), *Importance-Satisfaction Ratings Five-Year Comparison, SPA and ER Use, and Socioeconomic and Ecological Monitoring Comparison of Results 1995-96 to 2000-01*. NOAA.

[41] Vernon R Leeworthy and Peter C Wiley (2003), *Profiles and Economic Contribution: General Visitors to Monroe County, Florida 2000-01*. NOAA. We add that we were also provided with the statistical worksheets underlying the two surveys, and we have studied these (readable using the Statistical Package for the Social Sciences, or SPSS).

[42] Robert B Richardson and John B Loomis (2004), Adaptive recreation planning and climate change: A contingent visitation approach. *Ecological Economics* 50:83-99.

Chapter 5

[43] Rearguard action continues against this condition, most recently from the British House of Lords criticizing the IPCC's presentation of future warming. It argues that some indication should be given of the likelihood of different scenarios. It further questions the assumptions and methodology on which the most pessimistic scenarios are based. In addition it alleges that the IPCC tends to exaggerate dangers and lacks objectivity (Dick Taverne, Political Climate, *Prospect Magazine,* August 2005).

[44] Kees van der Heijden (1997), *Scenarios: The art of strategic conversation*, Wiley.

[45] Current Shell scenarios (www.shell.com) are not as specific as previous ones about alternative energy sources replacing fossil fuels. However, they explicitly address issues such as consciousness about climate change, the Kyoto Protocol, and biodiversity.

[46] Foresight (2005), Strategic Futures Planning: Suggestions for success (www.foresight.gov.uk).

[47] In crude terms, exchange rate-based comparisons between countries assume that one dollar buys the same in all countries, whether rich or poor, while purchasing power parity (or PPP) acknowledges that consumption patterns differ profoundly, making the equivalent of a dollar in local currency stretch further among the main population groups in poorer countries. Rice in an Indonesian village costs a fraction of what middle-class consumers spend in Jakarta supermarkets (or Americans or Australians spend in their retail outlets), as the author has personally surveyed in 1996-97. By adopting an exchange-rate-based comparison (which exaggerates the current difference in living standards between rich and poor), and furthermore assuming that the poorer nations would catch up with the richer ones over the 21st century, the IPCC projections exaggerated world economic growth, to an extent that became quite unrealistic in the global economics-driven 'A1' scenario.